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Increasing citizen engagement in sustainable architecture using augmented reality: A pilot study

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A R T I C L E I N F O

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A B S T R A C T

Sustainability processes aim to include citizens as it is their behaviour and use of the cities that will play a pivotal role in achieving sustainable communities. Yet, active participation of citizens can be challenging, mostly due to lack of information about the topic. Augmented Reality (AR) has been identified as a useful tool to provide information to people, yet it is unclear whether its use can contribute to achieve citizen engagement in sustainability. The present study explores whether the use of AR can increase people's understanding of sustainable architecture topics, thus increasing their interest and engagement. An experimental pilot study was designed, using a self-developed AR application (app). The AR app presented information on how different façade materials of a Sports Hall building in Oslo might impact the CO2-emissions. Two aspects were evaluated in the study: the technical aspect (related to the use of the AR tool), and the sustainability aspects (related to the users' engagement in sustainable architecture). Both aspects were evaluated via subjective assessments (i.e. how user-friendly, useful, realistic and satisfactory the app is evaluated for the technical aspects, and how users understand, get interested and engaged in sustainability aspects). In addition, possible effects of reported gender and professional background (experts vs non-experts) on the subjective evaluations were evaluated. The pilot study included 27 participants, who evaluated the AR tool using a Likert-scale to rate both the technical and the sustainability aspects. The statistical results showed that there were no significant differences between males and females or between experts and non-experts in the technical evaluation of the AR tool nor the evaluation of environmental interest. The results also showed positive correlations between the positive technical experience of the AR tool with the increment of understanding, engagement and interest of the users in sustainability. The findings show advancement in understanding the potential of the use of AR as a practical tool for increasing users' interest and engaging them into the creation of more sustainable communities.

1. Introduction

"Sustainable cities and communities" is one of the 17 sustainable development goals (SDGs) of the United Nations (United Nations, 2015), for which different initiatives and movements are working towards achieving sustainable, climate positive and circular communities. In Europe, the Green cities competition (European Commission, 2023), and the Circular Cities and Regions Initiative (CCRI) (European Commission, 2020) are examples of initiatives that work facilitating processes to achieve sustainable communities. In that sense, public participation processes are encouraged as it is emphasised that "*citizens are and should remain a driving force of the transition to sustainability*" (European Environment Agency, 2023). Already in 1992 the United Nations published the Agenda 21 indicating that for sustainable development, the broadest public participation should be encouraged (United Nations, 1992). More than three decades later this has not change, as the engagement and participation of public is considered a critical element for the implementation of the 2030 Sustainable Development Agenda, in which the 17 SDGs are listed. Specifically, it has been clearly indicated that the 2030 UN Agenda is "*of the people, by the people and for the people* (§52) *and*

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it is expected to be implemented with the participation of all countries, all stakeholders, and all people" (Mohammed, 2018; United Nations, 2015).

Certainly, when planning environment-friendly processes and practices in buildings and cities, citizens are an important part of the working processes as it is their behaviour and use of the cities that will have a crucial role in achieving sustainable communities (Huttunen et al., 2022; Trischler et al., 2023; Yang et al., 2022). In decision-making processes, the inclusion of citizens is commonly referred to as "participatory processes", in which different methods are used to encourage active participation by citizens. Yet, increasing environmental awareness and engagement among citizens is a complex challenge that requires multiple strategies and approaches, and that not always achieve a strong and continuous engagement.

Educating citizens, by delivering information about sustainability topics, is one strategy that can be used for raising environmental awareness and encourage participatory processes. The challenge lies in finding innovative educational directions that attract citizens and enhance their interest, thus engaging them in the topic. In that sense, different technologies have been tested as a means to engage citizens, ranging from digital social platforms to sensing technologies. For instance, Information and Communications Technologies (ICTs) are considered useful tools to educate citizens in sustainability topics (Carrión-Martínez et al., 2020). Augmented Reality (AR), as an ICT, is a technology that has different innovative aspects that can positively influence learning processes (Carbonell Carrera et al., 2018), and that has been identified as a useful tool to provide information and to engage citizens to specific topics (Russo, 2021). This brings forth the question of the impact that AR can have in delivering information and education to people, particularly in the context of sustainability and environmental awareness.

The present paper presents the results of an experimental study designed to evaluate the use of AR technology as a tool to inform and engage citizens about architectural choices that could impact sustainability. As such, this paper is structured as follows: Sub-section 1.1 presents the literature background of the study, in which the benefits and challenges of achieving citizen engagement in sustainability are presented. The sub-section argues that educating citizens by presenting them information is a pivotal action to achieve engagement. Sub-section 1.2 presents Augmented Reality (AR) as a tool for presenting information and educating citizens in sustainable and environmental issues and discusses studies that have tested the use of AR in sustainable education. Based on these sub-sections, Sub-section 1.3 presents the objectives of the study linking the previous sub-sections and outlines the research questions that this paper aims to respond. Section 2 presents the detailed information of all the components of the experimental method plan, i.e. the experimental design including the instrumentation (generation of AR application with the information presented), the evaluated variables in the study, the description of the participants as the study group, and the experimental procedure carried out in the study. Section 3 presents the results of the experimental study, starting with an analysis strategy on how the data is analysed, followed by a presentation of the statistical results. Section 4 presents the discussion of the findings, starting with the limitations of the study and recommendations for future work, followed by the discussion of the results connected to related work. The paper ends with Section 5 presenting an overview of the main findings and concluding with the implications of the results, and a final Reference section listing all the studies that have been referred in the paper.

