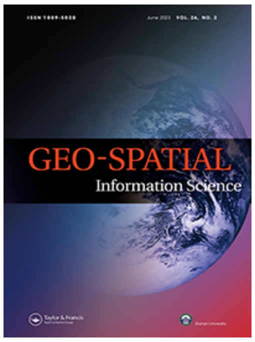

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Current and potential use of augmented reality in (geographic) citizen science projects: a survey

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ABSTRACT

Augmented Reality (AR) offers new opportunities for Citizen Science (CS) projects regarding data visualization, data collection, and training of participants. Since limited research on the usage of AR in CS projects exists, an online survey is conducted in this study by reaching out to CS project managers to determine the extent of its current use. The survey can identify areas where CS project managers themselves see the greatest potential for AR in their projects and reasons that exist against the use of AR. A total of 53 CS project managers participated in the survey and shared their opinions and concerns. Of all participating CS projects, only three are currently using AR. However, 27 CS projects indicated that AR could be beneficial for their project. Especially projects with a geographic focus, in which participants are involved in the process of collecting spatial data, expressed this opinion. Particularly in the areas "data visualization" and "attraction/motivation of participants" the projects identified potential for AR. Arguments against the use of AR named by 23 CS projects include remote study areas, financial considerations, and the lack of a practical use case. This study shows initial trends regarding the use of AR in CS projects and highlights specific use cases for the application of AR.

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Geographic Citizen Science (GCS); Augmented Reality (AR); immersive technologies; data visualization, data collection, attraction of participants; survey

1. Introduction

In recent years, Augmented Reality (AR) evolved from a new to an established technology used in a variety of fields (Elmqaddem 2019). These include but are not limited to industry (Reljić et al. 2021), education (Elmqaddem 2019; Garzón 2021), gaming (Bueno, Gallego, and Noyes 2020; Li et al. 2022), architecture & engineering (Delgado et al. 2020), medicine (Eckert, Volmerg, and Friedrich 2019), and science (Gazcón et al. 2018; Puertas et al. 2020). Especially due to the rapid development of mobile devices, AR can now be experienced in everyday life using one's own smartphone (Chatzopoulos et al. 2017; Muñoz-Saavedra, Miró-Amarante, and Domínguez-Morales 2020). By 2024, it is estimated that there will be 1.73 billion mobile devices worldwide that are AR capable (AR Insider 2021). As mobile devices continue to evolve, so do AR capabilities, which in the long run will lead to AR being seen as a mainstream technology by users (Sung, Han, and Choi 2022). AR is a method that aims to enrich the real world of a user by superimposing artificial objects on a digital screen (Chatzopoulos et al. 2017). This creates the illusion that the computer-generated objects are nearly touchable for the user and part of the environment (Milgram and Kishino 1994). In contrast to Virtual Reality (VR), an AR user does not completely immerse into a virtual world, but continues to perceive the real environment. VR differs from AR in that a 3D digital world is created on a computer, which is completely detached from the user's current environment. In an AR application, on the other hand, the user continues to perceive his real environment, which is only enhanced by digital objects, thus creating a new extended interactive environment (Dargan et al. 2023). Common devices used to display artificial objects in an AR environment are smartphones or AR glasses specially designed for this purpose (Arena et al. 2022; Chatzopoulos et al. 2017; Garzón 2021; Muñoz-Saavedra, Miró-Amarante, and Domínguez-Morales 2020).

AR is a method that has the potential to be used in various fields. Especially in science, AR offers a chance to present complex information in a comprehensible and accessible way, even for non-professionals. Thus, AR can also represent an opportunity for Citizen Science (CS). CS describes a process in which citizens volunteer to be involved in scientific projects (Dickinson et al. 2012; Lukyanenko, Wiggins, and Rosser 2020). The type of participation can take on different forms, as CS projects are quite heterogeneous (Lukyanenko, Wiggins, and Rosser 2020). For example, citizens can be integrated into the process of collecting new scientific data or into the analysis and interpretation of existing data (Lee, Lee, and Bell 2020). In many cases, the use of AR could enrich not

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only the participants' experience, but also the overall outcome of the project.

AR is already being used in CS projects. However, the available literature on the subject is still very limited. Currently, individual projects using AR are described in literature in the form of case studies (Albers, de Lange, and Xu 2017; Sermet, Demir, and Kucuksari 2018; Woolley et al. 2021), but very few publications discuss the advantages and potential of AR in general for CS projects. Often, AR is only briefly mentioned on the side, as for example in Mazumdar et al. (2018), who does point out that AR can be a promising approach to improve the data collection process, participant training, and participant motivation, but does not elaborate further on what an actual implementation of the suggestions might look like. Therefore, the aim of this research is to conduct a survey to identify how widely AR is being used in CS projects and how it is integrated into the projects. The survey will help answer the following research questions:

(1) To what extent is AR already being used in CS projects?
(2) In which areas do the project managers/initiators see the greatest potential for the use of AR in their CS projects (e.g. data visualization, data collection, training of participants)?
(3) What are arguments against the use of AR in CS projects?

It is noticeable that many of the recent case study publications refer to the use of AR in CS projects that use some form of spatial data (Buchanan, Pressick-Kilborn, and Maher 2018; Haynes, Hehl-Lange, and Lange 2018; La Salandra, Fraternali, and Frajberg 2018; Sermet, Demir, and Kucuksari 2018). This suggests that the use of augmented reality represents a greater added value for geographic oriented CS projects. Geographic Citizen Science (GCS) differs from CS in that the scientific data collected by volunteers have an explicit and intentional geographic reference (Haklay 2020). This shared spatial approach could connect GCS and AR. However, this assumption still needs to be verified or disproven. Therefore, all research questions defined above will be answered for CS projects in general and again more specifically for geographically oriented projects. This enables a comparison and allows to draw conclusions about whether the added value of AR is currently estimated to be higher in GCS projects.

In the following, existing approaches and possible uses of AR in CS projects are briefly reviewed. The methodological approach for the survey of CS projects is then explained and the results presented. In this context, two of the participating projects are presented in more detail in the form of a case study in order to illustrate concrete examples of the possible use of AR in CS projects. Afterward, the results are discussed and the most important findings of the study are summarized.

2. Related work

CS is a growing practice that allows citizens to participate in and collaborate on scientific projects (Vohland et al. 2021). It is successfully used in fields such as environmental and ecological sciences (Fraisl et al. 2022), astronomy (Odenwald 2018), education (Lüsse et al. 2022), earth sciences (Lee, Lee, and Bell 2020), and social science (Tauginienė et al. 2020). Despite the different research fields and participation approaches, many CS projects face similar challenges that need to be addressed. One of these challenges is attracting new participants to the project and continuing to retain existing participants. Strategies to attract new participants to the project are, for example, gamification (Bowser et al. 2013), rewards (Cappa et al. 2018), and feedback given by the community or the scientists involved in the project (Weeser et al. 2018).

