# INVESTIGATION OF THE ACCEPTANCE OF VIRTUAL REALITY FOR PLANNING DECISIONS IN EARLY DESIGN PHASES

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***ABSTRACT:*** *In recent years, with the increasing digitization of the construction industry, the potential benefits provided by the adoption of Virtual Reality (VR) have been shown especially in interdisciplinary networking among different stakeholders for which effective communication and information exchange methods are crucial. This is particularly significant during early design phases and associated decision-making processes where, despite its positive impact in terms of project's time and cost savings, VR adoption still has to reach its full potential. For this reason, this paper investigates to what extent the acceptance and application of VR has developed and identifies possible integrations in the early planning phases. By conducting a multi-year study with representatives from the construction industry, including qualitative and quantitative survey methods, the current use of VR and the requirements for future applications are determined. The study reveals that VR's importance for design visualization has increased, identifies architects' current requirements and integration barriers. Additionally, these requirements are compared with existing VR possibilities and an approach for exchanging different variants in a building information model will be examined. Based on these findings, VR can be integrated in application-specific contexts and software can be adapted to architects' needs for optimizing the digitization process.*

***KEYWORDS:*** *Virtual Reality, Decision Support, Early Design Phase, Design Visualization, Study*

## 1. INTRODUCTION

Virtual Reality (VR) has made significant advancements in recent years and is increasingly being employed across various industries to foster innovative solutions. In the construction industry, VR presents novel opportunities and revolutionizes the approach to project planning, design, and realization (Ozcan-Deniz, 2019). For designers, architects and clients, one of the biggest challenges in the construction industry is the difficulty in visualizing a building project in the early design phase. Traditional methods using 2D drawings and 3D models have inherent limitations in conveying an accurate representation or illusory stimuli (Paes et al., 2017). At this point, VR becomes an important factor. By using VR technology, users are able to enter an immersive virtual environment and experience the future building or infrastructure in 3D. Architects are able to visualize their designs in virtual environments, which enables them to improve their understanding of proportions, designs, and functionalities. Developers have the ability to take virtual tours of their future properties, giving them a realistic feel for the space and amenities. Moreover, VR enables improved collaboration between the various stakeholders in a construction project (Davila Delgado et al., 2020). This allows architects, engineers, developers and other stakeholders to collaborate together in the Virtual Reality environment, make modifications, identify problems and develop solutions even before the actual construction process begins. Besides saving time and money, this may also reduce potential errors and miscommunications.

There are different types of VR technologies, each offering unique approaches to allow immersion in virtual worlds. Tethered VR systems are powerful solutions that require a connection to a computer. They incorporate external sensors or cameras to track the user's movements and ensure precise interaction in the virtual environment (Casini, 2022). Established VR companies such as High Tech Computer Corporation (HTC), META, Valve and Windows are already indicating strong growth in the segment over the next few years (Steam, 2022). Standalone VR devices are autonomous items that do not require a connection to an external computer. Instead, they integrate the display, processor, and tracking technology into a single device and offer a certain degree of mobility and ease of operation. By introducing the Apple VisionPro and its release in 2024, there is a potential for the market in this segment to grow even more in the future, as other technologies from the developer have already had a strong impact on the respective sales market. Mobile VR effectively uses smartphones as displays and processing power for virtual experiences. It allows users to plug their smartphone into a VR headset and access a wide range of VR applications or games (Casini, 2022). Available hardware is suitable for both private and professional applications. Unity, for example, is an applied development environment in architecture for the visualization of VR projects (Boeykens & Gawade, 2013). Due to these market trends, developing technologies and fields of application, it is relevant to investigate the actual potentials and evolution of VR acceptance for the construction industry in Germany. Older studies, such as from the United Kingdom, indicate that integration is imminent in large parts of the construction

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industry (Bouchlaghem et al., 1996), and even more recent studies simply conclude that the AEC industry in the next few years is changing its previous path toward utilizing (Noghabaei et al., 2020). A study from Australia has adopted a similar approach to investigate the adoption of VR in the construction industry. However, this study is limited by a small sample size and the restriction of participants to the community of two universities in Sydney, Australia. As a result, there is no direct assessment of VR adoption among the stakeholders in the construction sector (Ghobadi & M.E. Sepasgozar, 2020). Country-specific surveys on the status of VR in the construction industry are rare, have been conducted many years ago, and do not include any follow-up studies. There is no specific data available for the construction sector in Germany.

Despite its potential benefits, there are several challenges associated with the use of VR for business purpose. Implementing VR technology in the workplace may be expensive, especially the initial investment in hardware and software. Additionally enquires employees to train and understand how to operate the equipment and navigate in the virtual environments effectively (Prabhakaran et al., 2022). VR technology often collects and stores user data, including personal and behavioral information. Maintaining data security and privacy is crucial to protect sensitive information and comply with regulations. To explore these and other similar potential barriers to the widespread adoption of VR in the construction industry, studies have been conducted in various years involving different target groups in the discipline. The study aims to capture the importance of VR for design visualisation in Germany and will explore the current requirements of architects and barriers for integration. A specially created sample application serves as a visual illustration of the VR possibilities and, in addition to the findings from the study, investigates the exchange of different design variants in a building information model.