1.1. *Citizen engagement: benefits and challenges*

The engagement of citizens is considered an action with multiple benefits. One of these benefits, as stated earlier, is that citizens' behaviour in their own communities determine to a large extent practices that can impact sustainability. Citizens who have a greater sense of social responsibility can contribute positively to achieving sustainable communities. Other benefits include engaging citizens by making them more aware of urban issues and so enabling them to act upon such issues (Balestrini et al., 2017), and empowering citizens to hold government authorities accountable (Elelman & Feldman, 2018). Although the latter aspect might seem a pressing point to authorities, this is seen as sharing both authority and responsibility, diminishing the pressure of government authorities of having to show results. The inclusion of citizens in participatory processes seeks thus to empower citizens to participate in sustainable practices at both small scale (e.g. users' behaviour and choices), and large scale (e.g. participating in policymaking together with city authorities). This promotes the creation of inclusive, robust and sustainable communities with a high degree of social justice.

Despite the different benefits of engaging and including citizens in such participatory processes, efforts have often failed to implement strong and continuous engagement due to different reasons. For instance, Elelman and Feldman (2018) discuss four reasons for the deterioration of participatory processes: *i.* Participants' focus on personal interests rather large common issues, *ii.* Diversity in participants' background and interests which impact the time allocated to build confidence among all participants, *iii.* Local environmental issues are usually seen as fraught with inequalities of power and divergent interests among stakeholders, and *iv.* The possibility of participatory processes in producing new conflicts if collaboration is unsuccessful. In addition, depending on the approaches and tools used to promote citizen engagement, further challenges may arise that negatively impact such efforts. For example, although sensing technology (i.e. technology that use sensors to acquire information about the surroundings) is effective in collecting live data, it has been shown to be difficult for the users to operate such technologies and to understand the output of the data collected (Balestrini et al., 2015, 2017). Moreover, crowdsensing technologies are often affected by GDPR issues and issues related to people's security (Ganti et al., 2011). These challenges linked to the use of such technologies can hinder people of using them, and thus limiting their applicability to citizen engagement efforts.

Nevertheless, any effort planned to engage citizens in sustainability discussions should start with one single premise: education. Using education as a means to contribute to engage citizens in environmental issues is not new. Although it dates back to the late 19th century, it was in the early 1990s that sustainability education was focused on increasing citizen engagement and capacity building for sustainable development (Wals & Benavot, 2017). Education is considered crucial for improving people's understanding of environmental issues, and has been proven to have an impact on pro-environmental behaviour, supporting environment-friendly policies and getting engaged in environmentally-positive activities (Meyer, 2015; UNESCO-LSE, 2013; Wals & Benavot, 2017). Sustainability education encompasses all kinds of formal and informal training, including adult education courses, basic school sessions, community initiatives and media campaigns among others. Naturally, the amount and quality of information that can be provided to citizens can determine the level of engagement which they will present. The way the information is presented is also an important factor for achieving interest and engagement. In that regard, innovative methods and ICTs are recommended to be tested and used in communication with citizens (Bibri & Krogstie, 2017; Bouzguenda et al., 2019; Pidgeon et al., 2014).

1.2. *Augmented reality as a tool for environmental awareness*

Augmented Reality (AR) is a technology that superimpose simulated virtual objects/elements to real-world images seen through a device (Azuma, 1997). In other words, AR presents the combination of real and virtual objects presented in a real environment. AR can be seen through different devices, i.e. a fixed camera that streams real world images into a computer screen, mobile smart glasses (e.g. Microsoft HoloLens or Google Glasses), and mobile handheld (e.g. tablets or smartphones) (Schiavi et al., 2022), the last two being the devices most commonly identified to be used with AR (Statista, 2024). The AR technology has received large attention in recent years and has been applied in several fields, e.g. gaming (Thomas, 2012), medical training (Dhar et al., 2021), military training (LaViola et al., 2015), education (Zhang et al., 2022), and architecture, engineering and construction (Chi et al., 2013).

AR together with Virtual Reality (VR) have been proven to be effective tools for the architectural field, in which 3D visualisations of projects can streamline design and construction processes. Both of these technologies (AR and VR) have been used at different stages of architectural and construction projects. Specifically, VR has been used more for the design phase of projects, VR and AR for the construction phase, and AR has been used more for the facilities management phase (e.g. activities related to maintenance and construction management) (Schiavi et al., 2022). Although VR seems to be used at a broader scale compared to AR, the rapid development of AR applications offers a promising future of possibilities using AR technologies not only during buildings' construction and maintenance but also during the design and planning phases (Chi et al., 2013; Russo, 2021). Moreover, AR is also considered useful for training and educational activities, yielding high levels of scientific production within the educational topic, particularly in the fields of computer science, social sciences and engineering (Abad-Segura et al., 2020).