The term AR was first used in the literature in the 1990s (Caudell and Mizell 1992). Since then, the interest in AR has steadily increased, which is also reflected in the number of publications on the subject (Sünger and Çankaya 2019). At present, mobile AR applications are primarily used on smartphones (Chatzopoulos et al. 2017). AR can be an enrichment for many fields of application, in part because the use of AR on the smartphone is still new enough that it holds some appeal for users. In the context of CS, AR can thus be a tool to attract new participants and engage them in a real-world learning experience (Tsivitanidou and Ioannou 2020).

Individually, AR and CS are both discussed extensively in literature. However, if searching for publications that address an overlap of the two topics, the number of available publications is still limited. In closely related areas of CS, such as public participation, AR is already being used more frequently. For example, the use of AR to convey impressions in urban construction projects to citizens is discussed by several authors (Boos et al. 2022; Mühlhaus, Jenney, and Petzold 2018; Silcock et al. 2021).

The literature found describes CS projects that use AR in the areas of data visualization, participant attraction, data collection, and navigation. Especially data visualization is suitable for a first deployment of AR in a CS project, because the implementation of the functionality can be done mostly independently from other content. For example, Woolley et al. (2021) describe an approach for visualizing 3D artifacts from a museum collection for scholars, citizen scientists, and the public with an AR mobile application.

With the help of the AR solution, users are able to place 3D artifacts on horizontal surfaces in their real environment and explore them from all sides. This offers the possibility of viewing artifacts that are not currently on display in the museum or to experience exhibits independent of the current location. It is also possible to display objects in the participants environment based on geographic positions (Ramtohul and Khedo 2022). Here objects are not displayed relative to the device of the participant, but are rather placed at exact geographic coordinates. This is possible through the integration of GPS and additional sensors in mobile devices. For example, Sermet, Demir, and Kucuksari (2018) describe an approach for displaying information about power line poles based in part on the GPS position and the orientation of the participant's device. Haynes, Hehl-Lange, and Lange (2018) demonstrate that AR can also be used for complex visualizations in the field of flood risk management. They present an approach that lets users experience directly on-site how the area would be flooded depending on different scenarios.

AR can be used in CS projects not only for data visualization, but also for data collection and navigation. Albers, de Lange, and Xu (2017) propose an approach that allows a CS participant to navigate to a precise location using AR and position themselves in exactly the right spot. Once the position is reached, AR is used to display a target, which the user points to with his mobile device until a photo is automatically taken. This allows a series of photos to be taken from the same position with a similar angle of view.

AR can also be used as a tool to attract and motivate participants. By offering something new, CS projects using AR could differentiate themselves from other projects and thus might appeal to more participants. Especially creative learning experiences using AR can be a motivating factor for younger participants to join the project (Lotfian, Ingensand, and Brovelli 2020). In this context, Gandhi et al. (2021) discuss how a CS game with integrated AR functionality needs to be designed in order to provide an exciting experience for the participants and still be of relevance for answering the research question of the project. Saßmannshausen et al. (2021) further demonstrated that AR can increase the motivation of younger participants in participatory processes by using a human-centered design approach while creating an AR application. Nevertheless, it should also be noted that while AR can visually enrich a project and offers many benefits, the use of the technology does not necessarily result in a more successful participation process, as this is highly dependent on the individual project context (Hunter et al. 2022).

3. Methods

To assess the extent to which AR is already being used in CS projects and to answer the research questions defined above, a mixed-methods research approach consisting of a case study within a survey as described by Yin (2009) is adopted.

3.1. Survey design

The online survey is addressed exclusively to initiators/managers/coordinators of CS projects (hereafter referred to as project managers) and not to the projects' participants. Of course, the participants are an important part of CS projects, but within the scope of this study, we will focus on the interest and the assessments of CS project managers in the topic of AR. Participation in the survey is independent of the CS project's research field and regardless of whether the project is currently using AR. The survey consists of a questionnaire of 36 questions in total. The 15 rules of Bernard (2017) were used as a guideline for the development of the survey questions and answer options. The majority of questions have predefined answer options to allow for comparability. This applies in particular to the questions that allow unambiguous answer options (yes-no questions, value ranges, agreement scales). In case of ambiguous answer options, suggestions were made, but there was also always the possibility to add an individual answer in text form ("other" option). In addition, some of the questions have optional text fields where the participant can provide more detailed explanations for previously selected answers. Depending on which answer options the participant selects, different follow-up questions are displayed, so that ultimately only a subset of the 36 questions needs to be answered by each participant of the survey. The complete list of all questions and the answers of the participating CS project managers are published in an openly accessible repository (see data availability statement).

The survey is designed to be anonymous. Participation in the survey can be terminated at any time without giving a reason. At the beginning of the survey, participants are informed in an introductory note about the aim of the survey and about the authors' research. Contact information is provided for questions, so that the authors could be contacted directly in case of uncertainties or further inquiries. Before the survey is started, the participant must give his consent that the collected data of the survey will be used for scientific purposes (publications, presentations at conferences etc.). The participant is also informed that the publication of the data is completely anonymized, so that no conclusion can be drawn about the individual projects. Following the guidelines of the Deutsche Forschungsgemeinschaft (German

Research Foundation) (2023) it was decided that this survey does not require ethical approval, since no research on humans is being done and no psychological or physical harm is to be expected from participation in the survey.

In total, the survey consists of three parts. The first part of the survey is designed to collect general information about the CS project. This includes the research field of the project, the approximate number of active participants, and the spatial extent of the project's research area. In addition, the first part of the survey inquirers whether spatial data are used in the CS project and whether the participants of the project are involved in collecting new spatial data. This information will be used later on in the analysis of the survey in order to distinguish between geographic and non-geographic projects.

The second part of the survey focuses directly on the use of AR. First, it is determined whether AR is already being used in the CS project. Depending on the answer, different questions are then presented to the participant. If AR is not yet being used, the focus is placed on whether the managers of the CS projects think that AR could be beneficial for their project and in which areas of the project they see the greatest potential. In the case of projects that already use AR, questions are asked about the exact use case and whether the project initiators have been able to identify a positive or negative effect on the overall outcome of the project since they started using AR.

The third part of the survey addresses the technical infrastructure of CS projects. In this section, it is determined if certain devices are needed for participation in the project, and if so, who provides these devices. In addition, the survey asks whether a mobile application is used in the project and which platforms it supports. Thus, the third part of the survey aims to reveal as much as possible about the technical infrastructure of the individual CS projects to enable an assessment of whether the existing infrastructure of the projects allows the adoption of AR solutions.

On a final page, the participant can enter the name of the CS project and whether contact is desired in case of further questions. These answers are purely voluntary and are not included in the evaluation of the survey and will not be published with the other responses.