The structure of this paper is as follows: Section 2 provides an overview of the research approach, presenting the research methodology and providing a supporting visualization for evaluation. The findings from the conducted studies are presented in section 3. In this regard, a categorization is carried out to investigate the potentials of VR on a topic-related basis. Section 4 discusses the findings and provides suggestions for future research.

## 2. BACKGROUND

### 2.1 VR in the construction industry

There are many potential applications for Virtual Reality in the early design phases for construction projects. Besides design presentations, simulations, marketing purposes and construction site inspections the collaborative planning is a significant factor. Simulations, for example, can be used to test specific aspects of a project, allowing for customizations to be made according to the building design. Virtual simulations of sunlight exposure provide insights into the materiality of building components (e.g., on the façade), light reflection and consider shadows on surrounding buildings and streets, while rain scenarios help to capture the direct runoff of rainwater on, around, and adjacent to a building in the early phases. For marketing purposes, the early design phase is less relevant. Instead, investors or potential buyers can be shown the project or building in detail, by a digital tour. VR-based construction site inspections allow for the early evaluation of safety measures as well as safety training and later monitoring of construction progress (Zhang et al., 2022). For many of these applications, a BIM interface is beneficial so that modifications can be made and saved directly in the Virtual Environment. These can be than done in virtual spaces, which enable teams from different locations to collaborate virtually on designs and plans, facilitating decision-making and coordination of work processes (Jensen, 2017).

### 2.2 Acceptance measurement

In terms of the acceptance of the technology in the construction industry, there is a need to operationalize it. For user acceptance, various models such as David's Technology Acceptance Model (TAM) in the field of innovation (Davis et al., 1989) or Kollmann's Dynamic Acceptance Model which was developed to analyze the acceptance of innovative goods can be utilized (Geldmacher et al., 2019). These are commonly applied in the field of information systems technology. According to the latter, the process of acceptance is divided into three levels:

- Attitude level: This level begins with the awareness of a product, which results in the user's interest and expectations.
- Level of action: In the process, the user makes initial tests and experiences that can result in a purchase and subsequent implementation for appropriate utilization.
- Utilization level: Regular access to the product ensures its continued use.

These levels span from the initial purchase decision to actual usage over time. The levels are interconnected, meaning that successful completion of one level leads to the next, ultimately culminating in the overall acceptance of a product. Therefore, assessing the overall acceptance necessitates examining all these levels. In this context, the potentials of the VR technology have a significant impact as they can positively influence the levels and therefore the overall acceptance.

## 2.3 Variant Management

In the early design phases, architects have various options for designing individual parts of the building. By using the Variant Management, it is possible to store and retrieve different variants for a specific building component in a digital building model. The methodology is designed to provide architects with decision support. This decision support can be advantageous for a virtual and immersive assessment of a project since different options for construction variants can be explored. The Variant Management encompasses three types of variants: Structure Variants, Function Variants, and Product Variants. Structure Variants refer to building elements related to the structure of the building, such as exterior walls. Function Variants are components that fulfill specific functions (e.g., columns), while Product Variants categorize individual products (e.g., windows) (Napps et al., 2021).

At the initial planning process, building elements must be categorized by an architect according to the three variants in order to ensure to find possible design alternatives later on. This categorization of elements into variants can either be done in a BIM software and provided with additional options (Napps et al., 2022) or based on the IFC data. The approach is performed in a graph-based format. Here, the exported IFC file of the model is transferred to a graph representation, whereby IFC entities are represented as nodes and IFC relationships as edges. Possible options are added to an existing variant in form of an option node, which results in the overall graph as a parallel possible option for an element (Napps et al., 2021). VR visualization allows architects to immersively experience the impact of a variant and how it compares to other stored options. If no options are stored in a model, problem-specific features can be specified for a variant in a separate database to obtain possible solutions from other projects as potential options. By choosing an option from another model, the selected option will be automatically stored as an option node to the graph. The selection of a design option can stem from either a calculation of similarity to other variants or on a specific aspect of investigation. Recently, Variant Management has been used to carefully evaluate design options or alternatives for cost efficiency and assessed alternatives to building components based on their costs to identify the optimal solution for a project (Napps et al., 2023).

# 3. RESEARCH DESIGN

The research design consists of primary research involving online surveys and expert interviews supported by a literature review to identify the current status and potentials of VR and its use in the early design phases. In order to investigate the current integration and acceptance of VR in the construction industry, a study over several years is conducted, as well as a determination of the acceptance of the technology among potential stakeholders. Acceptance has an important impact, as it is directly related to the usage. An identification of affected actors in the construction industry, the reduction to research-relevant stakeholders and the identification of actual potentials and the operationalization of acceptability is therefore necessary (Fig. 1).

