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Augmented Reality in Spatial Planning Applications:

A systematic literature review

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A systematic literature review

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Abstract

Traditionally, two-dimensional maps have been the main means of visualisation of data in spatial planning. These 2D representations require more cognitive abilities and are more difficult to understand compared to 3D spatial data. Augmented reality (AR) is an upcoming new technology able to visualise 3D spatial data and could therefore be a potential solution. To elaborate the potential of AR in spatial planning, this study presents a systematic literature review (SLR) which aims to provide an overview of currently existing AR technologies, the impact of AR on stakeholder engagement and collaboration in spatial planning applications and the possibilities and challenges that arise when using AR in spatial planning. Moreover, an AR prototype application is developed as a demonstration of currently available techniques and to present its potential for spatial planning projects. For the SLR, 70 open access articles have been reviewed. The results show the most often used hardware, software and data types for AR application development. Smartphones, Unity 3D and street-level images are the most often used hardware, software and data types. The SLR shows explanations for the currently limited integration of AR technology in spatial planning workflows. Moreover, this SLR shows the most prominent AR features of cutting-edge AR technology such as physical AR interaction and marker-based AR and the most prominent AR obstacles that hinder AR application development such as occlusion and GNSS inaccuracy. The developed AR prototype allows people to view the new Omnia building on Wageningen campus through their Android smartphones and also allows them to provide feedback through the prototype. The infancy of AR technology and its limited implementation in spatial planning workflows is discussed. A small selection of AR hardware and software types is used due to limited availability of AR technology and technical complexity. Furthermore, spatial planners find AR to be a complex technology but are aware of its future potential for spatial planning. Within the boundaries of currently existing hardware and software, other researchers are experimenting with several AR features such as physical AR interaction but encounter an array of consistent, hard to resolve AR obstacles.

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1. Introduction

1.1 Traditional 2D maps

Traditionally, maps have provided the main means of visualisation for spatial data. These two-dimensional representations of reality require people to use a certain amount of their own imagination and comprehension to be able to understand what 2D maps show. One could argue that the traditional method of using 2D cartographic maps comes with a lack of realism. Particularly in sectors such as spatial planning, 2D maps are unable to display the world as we see it through our eyes. Sectors such as engineering, construction works, and spatial planning would benefit from more realistic types of visualisations. For example, Mat et al, 2014, have proven that people are able to perceive a 3D landscape much easier compared to a 2D map. Particularly in spatial planning, Augmented Reality (AR) is a technology that could help improve the imagination and comprehension of planners by augmenting digital objects in the real world. Besides the improved realism of visualisations, and digital and interactive characteristics of AR, it could also help foster more stakeholder participation and collaboration in spatial planning.

1.2 Spatial planning

Attempts that include planning "processes of social, economic, and environmental change" (Yoshida et al, 2020) with particular goals in mind can be understood as spatial planning. Often these planning practices involve creating diagrams, maps, and other visualisations to communicate these goals with others involved in the proposed change of an area. Where spatial planning has traditionally been a top-down process of restructuring landscape areas, the role of the government has changed to a more facilitating one (Westerink and Kempenaar et al, 2017). The involvement of non-governmental stakeholders in the planning process that have affection for the area has increasingly gained importance (Westerink and Kempenaar et al, 2017). Stakeholder involvement in spatial planning increases the democratic value of the decision-making process. Moreover, this bottom-up approach allows for spatial planning goals that are more aligned to the needs of stakeholders in the area resulting in more successful and inclusive policy.

Al-Dalou and Abu-Shanab, 2013 describe 'e-participation' which is a term used to indicate ways in which stakeholders engage in projects of public or private institutions by using digital tools. They distinguish 4 levels of e-participation: E-informing, e-consulting, e-collaboration and e-empowering. E-informing is the most basic level of participation where stakeholders are informed about projects. E-consulting allows stakeholders to provide their opinions about a project. In e-collaboration stakeholders are actively involved in the processes of the projects although project officials will make the final decisions. E-empowering makes it possible for stakeholders to have full control over the project which allows them to make final decisions as well. These levels of e-participation can be used to specify the purpose of AR applications in spatial planning and to better align this purpose with the role of stakeholders involved.

1.3 Augmented Reality

AR is a technology used to place virtual objects in the physical space that can be observed by the user (Chalhoub et al, 2019). A perfect use of this technology would require the digital objects to seamlessly integrate with the physical world while allowing the user to interact with both the physical world and digital objects. This requires high precision in tracking the position and rotation of the user with very limited time lag (Devaux et al, 2018). While this seamless integration is still a challenge for many AR applications, sensors used for positioning purposes offer a fair amount of precision for AR applications that are continuously evolving (Carozza et al, 2014).

Besides the required accuracy in location and orientation, differences in lighting and occlusion between the virtual objects and the physical world is another source of development. If the virtual objects are sought to be integrated with the physical world in a photorealistic way, lighting and occlusion of the virtual objects must be adapted to the same conditions in the physical world (Devaux et al, 2018). Cameras currently on the market are robust and cheap enough to be used for creating many pictures as input for various kinds of 3D modelling software to create the AR scene (Carozza et al, 2014).

As a result of improvements in locational and orientational accuracy and reduced latency in the image processing, AR technology including its hardware and software capabilities and availability of data, has evolved rapidly over the last few years (Hugues et al, 2011). The latest technique used for AR development is the use of game engines such as Unity 3D and Unreal Engine. Game engines in general allow developers to create virtual 3D environments much faster using commands that used to require a lot of coding but are now greatly simplified and more accessible (Mat et al, 2014). By using game engine plugins such as Vuforia, augmented scenes can be created faster and more efficient.

1.4 Augmented Reality in practice

Various examples of AR applications have been introduced within scientific literature as well as in day-to-day use. The most famous example would probably be the game Pokémon Go which shows digital Pokémon creatures in real life through the smartphone of the user. This app shows the high locational accuracy that can currently be acquired with a smartphone. The app uses location services such as GPS, WIFI and mobile networks to determine the location of the user and to confront them with the Pokémon creatures that can then be caught (Boulos and Lu et al, 2017).

A different application of AR is described by Chalhoub et al. 2019, who argue that AR can be used for complex, repeatable construction tasks to allow a faster and more accurate way of constructing installations on building sites. The accurate positioning of boreholes or pipes in buildings can potentially be much better performed by AR driven techniques. An example of this is the development of an AR application that helps construction workers with the identification of underground sewage pipes. This app makes digging holes unnecessary while the sewage pipes are digitally projected on their exact location underground. This reduces effort and costs. Besides the use of AR in games and construction work, the technology has also been used for military purposes and in tourism. For example, soldiers have used AR glasses on the battlefield to provide themselves with spatial information such as elevation, distance to objects and identification of the enemy (Chmielewski et al, 2019). In tourism, AR apps have been created to inform people about destinations, real time crowd information and to improve sightseeing. An example is an app developed in Austria that helps tourists during a hike to identify mountain peaks that can be viewed from a distance to enhance the experience of the hike (Hugues et al, 2011).

1.5 Augmented Reality for spatial planning

The recent advancements in AR technology have led to more possibilities for people to analyse and visualise spatial data. As mentioned in section 1.1, AR can help to improve people's perception and comprehension of spatial data and can thus help to activate more people in planning processes. The inclusion of stakeholders in spatial planning through bottom-up policy has been fostered by many global and regional institutions (Imottesjo et al, 2018). Urban areas are best shaped through, as Imottesjo et al., 2018 discuss,

> "a multitude of decisions that accumulate and stream through time, subject to continual regeneration and renewal as conditions for development continually change".
>
> (Imottesjo et al, 2018).

Here, AR in combination with spatial data can act as a platform to support bottom-up policies for spatial planning. Studies have shown significant differences between experts and non-experts regarding the interpretation of visualisations of urban areas (Imottesjo et al, 2018). These differences can potentially lead to more creativity, inclusivity, and collaboration in an urban area. AR applications have the potential to act as a platform to exploit this form of collaboration between experts and non-experts by providing the ability to visualise new ideas directly into the real world.

1.6 Research needs

Innovating the ways of visualising data is very important to improve visual spatial thinking and cognitive processes of understanding and decision making (Devaux et al, 2018). AR can support the ability of people to see future plans in a real-life situation which helps improve the decision making process. Until now the use of AR has been discussed in case studies covering specific types of applications that use AR for analysis, visualisation, monitoring and data collection in various work fields.

To understand the current state of AR technology in relation to spatial planning, it is important to obtain insight in the progress that has been made over the years. According to Hugues et al, 2011, AR development can be drawn back to three main pillars. The first one corresponds to improved hardware technologies. The second pillar relates to improvements in software technologies and the third pillar entails the improved access and availability of spatial data (Figure 1). From a technological perspective it is important to understand the current state of AR in each of these pillars. Advancements in hardware capabilities will have to be aligned with advancements in software capabilities (Hugues et al, 2011) and adapted to the increasing availability of spatial data. Thereby creating new architectures that integrate the three pillars into more usable AR technology for non-experts on AR as well. Identifying the latest advancements is important for planners because it allows them to make well-considered decisions on their approach for using AR in spatial planning studies and it helps to recognize the added value of presenting their plans in 3D instead of conventional 2D representations. A systematic literature review (SLR) providing an overview of these technologies would therefore be of great value.

Apart from the technology itself, it is also important to know what the impact of AR is on improving communication, planning, participation, project management and policy making. The interactive nature of this technology could provide a platform between different stakeholders, experts, and non-experts. Understanding the way AR has been used in different situations could help identify the advantages and disadvantages of using AR in spatial planning and what can be done to improve its impact. A SLR can help to combine the experiences of a multitude of case studies and bring them together in a more general overview that can be used for future AR studies within spatial planning.

The SLR approach is an extensive methodology used to collect all existing knowledge on a specified topic and to synthesise this knowledge in a structured way (Kitchenham et al, 2009). The desired outcome of a SLR is an evidence-based overview of guidelines that follows from the accumulated knowledge (Kitchenham et al, 2009). No such SLR covering the use of AR in spatial planning has been found by the author to the best of his knowledge. Therefore, this will be the first aim of this study.

Apart from the need for a comprehensive overview of current AR technology, it is also important to demonstrate the current possibilities regarding the use of AR in spatial planning projects. Therefore, the second aim of this study is to develop an AR prototype application for a spatial planning project. This prototype will be developed with the aim to present the current AR techniques that can be used for spatial planning projects. This research will reflect on the technical possibilities and challenges that come with the development of such an AR prototype. Moreover, the AR prototype will adhere to one of the e-participation levels described in section 1.2. In this way the focus of the AR prototype can be adapted to the specific role of the stakeholders that will potentially use this application. To decide which specific AR technologies and workflows are needed in terms of hardware, software and data to develop the AR prototype, the outcomes of the SLR can be used as a guidance.

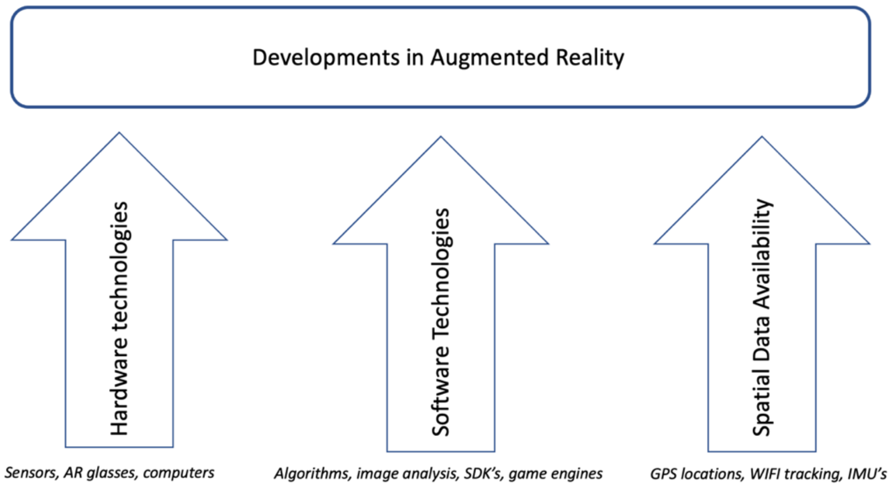

Figure 1: The three pillars of Augmented Reality technology development described by Hugues et al, 2011. Examples of these developments are given below each pillar.

2. Objectives and Research Questions

The purpose of this study is to provide an overview of developments in AR technology related to spatial planning applications. Specifically covering multi stakeholder collaboration strategies enabled by AR applications, by conducting an SLR. The intention for the SLR results is to indicate a selection of AR technologies that have been applied in case studies related to spatial planning and possibly other work fields. Moreover, the SLR will result in a general overview of AR applications linked to forms of multi stakeholder collaboration in case studies where AR has been applied. Both the selection of AR technologies and stakeholder collaboration guidelines will help to create an overview that could support the use of AR technology in spatial planning applications for future research. Furthermore, as a demonstration, a prototype AR application will be developed for a case study related to spatial planning to show the current technical possibilities regarding the use of AR in a specific spatial planning case study. The research objectives include the following:

1. *To review state of the art AR technologies suitable for deployment within the domain of spatial planners.*
2. *To investigate case studies on the impact AR has for improving communication, planning, participation, project management and policy-making.*
3. *To develop an overview for AR integration into spatial planning workflows.*
4. *To develop a prototype AR application as a demonstration of the technology and assess its potential for use in spatial planning.*

Based on the research objectives stated in this section, research questions have been formulated. Answers to research questions 1 to 3 will be the output of the SLR. Research question 4 will be answered by the development and assessment of the AR prototype:

1. *What types of AR technologies are being employed within the domain of spatial planning applications in terms of hardware, software and data?*
2. *In which ways do AR applications have an impact on stakeholder engagement and collaboration in spatial planning applications?*
3. *Which possibilities and challenges arise when using AR in spatial planning applications?*
4. *How can the developed prototype AR application promote stakeholder collaboration in spatial planning and how will this be validated?*

3. Materials and Methods

3.1 SLR search strategy

Only open access articles were used in the SLR to increase transparency and reproducibility of the study. This means that no subscription is needed to be able to access the articles. 8 digital sources were used to find relevant open access articles. Furthermore, a time frame was selected while AR is a fast-developing technology and therefore technologies that are too old might not be relevant anymore. A time frame between 2016 and 2021 was selected here because of the fast pace by which the advancements in computer science are developing (Pidel et al, 2020). Two techniques for searching were applied.