3.2. Survey distribution

The distribution of the survey was carried out in two phases. First, the survey was distributed through existing CS networks. For this purpose, national and international CS networks were first identified through an online search. Afterward, the networks were contacted and asked if they could assist in the distribution of the survey. The distribution through the networks was intended to reach projects with different research fields and methods in an unbiased way. The idea was to achieve a sample that reflects the heterogeneity of CS projects. At the same time, the networks have the advantage that a large number of projects can be reached with little effort. A total of 19 networks were contacted, eight of which agreed to help with the distribution of the survey. The distribution was done by using a combination of the following approaches: (1) re-sharing a social media post advertising the survey, (2) the promotion of the survey in the networks' newsletter, (3) a blog post on the networks' sites, and (4) in one case an internal networks' mailing list.

Unfortunately, very few responses were received using the distribution over the CS networks. Therefore, in the second phase it was decided to contact projects individually. For this purpose, the project lists of the CS networks were used and individual projects selected for contacting. The selection was based on whether contact information for the individual projects could be obtained and whether the projects were still active. For example, projects listed on CS network web pages, which had references to unreachable project pages, were directly excluded. In addition, further CS projects were identified globally by means of an internet search. The response rate from individual correspondence with the projects was considerably higher, but it should be noted that the authors had a greater influence on the selection of the CS projects contacted using this distribution approach and were thus able to control the sample to a greater extent. A total of 476 projects were contacted directly by e-mail and invited to participate in the survey.

3.3. Survey data analysis

Due to the described design of the survey, a qualitative analysis approach was chosen. This resulted in particular from the open-ended questions in which the participants were able to answer openly in text form in order to express their opinions and their own perspective on the topic. The open-ended responses were reviewed in their entirety, and in some instances individual categories were derived manually into which the responses could be divided. During the analysis of the data, an additional distinction was made between geographically and non-geographically oriented CS projects in order to be able to answer the research questions defined above in a deferential manner for both groups of CS projects.

3.4. Case study

As described above this study follows a mixed-research approach. Within the context of the survey two of the participating CS projects were selected as cases for a case study to enable both a deeper insight into the individual projects and into the views of the project managers regarding the use of AR.

The two cases were intentionally selected based on the results of the survey. One case highlights a CS project in which AR is already being used successfully and the other case describes a CS project in which the project manager sees great potential for the future use of AR. Additionally, it was ensured that both selected cases were GCS projects, as the focus of this study is on geographically oriented projects.

The case study evidence was collected from two sources: from available documentation and from focused interviews (Yin 2009). Documentation used included annual project reports, user manuals for participation in the project, and scientific publications. The documentation was either obtained directly from the official website of the CS project or provided personally by the project manager. The project managers of the selected cases were each invited for an interview. The interviews took place online and lasted about half an hour. The framework for the interview was a set of predefined questions, which were not necessarily processed in a fixed sequence. The interviews were rather conversational, so that the project managers were able to talk freely about their projects. Both CS managers agreed that their CS project can be mentioned by name in the case study, even though the previous online survey was conducted anonymously.

4. Results

4.1. Survey

The survey started in October 2022 and was open for participation for about three months until the end of the year. A total of 54 CS project managers participated in the survey and completed the questions. One record was eliminated from the data pool, because the survey was answered twice for the same project. Consequently, the responses of 53 CS projects were ultimately available for evaluation.

4.1.1. General project information

CS projects worldwide participated in the survey. The projects ($n = 53$) indicated that they are active on the following continents (multiple answers were possible): Africa (3), Asia (4), Australia/Oceania (5), Europe (20), North America (6), South America (6), and worldwide (12). The research fields in which the projects are located can be found in Table 1. Approximately 69.8% of the projects stated that they would classify themselves completely or partially in the "ecology & environment" field. But also, projects from the fields "education", "climate & weather", and "social science" are represented with seven or more participations each. Fields that are not directly listed in the survey, and thus fall into the "other" category, included art, cultural heritage, computer science, artificial intelligence, and urban studies/planning.

Table 1. Results for the question: in which field(s) is your project located? (multiple answers possible).

Field	Number of projects(n = 53)
ecology & environment	37
astronomy & space	2
medical & health	1
education	8
historical research	5
climate & weather	8
geology & earth science	4
social science	7
other	11

The number of active participants named per CS project varied greatly. Table 2 shows that the category "50–200 active participants" was selected most frequently. A total of 16 CS projects have classified their number of participants in this range. However, also CS projects with a larger number of participants are represented, one project even with more than 100,000 active participants. Most CS projects indicated that participation happens at irregular intervals (27). In contrast, a total of 12 projects stated that their participants contribute to the project on a regular basis, with six projects providing training to participants beforehand. 12 projects have reported that their participants usually participate only once and two projects stated that they follow another participation strategy. One of these projects, for example, has noted that participation takes place only in the context of collaborative events.

Of 53 projects, 49 indicated that they use some form of spatial data. Of these 49 projects, 39 projects have participants actively involved in the collection and generation of new spatial data. Thus, these 39 projects are defined as GCS projects in the following to allow a comparison of geographic oriented with non-geographic CS projects ($n = 14$).

Table 2. Results for the question: approximately how many active participants does your project have?

Number of participants	Number of projects(n = 53)
0–20	5
20–50	5
50–200	16
200–1,000	11
1,000 –10,000	13
10, 000–100,000	2
more than 100,000	1

4.1.2. AR in CS projects

In the second part of the survey, the projects shared their opinions and views on the use of AR.

A distinction was made between projects that already use AR, projects that do not yet use AR but would consider it beneficial for their project, and projects that do not see any added value in the use of AR.

4.1.2.1. Current use of AR.

In total, three CS projects indicated that they have already integrated AR as a method in their approach. In all three projects, geographic data are collected by the participants, consequently all three can be classified as GCS projects.

AR is used by the projects in the areas of "attraction/motivation of participants" (1), "training of participants" (1), "data collection" (1), "data visualization" (2), and "navigation" (1) (multiple answers possible). In addition, one of the projects stated that they are using AR to create artwork and for creating a "fun" experience for the participants. All three projects indicated that they added the AR functionality at a later point to the project. In one of the projects, neither positive nor negative effects on the overall project were observed after the integration of AR functionality. Another project stated that they added the AR functionality to "[raise] public awareness". Unfortunately, it was not explained further whether this approach was successful.

Another question in the survey inquires how important certain aspects were rated when it came to incorporating AR functionality into the project. The rating is on a scale from 1 (not important) to 5 (very important). A subset of the results can be seen in Figure 1. All three projects indicated that they considered it important (rating 5 or 4) that the AR functionality be "easy to use" for the participant. Furthermore, the projects rated it as important that the AR functionality "should run on the already available devices of the participants (no additional devices, like for example glasses, are necessary)". The projects also agreed in the rating that the use of AR "should not negatively affect/limit other functionalities of the project". All three projects considered this aspect as very important (rating 5).