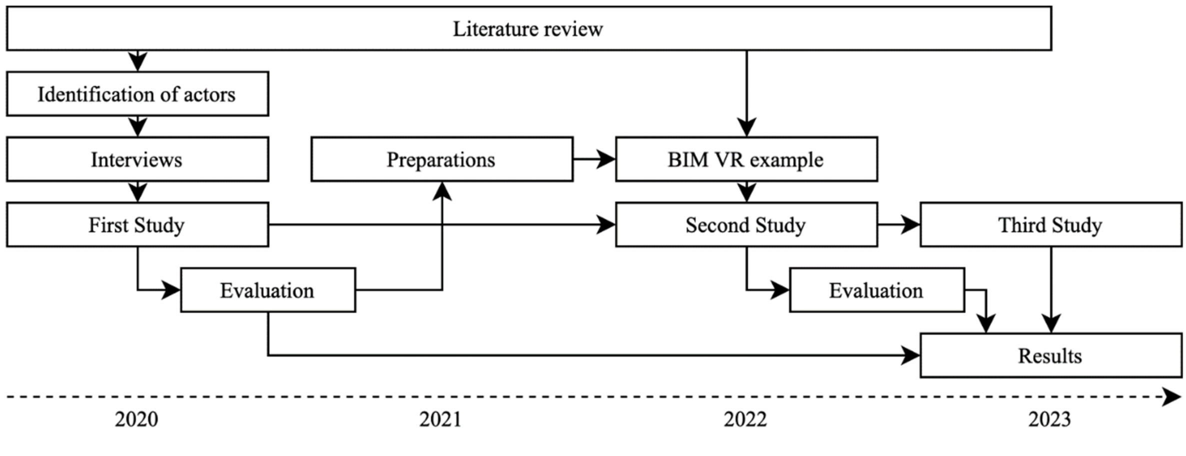



Fig. 1: Research design schedule.

In the construction industry, there are multiple stakeholders working together who might benefit from cooperation and coordination via VR in projects. This includes primarily architects, who have to consider the planning concept, the design wishes and ideas based on the requirements of the clients and on legal circumstances. A planning agency is a service company in which civil engineers, specialist engineers and planners work together. Geographers, geometricians and geoinformatics potentially can come into contact with VR in the planning process, for example, when it comes to generating city or terrain models or data bases. Real estate developers and investors are equally important actors who benefit from early visualization of the project in VR for new buildings, as well as for renovations and modernizations. Municipalities occupy a significant position due to the facts that, on the one hand, they have the primary role in the planning process in Germany, and on the other hand, they are highly significant as contractors for architects and investors (Emmitt, 2010). Of these, smart cities are highlighted, which are characterized by their significantly more innovative character compared to other municipalities. Furthermore, the public benefits from project renderings in VR, as they are able to receive a 3D visualization of the planning through the public participation required by law in Germany (§ 3 Abs. 1 BauGB) and do not have to rely on a planning knowledge of 2D plans and views.

Due to the limitation to the early design phases because of the increased relevance for planning decisions and error minimization (Østergård et al., 2016), not all of the mentioned stakeholders are of equal importance for potential usage and acceptance determination. Therefore, these are to be reduced due to the observation scope. In this context, the decision was made to specifically target architects and also gain insights into the overall sentiment of German cities. This approach allows for capturing aspects from both the supply side (architects) and the demand side (municipalities). Volunteers from the population were also invited to take part in a survey, as the Planning Act in Germany provides that they must be involved in construction projects and plans. For the identification of potentials, different assumptions resulting from research with regard to advantages and disadvantages for the use of VR were analyzed and summarized. These were formulated in various forms into neutral closed and open questions as much as possible.

## 3.1 Interview

In this research, the integration of interviews and surveys offers a broader and more comprehensive approach to gather data. Whereas interviews have a minor role in this study, they are instrumental in obtaining qualitative data and gaining deeper insights into individual experiences, which subsequently informed the design of the survey questionnaire (Rafidah Biniti Ab, Rahman, 2023). By combining these research methods, the results can be validated and triangulated, enhancing the overall reliability and credibility of the data and the interpretations made.

Table 1: Overview of the interviewees.

| | Year | Date | Leading questions | Gender | Country of origin | Field of expertise |
|---|---|---|---|---|---|---|
| **Interview 1** | 2020 | 7th July | 16 | female | Germany | PhD and urban researcher in the context of the digitalization of cities |
| **Interview 2** | 2020 | 13th July | 17 | female | Austria | Focus on urban development and public-private partnerships in digital context |
| **Interview 3** | 2020 | 16th July | 18 | male | Switzerland | Software developer for mixed reality and cloud computing |
| **Interview 4** | 2020 | 12th August | 14 | male | Germany | Honorary professor and member of a progressive digitization network |
| **Interview 5** | 2020 | 14th August | 12 | male | Austria | Chief marketing officer of an augmented and Virtual Reality startup |
| **Interview 6** | 2020 | 2nd September | 10 | female | Switzerland | Focus on Digital Real Estate and member of an innovation team |

At the outset of the study in 2020, interviews were conducted with specific stakeholders to shape the questions for the study and gather initial insights into the adoption, application, potentials, and barriers of using Virtual Reality in the construction industry. A total of six individuals from different disciplines were selected for expert interviews at various professional levels, which are shown in Table 1. Care was taken to include individuals with technical understanding, as well as scientific and practical knowledge of working with Virtual Reality in the construction industry. The six interviewees were equally distributed among the fields of software development, academia, and urban management and marketing (Tab. 1). All of them had experience with urban-level projects or collaboration with authorities responsible for planning. The experts represented both Germany and other European countries. The duration of the interviews, guided by specific questions, was approximately 60 minutes each. Starting with general topics, the discussions moved on to concrete questions about example projects and the involved actors. Due to partial critical comments on the topic and missing consents of personal data, the experts are anonymized.