First, searching for articles using a specific search query was applied. This search query was the input for the digital sources. In this search query, search terms that linked to the research questions were used. A rough initial search was performed to find articles relating to the research questions. From this selection of articles, the most commonly used keywords were identified and used in the search query. Furthermore, the use of Boolean operators and parenthesis helped to specify the importance of each keyword in the search query. The search query was:

("augmented reality" OR “mixed reality”) AND ((GIS OR ARGIS OR “geographic information system*” OR smartphone OR application OR “game engine”) OR (stakeholder* OR actor* OR collaborat* OR participat* OR “decision making” OR “stakeholder inclusion”)) AND ("spatial planning" OR "urban planning" OR “city planning” OR “landscape visualisation” OR “mobile visualisation” OR geovisualisation OR “smart cities” OR “urban design” OR “emergent planning”)*

Secondly, a snowball-strategy was used to obtain more relevant articles that might not have been identified with use of the search query due to use of other keywords for example. This strategy entails manually scanning the reference lists of the relevant articles obtained from the search query to obtain more relevant articles. Relevant articles in these reference lists have an older publication date compared to the publication date of the article in which this article was referenced. If the encountered articles were published earlier than 2016, corresponding to the time frame used for the search query, they were not used for this SLR. Moreover, the articles obtained from snowballing had to be open access as well, just like the articles obtained from the search query.

3.2 SLR article exclusion

Applying the search query on the digital sources and using the snowball-strategy resulted in a rough list of potentially interesting articles. To assess whether an article was relevant, the title, keywords and abstract were analysed. Exclusion criteria were used to apply filtering and to reduce the list of potentially interesting articles to a list of articles that were indeed relevant and interesting for answering the research questions. The exclusion criteria are listed in Table 1. Exclusion criteria 1 to 4 have been derived from Tummers et al, 2019 and Kitchenham et al, 2009 and relate to the format of an article. Exclusion criteria 5 to 7 relate to the contents of the article.

Table 1: The article exclusion criteria used to filter out irrelevant articles from the SLR search results. Criteria 1 to 4 have been derived from Tummers et al, 2019.

No.	Exclusion criteria
1	Article is not open access and not in English language.
2	Article does not validate current study (does not relate to your work).
3	Article is a duplicate.
4	Article is not an applied study.
5	Article does not describe AR or ARGIS technologies regarding hardware, software, or data.
6	Article does not describe stakeholder engagement and collaboration in AR applications.
7	Article does not describe AR in combination with spatial planning applications.

3.3 SLR article quality assessment

The list of articles that resulted from applying the exclusion criteria was assessed based on the quality of the content of the article. The article quality assessment criteria were listed in Table 2 (again partly derived from the work by Tummers et al, 2019). The article quality assessment was completed by reading the entire article and scoring it based on the quality assessment criteria. For each criterion, a score of 0 (quality criterion not met), 0.5 (quality criterion somewhat met) and 1 (quality criterion met entirely) was given for each of the criteria. Articles that had an overall score of less than 2.5 out of 7 points were excluded from the list and thus excluded from further analysis. These articles met too few quality criteria to be useful enough for answering the research questions. The articles that achieved the highest score were considered to contain useful information of the highest quality to answer the research questions. Most of the quality assessment criteria such as 1, 2, 3, 6 and 7 spoke for themselves. However, criterion 4 and 5 needed further explanation.

Table 2: The criteria used to assess the quality of the articles. For each criterion a score of 0, 0.5 or 1 could be given.

No.	Quality Assessment
1	Is the aim of the article clearly stated?
2	Is the scope, context and experimental design clearly defined?
3	Is the research methodology repeatable?
4	Does the journal in which the article is published have a high Q-score?
5	Is the research coupled with a real-life application?
6	Can the conclusions be drawn back to the original aim of the article?
7	Does the research align to the field of AR in spatial planning?

Criterion 4 was related to the Q-score of the journal the article was published in, and it indicated the quality of the journal. The WUR journal browser was used to look up the Q-score of each selected journal for which an article was assessed in the article quality assessment. All scientific journals in the WUR journal browser are ranked based on the impact of the scientific articles each journal contains. The Q-score is based on a ranking of all journals within a specific scientific field. It follows a distribution with four quantiles. A Q-score of 1 indicated that a journal belongs to the top 25% (first quantile) of all journals in a specific scientific field and therefore had a very high impact. A Q-score of 2 indicated that the journal is of good quality, meaning it belonged to the journals that had a lower but still valuable impact (second quantile) corresponding to the top 50%. Journals with a Q-score of 3 had a lower impact and journals with a Q-score of 4 had the lowest impact (Figure 2). Articles that were published in journals with a Q-score of 1 or 2 were considered very impactful and thus received a score of 1 for the article quality assessment. Articles published in journals with a Q-score of 3 or 4 were given a score of 0.5. Finally, if no Q-score was available for the article, 0 points were given on this quality assessment criterion.

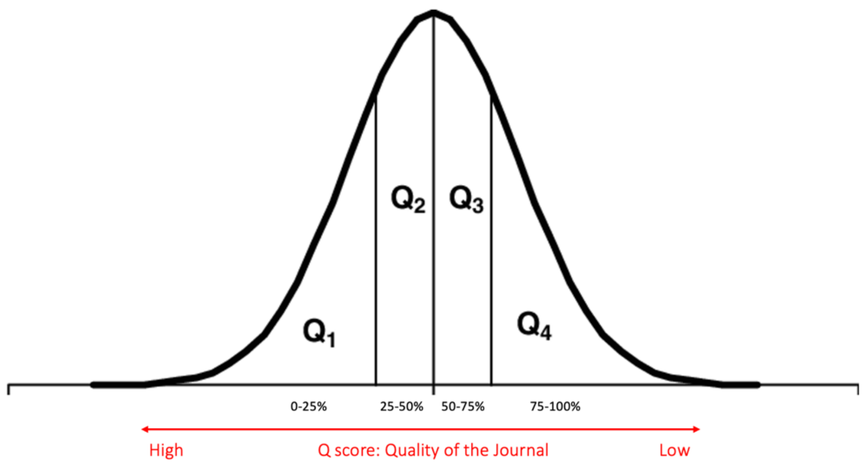

Figure 2: Article Q-Score distribution including the four quantiles that correspond to the number of journals with the same scientific impact.

Criterion 5 related to the question whether the article was described in a real-life application. This meant that the question was whether the AR application described in the article has been implemented and tested in a real-life situation. Articles that described the development of an AR application often test their application amongst a group of people other than themselves. This type of validation was considered best and given a quality assessment score of 1. Other articles described a type of validation in which only simulation data was used, or the application was only tested by the authors themselves. In that case, a score of 0.5 was assigned. In case no validation was described in an article, a score of 0 was assigned.

To validate the overall quality assessment scores given to the articles in this research, the quality assessment for a number of articles was done by more than one person. While most of the articles have been assessed by the author of this research only, a means of validation is important to avoid bias and misinterpretation of the quality assessment scores. Therefore, a random selection of articles was reviewed by two supervisors in charge of coordinating this research.

3.4 SLR article data extraction

The articles that obtained a quality assessment score of 2.5 or higher were then used for data extraction. Here, a data extraction form was created to make the extraction consistent for each article. The data extraction types obtained from each article can be found in Table 3. The table included the extraction of general information about the article such as the title, publication year and authors, and the extraction of information needed to answer the research questions. Data extraction types 1 to 12 entailed more general information about the article. This data was used to create a general insight into article statistics such as number of articles published per year or the comparison between quality assessment scores and digital source. In Table 3 the data extraction types 14 to 21 were relevant for answering the research questions. The “Identified Keywords” data type are the keywords identified while reading the article which were not listed as keywords by the article author but still deemed important. Table 4 shows which data extraction types were used for answering each of the research questions. After the data was extracted from the articles, the data was normalised for the data extraction types 16 to 21. This meant that data was grouped, and umbrella terms were defined to categorise this data. This improved comparability which made it less complex to count frequencies of specific word and phrasing occurrences and to derive patterns from the data.

Table 3: Listed in this table are the data extraction types indicating the information extracted from each article. This includes more general information as well as the information needed to provide an answer to the research questions. Some of the information to be extracted is derived from Tummers et al, 2019.

1	Article title
2	Authors
3	Journal or Conference Title
4	Publication year
5	Journal Volume
6	Journal Issue
7	Number of citations
8	Article Web Source
9	DOI
10	Author keywords
11	Number of references from snowballing this article reference list
12	Article Quality Assessment Score
13	Web link
14	Identified keywords
15	Article domain
16	Findings AR hardware technology
17	Findings AR software technology
18	Findings AR data
19	Findings stakeholder involvement in AR spatial planning applications
20	AR Obstacles
21	AR Features

Table 4: The data extraction types used to answer each of the research questions. RQ 4 is not answered from the SLR outcomes.

Research Questions	Data Extraction Types (Table 3)
1. *What types of AR technologies are being employed within the domain of spatial planning applications in terms of hardware, software and data?*	14, 16, 17, 18
2. *In which ways do AR applications have an impact on stakeholder engagement and collaboration in spatial planning applications?*	14, 19
3. *Which possibilities and challenges arise when using AR in spatial planning applications?*	14, 20, 21
4. *How can the developed prototype AR application promote stakeholder collaboration in spatial planning and how will this be validated?*	Not answered by SLR

3.5 SLR article data synthesis

The synthesis of the article data included the derivation of patterns from the data. Figure 3 shows the number of open access articles found in this SLR and published between 2016 and 2021. This number is substantially higher in 2018 and 2019. Figure 4 shows the article quality assessment scores for a selection of digital sources that were used to find relevant articles. The largest number of relevant articles came from Scopus and ResearchGate. Articles found in these sources generally received the highest quality assessment scores as well. Other digital sources used but not shown in this graph were Google Scholar, IOPScience, ScienceDirect and SpringerLink.

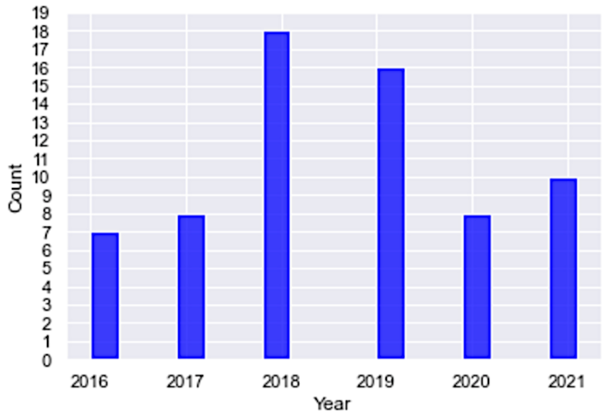

Figure 3: The number of articles per year analysed in this SLR.

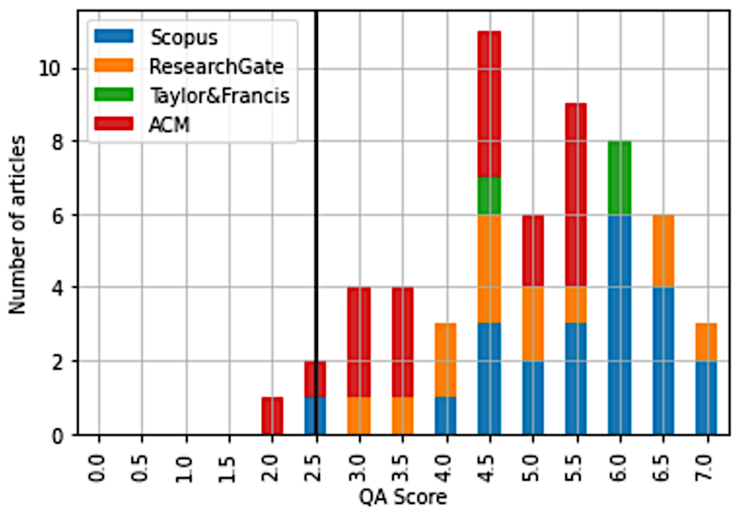

Figure 4: Quality assessment scores per digital source. The black line indicates the minimum score required for the article to be included in further analysis. This figure only shows the most relevant digital sources.

3.6 AR prototype development and validation

The development of the AR prototype serves as a demonstration of using AR technology in spatial planning. A prototype AR application called OmniaViewAR will be developed, taking into account the most commonly used AR hardware types, AR software types and data types. Moreover, a case study will be used to place the app into an existing spatial planning project. In this case, a new building on Wageningen campus is chosen.

The case study includes a recently built building called Omnia on the campus of Wageningen University. The aim of the prototype will be to visualise this new building in an AR scene including the area and buildings surrounding it. By pointing one's smartphone to a marker, the Wageningen campus will be visible in an AR scene including the new Omnia building. Several buttons in the prototype allow for moving through the AR scene to see Omnia from different perspectives and to zoom in and out. Figure 5 shows multiple wireframe designs that will be used for the setup of the prototype. This includes a start-up screen when the prototype is launched on the smartphone, a user interface including all the buttons and sliders to move through the AR scene and a screen showing the survey when the feedback button in the user interface is pressed.

This marker-based AR prototype will be developed for an Android smartphone. The workflow is presented in Figure 6. The input models that will be used are pre created 3D models of the new Omnia building and Wageningen campus buildings. The model of Wageningen campus buildings is called 3D BAG and is made freely accessible by Delft University and is also available for the entire Netherlands. Furthermore, satellite imagery of Wageningen campus and a QR code marker image are used as well as street-level images of Wageningen campus buildings which will be taken manually on site and used for texturing. 3DS Max modelling software will be used to reformat the Omnia building model for Unity compatibility and to downsize the Wageningen campus model because the number of buildings is probably too large and outside of the predefined area for the AR scene. Street-level images of the Wageningen campus buildings will be added to the Wageningen campus model to increase realism of the AR scene. The satellite image of Wageningen campus is used as base layer for the AR scene and will be obtained from Google Earth Engine. Furthermore, scripts are created for the buttons and sliders in the user interface of OmniaViewAR using C#, which is the default programming language used in the Unity game engine. Vuforia is integrated into Unity via a plugin that can be added when installing Unity. The Vuforia plugin will be needed to create the AR scene which will be activated by aiming the smartphone camera on the QR code marker image. This image is used for both downloading the prototype on the Android smartphone and for activating the AR scene when pointing the smartphone at this image. Further details on the processing steps that will be taken, are presented in Figure 6.

Linking back to RQ4, the goal of this prototype is to contribute to increased involvement of stakeholders in spatial planning. Based on the 4 different e-participation stages described in section 1.2 of the introduction, this prototype focuses on the e-consulting stage. Meaning that this prototype aims to allow people to provide their opinions on a proposed new building plan. By looking at a 3D model of the building in the area where it would be built through AR, people would be able to express their opinions on the new building by pressing the feedback button in the prototype. These opinions could then be collected and could serve as feedback for municipalities, contractors, and other interested parties. Instead of the ability to give feedback, the feedback button will be used instead to allow users to provide feedback on the prototype itself rather than the building. The actual ability to provide feedback on the building is beyond the scope of this research.