Considering the joint impact of AR, education/training, and architecture (in regards to sustainability and environmental awareness), research shows that the use of AR offers an innovative perception of architecture, promoting a better communication of ideas and environmental understanding (de Freitas & Ruschel, 2013; Hsu, 2015; Russo, 2021). For instance, Ayer et al. (2016) used AR in sustainable architectural education. Their study presents a task presented to architecture, civil engineering, and architectural engineering students, in which the students had to redesign and retrofit an existing building to improve its sustainable performance. A group of students used an AR educational game, whereas the other group used only blank sheets of paper or a paper-based equivalent to the game. Their results showed that the students who used the AR application could generate additional concepts with better overall performance compared to their counterparts who only used paper-based formats. Jardin (2023) also studied the integration of AR technology in environmental education interviewing 6 environmental education teachers and 20 students to gain insights from both perspectives. His results showed that both teachers and students acknowledged the potential of AR technology and found that AR offered an interactive connection with environmental concepts. This created a more captivating and memorable learning process, enhancing thus student engagement. Yet, his study also highlighted the need to have clear boundaries, particularly with students, to avoid digital distractions with the AR device and maintain a focused learning process.

Furthermore, AR applications aimed to increase people's awareness of environmental issues have found to be effective in promoting effective sustainable behaviours (Sitompul & Wallmyr, 2018; Wang et al., 2021). For example, the study of Wang et al. (2021) found that participants who used a serious game-based AR application significantly improved their knowledge on sustainability and issues related to climate change, while promoting sustainable behaviours. Likewise, Strada et al. (2023) also made use of a serious gaming AR application as educational approach to promote sustainability awareness. Their results showed not only that the AR game was effective in raising awareness towards sustainability, but that it also contributed to creating team collaborative actions among the participants even when collaborative actions were not required. Their results were promising as they showed increase in problem-management capabilities and a clear impact on sustainability education. Similar results were found by (Katika et al., 2021), who used Davis' Technology Acceptance Model (TAM) (Davis, 1989) to evaluate citizens' attitudes and engagement in sustainable practices after being exposed to an AR tool. Katika et al. (2021) used a web-survey to ask 127 study participants about different factors influencing their acceptance of the AR technology. Their results showed that AR could act as a tool for citizen engagement in efforts aiming sustainability. Another study by the same authors (Katika et al., 2022), used the User Engagement Scale (O'brien & Toms, 2008) in a web-survey to ask 127 citizens of the municipality of Karditsa, Greece and 101 citizens outside the municipality about AR and their level of engagement in sustainable practices. Their results were in accordance with the previous study, as they showed that the AR tool was successful in informing about sustainable practices (in particular about going from linear to circular economy), attract people's attention and increase their interest to the matter. Despite AR being identified as a promising technology which can demonstrate sustainability in both research and popular media (Sakhuja, 2021), more research is needed to uncover the possibilities that AR can offer to environmental awareness and citizen engagement in environmental issues.

1.3. *Study objectives*

While there have been a number of studies focusing on the use of AR in environmental issues, the research efforts are still limited as there is much that is left unexplored. Certainly, a review of scientific literature exploring Extended Reality (XR) technologies (i.e. term encompassing augmented reality (AR), virtual reality (VR), and mixed reality (MR)) in environmental applications found that empirical-knowledge regarding this topic is still limited and that further research is needed (Cosio et al., 2023). In their study, Cosio et al. (2023) identified three agenda points (or knowledge gaps) which research needs to address: thematic, theoretical and methodological. A thematic point focuses on advancing the understanding on how XR technologies are used in environmental sustainability; and a theoretical point focuses on understanding how different users can influence the effectiveness of XR technology and who might benefit most from its use. For instance, different backgrounds (experts in sustainable architecture vs lay people) might produce a different level of interest to environmental information being presented in AR.

Aiming to contribute to close these knowledge gaps, the main objective of the present study is to increase the understanding on how AR technology can increase citizen engagement in sustainable architecture (related to point i). Another objective is to explore whether the professional background of the users have an effect on the level of engagement they gain after using AR technology. Specifically, whether there are significant differences among people working with sustainable architecture, e.g. architects and city planners, and lay people (related to point ii). Thus, this paper presents the results of an experimental design designed to address the following research questions.

RQ1: Can AR technology increase people's understanding, interest and/or engagement in sustainable architecture?
RQ2: Are there any difference between genders and between people working with sustainable architecture and lay people on how engaged they become after using AR technology?

To address these research questions, an AR application was developed to be used in an experimental pilot study to explore a possible effect of the AR app on citizen engagement. The methodological approach of the pilot study is described in the subsequent sections.