## 3.2 Study

Quantitative research uses standardized surveys to collect data for a large sample size of individual people, groups of people or institutions. The methodology is used to analyze and describe mass phenomena. Online surveys are characterized by their monetary advantage, location independence of the respondents and low temporary effort of collection and evaluation (Mellinger & Hanson, 2021). No related data is stored in the questionnaires, which ensures honest statements and opinions. The questionnaires were initially distributed individually to different groups of persons (Planning and architectural offices) and later by a random principle, e.g., with the help of the inclusion in the newsletter of the Federal Chamber of Architects of North Rhine-Westphalia. The surveys were provided as an online survey and sent via link to the appropriate contacts. Three surveys were conducted over the course of three distinct years, with each survey period lasting approximately six weeks. The initial survey was carried out in July 2020, followed by a subsequent survey in July 2022, and a third in mid of July 2023 (Tab. 2).

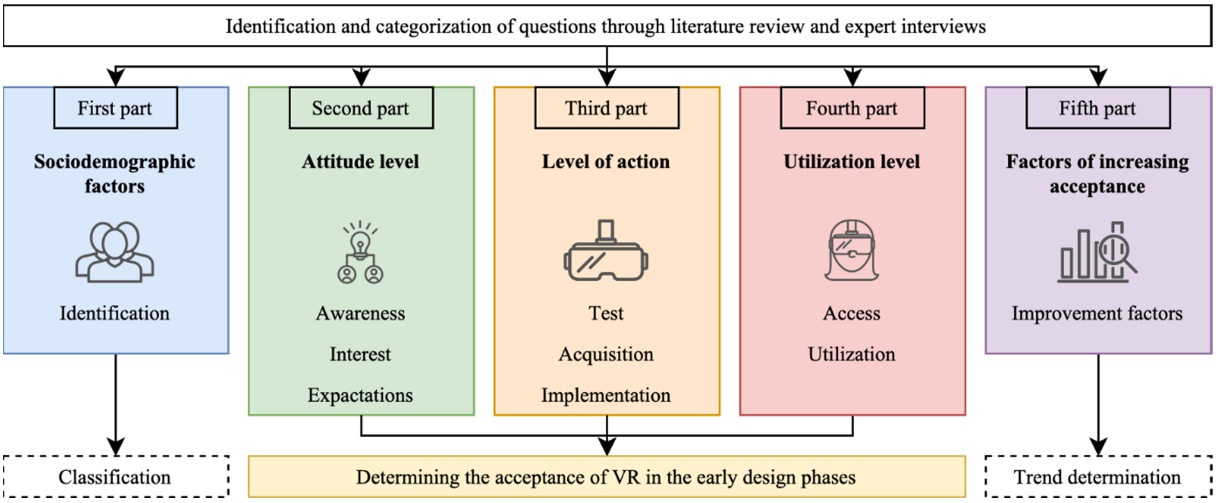



Fig. 2: Structure of the first study according to the acceptance measurement and for the evaluation of trends.

The first study from 2020 was a large-scale study, a deliberate combination of closed (yes/no) questions and open-ended questions was used to capture the situation of Virtual Reality in the construction industry as accurately as possible from different perspectives (Fig. 2). For the first study in 2020, different municipalities and smart cities were drawn from a sample of all German cities. Based on the cities identified, planning offices were selected in each case. Due to the significance of public participation (§ 3 Abs. 1 BauGB) and the benefits identified in the literature, the survey was conducted among both the identified stakeholders in the construction industry and a small sample of the population in Germany. In total, the first study thus consisted of four individual surveys. The sample size was chosen equally for the first three categories (Tab. 3). One follow-up reminder email was sent after half of the survey period.