4.1.2.2. Potential use of AR.

Of 53 projects, 50 indicated that they do not currently use AR. Of these, 27 projects stated that AR could be beneficial for their project. The other 23 projects do not currently see any useful application for AR. Thus, approximately 54% of the projects not currently using AR consider the technology to be beneficial for the overall outcome of the project. Dividing the 50 projects into geographic (n = 36) and non-geographic (n = 14) CS projects, the distribution shifts (Figure 2). Among CS projects classified as geographic, 61.11% of the projects indicated that AR could add value to their project, compared to only 35.71% of the non-geographic projects. Grouping all projects according to their research field, it is

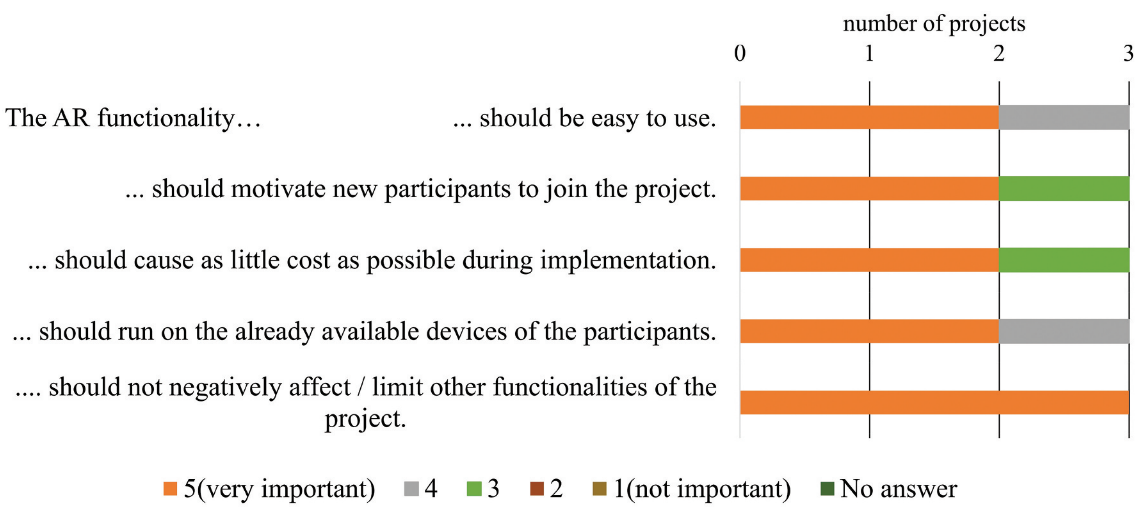

Figure 1. Selection of the responses (n = 3) for the question: Please rate how important the following aspects were to you when you decided to integrate AR functionality into your project.

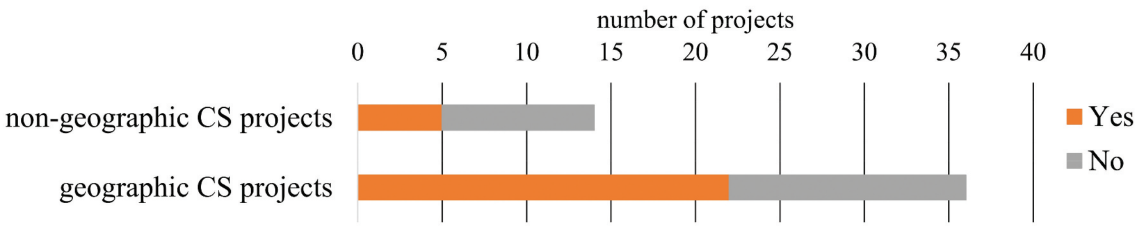

Figure 2. Responses (n = 50) for the question: Do you think your project could benefit from AR? divided into non-geographic and geographic CS projects.

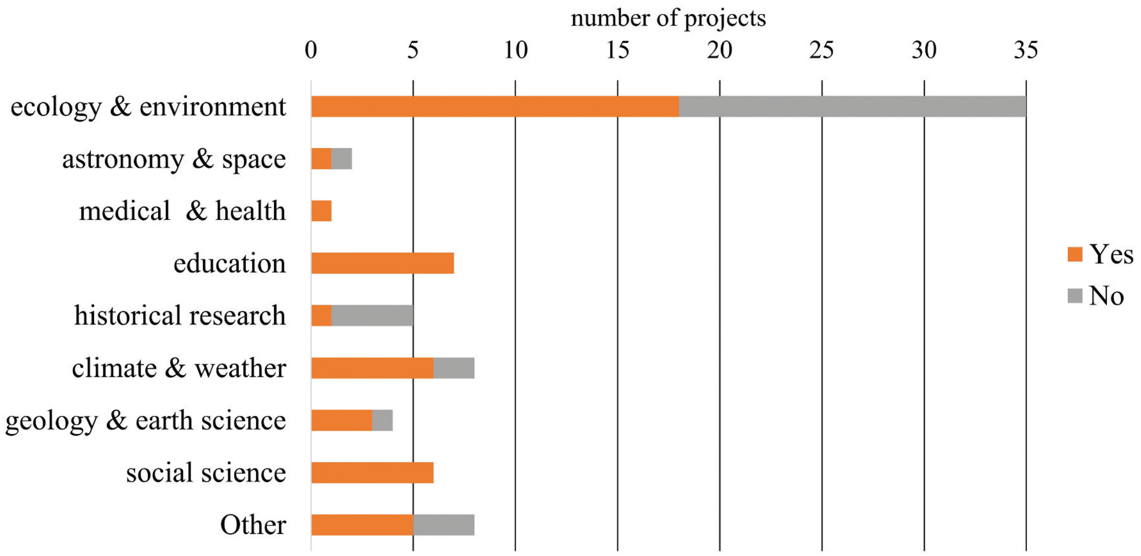

Figure 3. Responses (n = 50) for the question: Do you think your project could benefit from AR? grouped by research field (multiple answers for research field possible).

noticeable that especially the projects in the fields "education" and "social science" consider AR to be beneficial for their project. All projects in these fields agreed that they could benefit from an AR approach (Figure 3). In the largest group, "ecology & environment", the assessment is more balanced, with about half seeing advantages in the use of AR technology and the other half not convinced that AR will advance their project. But if considering only those projects that indicated "ecology & environment" as their exclusive field of research (23), only 34.78% see AR as beneficial.

The greatest added value of AR is identified by the 27 projects in the areas of "attraction/motivation of participants" (20) and "data visualization" (19). However, potentials for the areas "training of participants" (16) and "data collection" (14) were also indicated by the participants of the survey (Figure 4). To this end, several projects described specific use cases in which they could envision using AR. One project described that they are currently training their participants through a combination of online and face-to-face in-water training. The project already considered using immersive technologies to assist in the training process by letting participants experience underwater 360° images, but currently the creation of such a solution is considered to be too time intensive (response id: 15).