2. Method and procedure

This study used the Voldsløkka School and Cultural area located in Oslo, Norway. The Voldsløkka school opened in 2023 and is the first energy-plus school in Oslo, Norway. The Voldsløkka project includes the construction of new buildings, including a Sports Hall, which will be built next to the school and will have similar sustainable solutions as the school building (e.g. implementation of BIPVs). Yet, the construction of the Sports Hall has not started, and the space destined to the hall remains unbuilt. This study made use of the Sports Hall as a simulated building in the AR application. The Sports Hall was selected to allow its positioning in the actual area in which it will be built. This benefited from the visual information acquired from the real urban background and ensured a better visualisation and understanding of the building in its context. The experimental sessions thus occurred at the area next to the Voldsløkka School to visualise the Sports Hall using the AR application.

2.1. Experimental design

Considering the focus of the study, which seeks to explore whether AR increase citizen engagement in sustainable architecture, the AR app aimed to provide information to the study participants about the CO2-emissions that different building elements may produce. To this end, the interface of the AR application was designed to increase the understanding of environmental issues, by offering information about the characteristics of different building elements and how the choice of these can either increase or decrease the CO2-emissions which impacts the natural environment. The following sub-sections describe the generation of the AR application, the information provided in such tool and the method used to evaluate whether AR was useful in increasing the users' environmental awareness in architecture.

2.1.1. Development and programming of the AR application

The development of the AR tool was first assessed in a previous test conducted by Dimmen and Oksvold (2022). The mobile AR application was developed using the Unity engine. Based on AR requirements, the Galaxy Tab S8 5G, introduced in March 2022, was selected. The device has an 11.0-inch LCD display with 1600 x 2560 pixels resolution and a 274 ppi density providing a large, high-resolution display for viewing. Its LCD can achieve up to 420 units of brightness, addressing viewability limitations observed in many OLED screens for well-lit outside environments. With a weight of 507 g, the tablet was practical for handheld AR interactions, as the one developed for this study. The camera system's main backwards-facing 13 MP sensor was also suitable for the AR task. The device's 1080p video recording, ARCore depth API support, accelerometer, and gyroscope further enhanced its AR capabilities.

The AR elements of the implementation was performed using ARFoundation with Google ARCore. Localization of the 3d building models in the world at spawning was handled using image detection of a physical sign with a QR Code (the 3d world was adjusted based on the physical signs positioned). Although Google ARCore advice against using QR codes for image recognition, the approach worked well in our case, as only a single QR code was used so there was no ambiguity in the initial detection.

Furthermore, backend was implemented for future use. This backend supported automatic converting and packaging 3d objects and information for download to the handheld device, as well as handling user data gathering. However, to ensure no interruptions, a hardcoded version that did not utilize the backend was used in this experiment.

The building developer, i.e. the manager of the design and construction of the Sports Hall building, provided a reference 3D model. To improve the application performance, the model was simplified using Blender 3.2, a modelling software. The adjusted model had 11,342 vertices and 19,630 edges. Operating under the assumption of a level ground surface, terrain modelling was not needed. Additional 3D models and materials to be shown in the building model were also developed using Blender, and subsequently imported into Unity.

From a user interaction perspective, the AR interface was conceptualised to allow participants to securely hold the tablet with one hand while interacting using the other. This configuration was informed by preliminary tests (Dimmen and Oksvold, 2022), revealing a user inclination towards uncomplicated and user-friendly technological methods.

2.1.2. Information about the building elements provided in the AR application

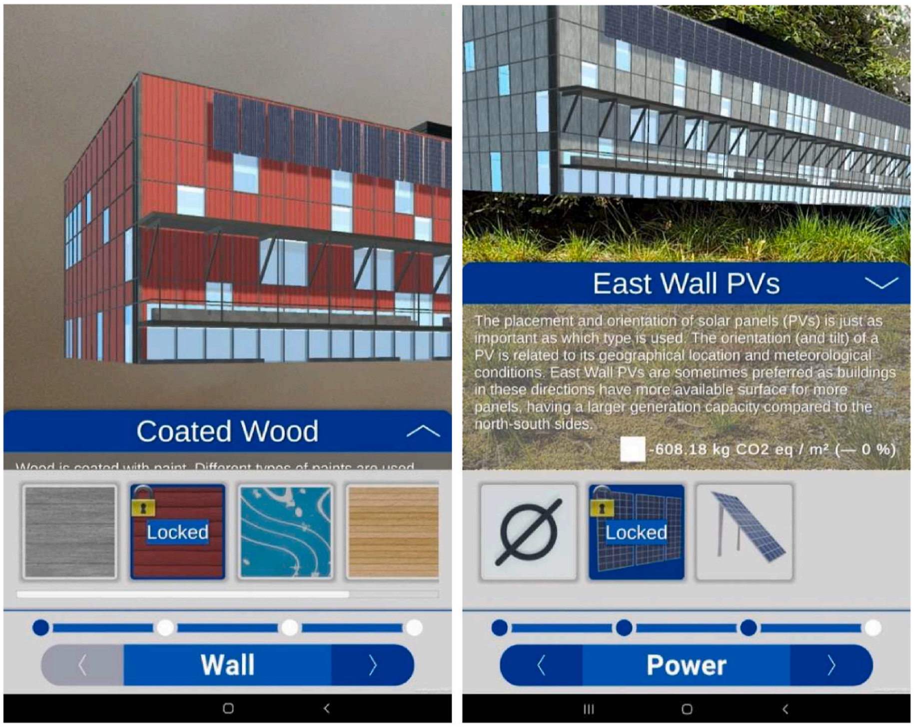
Given that the visualisation of the building was set from an outside point of view, different façade elements were selected to be simulated. Three categories were selected for the façade elements: i. Wall, presenting different wall materials; ii. Glass, presenting two types of glazing for the building openings; and iii. Power, representing the use of photovoltaic (PV) panels in either the façade or the roof of the building. Each category of façade element presented more than one alternative (see Fig. 1), which allowed the comparison between the different options regarding their CO2-emissions. Each alternative was visualised containing a brief informative text about the material characteristics, and information regarding the CO2-emissions of the material per square meter (CO2 eq/m^2). This included considerations for the material volume and encompassed a maintenance timeline of 60 years.