The AR prototype will be tested and validated with use of a survey that can be accessed by pressing the feedback button. The survey will consist of 10 questions which are shown in section 6 of Appendix 1. 3 questions are related to the technical workings of the prototype such as the prototype installation and user interface. 2 questions are focused on the degree of immersion the users experienced when using the prototype. 3 questions are used to obtain information on respondents' previous experiences with AR as well as their opinion on the use of AR in spatial planning projects. 8 out of 10 questions are multiple choice questions and 2 are open questions. The aim is to obtain at least 20 people to test the prototype including their answers on the survey.

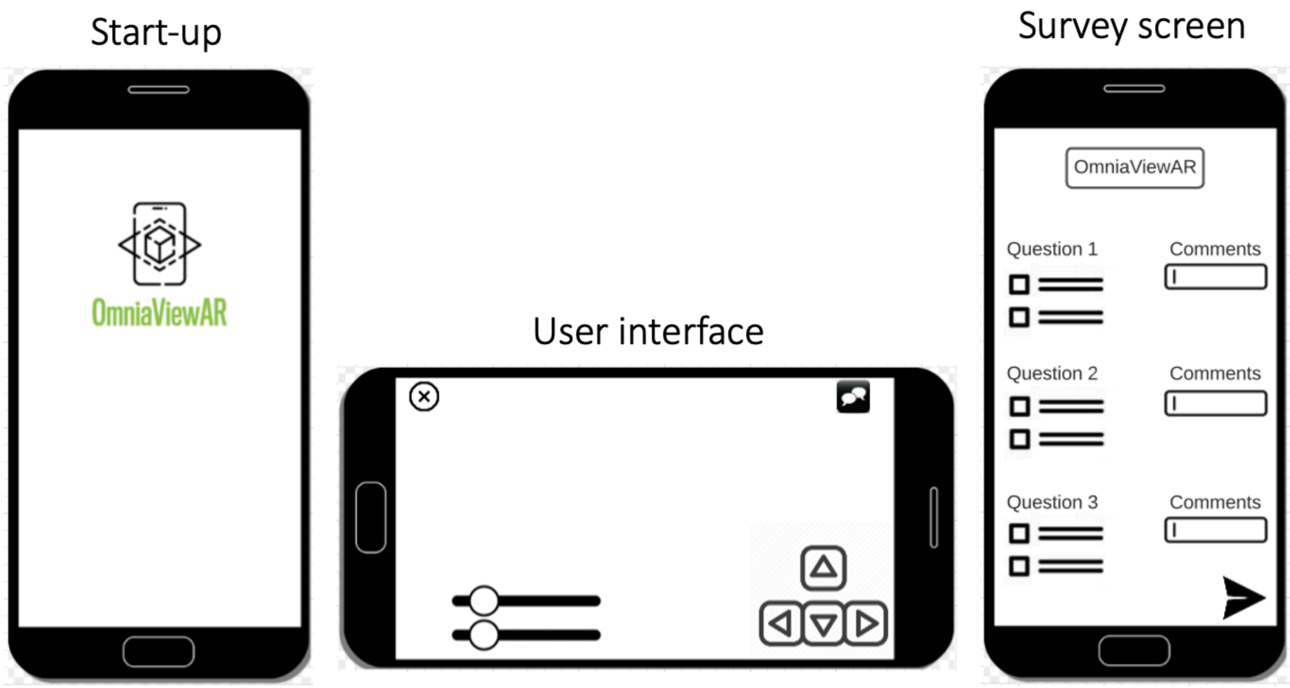

Figure 5: Multiple wireframe designs showing the proposed design of OmniaViewAR. The start-up screen (left), user interface (middle), and survey screen (right).

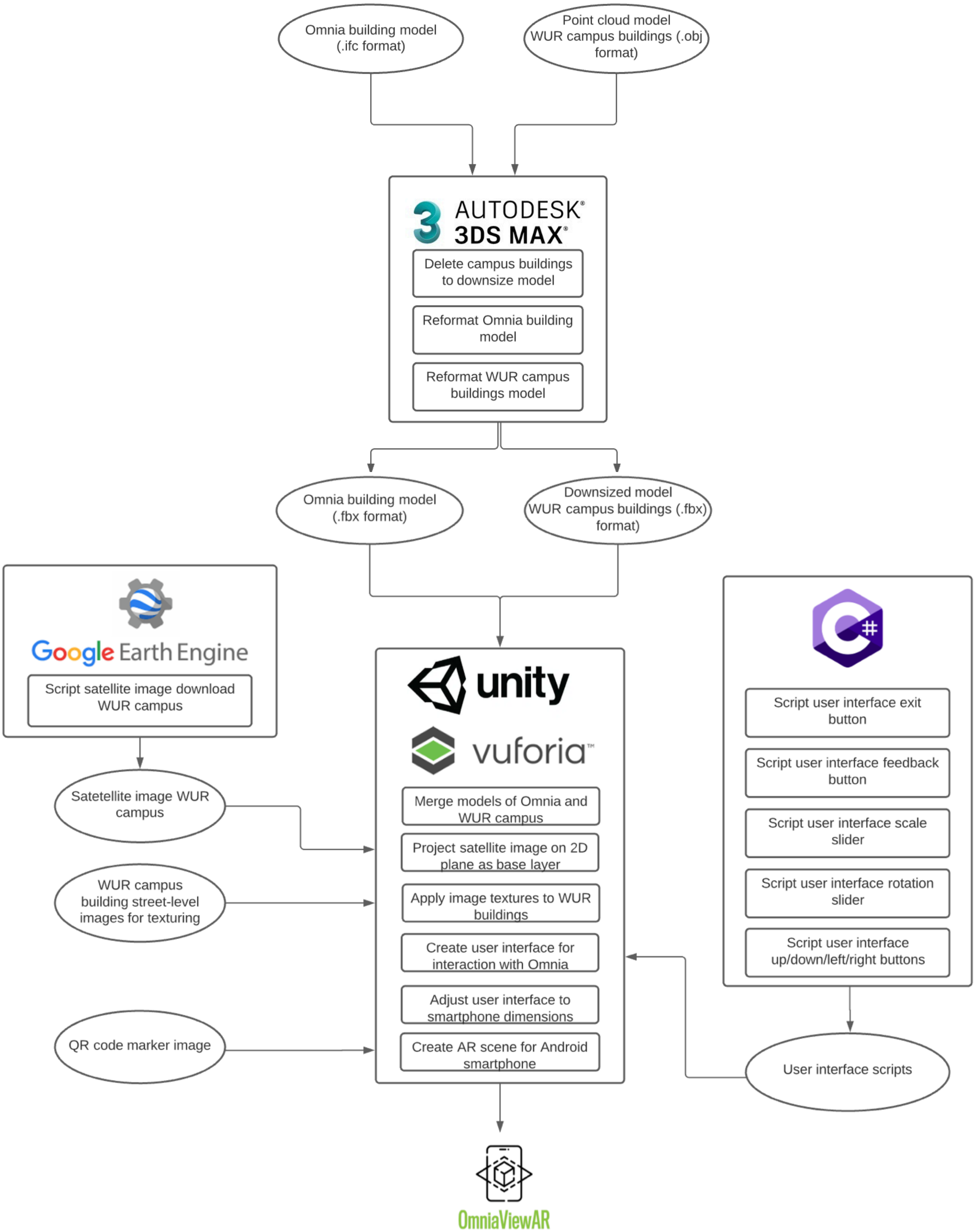

Figure 6: Flowchart showing the process of building the OmniaViewAR prototype application.

4. Results

The results are divided in separate sections. Section 4.1 describes the different types of AR hardware, software and data found in the articles reviewed for the SLR. Furthermore, the most occurring technology combinations applied in the articles will be described. This section provides the input to answer RQ1. Section 4.2 includes the findings on stakeholder involvement types related to AR for the SLR. Furthermore, it divides these stakeholder involvement types into possibilities and challenges related to the role of stakeholders in AR spatial planning. This section offers the input for a solution to RQ2. Section 4.3 describes the AR features and obstacles identified in the articles of the SLR. First, definitions are provided on what AR features and obstacles are, followed by an elaboration on the most prominent features and obstacles found in the articles. Findings in this section offer the input to answer to RQ3. Section 4.4 shows the results of the AR prototype. First, the visual characteristics and workings of the app will be shown after which the results of the app testing and validation will be presented.

4.1 Augmented reality technology

4.1.1 AR technology findings

In terms of AR technology, this SLR has been focusing on deriving three types of technology from the articles, being AR hardware types, AR software types and data types. Figure 7 shows a directed graph of all AR hardware types and software types that were used in the SLR articles. From a total of 70 articles that were analysed after filtering articles on exclusion criteria, 68.6% have discussed AR hardware types specifically. AR software types have been discussed in 71.4% of the articles. The edges in the directed graph in Figure 7 show the combinations between AR hardware types and AR software types that were applied in the articles. It can be observed that most articles tend to use the same types of AR hardware and AR software combinations while some types have much more edge linkages compared to others. For example, in Figure 7 the AR hardware type head mounted display (top) has considerably more edge linkages with different AR software types compared to external GPS receiver (top left) and the AR software type Unity 3D (right) has more edge linkages with other AR hardware types compared to Blender 3D design (bottom left).

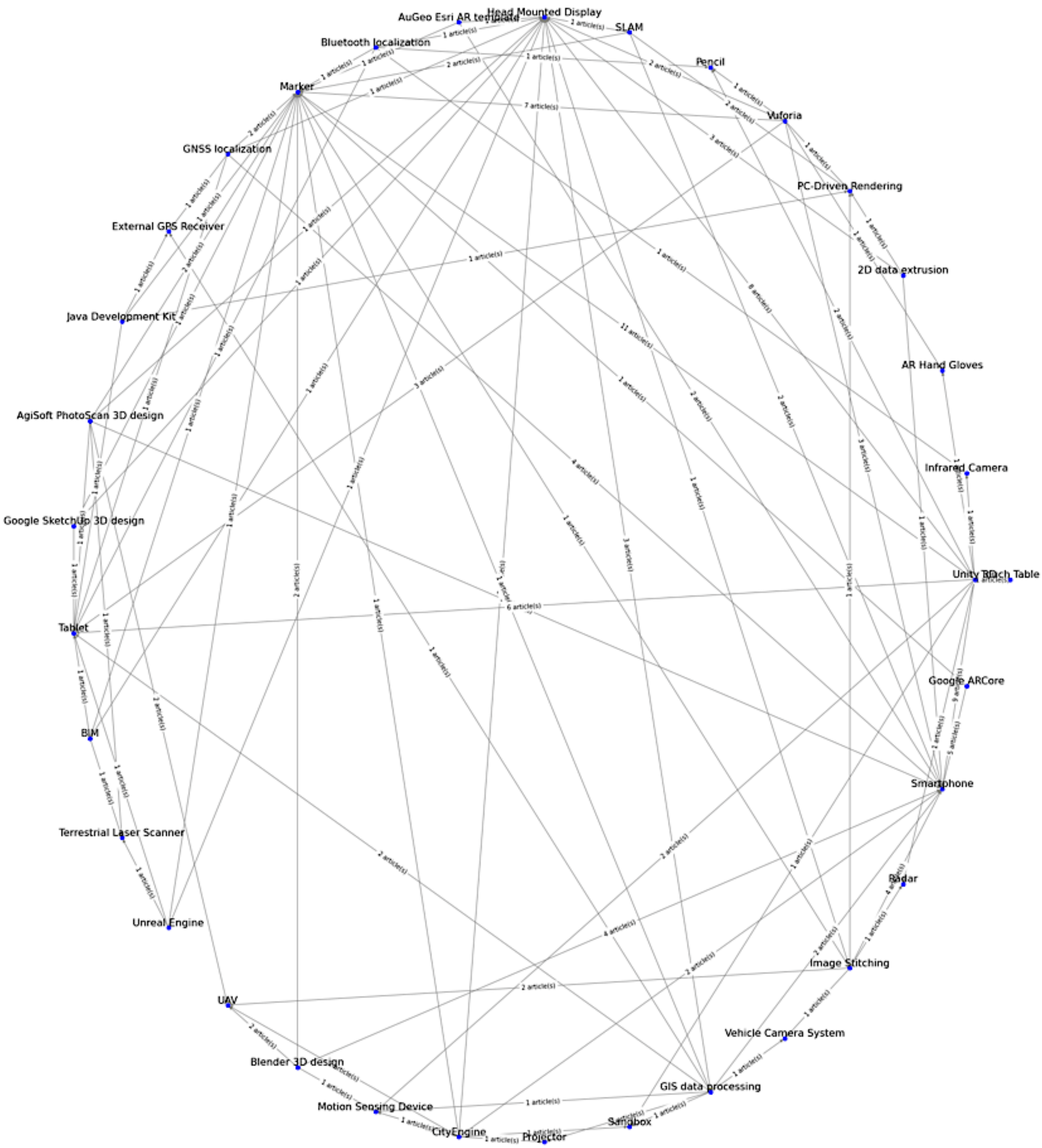

Figure 7: Directed graph showing the different combinations between AR hardware and AR software types on the nodes and the number of articles along the edges where these combinations were used in.

4.1.2 AR hardware types

From all 70 reviewed articles, the AR hardware type smartphone is linked with edges to a selection of 12 different AR software types (Figure 7). These 12 edges represent 40 articles in which smartphones have been applied which corresponds to 57.1% of the articles. Smartphones are therefore the AR hardware type most used in this study. Smartphones are perceived as the most accessible piece of AR hardware considering its low costs and easy integration with Unity 3D. For instance, Blut and Blankenbach, 2021, developed an AR application for which an urban 3D model was built in Unity 3D to be later implemented in a smartphone-based pose tracking system. Fenais and Ariaratnam et al, 2019 develop an AR application called XR-GIS that uses Unity 3D for creating a model of underground pipelines which can then be visualised through a smartphone. Other AR hardware types that have been applied in many articles are markers (52.9%), head mounted displays (40%) and tablets (25.7%).

The improved quality of smartphone cameras, GPU's and CPU's make this hardware type relatively cheap and accessible. AR applications that require more mobility such as navigation, monitoring on site or AR games make more use of smartphones. Tomkins and Lange, 2019 use an AR smartphone app for on-site flood visualisation and Stylianidis and Valari et al, 2020 created an AR smartphone app for on-site underground utility inspection.