Another project, in which participants are involved in measuring rainfall, states that AR can be used in their research to visualize the impact of heavy rainfall in low-lying urban areas. This visualization could be used as a motivating factor for participation, but also for educational purposes only. In addition, the project could also envision displaying the measurement

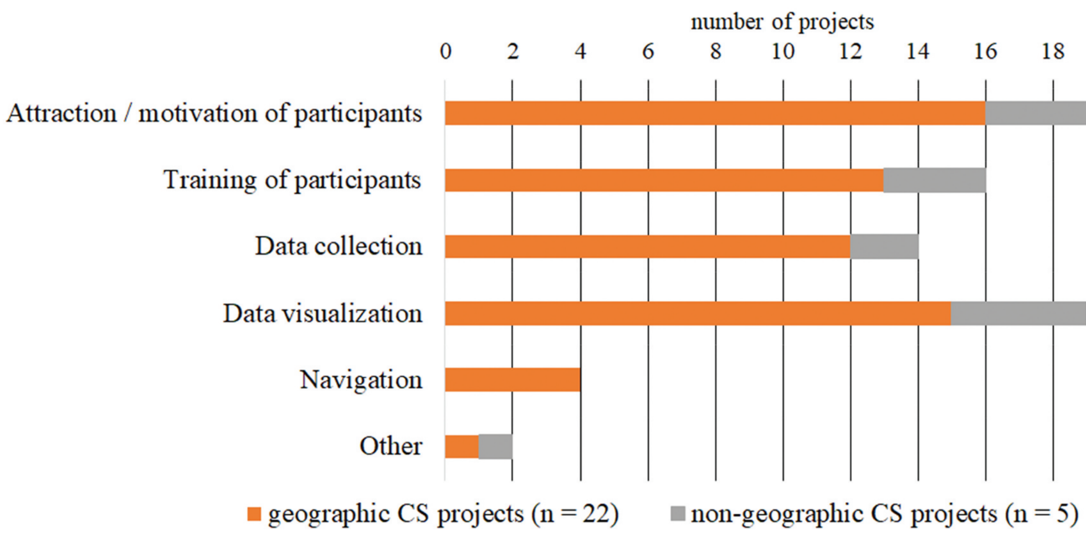

Figure 4. Responses (n = 27) for the question: in which areas could the added value of an AR functionality lie for your project (multiple answers possible)?

results in real life environment, so that a participant can walk through the city and, with the help of immersive AR technology, see how much rain was measured at certain locations (response id: 48). Yet another project described that an interactive AR solution could be useful, for allowing participants to remotely collect location data through annotation without having to enter hazardous areas (response id: 67).

Of all 27 projects that rated AR as beneficial for their project, 24 projects consider it “very important” that the AR solution is “easy to use”. In addition, 22 projects consider it “important” or “very important” that the AR solution “should run on the already available devices of the participants”.

4.1.2.3. Exclusion criteria for the use of AR.

A total of 23 projects indicated that the use of AR in their project would not be beneficial. Many of the projects gave specific reasons, which are presented in Table 3. The reasons and comments are grouped into categories, in order to highlight the overarching concerns for using AR in CS projects. Based on the comments, six categories are identified.

The first category concerns the available resources and the costs involved in providing an AR solution within a CS project. It was noted that special technical equipment required by CS participants is a potential obstacle. It would result in large groups of participants being excluded from the project, making the entire project less accessible.

Another barrier that projects see when it comes to integrating AR is the operation of participants in remote areas. Two projects pointed out that the participants in their projects are usually at sea, which means that a mobile cellular connection is not always available. An AR solution would therefore have to be available offline in order to be used in the project, because satellite connections should not be mandatory for participating.

Another reason given was the demographic composition of the group of participants in the CS project. One project stated that their group of participants consists mainly of volunteers aged 60+ years and therefore many of them are not particularly affined with technology. Thus, the use of AR technology might even be disadvantageous and would lead to confusion. This is closely connected to the comment of one of the projects that the use of AR in their project would not be beneficial, as it would distract from the actual goal of the project. The participants in this project should experience nature around them and reconnect with it. The use of a challenging technology can be a distraction and causes the actual goal of the project to recede into the background.

Another point that many projects mentioned is that they currently cannot identify a relevant use case for AR in their project. In particular, monitoring projects where participants collect data in the field noted that they could not think of a use case where AR could be helpful.

Closely related to this, two projects noted that AR can be a nice extra, but in their projects, it would not directly enhance the methodological approach and thus would not really add value to the task or the overall project.

4.1.3. Technical infrastructure

All 53 projects indicated that their participants use technical equipment as part of the project. This can be, for example, a smartphone, a desktop PC, a tablet, or a senor. Of all projects, 81.13% stated that the participants own the required devices themselves. In contrast, eight projects indicated that not all of the equipment has to be supplied by the participant, but that some of the equipment is provided as part of the project. In two projects the entire equipment is provided for the participants. Among the mentioned equipment provided are: meteorological stations, temperature/depth/air quality/GPS sensors, microscopes, oceanographic instruments, and video cameras.

In total, 44 projects indicated that their participants use an application that was developed or customized specifically for the project. Most often the projects integrate a web application into the participation process (Table 4). However, a native mobile application is

Table 3. Projects’ assessments of why AR is not beneficial for their project (a selection of responses).

Category	Comments from the projects
Resources & costs	• *“cost of AR headset/technology make it less accessible [. . .]”* (response id: 14) • *“[. . .] our project as well as contributors do not typically possess the resources typically required for such a[n] [AR] tool [. . .]”* (response id: 65)
Network connection	• *“Study operates at sea and a satellite connection is unrealistic for most citizen scientists due to the cost”* (response id: 50) • *“Data collection for my project happens on boats, offshore and outside cell coverage.”* (response id: 54)
Participant group	• *“Most of our volunteers are 60+ years old and many are not technologically inclined. [. . .]”* (response id: 23)
Distraction	• *“[. . .] And maybe it is even distracting from our goals: we encourage people to go out in nature, collect nature experiences, reconnect with nature.”* (response id: 41)
No use case	• *“[. . .] I can not imagine how [. . .] AR [helps] to meet a squirrel o[r] find a snowdrop.”* (response id: 44) • *“I do not see any use of AR in counting birds, unless they improve the identification of species.”* (response id: 27) • *“Because our project is about field observation”* (response id: 18) • *“The project is mostly transcribing or interpreting text. [It] does not take part in a physical place.”* (response id: 32)
No added value	• *“It wouldn’t add value to the tasks”* (response id: 69) • *“AR would be a nice extra or background information [. . .], but it does not directly affect the methodology of the project.”* (response id:71)

Table 4. Results for the question: what kind of application is used in your project? (multiple answers possible).

Type of application	Number of projects (n = 44)
web application	32
native mobile applicationother	25
other	5

Table 5. Results for the question: which platforms does your native mobile application support? (multiple answers possible).

Platform	Number of projects (n = 25)
Android	24
iOS	20
Windows	7
other	1

also used by 25 projects. In addition, 16 projects indicated that they use a combination of both, a web application and a native mobile application.