The calculation of the materials' impact factors is given as CO2 equivalent emissions. These are calculated by averaging the CO2eq impact factors of representative materials and building parts given in Environmental Product Declarations (EPDs) issued by materials and building component producers in Norway (sourced from www.EPDnorge.no). Calculation of the impact factor is given for the stages A1-A3 (CO2eq emissions produced at the factory gate according to NS-EN 15804:2012) and it is calculated for 1 m^2 of material. The different thicknesses of the cladding materials used in the AR tool have been normalized to a uniform 20-mm thickness. The three categories with their respective alternatives and the provided information about CO2 emissions are listed in Table 1.

As one focus of the study was to provide information about the CO2 emissions of the different façade elements, such objects were designed as fixed solutions, meaning that they could not be manipulated by the users. This ensured that the focus was on the information provided of the material alternatives and not on different design alternatives.

Regarding the alternatives for the PVs, there is only one position depicted in the building façade (i.e. PVs located in the east wall), see Fig. 1. This location was selected due to the visualisation of the east wall façade of the building in relation to the point of view from which the study participants used the AR application. Other façade positions would not have been able to be sufficiently visualised in the application. A second alternative was the positioning on the building roof, and a third alternative was no use of PVs. As expected, the alternative "no-PVs", in which no PVs could be visualised in the application, presented the value "0″ for emissions, as was chosen to allow comparison between the use and no-use of PVs in buildings. It is also to be noted that the emissions values for the PVs are negative. Naturally, these do not produce CO2-emissions but, on the contrary, produce power that can supply the building itself. Moreover, when calculating the net emissions associated with PV panels, parameters such as sunlight incidence angles, coverage area, and similar longevity metrics were evaluated. These determined values were subsequently hardcoded into the AR application.

Inside each of the three categories of façade elements, one material alternative could be "locked" by the users for comparison purposes. This means that while one material was locked, the other materials visualised would produce either a decrease or increase percentage in relation to the locked material. Each of the three categories of façade elements were designed in tabs inside the AR application, one tab for each category, see Fig. 1. Once the users chose an alternative for a category, they could move to another category tab to select a material. The order of the tabs did not follow any specific principle, meaning that the users could move forward or go back to the tabs as desired. Finally, the AR application had a closing tab that presented a summary with the alternatives chosen by the user, with their respective total emissions value. Fig. 1 shows the interface used for the AR application. Unfortunately, the screenshots were not taken at the experimental field (i.e. the Voldsløkka school and cultural area), but it still serves for representing some of the different alternatives and the information offered, as shown to the study participants.



The placement and orientation of solar panels (PVs) is just as important as which type is used. The orientation (and tilt) of a PV is related to its geographical location and meteorological conditions. East Wall PVs are sometimes preferred as buildings in these directions have more available surface for more panels, having a larger generation capacity compared to the north-south sides.

-608.18 kg CO2 eq / m² (— 0 %)

Fig. 1. Screenshots of the AR application depicting some wall alternatives and the two types of PVs.

Table 1

Categories and alternatives of façade elements presented in the AR application.

Category	Alternative	Emissions (kg CO2 eq/m2)
Wall	Burned wood	2.29
	Coated wood	2.34
	Composite panel	17.7
	Impregnated wood	4.9
	Concrete blocks	63
Glass	Tempered glass	54.6
	Stained glass	54.6
Power	East-wall PVs	−608.18
	Roof PVs	−1483.94

2.2. Evaluated aspects

In order to evaluate the usefulness of the AR application to increase users' interest and engagement in environmental issues, their opinions and subjective impressions were measured after having used the AR tool. The evaluations of the users was recorded using a digital questionnaire provided to the participants, who after scanning a specific survey QR-code they could respond to the questionnaire using their own mobile phones. Two main aspects were evaluated, here called sustainability aspects and technical aspects.

As discussed in Section 1.1, efforts to engage citizens should start with education as a starting point. As such, four sustainability aspects were selected based on common instruments in education, as presented by Finn and Schrodt (2016). These consisted of: i. Understanding, to evaluate the level of comprehension of the relation between building elements and energy; ii. Engagement, to evaluate the reported willingness to get more engaged in sustainability issues; and iii. Interest, to evaluate the level of interest in building elements and sustainability. In addition, and due to the focus of the study, the fourth aspect focused on iv. Citizen feedback, to evaluate people's opinions of the AR tool as a mean to collect input from citizens.