Although head mounted displays are considerably more expensive compared to smartphones or tablets, this AR hardware type has been applied most often besides smartphones. The Microsoft HoloLens 2 has been used most often. Articles developing AR applications that require more locational precision or need more graphics processing power make use of a head mounted display. Sereno and Besançon et al, 2019 use multiple Microsoft Hololenses for a collaborative 3D data analysis tool. Syberfeldt and Danielsson et al, 2017 provide a performance comparison of several head mounted displays.

Tablets are the third most used AR hardware type. Tablets have comparable computational and graphical capabilities to smartphones. The larger screen of the tablet allows for easier interaction and collaboration between multiple app users. For instance, Ayer and Messner et al, 2016 develop an AR application for building design education for which a tablet is more convenient in teacher-student interactions. Goudarznia and Pietsch et al, 2017 use a tablet-based AR application to evaluate the acceptance of a new landscape design from the inhabitants of Bernburg, Germany. The advantage of a bigger tablet screen and easy portability in outdoor conditions is likely to be more convenient compared to smartphones and head mounted displays.

4.1.3 AR software types

An AR software type that has been used often is Unity 3D for example, the software package is linked to 11 different AR hardware types in 43 articles (Figure 7). A percentage of 61.4% of the articles makes use of Unity 3D for AR applications. This AR software type is therefore the most used AR software type in this study. Other AR software types that have been used in many articles are Vuforia (25.7%), GIS software (18.6%), and CityEngine (15.7%).

The reviewed articles use Unity 3D as the software tool for 3D modelling. Unity 3D allows for easy integration with mobile devices such as smartphones and tablets. This game engine offers a wide variety of plugins such as OpenCV, MRTK and Vuforia. The application called 'Immercity' was developed with use of Unity 3D and Vuforia by Taupiac and Rodriguez et al, 2018 wherein urban information such as location, opening hours and public transport information is visualised through AR. Other examples are Fenais and Ariaratnam et al, 2019 who use Unity 3D for mapping underground pipelines to be visualised in an augmented scene for easy localisation on site and Kim and Lee, 2016 who used a Unity-generated 3D model for direct AR augmented object manipulation with a Leap Motion Sensor.

The effortless integration of Vuforia with Unity 3D enables one to create an AR scene in Vuforia from the virtual model created in Unity 3D. This specific approach has been applied in 11 articles. For example, Blut and Blankenbach, 2021 combine the Unity 3D game engine with the AR capabilities of Vuforia to develop a pose tracking system for better alignment of augmented objects in the real world. Kassim, 2019 developed an educational AR application supported by Unity 3D and Vuforia called AREEE that lets students interact with augmented structures in engineering classes.

Other software types (e.g. GIS software) are used to pre-process, analyse, and transform spatial data for 3D modelling. 13 articles use GIS software such as Wang and Wu et al, 2018 who create a new app development architecture using GIS data as input for an AR application running on Microsoft Hololens. Afrooz and Ballal et al, 2018 create a participatory geodesign application that uses GIS data in an AR Sandbox.

CityEngine is another software package for 3D modelling from Esri specifically designed for modelling urban areas. CityEngine has been used in 11 articles including the article from Marques and Tenedorio et al, 2017 in which CityEngine modelling is used to display cultural heritage in an AR scene. Moreover, Boulos and Lu et al, 2017 present AR applications related to public and environmental health that use CityEngine models as a basis.

4.1.4 AR hardware software combinations and preferences

The outcomes of the SLR give insight into the different approaches that have been applied in the articles when AR applications were developed. For instance, the most occurring AR hardware - AR software combination is using markers and Unity 3D. This combination occurs in 11 different articles (Figure 7). For example, Tomkins and Lange, 2019 use this combination in the development of an AR application that uses an AR Sandbox for spatial planning collaboration in a workshop setting. Kaimaris and Roustanis et al, 2021 use markers and Unity 3D to create an AR application for inspection of cultural heritage.

The distribution of different AR hardware types and AR software types is not equal. Some types are used considerably more than others. AR hardware types such as touch table (1 article), projector (2 articles), AR hand gloves (2 articles) and vehicle camera system (2 articles) have only been applied in a low number of articles. Touch tables has only been used in an AR workshop setting. A projector has been used in an article describing AR as a tool for a collaborative visualisation approach in combination with the AR Sandbox.

Regarding AR software types, Google SketchUp, Java Development Kit and Unreal Engine have only been applied in 3 or 4 different articles. Compared to other 3D modelling tools such as Blender (9 articles) and AgiSoft PhotoScan (9 articles), Unreal Engine has been used in an article by Banfi and Brumana et al, 2019 for digitising and modelling of historical buildings that can then be shared via the cloud. This information indicates that there are clear preferences for specific types of 3D modelling and AR software compared to other software types.

4.1.5 AR data types

Different from AR hardware and software types, specific data types are applied considerably less. Only 28 out of 70 articles mention any specific type of data. Figure 8 shows the different data types that have been identified from the articles including the number of articles they occurred in. Most data types applied were used for 3D modelling after which the 3D model served as input for the AR application. The data type most used is street-level images which was applied in 13 different articles. Moreover, open data portals and Digital Elevation/Terrain/Surface models (DEM/DTM/DSM) have been used in 9 and 7 articles. For example, Kido and Fukuda et al, 2021 use an open dataset called Cityscapes that includes a large number of images in real world urban settings that they use as training data for a semantic segmentation model. Rydvanskiy and Hedly, 2021 use digital elevation models as input for their AR scene showing flooded urban areas. Street-level images are used in articles as input for 3D modelling. Especially when modelling urban areas and cultural heritage this approach is often used. While collecting street-level images is relatively labour intensive, 3D models created using this approach are of smaller scale compared to 3D models created with aerial or satellite images for example. Additionally, several articles describe the trade-off between the amount of detail in a 3D model and the scale of the model. Depending on the purpose of the AR application, authors choose for more detailed 3D models with a smaller scale or less detailed 3D models with a larger scale in order to maintain reasonable rendering speeds on the hardware that is used.

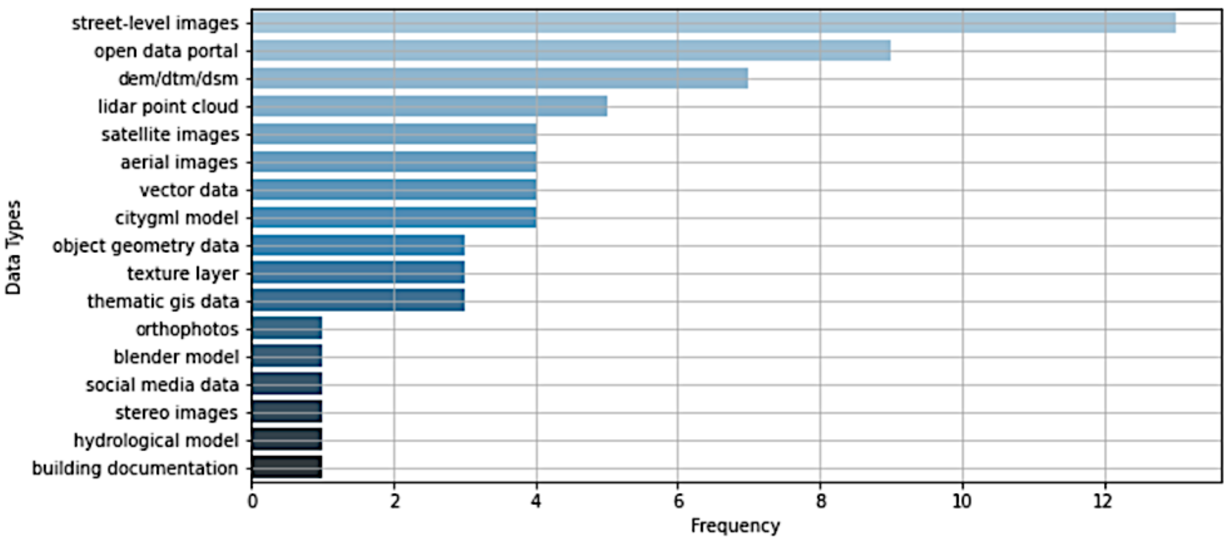

Figure 8: Frequency table showing data types compared to their number of article occurrences.

4.2 Stakeholder engagement in AR spatial planning

4.2.1 AR stakeholder involvement findings

Besides the technological aspects of AR described in section 4.1, articles have been reviewed for types of stakeholder involvement in AR spatial planning as well. From the 70 articles that were analysed, 39 articles have mentioned some type of stakeholder involvement in relation to AR. These relations were not specifically linked to spatial planning applications. In fact, only 13 of 39 articles applied AR to spatial planning and stakeholder involvement specifically. The other 26 of 39 articles described forms of stakeholder involvement and collaboration not linked to spatial planning particularly. Main themes reoccurring in the articles are cultural heritage visualisation (4 articles), AR games (5 articles), AR for educational purposes (3 articles) and navigation (7 articles).

4.2.2 Difficulties related to stakeholder engagement

Figure 9 shows the different stakeholder involvement types found in the 39 articles. Complex technology has been the stakeholder involvement type found in 12 articles and was the most occurring one.

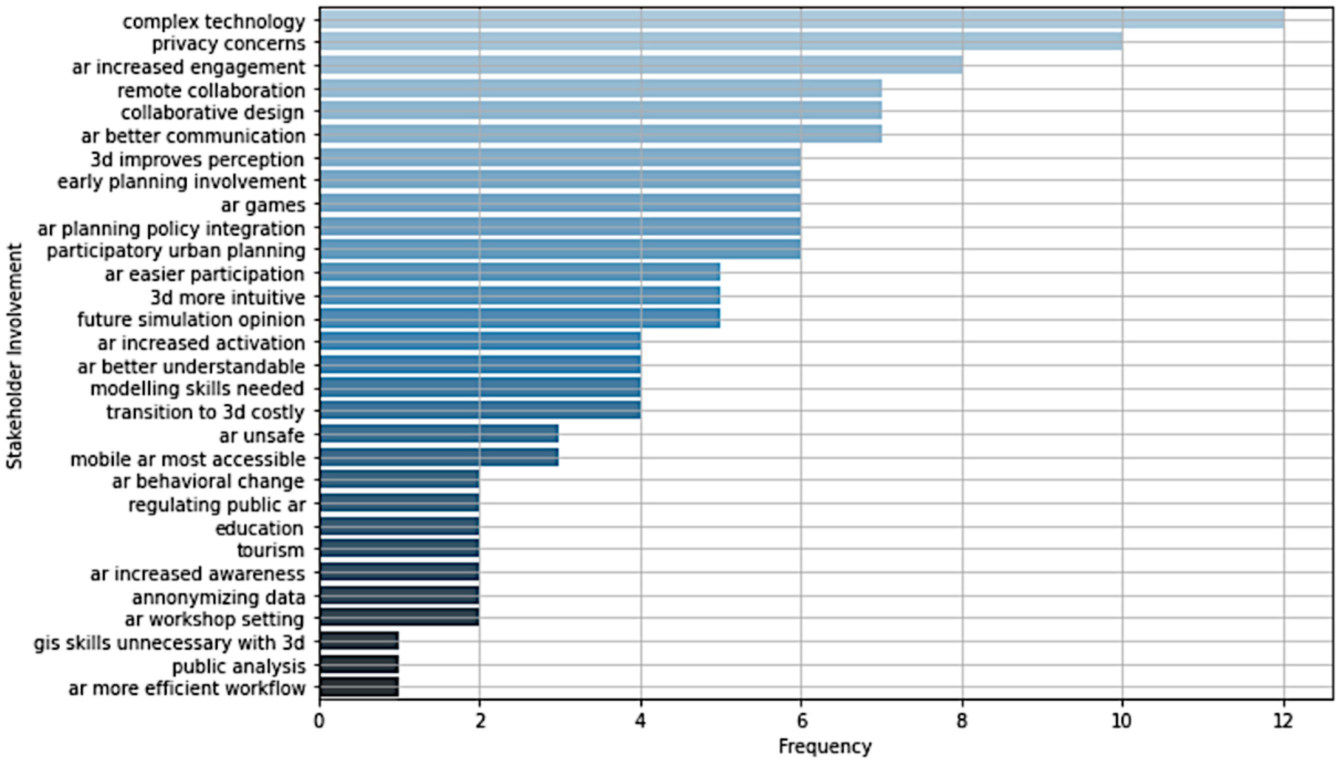

Figure 9: Frequency table showing stakeholder involvement types compared to their number of article occurrences.

This indicates that AR is still in its infancy while complex technology suggests that AR in spatial planning is not easily usable and complex to integrate. For example, Trivedi and Dubey, 2020 argue that AR is still a growing field and merely focused on gaming. Furthermore, they state that currently available hardware is not ready for mass implementation and too complex to operate. Only 13 of 39 articles, as mentioned in section 4.2.1, apply AR in spatial planning which amplifies the indication of limited AR implementation. Another stakeholder involvement type found is privacy concerns. In 10 articles privacy concerns have been described. Which adds to the indication that AR does not have a prominent role in the spatial planning domain. Articles describe privacy concerns of many types. Du and Li et al 2019 present an AR social media platform. In this article they describe the concern of sharing locational data of people and personal data visible in the AR scene. Azuma, 2019 argues that AR glasses helping as a virtual assistant could undermine the user's privacy while such an assistant needs to know much personal information to be effective.

4.2.3 Possibilities for AR stakeholder engagement

AR increased engagement is a stakeholder involvement type found in 8 articles and is the third most mentioned stakeholder engagement type (Figure 9). This type suggests that authors found that AR can foster collaboration between people and that it can serve as a means to bring people together compared to more conventional spatial planning approaches. Fistola and Rocca, 2018 and Kitchin and Young et al 2021 and Skaaland and Pitera, 2021 describe case studies in which AR is used to involve people in participation processes using AR technology.

Although the two most occurring stakeholder involvement types, complex technology and privacy concerns suggest that the implementation of AR in spatial planning is currently complex and limited, other types such as AR increased engagement and remote collaboration imply that authors foresee a useful purpose for AR which will improve in the future. AR increased engagement, remote collaboration, collaborative design and AR better communication suggest that AR can help people working and communicating together more easily. For example, Ayer and Messner et al, 2016 note that AR games are much more intuitive compared to conventional teaching methods in engineering education and therefore improves communication between the teacher and his or her students. Fegert and Pfeiffer et al, 2020 investigate the effectiveness of using AR to consult the public in infrastructural projects. They find that e-participation improves the involvement of the public into the participation process, but that limited AR experience limits the public's ability to be fully engaged.