Table 5 shows the supported platforms for the projects' native applications. With the exception of one project, all indicated that their native mobile application supports the Android platform. Furthermore, 80% of the projects with a native mobile application support the iOS platform. Windows is supported by the fewest projects, with only seven mentions. 16 projects indicated that their native mobile application supports at least two of the aforementioned platforms. Of these 16 projects, seven indicated that an individual application was developed for each of the supported platforms and six indicated that a cross-platform approach was pursued. Three project managers were unable to provide specific information on the implementation of the mobile application.

The survey also inquired about the resources used by the nine projects that do not provide a customized application for their participants. Two projects stated that they use existing messaging services to connect participants. Another tool to share data used by the projects is social media. Participants can easily share collected data, especially photos, without the need to install an additional application. Traditional data collection using pen and paper was also named. In this case, the project in question indicated that the data collected are transmitted via e-mail and then transcribed by hand. Finally, attending online group discussions was also mentioned as a way to connect with project participants without a project-specific application.

4.2. Case studies

In the following, two selected CS projects are presented as part of the case study. This is intended to show how AR can be used in practice in a CS project. The first project to be introduced is called *Sensafety* (https://www.sensafety.org/). The project is already using AR successfully to attract new participants by offering new ways of visualization while exploring the already collected data. The second project is called *Niagara Coastal's Visual Assessment Survey Tool (VAST)* (https://www.niagaracoastal.ca/vast). The project is not yet using AR but can envision a purposefully use case for AR during the data collection process.

4.2.1. Sensafety

Sensafety is a CS project launched by a research group at the Technical University Berlin, Germany. The project allows citizen to share their personal perceptions of safety in public spaces in order to reveal the perceived safety in urban environments. The project offers participants the possibility to collect data via a mobile application and to inspect the collected safety information of other users directly in the application. In addition, the project provides a web application in which the already collected data can be viewed in an interactive map. The mobile application is implemented for the platforms Android and iOS and operates with location-based services in the background to determine the position of the participant. During data collection, the position of the participant is captured together with a time stamp to allow a differentiated evaluation of the perceived safety at different times of the day. The mobile application offers three views through which the participant can explore already collected data. The map view Figure (5a) allows the data to be viewed for a large-scale area, the compass view Figure (5b) allows the data located in close proximity to be explored by cardinal direction, and the AR view Figure (5c) allows the data to be explored by projecting the results directly into the participant's environment using the camera view (Rodriguez Garzon and Deva 2019).

The project manager of *Sensafety* explained in the interview that the AR feature was primarily used to attract new participants to the project in order to get them to install the application on their mobile devices. Altogether, the AR feature has worked very well as an incentive for participation within this project.

- "[. . .] overall it was very positively received by the people. They thought it was kind of cool. They tried it out right away, in all directions [. . .] it was almost always the first feature they tried out." (*Sensafety* project manager, 6th of January 2023) (translated from German)

However, it could be observed that the participants of the *Sensafety* project mainly used the AR functionality at the beginning of their participation. Long-term participants stopped using the AR functionality.

(a) Map View (b) Compass View (c) AR View

Figure 5. Sensafety app views (reproduced with permission form Rodriguez Garzon and Deva, sensafety: crowdsourcing the urban sense of safety, published by advances in cartography and giscience of the international cartographic Association, 2019 (Rodriguez Garzon and Deva 2019)).

- "It's something that people use once at the beginning, and great, it's fancy and all, but no longer in ongoing operation" (*Sensafety* project manager, 6th of January 2023) (translated from German)

The mobile application offers several options to explore collected data, so it is not mandatory to use the AR functionality. In the long run, participants seem to find other visualization options more convenient than the AR view.

The interview also revealed that the implementation of an AR solution is not trivial and can take quite some time. In the *Sensafety* project, the decision was ultimately made not to use any of the existing AR frameworks to implement the functionality, as these were not suitable for the required use case. Thus, the entire AR functionality was implemented independently. This was possible due to the existing expertise within the team.

- "[. . .] most CS people I have interacted with are not computer scientists and *Sensafety* is a project, which is rather the exception, it is initiated and implemented by computer scientists" (*Sensafety* project manager, 6th of January 2023) (translated from German)

Positive is that the AR functionality could be implemented quite separately from the rest of the application. Thus, one developer could intensively focus on the implementation of the AR functionality, while the development of the rest of the application continued normally. According to the project manager of the *Sensafety* project, the implementation of the AR functionality nevertheless took up a large portion of the total implementation time of the overall application. Especially the user-friendly representation of data in the AR view turned out to be challenging.

4.2.2. Niagara coastal's Visual Assessment Survey Tool (VAST)

VAST is a project launched by the organization Niagara Coastal. The focus of the project is on collecting data about the shorelines of the Great Lakes (Ontario, Canada) with the help of individual participants and local groups. The aim of the project is to monitor changes to the shoreline while engaging local residents in protecting the Great Lakes area. Three different aspects are monitored: the wash-up of Cladophora algae, the erosion along the shorelines, and the aesthetic quality of beaches. The monitoring is done by participants taking surveys and photos along the shoreline. The participants navigate to predefined benchmarks, answer a survey, and take photos in different directions along the shoreline. It is essential that the correct position is taken as described in the instructions and that the camera is aligned correctly so that the resulting photo shows a similar section of the shoreline as the photos already taken at this benchmark. Fixed objects along the shore, such as houses or trees, can serve as orientation to align the photos. From all photos a time series can be created to highlight the change over time. Finally, the collected and processed data is made available to community coastal managers to help in the decision-making process. The web-based solution ArcGIS Survey123 (https://survey123.arcgis.com/) provided by Esri is used by the participants to answer the relevant questions and to upload photos. The application is freely accessible by the participants but since ArcGIS Survey123 is a proprietary software the customization and extension of the solution is limited. For example, the implementation of own functionality is possible only to a very reduced extent.

In the interview, the *VAST's* project manager described the areas in which AR could enrich the project. Primarily, AR could be used to assist participants in taking photos. To ensure that the photos taken can be processed and added to a photo series, all photos should show a similar section of the shoreline. Currently, this is achieved by using a reference image, which the participant manually compares with the photo taken. AR could be used to overlay the reference image directly on top of the camera view, making it easier for the user to align the camera and verify that the sections of both images match. The participant would be guided through the data collection process with the help of AR to enhance the quality of the photos taken. A concept has already been developed by *VAST* and a proposal submitted to implement this solution in a completely new application.

- "[...] we do have a proposal to create an app with AR that will assist users in overlaying existing images on top of what they are seeing in the field [...] to ensure that they always taking the [photo] from the same spot and in the same aspect." (*VAST* project manager, 31th of January 2023)

Another idea is to use AR for navigation in order to make it easier for the participants to find the benchmark. Currently, the positions that the participants are supposed to take are described (e.g. starting from a volleyball net pole, five steps toward the shore), but of course following this approach the final position of the participants varies. Using an AR view, the position could be displayed directly in the participant's environment, making it easier to find.