Table 2: Overview of the studies.

| | Year | Questions | Question type | Participants | Country of origin | Estimated duration | Objective |
|---|---|---|---|---|---|---|---|
| **Study 1** | 2020 | 16 | Mixed | 60 + 55 | Austria, Germany, Switzerland | 12min | Large-scale data acquisition |
| **Study 2** | 2022 | 19 | Mixed | 53 | Germany | 10min | Data acquisition for comparison |
| **Study 3** | 2023 | 9 | Closed | 11 | Germany | 3min | Data acquisition for trends |

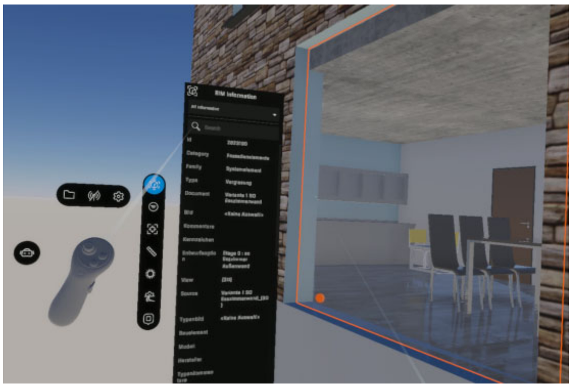
Although the second study was conducted for the use of BIM and Variant Management, it includes a thematic block on VR. Therefore, the second follow-up study aimed to capture potential changes and trends in the adoption and acceptance of VR in the field. The last study was designed to collect final determining factors and is still ongoing. Only single choice questions were used in the third survey to compare most significant factors for the success or failure of VR integration and adoption with the previous ones. Actually, the survey period of the last one has not yet ended. The number of questions varied depending on the study. Overall, the studies were designed with a range of 6 to 16 questions. For the last one, a lower number of questions was used to ensure quick completion by the participants. However, the structure always followed a systematic framework, starting with the general use of VR for projects, followed by exploring advantages and disadvantages, as well as other criteria for measuring the potentials and acceptance. The questions were selected according to the operationalization of acceptance and divided into corresponding categories. In this regard, besides dichotomous and multiple-choice questions, Likert-scale survey questions and question types such as ranking and matrix questions were predominantly employed. A total of (60 (+ 58 participants from the general Population) + 53 + 11) participants were involved in these multi-year's studies, whereby it is to be mentioned that not all respondents answered each question. An overview about these studies is shown in Table 2.

### 3.3 Experimental realization of the Variant Management in VR

The study was supported with images to enhance participants' understanding of the use of Virtual Reality in the construction industry (Fig. 3). Towards this intent, a building was created which also served as an evaluation example to explore any potential opportunities and barriers in the realization of a project, focusing on the adaptation of a building design in VR. The building information model was created in Autodesk Revit and exported to Unity for visualization in a virtual environment (Fig. 3a). Utilizing the Unity Reflect Review enables design validation before and during a project. For this purpose, various options for building elements were modeled, such as different window variations, doors, and facade options (Fig. 3b & 3c), allowing architects to experience the changes in the building from both the interior and exterior perspectives. This approach aligns with the practical work of architects who evaluate different design variants for a building in early design phases and experience modifications in 3D to gain a better understanding of the effects of different building elements (Fig. 3d).


(a)


(b)


(c)


(d)

Fig. 3: (a) Building information model, (b) Building design variant in Unity, (c) Checking for stored design options with information and live interaction (Oculus Quest 2), (d) Customization and comparison.

# 4. FINDINGS

The initial study aimed to explore the current state, potentials, and acceptance of Virtual Reality (VR) in various sectors of the construction industry. To achieve a comprehensive understanding, the study included not only planning offices but also municipalities, smart cities, and segments of the general population in Germany. The subsequent two follow-up studies, however, narrowed their focus to examine planning offices primarily. This decision was driven by the fact that planning offices play a central role in the planning phases, whereas municipalities, smart cities, and the population are more closely associated with the final outcomes of completed projects. The results are categorized in sub-sections to facilitate comparisons of the studies. A total of 182 responses from the studies can be evaluated for this purpose. The three acceptance levels are considered in the discussion.

For the findings, the abstentions were mostly omitted from graphical representation to maintain clarity. The evaluation of the study is divided into three parts. Beginning with an assessment of VR's awareness and integration in the construction industry, it is followed by an exploration of its potentials and barriers. Findings regarding the creation of the VR example project, including various design options and the implementation are shown afterwards. In the discussion, the level of acceptance of VR technology in the construction industry is presented in the context of the demonstrated measurement process.

The response rates for the first study, illustrated in Table 3, range from 28% to 48%. Additionally, 58 individuals from the population participated. Incomplete responses to questions were not included in the response rate and were also excluded from the results. For the subsequent studies, voluntary participation was encouraged among different offices, because the response rate was the lowest in 2020. Based on a large-scale study examining 8,672 surveys and 1,071 online surveys in educational research, a weighted average response rate of 44.1% for online surveys in educational fields was identified (Wu et al., 2022). Different online survey platforms indicate an acceptable response rate between 5% to 30% and values above this correspond to a very good response rate (Chung, 2022; Le Masson, 2023). In the study from 2022, there were several abstentions on some questions, which resulted in the lowest rate for answering a specific question at 41 out of 53 participants (77.3%). All questions for the year 2023 were completed.