4.3 Features and obstacles in AR

4.3.1 Definition of AR features and obstacles

Besides the identification of AR technologies and types of stakeholder involvement, specific AR features and AR obstacles have been identified as well. AR features encompass special techniques and approaches that have been used in the articles for AR application development. These can be solutions to known challenges in AR application development, specific techniques used, or uncommon functionalities created for AR applications. Obstacles include all difficulties that have been encountered with AR applications. These can be obstacles encountered during 3D modelling, data processing, hardware/software limitations or issues while using the AR app for example.

4.3.2 AR features

Regarding the features, 40 out of 70 articles have been identified that describe specific features related to AR application development (Figure 10). The feature most occurring is physical AR interaction, which entails different ways in which the app-user can interact with the augmented scene. Examples of physical AR interaction are hand tracking, eye tracking, head tracking, pose tracking and voice control. These types of physical AR interaction have been identified in 11 different articles. For example, James and Bezerianos et al, 2020 present a system that combines AR and shared displays for personal navigation that allows the user to adapt the direction of movement through head tracking.

Other features used in a relatively large number of articles are marker-based AR and cloud computing, found in 11 and 7 different articles respectively. Marker-based AR is a technique used in AR that uses physical objects in the real world as anchor points for virtual object placement through image recognition. Articles from Syberfeldt and Danielsson et al, 2017 and Kassim, 2019 use specific images as anchor points while other articles such as Quandt and Knoke et al, 2018 and Blanco-Pons and Carrión-Ruiz et al, 2019 present feature detection applied on objects from the physical environment surrounding the AR scene such as trees, rocks or benches. This can be understood as markerless AR. Diao and Shih, 2018 develop an AR building evacuation application that does not rely on specific marker objects. Shih and Chen, 2020 developed an AR application that compares past and present building facades without the need for marker detection.

Cloud computing was used in 7 articles and is a technology-focused feature used to speed up data processing. Rendering and projecting virtual objects in the augmented scene requires a considerable amount of processing power. In case the hardware used for the application does not have a CPU and/or GPU that is strong enough, cloud computing can be used to allocate parts of data processing to external servers. Cloud computing allows multiple users to see the same information in an AR scene which is what Kassim, 2019 is using in an educational setting. The AR application renders AR structures from Google Cloud for each student to be viewed in the same way. García-Crespo and González-Carrasco et al, 2016 developed CESARC which is an AR cultural entertainment system for smart cities. Cloud computing in this case allows urban data to be collected and processed in the cloud meaning that multiple users can access and visualise this data in their AR scene.

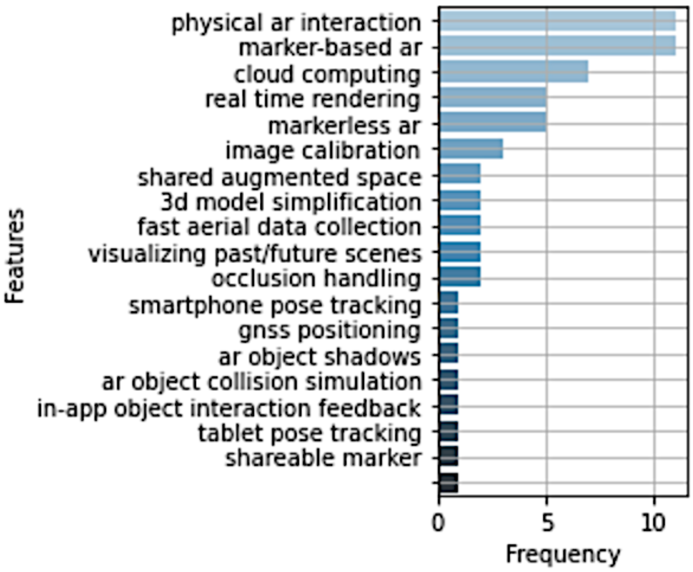

Figure 10: Frequency table showing stakeholder involvement types compared to their number of article occurrences.

4.3.3 AR obstacles

Different types of obstacles related to the development and use of AR applications have been identified from the reviewed articles. From the 70 articles included in the data analysis 51 articles describe obstacles encountered during AR development and use. Figure 11 shows all AR obstacle types that were mentioned in the 51 articles. The 3 most prominent obstacles found are occlusion (13 articles), GNSS inaccuracy (11 articles) and 2D or 3D format incompatibility (9 articles). Occlusion and GNSS inaccuracy are obstacles encountered during the use of the AR application and 2D or 3D format incompatibility is encountered during AR application development.

In case of occlusion, physical objects are hidden behind augmented objects limiting visibility and potentially hiding information within the AR scene. For instance, Rydvanskiy and Hedley, 2021 encounter problems with virtual content getting lost behind physical objects which requires their flood visualisation app to be restarted when that happens. Yagol and Ramos et al, 2018 describe occlusion problems as well. In their ARUJI application, Points of Interest (POI's) are displayed on top or behind each other when the distance between the user and the POI's is larger.

GNSS inaccuracy entails the misplacement of augmented objects in the physical world due to inaccurate positional information from satellites for example. Rodriguez and Huang, 2017 describe inaccurate GPS positioning in their smartphone-based AR app due to the presence of large buildings blocking the connection with satellites.

2D or 3D format incompatibility is an obstacle encountered during the development of AR applications. This obstacle entails the misalignment between data formats and required input for AR or 3D modelling software. Many spatial data sources such as data portals offer datasets in varying formats which makes creating 3D models and the AR application itself more complex and more time consuming. Marques and Tenedorio et al, 2017 touch upon difficulties in interoperability between GIS systems and 3D data related to the wide variety of data formats. Stylianidis and Valari et al, 2020 point out that the real time performance of their LARA system is limited due to the large number of data format conversions necessary to connect the different modules to the LARA system with each other.

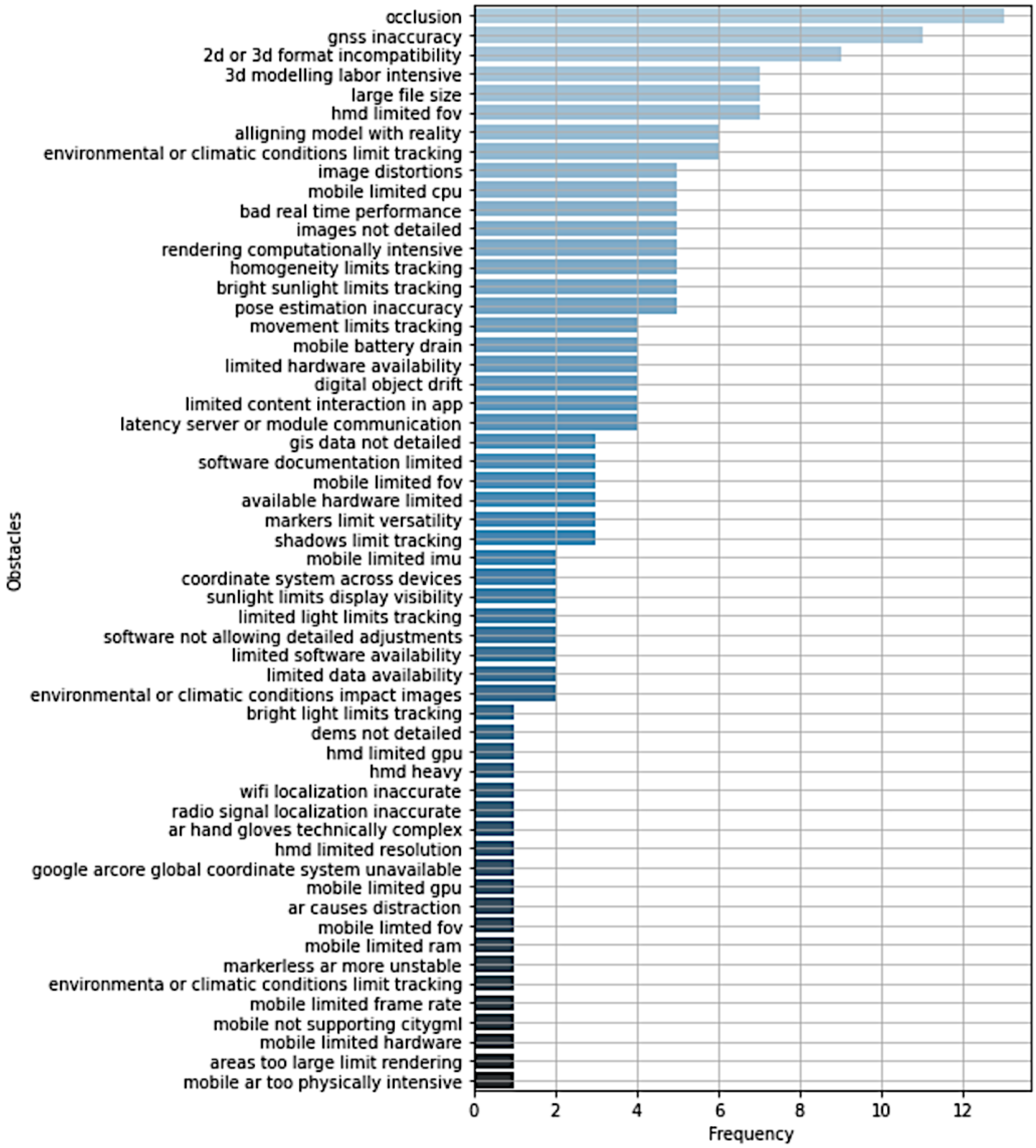

Figure 11: Frequency table showing AR obstacle types compared to their number of article occurrences.

Some of the AR obstacles can be linked to AR features showing that the most often occurring obstacles are known challenges and that AR application developers try to find ways to solve these. For example, the AR obstacles rendering computationally intensive and large file size, which were mentioned in 5 and 7 articles (Figure 11) can be linked to the fAR eature 3D model simplification mentioned in 2 articles. Marques and Tenedorio et al, 2017 use Agisoft PhotoScan for 3D modelling. By downscaling the resolution of the images in the dataset and the number of images they decrease the size of the dataset which consequently decreases processing time of their AR application on a smartphone.

Another example of such a combination between AR obstacles and AR features is limited content interaction in app and physical AR interaction. 4 articles describe a lack of interaction with virtual objects in their AR application as an obstacle. These are Du and Turner et al, 2020, Noghabaei and Heydarian et al, 2020, Kim and Lee, 2016 and Hubenschmid and Zagermann et al, 2018. 11 articles provide potential solutions and describe different ways of applying types of physical interaction within AR applications. For example, Rydvanskiy and Hedley, 2021 apply articulated hand tracking to their AR application that allows the user to manipulate augmented objects that are close by including pinching and grabbing the object. More potential complementary relations between AR features and AR obstacles are described in section 5.3.2 of the discussion.

4.4 AR prototype

4.4.1 AR prototype characteristics

The AR prototype called OmniaViewAR works on Android smartphones and was developed using Unity 3D game engine together with Vuforia. Figure 12 shows the setup in Unity that was created for OmniaViewAR including the different GameObjects in the AR scene. The AR scene would activate when aiming the smartphone on the QR code marker. This QR code marker was a printout of a QR code. The AR scene could be scaled and rotated to match the size of the room the prototype was used in. Figure 14 shows different perspectives of the AR scene which could be adjusted using the user interface. A rotation slider, scale slider and buttons for up, down, left and right were added to the user interface which can be seen in Figure 13 and figure 15. Furthermore, the user can also physically move the smartphone to move through the AR scene. The feedback button (top right) in the prototype can be pressed to redirect the user to a feedback form. In a hypothetical situation this feedback button could be used to allow app users to express their opinion about the building which could be valuable information to municipalities and contractors to adapt the new building to the stakeholder's wishes. For this application however, the feedback button redirected the user to a feedback form with questions on the performance and user-friendliness of the prototype and questions on their opinion on using AR for spatial planning purposes.

Based on the SLR findings, it was clear that the prototype should be developed in a way that it would be easy to distribute and install for users remotely to reach as many people as possible and to reduce the complexity of using the prototype to a minimum. Therefore, this prototype can be downloaded and installed by scanning the QR code marker image. The QR code marker image was used for downloading the prototype and activating the AR scene.

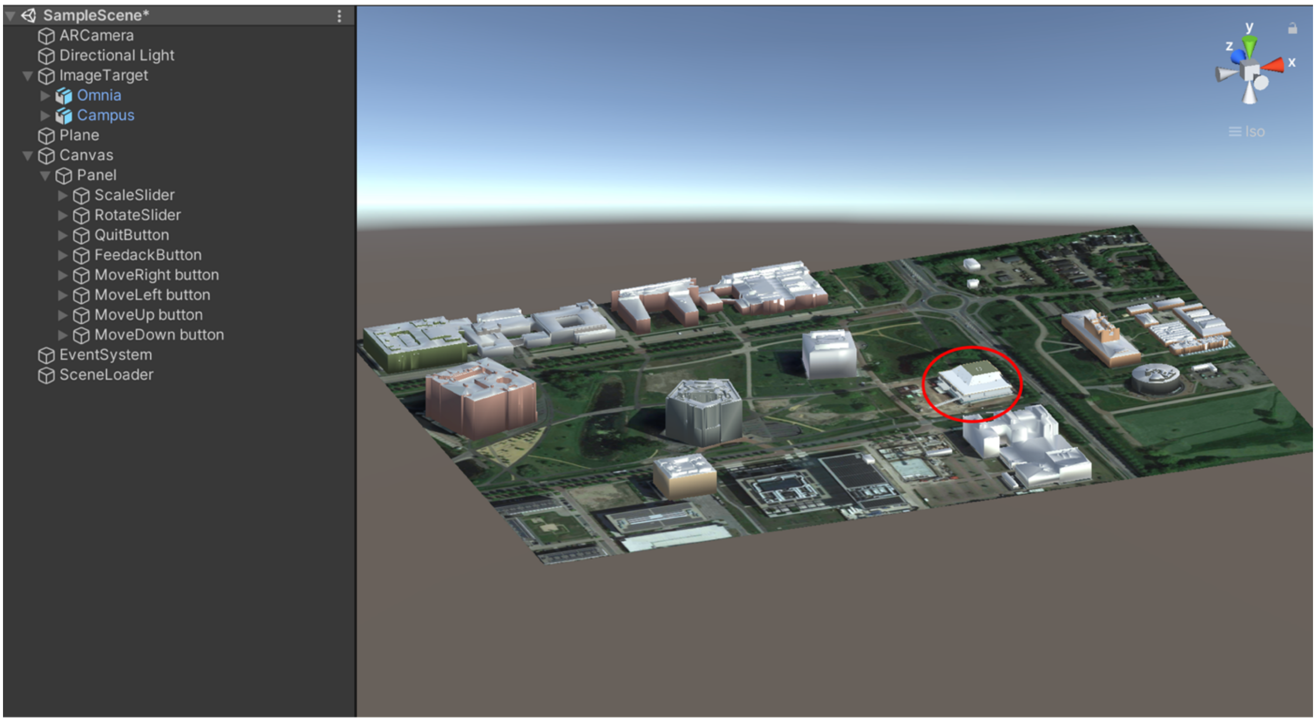

Figure 12: The AR scene in Unity showing the Omnia building in the red circle. The pane on the left shows the different GameObjects that have been used to create this AR scene.