- "[...] one use case that we are looking at is having a pin appear [so] that if you are using your camera, it can direct you where that pin is in the landscape so you can walk toward it." (*VAST* project manager, 31th of January 2023)

AR could thus make an important contribution to improving the photos taken by guiding participants through the collection process. The added value of AR within the *VAST* project thus lies in the areas of data collection, navigation, and data visualization. The project manager does not see AR as a motivational factor for participation in the project, but it would be a useful tool for conveying the project's content message in an impressive way.

- "[...] so being able to see an overlaid photo of how the shoreline used to look would be a tremendous story telling tool to let people know how drastically the shoreline has changed in a single year which can help to build that public support for the protection or conservation." (*VAST* project manager, 31th of January 2023)

Despite the good ideas for the utilization of AR, it is currently not certain whether these can actually be realized. Financial considerations play a role, but also the lack of technical expertise within the *VAST* team delays the implementation.

- "[...] what holds us back, from a lot of things, is usually financial capacity as well as expertise. [...] as conservationists we are not well worth in computer technology and so creating these things ourselves can be a bit out of the question." (*VAST* project manager, 31th of January 2023)

5. Discussion

The results of the survey reveal an initial assessment of the extent to which AR is currently being used in CS projects and for what purposes. Overall, it is important to point out that the sample of the survey is too small to allow a meaningful statistical evaluation, therefore a qualitative approach was adopted. Moreover, the ratio between geographic and non-geographic projects is not balanced. Thus, although a comparison between the two groups is possible, the results would be more resilient if the number of participating projects from both groups were within a similar range. Additionally, the CS projects invited to participate in the survey had to be chosen manually, meaning that the authors had an influence on the selection of the sample. As a result, certain CS project groups may be over- or underrepresented in the survey. In addition, due to the language barrier, it was difficult to identify an equal number of projects on all continents, which could lead to a spatial bias in the results. This concerns especially the Asian and the African continent. It is also possible that CS project managers, who are generally interested in AR, participated more frequently in the survey. CS projects where managers do not currently see potential applications for AR may therefore be underrepresented, as they may not have responded to the survey in the first place. Nevertheless, important insights can be gained from the answers of the projects, which can be incorporated into further research projects or tested in the field. Thus, despite the small sample size, the survey can help to identify initial trends regarding the use of AR in CS projects and provide answers as to why AR is seen as beneficial by some projects and why not.

5.1. Current use of AR

The survey shows that AR is already used in CS projects. In total, three of the participating projects stated that they have integrated AR successful into their methodological approach. Due to the low absolute number of projects, it is not possible to identify whether AR is primarily used in geographic or non-geographic projects. The fact that all three projects can be classified in the category of GCS projects can also be a coincidence given the size of the sample. Thus, a comparative assessment of the current extent of the use of AR in geographic and non-geographic CS projects is not possible based on the survey findings. Overall, the results of the survey suggest that the use of AR in CS projects is not yet well established. However, they show that a retroactive integration of AR into already running projects can be quite successful and can thus provide an impulse for CS projects that are already thinking about an integration of AR. The presented project from the case study has demonstrated how a practical usage of AR in a CS project can look like. In the *Sensafety* project, AR is used for data visualization and thus offers an incentive for potential participants to install the project's mobile application. Since the implementation of the AR functionality can often be done detached from other functionality of the mobile application, this could represent a promising approach for existing CS projects to extend their own applications.

5.2. Exclusion criteria for the use of AR

The reasons why AR is not seen as beneficial by projects are manifold. In part, the specific circumstances of the projects (participation happens at sea) are the decisive factor for the technology not being seen as suitable. On the other hand, many projects stated that they currently cannot identify a meaningful use case of AR in their project design. This statement may apply to many CS projects, but it should also be questioned critically. Of course, the lack of imagination in finding a use case can also be attributed to the fact that individual project managers may not had much contact with AR in general and therefore might not assess how wide-ranging AR can be used. In addition, it should be taken into account that just because the project managers do not see any use case or added value in the use of AR, this does not necessarily also apply to the participants in the project. Some possible applications, which might be considered helpful or motivating by the participants of the project, might only emerge in the course of a dialogue.

The costs of implementing an AR solution are also regarded as a constraint by many CS projects. Even projects that indicated that AR could be beneficial for their project noted that implementation would not be feasible in the near future for financial reasons. Especially in the personal comments at the end of the survey, projects described in detail that the use of immersive technologies is not possible due to an overall lack of funding. Another problem that was mentioned is a lack of technical expertise in the team to attempt the implementation of an AR solution. The focus of a CS project is on the research questions, which means that the expertise of the people involved is also in this area and not necessarily in the field of computer science. This was demonstrated very clearly in the case study. The *VAST* project already thought of several promising ideas for redesigning the data collection process with the help of AR, but at the moment the technical expertise within the team is not sufficient to implement them, meaning that financial resources will need to be raised in order to hire a full-stack developer. An exception to the reasoning is the *Sensafety* project, because extensive technical knowledge is available within the team. Thus, in addition to the financial aspects, the lack of technical expertise also represents a reason why few CS projects have ventured to implement AR functionality within their project.

In general, it can be observed that projects that have classified themselves in the field of "ecology & environmental", and in which participants take part in the collection of field observations, were significantly less likely to identify a use case for AR. Thus, it can be assumed that AR is currently not considered an attractive addition to monitoring projects, neither for data visualization nor for data collection. This is surprising, since projects in this area often have a spatial component and would therefore be, generally speaking, well suited for the use of AR. The results are even more conclusive for projects in which the participants are mainly involved in the process of transcribing historical documents. All three projects in this field indicated that they do not see any application of AR in their approach. This statement can possibly also be applied to projects that focus exclusively on the classification of images, for example via the platform *Zooniverse* (https://www.zooniverse.org/). In both cases, the task done will mainly be executed at home using a PC and thus only take place in a virtual space.

These similarities may contribute to the lack of appeal of AR for both project groups. However, since no projects from the field of image classification participated in the survey, this consideration remains an assumption.

A contrasting picture emerges from the results of the survey with regard to CS projects in the field of education. Here, AR is considered beneficial by all participating projects. AR has already been used successfully in education for over 25 years and has become considerably more accessible since 2010, due to the rapid development of mobile devices (Garzón 2021). Thus, it is not surprising that CS projects that prioritize the education of their participants also see increased opportunities for the use of AR.

5.3. Potential use of AR

The greatest potential for the use of AR is identified by the projects in the areas of "attracting/motivating participants" and "data visualization". It is noticeable that no major differences exist in the assessments between geographic and non-geographic projects. Percentage-wise, the two groups estimate the added value in the different application areas similarly. The only outlier can be observed in the area of "navigation". Here, only GCS projects indicated that AR could add value in this area. However, this can be explained by the fact that non-geographic projects are often not location-bound and thus a navigation component is generally not purposeful, whether implemented with AR or not.