The technical aspects were based on the "Technology Acceptance Model" (TAM), proposed by Davis (1989), who indicated that, among other dimensions, the perceived usefulness and the perceived ease-of-use condition the acceptance and attitude towards new technology. As such, the selected aspects were included in the analysis: i. User-friendliness, which is related to the ease-of-use; ii. Usefulness, to evaluate the perceived usefulness of the AR tool for information purposes; and iii. Amount of information, to evaluate the users' opinions on the appropriateness of the information that they receive. Additionally, the satisfaction and the realism of the AR visualisation were also included in the analysis. Both the sustainability and the technical aspects were evaluated by the study participants by using a psychometric rating scale, namely the Likert scale (Likert, 1932), known to measure people's attitudes and opinions. While the 4 sustainable aspects and 3 technical aspects were measured using a 5-point Likert scale, the evaluations of the satisfaction and realism of AR visualisation were measured using a 5-point Likert-type scale. The Likert scale ranged from Strongly disagree to Strongly agree, whereas the Likert-type scale ranged from Very unsatisfied to very satisfied. Table 2 presents the different aspects evaluated and their respective questionnaire items.

2.3. Participants

The participants of the study were mainly recruited via mailing lists and posts on social media groups. The total sample size consisted of 27 people (15 female, 12 male), between 22 and 63 years old ($M = 33.9$, $SD = 11.1$). The group of participants consisted of people with and without architectural and/or sustainability training, in which 12 (44.4%) had received training (representing the "experts" group), and 15 (55.6%) had not received previous training (representing the "lay people" group). The majority of the participants had a high educational level, 92.6% of the participants received university education, and 3.7% achieved a PhD degree. Only one person reported to have a middle educational level (i.e. high school). While 7 participants (25.9%) reported to have used an AR application before, 17 participants (63%) reported not to have used or experience AR before. Only 3 participants (11.1%) were unsure of having experienced AR. Although no sensitive information was

Table 2
Evaluated aspects in the study with their respective questionnaire items and scale used.

Aspects	Questionnaire item
Sustainability aspects – *After having used the app …*	
Understanding	*I have understood about the importance of building elements for sustainability.*
Engagement	*I want to be more engaged in knowing about the buildings/areas in my neighbourhood in relation to sustainability (e.g. inform politicians and leaders, participate in neighbour meetings)*
Interest	*I want to know more about sustainable options for building elements.*
Citizen feedback	*I think that it can contribute to get feedback from citizens regarding design preferences.*
Technical aspects	
User-friendliness	*I think that the AR app was user-friendly (easy to understand and use).*
Amount of information	*The amount of information in the app was appropriate.*
Usefulness	*The app is useful to inform citizens about planned building projects.*
Satisfaction	*How satisfied are you with the experience of AR as a visualisation tool?*[a]
Realism	*How satisfied are you with the realism of the AR visualisation?**

Table notes.
[a] Questionnaire items evaluated from "very unsatisfied'' to "very satisfied".

collected, personal information of the participants was collected for demographic purposes (i.e. age, reported gender and level of education). It is to be mentioned that following gender diversity guidelines, the questionnaire included extra options to woman/man binary alternatives. Considering the collection of personal information, an application to perform the study was sent to *Sikt* – The Norwegian Agency for Shared Services in Education and Research, which granted the approval. Table 3 presents the demographics of the experimental study divided by two studied groups: Experts and lay people.

2.4. Experimental procedure

The pilot study was conducted during five days in March 2023 at the area in which the Sports Hall will be located, i.e. next to the Voldsløkka School, in Oslo Norway (see Section 2). The experimental procedure was maintained equal for all the participants, meaning that all experimental sessions followed the same established protocol. The participants were asked to select a time slot during the experimental days that best fitted their schedule. They were asked to meet the experimenter at the Voldsløkka School, where they were welcomed to the study and received practical information (i.e. experimental protocol and their rights as participants). The practical information also included basic instructions regarding the operation of the AR application. After having the opportunity to ask questions about the procedure and agree to participate in the pilot study, the participants were instructed to scan a QR-code kept at a fixed point, which they could scan with their own mobile phones in order to answer a digital pre-test questionnaire. The pre-test questionnaire presented first the written information about their rights as participants as suggested by the Norwegian Agency *Sikt* (including withdrawal without reason at any time and their right to request their data to be erased). After having read the information, they signed their consent to participate in the study as an option in the pre-questionnaire. The pre-test questionnaire then collected demographic data, i.e. age, reported gender, educational level, main occupation, and whether they had used an AR application before (see Section 2.3). After having filled out the pre-test questionnaire, the participants were handed a tablet (Samsung Galaxy Tab S8) containing the AR application ready to be used and were pointed out the position from which they should carry out the experiment. The position was fixed, meaning that the participants could not move from their position. The participants had some minutes to be acquainted with the application before the experiment began. Right after, the participants were free to explore and use the AR application as long as they wished (see Fig. 2). When the participants felt satisfied with having used the AR application, a new QR-code was handed to them so they could scan it and answer a digital post-test questionnaire. The post-test questionnaire presented the questions described in Section 2.2. At the end of the experiment, a debriefing interview was conducted by the experimenter to collect extra information that could impact the results of the experiment. It is also to be mentioned that the experimenter was close to the participants during the course of all experimental sessions to observe any unusual behaviour and/or to aid the participants in case any technical error with the application would occur. The experimenter's observations were logged in a technical log document. The experimenter did not restrict the time used by the participants when using the AR application nor when answering the digital questionnaires; however, the experimenter noticed that there was an average of 25–30 min for the entire experimental session to take place.