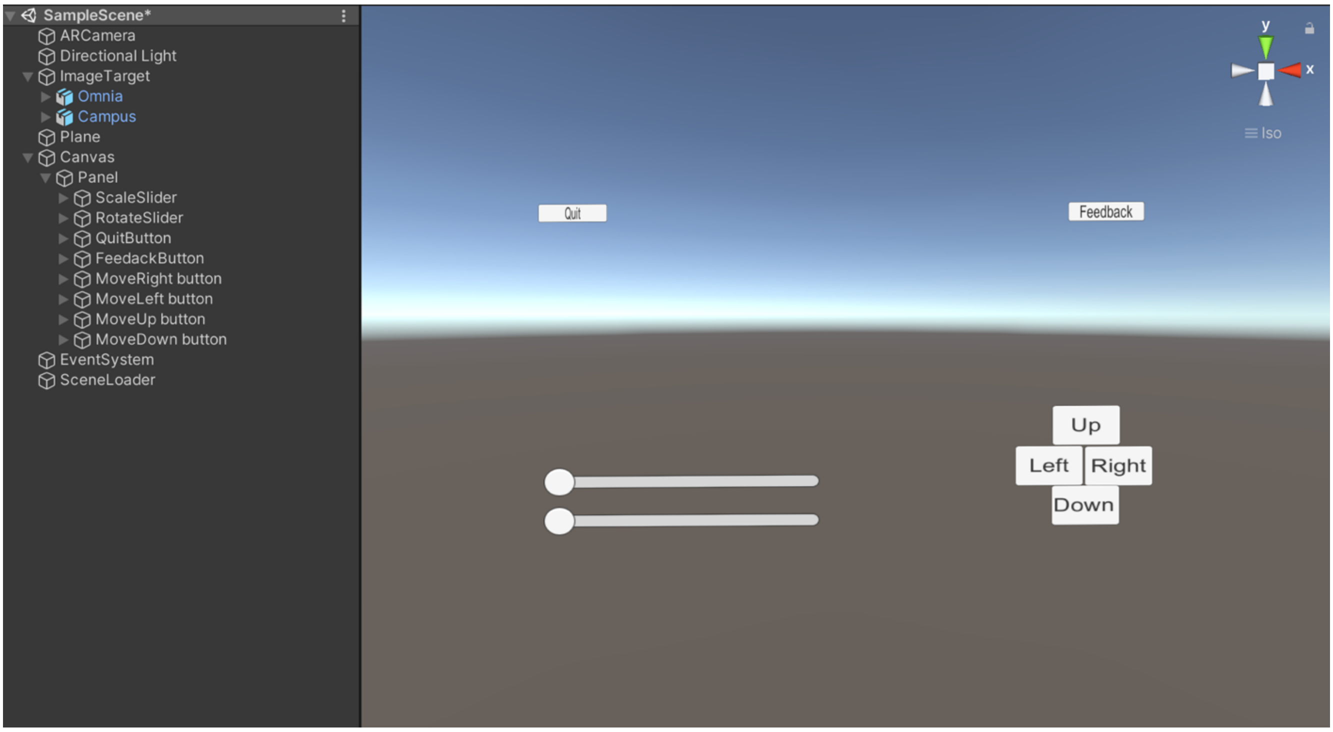

Figure 13: The AR scene in Unity showing the user interface created to interact with the Omnia building. A separate GameObject for every button and slider was created and added to a Canvas object. Which is shown in the pane on the left.

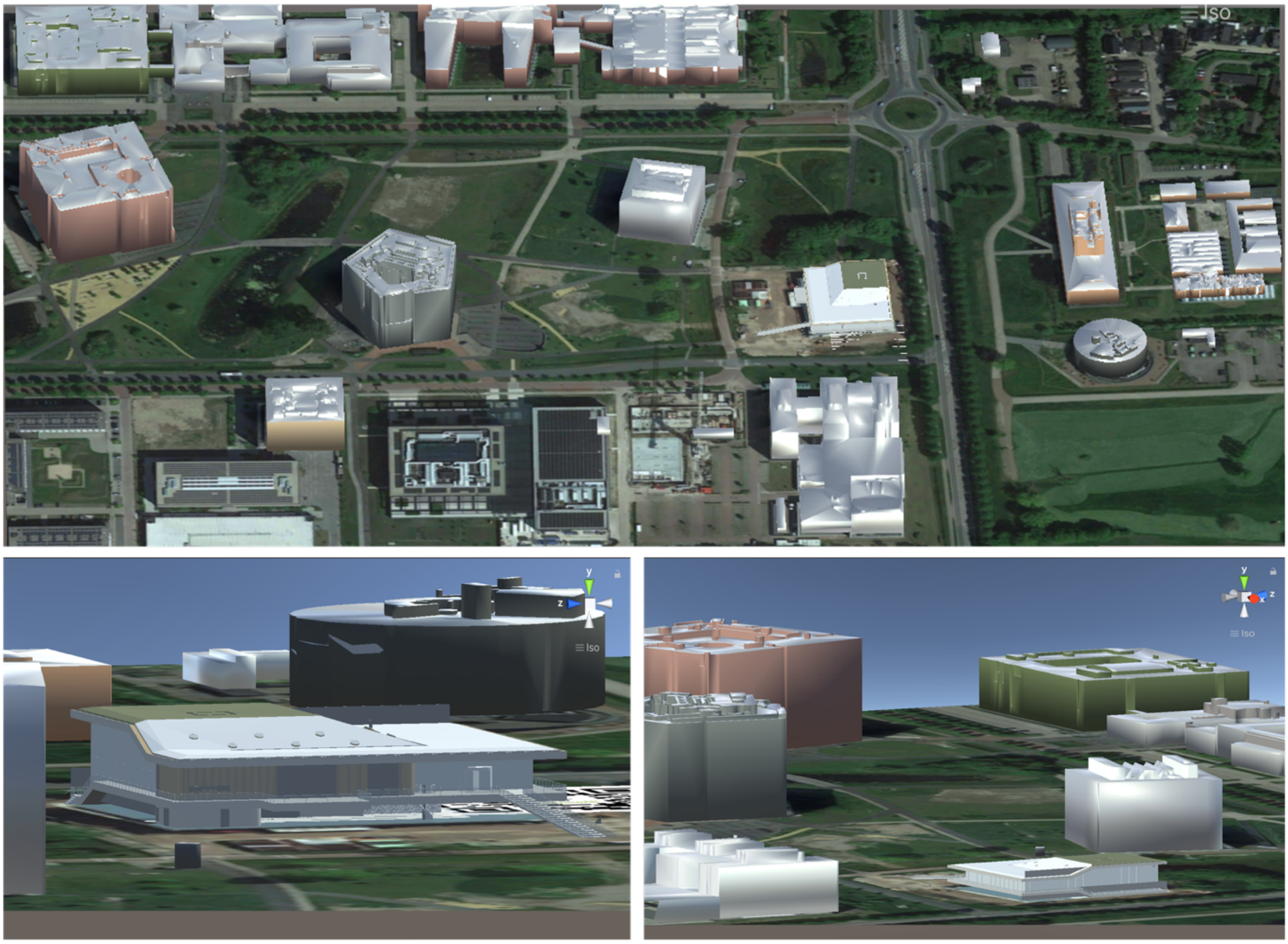

Figure 14: Multiple views of the AR scene in Unity showing the Omnia building from different perspectives. The viewing perspective could be changed using the user interface.

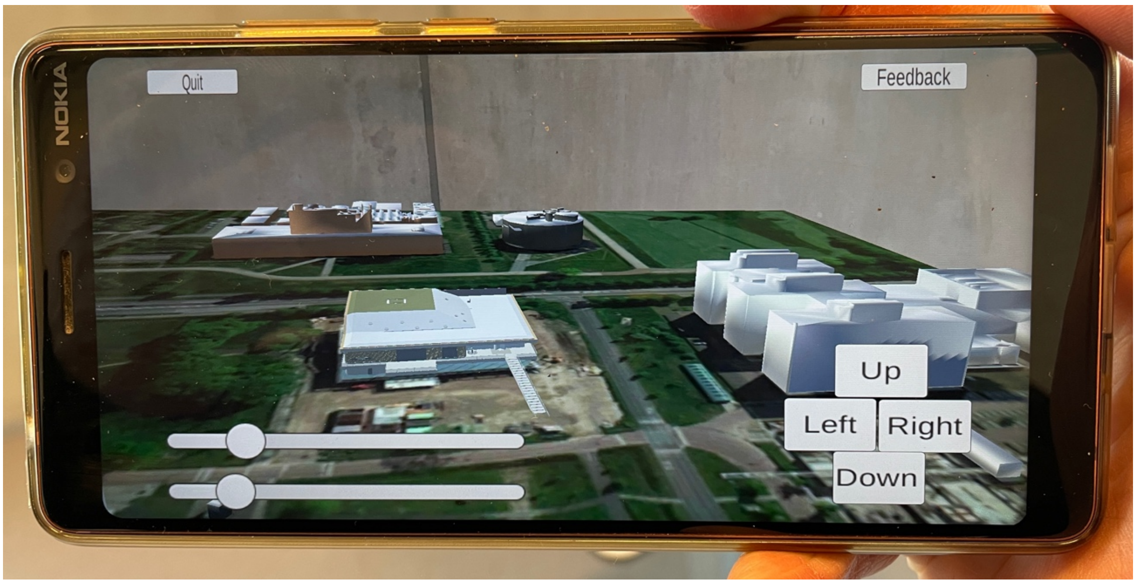

Figure 15: An image showing the user interface of OmniaViewAR on an Android smartphone including all buttons to view Omnia from different angles.

4.4.2 AR prototype validation

The AR prototype has been tested by a group of people. This group consisted of 12 people which were students and employees from Wageningen University. As described in section 4.4.1, the prototype could be downloaded using a QR code. This QR code was distributed via email and social media. Users had to print this QR code to download the prototype, this QR code was also the marker to activate the AR scene. After using the prototype, the testers were asked to press the feedback button which would lead them to the feedback form. The analysis of answers to these questions is presented in Figures 16, 17 and Table 5.

The questions in Figure 17 are related to the experience of OmniaViewAR. These are multiple choice questions where respondents could choose whether they agreed with the proposition or not. The survey results are varied with responses ranging from totally agree to totally disagree. Although people had very little experience with AR applications overall (Figure 16), responses on the questions in Figure 17 are generally more positive. 11 out of 12 respondents would prefer an AR app over a conventional building plan (Q8). On the other hand, not all respondents were able to install and start the app smoothly (Q2). Moreover, the interaction with the user interface was in 3 cases not satisfactory (Q3). 11 out of 12 users experienced a high degree of immersion (Q6) and for 8 respondents the AR app was sufficient to have an opinion on the Omnia building (Q7).

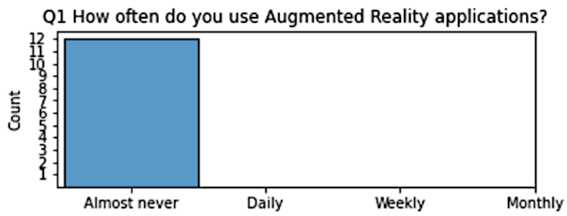

Figure 16: The survey results of the validation of OmniaViewAR including question 1 about the frequency of AR app usage.

Table 5 shows the different advantages and disadvantages of AR applications for spatial planning projects that respondents have mentioned in survey questions 9 and 10. The advantages and disadvantages are categorised into keywords. In general, the biggest advantages that have been mentioned are the improved imagination AR provides, a clearer and bigger oversight of the new building and its surroundings and the improved accessibility for younger generations. The biggest disadvantages are generally the risk of people not understanding how the app works or how to install it. This is a disadvantage often mentioned. Moreover, respondents mentioned disadvantages such as less face-to-face interaction when using AR applications, the AR scene being too idyllic, the irrelevance of maquettes and drawings when AR is used, and the need for a smartphone.

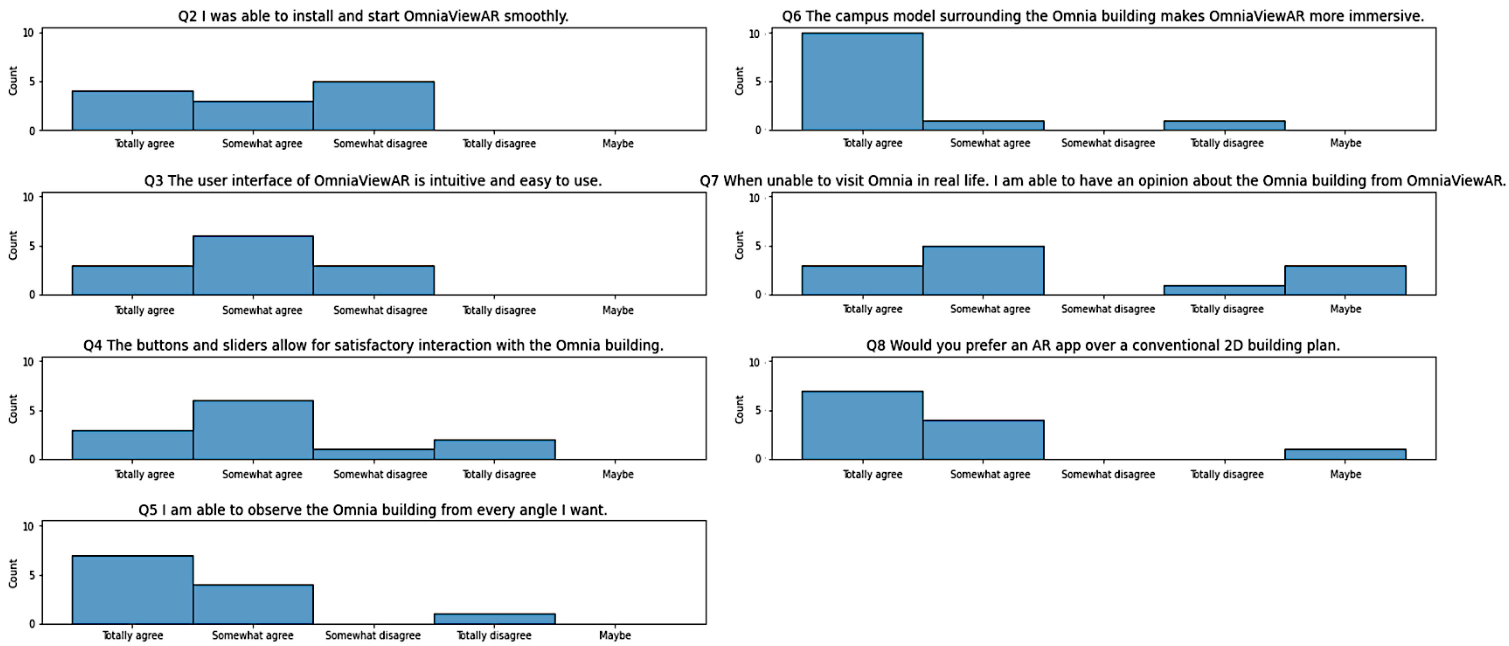

Figure 17: The survey results of the validation of OmniaViewAR including questions 2 to 8 about the app experience.