With regard to the area of data visualization, different forms of utilization of AR were described by the projects. Some projects see the added value in making the already collected data visible for the participants of the project and the general public. This could be especially interesting when data are collected at locations that are not normally accessible to the public. For example, one project described that 360° underwater images could be visualized using AR so that non-divers can also experience the marine environment. This is an approach that can be used in CS projects with different backgrounds and research fields. AR could thus be used as an opportunity to communicate the relevance of the project to potential participants and the general public by visualizing data in 2D or 3D in an engaging way. Through the use of AR, the data and objects shown become more tangible for the user and thus the relevance of the project may also be more comprehensible for laypersons.

In contrast to data visualization, only 14 projects have seen added value in data collection. However, the case study has shown that in individual cases the use of AR in data collection by the participant is also conceivable and could be a valuable addition to the project.

Only 13 projects stated that they could envision using AR for participant training. This low absolute number of projects is surprising, since especially the training of participants in CS projects can be designed in a creative and often location-independent way. For example, the use of AR could be conceivable in CS projects where participants are primarily involved in the process of recording animal and plant sightings. For example, 3D models of difficult-to-identify species could be presented to the participant during the training by using AR, with annotations to draw attention to specific characteristics of the species. By presenting the training material in 3D, the training process can be designed in an engaging way and important information can be presented vividly. The use of AR during training could thus be carried out regardless of location, so that a missing internet connection at the actual research site would not be problematic. The data collection itself could then take place without the use of AR in order to allow the participants to concentrate only on the task and their environment. It therefore remains to be seen whether AR will also be used more frequently in the training of participants in the future. At present, the CS projects surveyed do not attach too much importance to the technology in the area of training, although interesting approaches can certainly be identified for CS projects, even for the dominant field of "ecology & environment".

5.4. Technical infrastructure

The existing technical infrastructure of CS projects plays an important role in the implementation of distinct AR use cases. Both the projects that are already using AR and the majority of projects that see AR as beneficial indicated that it is very important to them that an AR solution runs on the participants' already available devices. Nowadays, the use of AR does not necessarily mean that expensive technical devices, like for example AR glasses, have to be integrated into the work flow of the projects. Often, simple use cases of AR can be implemented with the technical devices already used by the participants (e.g. smartphones) (Arena et al. 2022), as the *Sensafety* project has demonstrated. This eliminates costs for the participants and keeps the project accessible. Therefore, part of the survey was devoted to inquiring which technical devices and solutions are already in use. More than 80% of the projects surveyed stated that they already use an application that was developed or customized specifically for the project. Thus, these projects already have an infrastructure that supports the use of AR. Today, a simple web-based deployment of AR is possible (Qiao et al. 2019), which means that AR functionality can also be integrated into existing web applications as an additional feature. Particularly simple use cases, such as a basic visualization of existing 3D models, offer an easy entry point into immersive technologies. Especially these simple use cases are suitable for a web-based implementation. For more complex use cases, AR can be deployed using native mobile applications.

The survey revealed that approximately half of the participating CS projects already offer a native mobile application to their participants, making an extension of the existing solutions conceivable. But even if the infrastructure is already in place, the question is whether implementing AR capabilities is feasible and financially viable with existing expertise. The positive side is that AR use cases can be scaled. It is not necessary to implement a complex use case right at the start. Especially at the beginning it can be useful to start small, to save costs, and to see how the participants accept the new functionality. Existing AR frameworks can be helpful, as they already offer a wide range of functionality and can be easily integrated into the mobile application of the projects. Especially AR frameworks that can be used across platforms are a practical solution for CS projects (Berger and Gerke 2022).

Due to the heterogeneity of the CS projects, it must be determined in each individual case in which area AR can be integrated best. This applies to both geographic and non-geographic projects. If the decision is made to implement an AR solution, then the different participant groups of the CS projects should be considered. Attention should be paid to the inclusion of different age groups, as the requirements for a user-friendly application can change with the user's age (Seifert and Schlomann 2021). Apart from the age group, factors such as gender and different levels of education should also be considered, as shown by Katika et al. (2022). Only then can an inclusive AR application be created that meets the needs of the diverse participant groups of CS projects. In addition to user-friendliness, the design of an AR application should also focus on the user's expectations. For example, Hunter et al. (2022) have demonstrated that users in public participation processes prefer AR applications in which existing data is not only visualized by using AR, but in which they are actively involved in the creation of new data.

However, in general, the survey showed that AR is seen as a useful tool and could be beneficial for many but not all kinds of CS projects.

6. Conclusions

Returning to the research questions that form the basis for this study, unfortunately it is not possible to sufficiently answer all three research questions solely based on the survey results, because of the low number of participating projects in the survey. Nevertheless, the results offer an initial insight into the current spread and application of AR in CS projects.

The survey revealed that AR is already being used successfully in individual CS projects. The fact that all CS projects that already use AR and participated in the survey are geographically oriented projects may have been a coincidence given the small sample size. However, with the help of the case study, it was possible to demonstrate a successful application of AR in a CS project and to gain an impression of what an explicit implementation could look like.

Among the CS projects that do not yet use AR, it could be observed that GCS projects were more likely to identify an AR use case for their project than non-geographically oriented CS projects. Particularly in the areas of data visualization and participant motivation, the projects currently see the greatest potential for the use of AR. Many of the CS projects surveyed were able to describe detailed use cases that would be beneficial for their project.

Important reasons against the use of AR in individual CS projects could also be identified. The absence of a meaningful use case was listed most frequently by the CS projects. However, financial considerations and the special circumstances of the study area in which the participants operate were also listed as reasons why the use of AR would not be beneficial.

A limitation of this study is that it did not investigate to what extent AR actually contributes to the improvement of CS projects. Therefore, future studies should investigate whether, for example, an AR solution actually results in increased participation in the project or in improved data quality. Another point that should be explored is the process of the technical implementation of an AR application that is specifically designed for the use within a CS project. Since many project managers have noted that an integration of AR into their projects currently fails, in part due to financial resources, it should be analyzed whether there are similar use cases for the use of AR across multiple projects, so that it may be worthwhile to implement a generalized application that could benefit multiple CS projects.

It is important to note that while this study shows trends in how CS project managers view the potential for using AR in their project, it does not take into account the participants' side. The project managers can make a start and integrate AR functionality into the projects, but ultimately the participants will decide whether it will be adopted or not. The discussed case study has shown that even good ideas and skillful implementations do not necessarily lead to the participants using them permanently. Therefore, in the course of further studies, it should be examined which requirements participants place on an integrated AR solution within a CS project and how these are ultimately accepted.

It therefore remains to be seen whether AR will become established in CS. However, interest in the technology seems to exist, at least on the part of the project managers.

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Data availability statement

The data that support the findings of this study are openly available at https://doi.org/10.24355/dbbs.084-202305081621-0. Please note that due to the anonymous design of the survey, answers that could be used to draw conclusions about the respective projects have been edited.

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