Table 3
Demographics of the experimental study.

		Experts	Lay people
Number of participants		12	15
Gender	Male	4 (33.3%)	8 (53.3%)
	Female	8 (66.7%)	7 (46.7%)
Age	Range	23–53	22–63
	M (SD)	31.7 (8.2)	35.7 (12.9)
Educational level	Basic/Middle school	–	1 (6.7%)
	University	12 (100%)	13 (86.6%)
	PhD	–	1 (6.7%)
Experience with AR	Yes	2 (16.7%)	5 (33.3%)
	No	8 (66.6%)	9 (60%)
	Not sure	2 (16.7%)	1 (6.7%)

3. Results

3.1. Analysis strategy

Considering the focus of the pilot study, in which the first RQ seeks to respond whether AR technology can increase people's understanding, interest and/or engagement in sustainable architecture, the study had as strategy to evaluate the association between two variables, i.e. the technical aspects of the AR app, and the sustainability aspects, as described in Table 2. Seeking to explore the association between the study variables and considering the level of measurement of the scales used in the study, the data was analysed using a non-parametric correlation analysis, specifically the Spearman's rank-order correlation coefficient test. The assessments of statistical assumptions were performed to evaluate the suitability of Spearman's correlation for this study. The assumption of the level of measurement was confirmed due to the use of Likert and Likert-type scales, which are commonly considered to be of an ordinal nature. All the scales of the study were responded by the study participants, yielding paired observations as a second assumption suitable for the correlation analyses.

For the second RQ, which explores whether there are differences between experts and lay people on their level of engagement in sustainable architecture, the data was also analysed using Mann-Whitney *U* Test. The assessments of statistical assumptions were also performed to confirm the suitability of the statistical test. As discussed earlier, the assumption related to the level of measurement of the data was met due to the ordinal nature of the Likert and Likert-type scales used in the study. The assumption of the independence of the groups was verified by analysing the data in 2 categorical and independent groups: i.e. experts

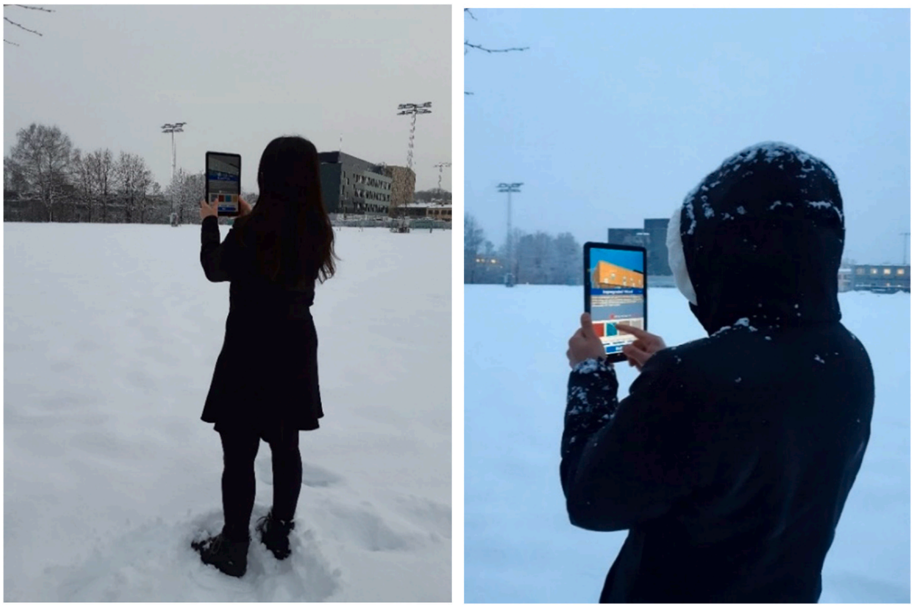


Fig. 2. Participants using the AR application at the experimental location.

and lay people. The assumption of independence of observations was confirmed by the study design, as there was no relationship between the observations in each group. This means that the data collected from the experts group are not represented in the lay people group and vice versa. Finally, the assumption of non-normality of the data was verified by using the Shapiro-Wilk test, which is considered appropriate for sample sizes below 50, as this study presents. All the calculated significance values were below 0.05, indicating that the data was not normally distributed, confirming thus the last statistical assumption for the Mann-Whitney *U* test (Field, 2009).

To allow comparison with the literature, descriptive statistics (means and standard deviations) for all the studied variables are reported in Table 4.