Table 5: The survey results of the validation of OmniaViewAR including question 9 and 10 on the biggest advantages and disadvantages of using AR for spatial planning projects.

What would be the biggest advantage of using Augmented Reality (AR) apps to ask for opinions from civilians in spatial planning projects?	What would be the biggest disadvantage of using Augmented Reality (AR) apps to ask for opinions from civilians in spatial planning projects?
Individual exploration	less face-to-face interaction
More curiosity	more resistance with clearer representation
Clearer insight	people don't understand app
More fun	people not digitalised
Reach younger generation	older people unable to use app
Simple enough for older generation	effort to install and use app
Increased imagination	people less digitally advanced
fit of new buildings	people don't understand app
fit in landscape	view is too idyllic
3D improves height imagination	need for electricity and internet and smartphone
fit in environment	less portable to remote areas
more immersive	looks uglier
see bigger picture	Importance maquettes and drawings fades
more immersive	
better feeling of surroundings and proportions	

5. Discussion and Recommendations

5.1 Indications from AR technology

5.1.1 Research question 1

What types of AR technologies are being employed within the domain of spatial planning applications in terms of hardware, software and data? This research shows that the array of different hardware and software types is limited which indicates that most AR applications make use of similar and well-known technologies. The smartphone is the most applied hardware type for AR applications. This device is relatively cheap, easy to operate and most accessible to people. The AR software type most often used is Unity 3D. This game engine together with AR plugins such as Vuforia form the basis of most AR applications in the reviewed articles. In terms of data, most AR applications do not make use of already existing datasets. Authors rather collect data themselves which is used primarily for 3D modelling. Most applications have used street-level images for 3D modelling to create the AR scene.

5.1.2 AR technology preferences

The results regarding the findings on AR technology indicate that particular types of AR hardware and AR software are used more often than other types. Hardware types such as smartphones, markers and tablets are used in considerably more articles compared to AR hand gloves, AR pencils and projectors for example. This accounts for software types as well. Unity 3D, Vuforia and GIS data processing are used far more often compared to 2D data extrusion, Unreal Engine or Java Development Kit. This indicates that most authors tend to adhere to similar ways of implementing AR technology into their projects and waive from less well-known technology. Developing a smartphone AR application with use of Vuforia has been done more often than developing an AR app using AR hand gloves in Unreal Engine. This preference for well-known AR development strategies has a positive effect on these particular types of AR hardware and software because these technologies will be refined and further developed. This creates a positive feedback loop causing people to use well-known technologies even more because of this refinement and development. On the other hand, technologies used less often such as Sandboxes, vehicle camera systems or Google ARCore and SLAM are used less which decreases the development speed of these technology types. Considering the unfamiliarity and recent introduction of AR in the spatial planning domain, it is recommended to focus on the most often used hardware, software and data types for spatial planning projects while these technologies are better implementable in spatial planning workflows and likely to be more familiar to stakeholders in the spatial planning project.

5.1.3 Accessibility differences

The large differences between the use of particular types of AR hardware and AR software compared to others is likely to be linked to differences in accessibility of these technologies as well. Hardware and software types that are cheaper, more common and less technically complex are preferred over expensive, less common and complex types of hardware and software. More information on how to use these technology types is available as well. For example, smartphones are used in more AR applications compared to AR hand gloves while smartphones are more accessible to people in terms of costs and technical complexity. Moreover, everyone uses smartphones which makes the AR application more easily used in larger groups of people. Especially, the Unity game engine is a popular software type for 3D modelling and is easily integrated with Vuforia to create an AR scene. While Unreal Engine is a game engine with similar capabilities as Unity 3D, this software type is used far less. Considering the aim of increasing the involvement of stakeholders in spatial planning projects, it is recommended to focus on the technology that is most accessible in terms of costs, ease of distribution and technical complexity to stakeholders in order to decrease the effort needed for stakeholders to participate.

5.1.4 Data use in AR applications

Regarding the use of data in AR applications, it is interesting to note that the use of ready-made publicly accessible 3D data is not common in the AR community. The results show that street-level images are used in most studies. Within these studies, the images are often collected by the authors themselves and used as input for 3D modelling. While open data portals are the second most used source of data in this study, most of the data from these portals have a 2D format for which the third dimension needs to be added to create the AR scene. Therefore, recommended opportunities for improved data availability would be to make 3D data more widely accessible because most public data is provided in a 2D format at this moment. The third dimension can be measured in multiple ways with use of LiDAR, photogrammetry or radar height estimations which would be a useful addition to existing 2D datasets and would improve the realism of 3D objects in the AR scene.

5.2 Indications from AR stakeholder involvement types

5.2.1 Research question 2

In which ways do AR applications have an impact on stakeholder engagement and collaboration in spatial planning applications? Due to the low number of articles found that describe AR technology in the context of spatial planning, insights on the impact of AR on stakeholder engagement and collaboration are limited. The extent to which AR is integrated into spatial planning workflows is still limited. The technology is still relatively new and unknown to planners. Studies into the effect of AR on stakeholder engagement and collaboration are therefore scarce. The most prominent data extraction types found were complex technology and privacy concerns. This adds to the indication that planners are unfamiliar to AR and not yet seemingly ready to adapt their more conventional spatial planning approaches to the use of AR. However, stakeholder involvement types such as 'AR increased engagement', 'collaborative design' and '3D improves perception' are examples found in this study that show that AR is recognized as a useful addition to future spatial planning projects. A recommendation would be to allow for exploration of AR technology within spatial planning projects. Currently existing regulatory frameworks for spatial planning projects are standardized and do not leave much space for innovation in terms of time and cost which has been pointed out in articles such as Kitchin and Young et al, 2021. Therefore, it is recommended to adapt these frameworks to allow for exploratory research on the use of AR in spatial planning.

5.2.2 Lack of AR spatial planning applications

Following from the results on stakeholder involvement types in spatial planning applications, it can be argued that spatial planning applications are scarce in the array of AR scientific publications. As stated in the results, only 13 of 70 articles included in this study, described AR spatial planning applications specifically. The other 57 articles described AR applications in other domains such as engineering, social media, education or navigation. This indicates that AR currently does not yet have a prominent role in the spatial planning domain. This notion is confirmed by several articles including Trivedi and Dubey, 2020 and Skaaland and Pitera, 2021. They have pointed out that AR is still a complex technology, and that people are still unfamiliar to this type of visualisation which is enforced by the outcomes of the survey in Figure 16 as well. Spatial planning still relies on 2D visualisations. As Kitchin and Young et al, 2021 point out, planners are still bound to more conventional planning procedures and guidelines which do not allow for new types of visualisations due to bureaucratic, time and cost constraints. Despite the limited implementation of AR in spatial planning projects, authors such as Sassmannhausen and Radtke et al, 2021 describe positive reactions from spatial planners who are in general enthusiastic about this new technology and foresee potential for AR in future spatial planning projects. In order to integrate AR into spatial planning workflows, planners will have to adapt their planning approaches to allow new techniques and technology to be implemented. Future recommended actions would therefore be to conduct more research into the possibilities AR specifically provides to the spatial planning domain and to focus on more involvement of the spatial planning domain in future development of AR technologies.

5.2.3 Different stakeholder involvement types

When analysing the different stakeholder involvement types from the results, one can make a distinction between types that can be seen as a positive consequence of implementing AR in spatial planning and stakeholder involvement types that could hinder this implementation. In Table 6 this distinction is presented.

Most of the stakeholder involvement types help fostering AR spatial planning implementation. These types describe how AR could improve people's cognitive abilities to understand visualisations. 3D more intuitive, AR better understandable, AR behavioural change and AR more efficient workflow are examples of that notion. Other types point out that AR could be the platform bringing people together in spatial planning projects. AR increased engagement, remote collaboration, collaborative design, AR better communication, early planning involvement, participatory urban planning, AR easier participation, AR increased activation, mobile AR most accessible and AR increased awareness are stakeholder involvement types suggesting this.

Stakeholder involvement types that have a negative effect on AR spatial planning implementation relate to 3 main themes: complexity of AR technology, high implementation costs and concerns related to data privacy. Complex technology, modelling skills needed and GIS skills unnecessary (Table 6) are types indicating that spatial planners currently do not possess the necessary skills and knowledge to use AR in their spatial planning projects. AR planning policy integration and transition to 3D costly have been mentioned in articles indicating that transforming the current spatial planning workflows and especially the regulatory frameworks that are currently based on 2D analysis and visualisation is too costly and not worth changing their spatial planning approach. Considering that AR technology is not fully developed and accessible to every spatial planner enforces this argument. Privacy concerns, AR is unsafe, regulating public AR, anonymizing data and public analysis are stakeholder involvement types relating to privacy concerns. As with many new technologies, people are not keen to embrace new technologies instantly. Potts and Jacka et al, 2017 and Awang and Majid et al, 2020 and Goudarznia and Pietsch et al, 2017 have done surveys to map different opinions of people on AR. García-Crespo and González-Carrasco et al, 2016 show that people are afraid of their personal data being exposed to others.

Table 6: An overview of the Stakeholder involvement types found in the articles. A distinction can be made between types that foster AR spatial planning implementation and others that hinder it.

Stakeholder involvement types fostering AR spatial planning implementation	**Stakeholder involvement types hindering AR spatial planning implementation**
AR increased engagement	Complex technology
Remote collaboration	Privacy concerns
Collaborative design	AR planning policy integration
AR better communication	Modelling skills needed
Early planning involvement	Transition to 3D costly
AR games	AR is unsafe
Participatory urban planning	Regulating public AR
AR easier participation	Anonymizing data
3D more intuitive	GIS skills unnecessary with 3D
Future simulation opinion	Public analysis
AR increased activation	
AR better understandable	
Mobile AR most accessible	
AR behavioural change	
Education	
Tourism	
AR increased awareness	
AR workshop setting	
AR more efficient workflow	

5.3 Indications from AR features and obstacles

5.3.1 Research question 3

Which possibilities and challenges arise when using AR in spatial planning applications? AR features are specific characteristics of the application design and usage. Physical AR interaction is the feature most mentioned in the reviewed articles (Figure 10). Authors have experimented with different ways of interaction with the AR content such as hand, eye, head and pose tracking of the user. Furthermore, the AR feature marker-based AR is mentioned frequently indicating that most AR applications are marker-based instead of markerless. Different types of AR obstacles have been mentioned extensively in the articles. The large variety of obstacles is an indication that AR application development is a complex task and is therefore not yet easily implementable in spatial planning workflows. AR obstacles are related to AR tracking, data processing, hardware limitations, locational inaccuracy, unavailable tools and the AR application experience. It has been shown that a number of AR features could serve as potential solutions to AR obstacles.

5.3.2 Complementary AR features and AR obstacles

The results of the AR features and obstacles show that the number of obstacles that have been identified from the articles is larger compared to the number of features. A total of 56 different types of obstacles have been described and 18 features have been extracted from the articles. One could argue that the number of 56 different obstacles indicates that the development of AR applications comes with a relatively large number of recurring challenges compared to the features that have been identified. The number of features is considerably less and although not all features are necessarily complementary to the obstacles, it suggests that there is currently a limited number of solutions to the identified AR obstacles. However, some of the features and obstacles are complementary to each other to a certain extent. In other words, these features provide possible solutions to the corresponding obstacles. These are presented in Table 7. It has to be noted that the features are only potential solutions to the obstacles. The context and specific details of the articles in which these obstacles and features were described have not been taken into account when pairing the features and obstacles in this table. Most of the articles present similar obstacles in AR application development. More oversight on potential solutions to these obstacles might be desirable. It is therefore recommended to put more effort into creating overviews of existing AR features and AR obstacles and to investigate to what extent obstacles can be solved by these features.

Table 7: The AR obstacles with their complementary AR features which can be considered as potential solutions to these AR obstacles. Furthermore, the AR obstacles have been categorised.

	Complementary AR Obstacles and AR Features	
Obstacle category	**AR Obstacles**	**AR Features**
AR tracking	Occlusion	Occlusion handling
	Image distortions	Image calibration
	Environmental or climatic conditions impact images	Image calibration
	Environmental or climatic conditions limit tracking	
	Homogeneity limits tracking	
	Bright sunlight limits tracking	
	Movement limits tracking	
	Shadows limit tracking	
	Limited light limits tracking	

	Bright light limits tracking	
Data and Processing	3D modelling labour intensive	3D model simplification, fast aerial data collection
	Large file size	Cloud computing, 3D model simplification
	Images not detailed	
	Areas too large limit rendering	Cloud computing, real time rendering, 3D model simplification
	2D or 3D format incompatibility	
	GIS data not detailed	
	DEMs not detailed	
Hardware Limitations	Mobile limited CPU	Cloud computing
	Bad real time performance	Cloud computing, real time rendering, 3D model simplification
	Rendering computationally intensive	Cloud computing, real time rendering, 3D model simplification
	Mobile battery drain	Cloud computing, 3D model simplification
	Latency server or module communication	Cloud computing, real time rendering, 3D model simplification
	Mobile limited IMU	Tablet pose tracking
	HMD limited GPU	3D model simplification
	Mobile limited GPU	3D model simplification
	Mobile limited RAM	Cloud computing
	HMD limited FOV	
	Limited hardware availability	
	Mobile limited FOV	
	HMD heavy	
	AR hand gloves technically complex	

	HMD limited resolution	
	Mobile limited framerate	
	Mobile not supporting CityGML	
	Mobile limited hardware	
Locational Inaccuracy	Pose estimation inaccuracy	Markerless AR
	Coordinate system across devices	Shared augmented space
	WIFI localization inaccurate	GNSS positioning
	Radio signal localization inaccurate	GNSS positioning
	Markerless AR more unstable	Marker-based AR
	GNSS inaccuracy	
	Digital object drift	Marker-based AR
Unavailable Tools	Software documentation limited	
	Available hardware limited	
	Software not allowing detailed adjustments	
	Limited software availability	
	Limited data availability	
	Google ARCore global coordinate system unavailable	
AR applications experience	Aligning model with reality	Real time rendering, image calibration, occlusion handling, AR object shadows, AR object collision simulation
	Limited content interaction in app	Physical AR interaction, in-app object interaction feedback
	Markers limit versatility	Markerless AR, shareable marker
	Sunlight limits display visibility	
	AR causes distraction	
	Mobile AR too physically intensive	

5.3.3 AR obstacles

The types of AR obstacles can be further categorised to get a better insight into the overall challenges for AR applications. This categorization of AR obstacles is indicated in the first column of Table 7 and shows the different types of obstacles. As can be observed in Table 7, most of the obstacles are related to hardware limitations. The array of available hardware types is currently limited. Only a small number of head mounted displays, tablets and smartphones are available. Where head mounted displays are relatively expensive and smartphones and tablets lack the computational capabilities needed for more advanced AR applications. Furthermore, interestingly there is a large array of different tracking obstacles. Different kinds of environmental factors have been described as sources of AR tracking disturbance. Most of these sources affect and change the visual characteristics of real-world objects which makes image recognition a lot more complex.