Table 3: Response rate of the first study 2020.

| | Sample | Incomplete responses | Complete responses | Average time needed | Response rate |
|---|---|---|---|---|---|
| **Municipalities** | 50 | 23 | 19 | approx. 6min | 38% |
| **Smart Cities** | 50 | 37 | 24 | approx. 7min | 48% |
| **Planning and architecture offices** | 50 | 16 | 14 | approx. 6min | 28% |
| **Population** | - | - | 58 | approx. 5min | - |

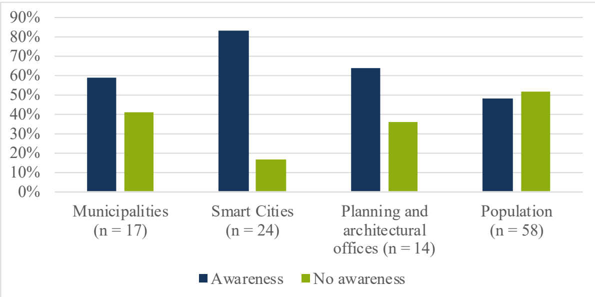
## 4.1 Actual awareness and integration

The study reveals that both awareness of Virtual Reality for the use in the construction industry and the resulting potential work experiences vary among the surveyed groups. It is evident that the majority of direct planning stakeholders (Municipalities, Smart Cities, and planning and architectural offices) are aware of the application of VR in this context, while the general population is more divided. The division among the public was already suspected during the interviews, as one expert from the scientific perspective believes that citizen participation regarding the acceptance of the technology is currently most advanced, while the software expert is of the opinion that the public is still unaware of it all. However, all interviews indicated that awareness among the population is increasing with a growing number of VR projects, and through the gamification factor, the usage and involvement of the population in projects can be enhanced. Some pilot projects from practitioners can confirm this impression.

Concerning Smart Cities and municipalities, the experts assumed that they are already aware of the technology, but the adaptation processes are challenging. The interviewees with practical background are already familiar with cities that work on projects in VR, but they point out that Smart Cities are likely to take the lead, while other municipalities may wait and observe these developments. However, it is said, that there is a general interest in the topic. It is also noted that larger cities might have a higher interest than smaller towns. Out of 24 respondents, 20 (83.3%) demonstrated the highest awareness of VR technology and its application in favor of Smart Cities, whereas 10 out of 17 municipalities (58.8%) showed awareness of the technology (Fig. 4). Two municipalities did not reply.

Regarding the planning offices, a relatively low penetration of awareness and the resulting integration and application was predicted by the interviewees before the study. First movers would take the lead here, but the technological novelty would not initially revolutionize conventional planning processes. Offices that deal with renderings at a high level are said to experience increased interest, as it enables them to maintain or even improve quality standards. Among the surveyed offices, 9 out of 14 (64.3%) had heard of VR (Fig. 4), and 5 out of 9 (55.5%) had already worked with it (Fig. 5), indicating a high level of awareness and practical experience. Regarding to the work experience, among Smart Cities and municipalities, the percentages were 50% and 30% (Fig. 5). In relation to their previous awareness levels, with municipalities having the lowest percentage of work experience.

The study from the year 2022 depicted that the utilization of VR for the actors within architectural and planning offices is nearly 10% higher than in 2020. According to the 2023 study, this positive trend is not continuing, as 54.5% of these offices report that they have already integrated VR into their everyday work (Fig. 7). This indicates that the level has adjusted to the 2020 level. However, the willingness to use it (71,4% in 2020) continues in a moderate form in 2023 (54,6%).



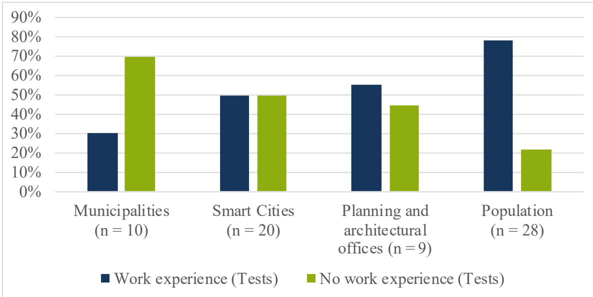
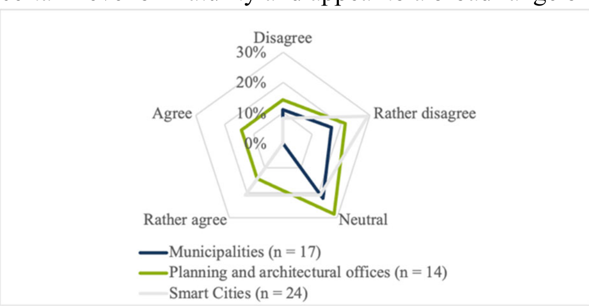




Fig. 4 (left): Comparison of the awareness (2020).

Fig. 5 (right): Comparison of the practical experience (2020).

Interest in the utilization was captured by questions regarding the willingness to incorporate Virtual Reality into the daily work routine and is shown in Figure 7. With the aid of an example integrated into the questionnaire, even participants who were previously unfamiliar with its application could partake in the question. As a result, it becomes apparent that 31.6% of the surveyed municipalities are ready to use VR in the near future, and 63.2% are neutral and do not reject the possibility of potential future adoption. Among Smart Cities, 50% express a willingness to use VR, with no direct rejections. As for the planning firms, 42.9% of the respondents have an interest in its utilization only 2 out of 14 offices do not want to use VR in future. In the year 2022, a highly positive trend was observed regarding the financial benefits derived from the implementation of technology among these actors (Fig. 7). One disadvantage, however, is the readiness of the hardware, which negatively affects the potential utilization. This primarily concerns the urban stakeholders, as five municipalities (26.3%) and six Smart Cities (25%) are not willing to provide hardware for meetings with other stakeholders, while one office (7%) is unwilling to do so (Fig. 7). The experts also perceive the provision of hardware, especially for small offices and small cities, as challenging. Experts in technology hinted in 2020 that with the introduction of Apple's proprietary software, both the general population and the cities and planning offices would benefit since these devices would reach a certain level of maturity and appeal to a broad range of citizens.



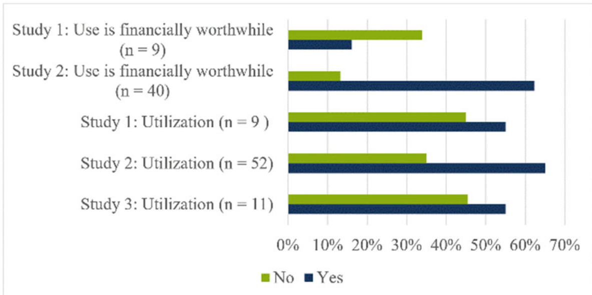




Fig. 6 (left): Comparison of the potential utilization (2020).

Fig. 7 (right): Comparison of the utilization propensity and financially worthwhile for offices (2020-2023).

As the potential utilization is related to the expectations of the technology, these expectations were also collected accordingly. For this purpose, three categories were identified, and the respondents were asked to indicate the extent to which they agree with each statement. Despite some negative remarks, the expectations regarding VR are predominantly aimed at achieving more efficient workflows with other stakeholders, improved communication, and increased public participation. The 2023 results confirm that, but reveal that respondents overwhelmingly agree that the use of VR in the construction industry is neither in high nor low demand. However, most respondents (72,3%) agree that VR representations have a high impact on the construction industry.

## 4.2 Identified potentials and barriers

The assessed potentials arising from the utilization of VR in the AEC industry are contrasted with the barriers encountered based on diverse experiences, offering a comprehensive comparison. Various response options identified in the literature and the interviews were given to capture the potentials and barriers for integrating Virtual Reality in the construction industry, with multiple responses allowed. The results primarily stem from the extensive study conducted in the year 2020. Trends are being verified with the two additional studies.

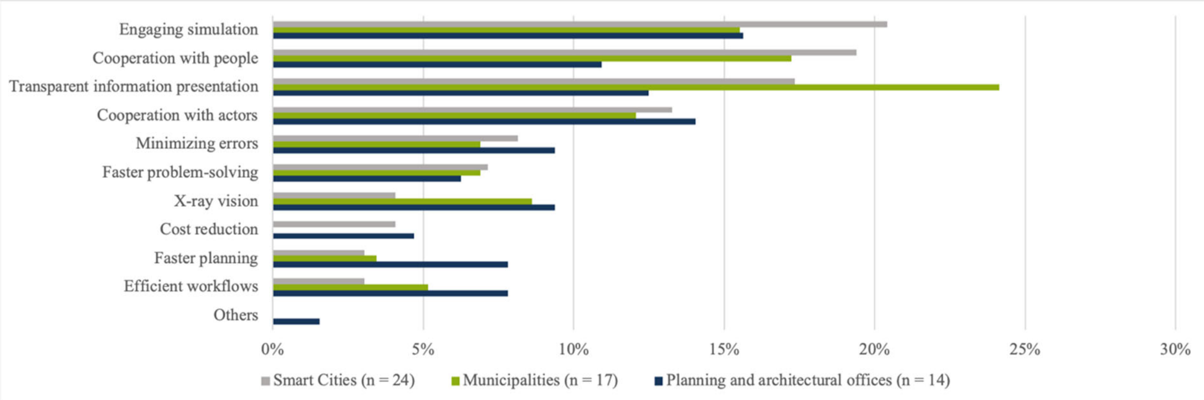



Fig. 8: Results of the first study on the potentials of the use of VR in the construction industry.


Fig. 9: Results of the first study on the barriers of the use of VR in the construction industry.

The most significant advantage, cited by 71.4% of planning offices, is the ability to create appealing simulations, followed by nine offices (64.3%) that agree to the advantage in better collaboration with other planning stakeholders (Fig. 8). Error minimization gained the greatest advantage among respondents in 2023 (36,4%). As the most significant disadvantage (71.4%), these stakeholders mention the financial burden. The two additional studies also confirm, with the highest number of agreements, the potentials of VR for simulation and collaboration, identified as the greatest potential for planning offices and their respective stakeholders. Additional monetary expense remains the most important barrier factor across the board, even within the study group (Fig. 9).