5.3.4 AR features

Table 7 shows that not all AR obstacles are provided with a potential solution from the AR features. Most AR features provide potential solutions to hardware limitations. Especially, cloud computing could provide a solution to the limited computational capabilities of AR hardware by sending data to the cloud to be processed there and then to be sent back to the smartphone, tablet or head mounted display. Another AR feature that could decrease the computational load is 3D model simplification. This method is applied in several articles including Marques and Tenedorio et al, 2017 and Kitchin and Young et al, 2021. The trade-off here is of course the simplification of the AR application which -in some cases- is not desirable while it negatively affects the degree of immersion of the AR scene. Not all features have been identified as potential solutions to the AR obstacles. Some of them such as in-app object interaction feedback and visualising past/future scenes are AR features not oriented towards specific AR obstacles.

5.4 Indications from AR application

5.4.1 Research question 4

How can the developed prototype AR application promote stakeholder collaboration in spatial planning and how will this be validated? The AR prototype application OmniaViewAR shows the potential of using AR for e-consulting the public about a new building. The application allows people to view the new building from everywhere they want using their smartphones. This app improves stakeholder involvement and collaboration by making building plans more easily distributable, more accessible and easier to understand compared to conventional building plans. The validation of OmniaViewAR has been done by means of a survey distributed among app testers. The survey outcomes show that respondents were positive about the increased degree of immersion when using AR for spatial planning and the fact that AR triggers more curiosity and activates younger people. On the other hand, people experienced difficulties when installing and using the app. Moreover, many respondents foresee issues for people who would not know how to install and use the app. Regarding this prototype, it is recommended that user guidelines need further improvement to make installation and use less complex and to make the app accessible to more people. Furthermore, in terms of validation, the limited experience of most people with new technologies such as AR has to be considered when creating feedback surveys to avoid biased responses due to the awe effect.

5.5 Limitations of the study

5.5.1 Multi interpretability of the results

Although the methodological structure of this study is quite similar to that of other SLR's, there are some limitations of this study that need further elaboration. First, the multi-interpretability of the results has to be addressed. This is especially present in the results on stakeholder involvement types and AR obstacles. Both of these results have been presented in frequency tables showing the number of occurrences for each of the obstacles and stakeholder involvement types. It can be argued that some of the stakeholder involvement types can also be interpreted as AR obstacles. Examples are complex technology, privacy concerns, modelling skills needed, transition to 3D costly and AR unsafe. The question whether these data extraction types belong to either stakeholder involvement or AR obstacles depends on the context of the article in which these data extraction types were found. The examples of stakeholder involvement types given in this section were in most cases derived from people's opinions. A number of articles have presented surveys and questionnaires as a means for validating their AR application. While these types thus represent people's opinions they have been considered as stakeholder involvement types and not AR obstacles. It is recommended for future studies to delineate data extraction types as strictly as possible to avoid this similarity in different parts of the results.

5.5.2 Inconsistent data extraction

Another point of consideration are the slight inconsistencies in the data extraction. The results offer insight into the types of AR hardware, AR software, data types, AR features and AR obstacles that have been used in the articles for AR application development. As mentioned before in section 5.5.1, the data extraction is depended on the context of the articles. The context of each of these articles is different which means that the authors have made different decisions on what to mention in their articles and what to leave out. Especially for the results on AR features it is likely that not all AR features have been successfully extracted from every article. Some of these AR features are less prominently mentioned in the articles and are thus not recognized as AR features although these features were definitely used in the particular AR application. For example, the AR features marker-based AR and markerless AR have been mentioned in 11 and 5 different articles. At the time of writing, marker-based AR and markerless AR are the only AR types that exist. An AR application is either using marker-based or markerless AR which would mean that out of the 70 reviewed articles in this study the frequency numbers of 11 and 5 in Figure 10 should be much higher. The problem is that in most of the articles (54 articles in this case) marker-based AR and markerless AR have not been explicitly mentioned and thus have not been included in the data extraction. More specific data extraction types can be used to avoid this. It is recommended to conduct a preliminary study before the start of the SLR. Main types of data one would like to derive from the SLR articles can be identified in this way. Which can then be used to define data extraction types which are more easily identifiable from the SLR articles. In this way one is more prepared on what to expect from the articles and less dependent on the context of the article and information on AR technology that is possibly not mentioned by the author but certainly used in the study.

5.5.3 Open access articles only

The 70 articles reviewed in this SLR are all open access articles meaning that they are freely accessible to anyone without the need of subscriptions or payments. Open access articles have been used in this study because it improves the transparency, reproducibility, and legitimacy of this study while people are able to verify the results that have been obtained from this SLR. However, the number of open access articles in the domain of AR and spatial planning is relatively low compared to the number of articles in this domain that are not open access. Consequently, it is possible that valuable information related to AR technology and stakeholder involvement in spatial planning has not been included in this study because these articles were not open access. It is therefore recommended to conduct more research into AR for spatial planning using articles that are not open access.

5.5.4 AR prototype validation

The developed AR prototype was validated by means of a survey that could be accessed from within the prototype by pressing a button. 12 respondents have provided feedback through this survey. Respondents have reported that the prototype did not work for them and hence they were also not able to provide feedback. Technical issues such as the user interface not being visible or misaligned, black screens or cases where the AR marker was not detected properly have been reported. Questions Q2 until Q6 of the survey (Figure 17) are related to the technicalities of the application. It can be argued that the feedback is likely to be biased because only respondents for whom the prototype worked were able to provide feedback. This means that the feedback on the technicalities of the prototype is likely to be too positive. Moreover, the number of 12 respondents is probably too low to derive significant conclusions from the validation results and instead gives an indication on the user experience only. Due to time constraints and the technical issues that restricted some respondents, the number of respondents could not be increased. Figure 16 shows that all respondents were unfamiliar to AR applications which could have affected their responses. Respondents might have been awed by this new technology influencing them to respond overly positive in the survey. Especially for questions Q2 until Q6, responses are affected because respondents have no other AR application experience that they can use to compare this application to. Instead, other questions that take this limited experience into account might have been more useful. For example, more questions that compare conventional spatial planning consultation strategies with AR technology, which is only addressed in Q8 of the survey. It is recommended to provide multiple ways of giving feedback on the prototype to avoid missing feedback from people for whom the prototype did not work instead of only via the feedback button. This would resolve some of the bias present in the survey results. Furthermore, questions in the survey are recommended to be adapted to the notion that respondents are generally not familiar to AR applications and might therefore react overly positive to survey questions about the workings of the prototype.

6. Conclusion

This research aims to show a comprehensive overview of the currently available AR technologies in terms of hardware, software and data. The array of different hardware, software and data types is limited. Most AR applications make use of similar approaches such as the use of a smartphone as the most often used AR hardware type in the reviewed articles, Unity 3D as the most often used AR software type, and street-level images as the most often used data type for AR application development within the reviewed articles.

This SLR aimed to discover the impact of AR on stakeholder engagement and collaboration in spatial planning projects. The low number of reviewed articles found in which AR applications are linked to spatial planning indicates that the impact of AR on stakeholder engagement and collaboration in spatial planning is limited. AR is not yet integrated into spatial planning workflows because the technology is relatively new and unknown to spatial planners. Complex technology and privacy concerns were data extraction types most often found in this SLR amplifying this notion. Contrastingly, 'AR increased engagement', 'collaborative design' and '3D improves' perception were other data extraction types found that show the recognised potential of AR in future spatial planning workflows.

The different AR features and AR obstacles in relation to the development and use of AR applications have been derived. The most often occurring AR feature is physical AR interaction encompassing different ways of interacting with the AR scene such as hand tracking, head tracking and pose estimation. Marker-based AR is the second most often found AR feature showing that most applications make use of markers for accurate virtual object positioning. Apart from the AR features, an extensive array of AR obstacles limiting AR application development have been identified as well, indicating that AR applications are still complex to develop and use. AR tracking, data processing, hardware limitations, locational inaccuracy, unavailable tools and the AR application experience are different categories for which AR obstacles have been found in the reviewed articles.

As a demonstration of currently existing AR technology for spatial planning projects, the AR smartphone prototype OmniaViewAR has been developed. This marker-based application allows people to view a new building called Omnia from multiple perspectives in an AR scene of Wageningen campus. The prototype is developed with the most often used AR software type in the SLR, Unity 3D and runs on the most often used AR hardware type from the SLR results which is a smartphone. This prototype aims to improve stakeholder engagement and collaboration in spatial planning by making building plans more accessible, understandable, and more easily distributable. The survey outcomes served as a validation of the prototype and showed that respondents were generally positive about the increased degree of immersion and the ability of AR to trigger younger generations for spatial planning projects. However, there were difficulties with installing and using the prototype which has caused a likely bias in the survey results.

The outcomes of the SLR and experiences from the AR prototype show that AR in spatial planning is still a technology in development. Most of the applied studies that were found in the SLR, present AR applications not linked to spatial planning practices. AR technology itself has not been developed enough in terms of technological capabilities, ease of use, reliability, and accessibility to be implemented in spatial planning workflows. However, the potential benefits of using AR in spatial planning have been recognized in several articles reviewed in this SLR and is indicated by the survey results of the AR prototype as well. Moreover, the development of the AR prototype is an example of how AR can be of use in future spatial planning projects by engaging more stakeholders and making building plans more accessible on people's smartphones and more understandable and attractive due to the increased degree of immersion compared to the conventional 2D plans currently used.

The limitations of this study include the multi-interpretability of the data extraction types, inconsistent data extraction, the use of open access articles only and the validation of the AR prototype. The multi-interpretability of data extraction types can be avoided by defining more delineated umbrella terms that allow for a clearer separation of the data depending on the context of the article in which the data was found. The inconsistent data extraction can be mitigated by defining more specific data extraction types before starting the data extraction. These more specific data extraction types can be obtained by doing a preliminary study before the start of the SLR to identify the main types of data one would like to derive from the SLR articles. In this way one is more prepared on what to expect from the articles and less dependent on the context of the article and information on AR techniques that is possibly not mentioned by the author but certainly used in the study. The possibility exists that useful information on AR in spatial planning was left out of this study because it was published in articles that were not open access. Conducting a SLR using articles that are not open access would be recommended in this case, it might result in more articles linking AR to spatial planning as well. The validation of the prototype can be improved by allowing people for whom the application did not work to access the survey from outside the prototype instead of only via the feedback button within the prototype. This would resolve some of the bias present in the survey results. Furthermore, questions in the survey are recommended to be adapted to the notion that respondents are generally not familiar to AR applications and might therefore react overly positive to survey questions about the workings of the prototype.

Opportunities for future research would be investigating specific AR workflows for the spatial planning domain. First, this includes comparing benefits and challenges between the use of AR as a means of visualisation against the existing, more conventional ways of visualisation for each spatial planning project specifically. Secondly, effort needs to be put into making spatial planners aware of the specific techniques and possibilities of AR to increase their understanding. Thirdly, the regulatory frameworks of spatial planning projects currently existing will have to be adapted to allow AR technology to be implemented.

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Appendix 1

This overview includes all data that has been used for this thesis. It can be found in the folder "MSc Thesis Luc van Dijk". Please mind the confidentiality of some of the datasets.

- 1. Datasets
    - SLR_Data
        - Report_Figure3.csv
        - Report_Figure4.csv
        - Report_Figure7.csv
        - Report_Figure8.csv
        - Report_Figure9.csv
        - Report_Figure10.csv
        - Report_Figure11.csv
        - Report_Figure16.csv
        - Report_Figure17_Q2.xlsx
        - Report_Figure18_Q4.xlsx
        - Report_Figure18_Q5.xlsx
        - Report_Figure18_Q6.xlsx
        - Report_Figure18_Q7.xlsx
        - Report_Figure18_Q8.xlsx
        - Report_Table5.xlsx
        - SLR_ArticleDataExtraction.xlsx
    - AR prototype_Data
        - AR prototype logo
        - Campus.fbx
        - Omnia_building_model_CONFIDENTIAL.ifc CONFIDENTIAL DATA, NOT TO BE DISTRIBUTED
        - Omnia_CONFIDENTIAL.fbx CONFIDENTIAL DATA, NOT TO BE DISTRIBUTED
        - OmniaViewAR (Unity Project)
        - OmniaViewAR_printout.pdf
        - OmniaViewAR.apk
        - Satellite image WUR campus
        - WageningenCampus_model.obj
- 2. Documentation
    - MSc MGI Thesis Report Luc van Dijk
- 3. Presentations
    - Colloquium presentation.pptx
    - Midterm presentation.pptx
- 4. Questionnaires
    - OmniaViewAR_ValidationSurvey.pdf
- 5. Scripts
    - SLR_JupyterScripts
        - Report_Figure_3_4.ipynb
        - Report_Figure_7.ipynb
        - Report_Figure_8_9_10_11.ipynb
        - Report_Figure_16_17.ipynb
    - AR prototype_C#Scripts
        - Down.cs
        - Down.cs.meta
        - Left.cs
        - Left.cs.meta

        - Right.cs
        - Right.cs.meta
        - ScaleAndRotateSlider.cs
        - ScaleAndRotateSlder.cs.meta
        - SceneLoader.cs
        - SceneLoader.cs.meta
        - Up.cs
        - Up.cs.meta
        - UrlOpener.cs
        - UrlOpener.cs.meta

- 6. Videos
    - OmniaViewAR smartphone clips
        - OmniaViewAR_clip1.MOV
        - OmniaViewAR_clip2.MOV