The three most significant potentials of the municipalities are transparent presentation of information (24.1%), improved collaboration with the population (17.2%), and the creation of appealing simulations (15.5%) (Fig. 8). The most significant barriers are the financial burden (22.7%), followed by the potential need for hiring new personnel, longer adaptation time, and the requirement for high computing power, each cited by 15.2% (Fig. 9).

For Smart Cities, the potentials are in the same three categories but with different weights (Fig. 8). The potential areas are transparent presentation of information (17.6%), improved collaboration with the population (19.4%), and engaging simulations (20.4%). As barriers for the integration of VR in the construction industry, the major concerns are the financial expense (37.3%), the need for hiring new personnel (27.1%), and challenges in operating the technologies as well as a low demand (13.6%) (Fig. 9).

In the study, the indicated potentials, based on the cumulative votes, outweigh the cumulative number of votes for the barriers.

### 4.3 Practical implementation

During the implementation of the Variant Management for visualization in VR, minor obstacles initially emerged, as saved building options cannot be stored directly in the software environment. Instead, only the selected variant is saved as a Revit file. In consequence, two versions of the designed building had to be saved for the visualization, each with different variants selected. Finally, the visualization is performed with Unity Reflect Review.

Another complication occurred attempting to use the Revit files directly in Unity Reflect Review, as the Unity Engine does not support the Revit format (.rvt). Alternatively, saving the file in the format (.fbx) facilitated the export and import of 3D objects, 2D objects, light sources, cameras and materials between Autodesk software programs and, since 2017, also between Unity. However, the object is displayed generically and in grey because Unity does not recognize the materials from Revit. Manual input of new materials that are recognized by the Unity library does not include all Revit materials and proves to be too time-consuming. Solving the problem is to alternatively use the IFC file for the two models and import it into Unity. A script then allows the BIM metadata to be retrieved and displayed within the object by having the script read the elements' information from the IFC file. It is important that the IFC file comes from the same 3D model referenced by the FBX file.

## 5. DISCUSSION

The studies have demonstrated that among the examined direct planning stakeholders, there is a predominant awareness of VR for planning processes. Many of these respondents also exhibit an interest in usage, some of which has even slightly increased. They highlight significant expectations of VR for planning tasks, aligning with the identified current capabilities. The results of the first study indicate that several municipalities, half of the surveyed Smart Cities, and the majority of the surveyed planning offices have already worked with and tested VR. While the willingness to acquire suitable hardware was generally portrayed as positive in all studies, the highest barrier, particularly for planning offices, was the financial extra expenditure. In terms of implementation progress in daily operations, a positive trend can be observed from 2020 to 2022. However, the results from 2023 potentially suggest a plateauing. It should be noted, however, that the study does not reflect the total number of offices, so the results from 2023 should rather be understood as a sample for trends. The provision of hardware is accompanied by the already examined acquisition. The willingness to use VR is strongly pronounced among the examined stakeholders, and the potential provision of hardware for meetings with other stakeholders is partially available. Ultimately, the utilization rate over the years demonstrates a significant practical application of VR, even though it appears to be slightly declining in 2023. This trend could potentially be attributed to a lack of demand for VR implementation in projects from contractors (cities and investors), for instance. Regarding the application, some experts see the advantage in the mobile use of VR, as it lowers the entry barrier and in the developments of the products and integration in a broad market. Overall, it can be observed that there was a solid basis for the acceptance of VR in the construction industry for planning decisions, which has continued to grow over the years. The majority of the sampled planning and architectural offices exhibit attitudinal (Level 1) and application (Level 2) behavioral acceptance. However, because utilization (Level 3) depends on certain factors, such as personnel, acquisition, strategic planning and access the acceptance of usability in 2020, is present in less than half of the offices. However, the subsequent studies have shown that the utilization of VR has not declined, which has led to the fact that the third level of acceptance has now also been reached by the majority. Among the smart cities, there was already an overall acceptance in 2020, according to the results of the majority of respondents, whereas the municipalities were not yet able to achieve an overall acceptance at that time, due to a lack of awareness, the resulting lack of test phases and a low willingness to invest. This results in poor values for this actor at all three levels of the acceptance measurement.

While the mentioned potentials and barriers indeed prevail, an individual weighting of factors is not feasible. For instance, a barrier might be so formidable that it cannot be overcome, as exemplified by the purchase of software for small design firms or cities. Nevertheless, the results of the assessment of monetary readiness for the adoption of VR software in comparison to its benefits have demonstrated that numerous architects and engineers have been able to enhance the integration and implementation of VR. By surveying the barriers among the different stakeholders, it was possible to identify factors for increasing the acceptance of VR for the visualization of planning in early design phases, which can be addressed accordingly from the developer perspective as well as the user perspective in further research.

The provided example has demonstrated that visualizing digital buildings in Unity using the IFC format of a model is straightforward, while the exchange of design alternatives with the Variant Management is a bit difficult. In the future, an alternative approach could be explored to better integrate the stored options in this regard. Visualizing projects in the early design phases provides added value for stakeholders, and there is a recognizable public interest in VR visualization of the final product for public information activities and cooperation with other stakeholders.

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