The data was analysed using IBM SPSS Statistics software version 29.0.1.0, and an alpha value of 0.05 was used as the cut-off point for the statistical results. The following sections present the main findings for both statistical tests used for the data analysis.

3.2. Correlation analyses: Spearman's rho

The results for the Spearman's Rank-Order Correlation test are reported in Table 5. Notice that due to space, some of the variables have been shortened and coded. As such, the letter "T" refers to the technical aspects, and the letter "S" refers to the sustainability aspects. For better identification of the significant results, these are marked with a light grey colour and bold text.

The statistical results of the Spearman's rho analyses indicate that three technical aspects had positive correlations with the people's understanding, engagement, interest and feedback. Specifically, two technical aspects presented moderate positive correlations with sustainability aspects. The first technical aspect was the user-friendliness of the AR app (T1, see Table 5), in which the correlation results suggest that as the evaluations of the user-friendliness of the AR app increased, the engagement, interest and contribution as citizen feedback also increased. The second technical aspect that had a moderate positive correlation with sustainability aspects was the usefulness of the AR app (T3, see Table 5), in which the Spearman's correlation results suggest that as the study participants evaluated the usefulness of the AR app higher, so did they with the understanding and interest in sustainable architecture.

The Spearman's correlation analyses yielded also other results. In particular, the statistical results indicated that as the engagement of the participants increased, the interest in sustainable architecture also increased. Likewise, the results showed that as the participants' interest in sustainable architecture increased, the willingness to provide citizen feedback also increased. Finally, the results also showed that as the evaluation of the amount of information increased, the usefulness of the AR app also increased. These results suggest that the study participants may have found the AR app more useful when finding the amount of information more appropriate. However, as that association was weak ($r_s = 0.381$), and not part of the scope of the study, the findings will no further be discussed.

According to the benchmarks commonly used when interpreting correlation coefficients (Dancey & Reidy, 2007; Field, 2009), all the significant correlations of the study were of a moderate positive effect, with exception of the correlation between the two technical aspects which had a weak association, as described above.

3.3. Differences between groups: Mann-Whitney U test

The statistical results for the Mann-Whitney *U* test are reported in Table 6. The results indicate no significant differences between the responses obtained from the experts and the lay people for all the studied variables. Moreover, and considering that the data allowed for further analyses regarding possible differences between the reported gender of the study participants ($N_{female} = 15$, $N_{male} = 12$, as described in Section

Table 4
Data means and standard deviations of the study variables ($N = 27$).

Aspects	M	SD
Sustainability aspects		
Understanding	3.81	0.83
Engagement	3.74	0.94
Interest	4.04	1.02
Citizen feedback	3.89	1.05
Technical aspects		
User-friendliness	4.00	0.83
Amount of information	3.30	0.99
Usefulness	4.00	1.00
Satisfaction	4.59	0.75
Realism	3.78	0.85

Table 5
Numerical results for the Spearman's rho (r_s) analyses ($N = 27$).

		T1	T2	T3	T4	T5	S1	S2	S3	S4
T1_U. friendly		–								
T2_Am. info.	Coeff.	.351	–							
	Sig.	.072								
T3_Usefulness	Coeff.	.234	**.381**[a]	–						
	Sig.	.240	**.050**							
T4_Satisfaction	Coeff.	−.166	.182	.237	–					
	Sig.	.407	.362	.234						
T5_Realism	Coeff.	.011	.165	−.016	−.237	–				
	Sig.	.958	.411	.936	.234					
S1_Understand.	Coeff.	.121	.077	**.467**[a]	−.271	.067	–			
	Sig.	.547	.703	**.014**	.171	.739				
S2_Engagement	Coeff.	**.442**[a]	.153	.051	−.288	.034	.281	–		
	Sig.	**.021**	.447	.802	.145	.867	.156			
S3_Interest	Coeff.	**.456**[a]	.373	**.466**[a]	−.182	.101	.318	**.418**[a]	–	
	Sig.	**.017**	.055	**.014**	.365	.617	.106	**.030**		
S4_C. feedback	Coeff.	**.471**[a]	.368	.247	.086	.086	.225	.185	**.487**[b]	–
	Sig.	**.013**	.059	.215	.668	.670	.259	.356	**.010**	

Table notes.

[a] Significant at the 0.05 level (2-tailed).

[b] Significant at the 0.01 level (2-tailed).

Table 6
Results for the Mann-Whitney *U* test on differences between experts and lay people.

Test variable	Group	Ranks			Test Statistics			
		N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig (2-tailed)
T1_U. friendly	Experts	12	13.08	157.00	79.00	157.00	−0.60	0.55
	Lay people	15	14.73	221.00				
T2_Am. Info.	Experts	12	11.29	135.50	57.50	135.50	−1.67	0.10
	Lay people	15	16.17	242.50				
T3_Usefulness	Experts	12	12.92	155.00	77.00	155.00	−0.671	0.50
	Lay people	15	14.87	223.00				
T4_Satisfaction	Experts	12	15.58	187.00	71.00	191.00	−1.21	0.23
	Lay people	15	12.73	191.00				
T5_Realism	Experts	12	13.79	165.50	87.50	165.50	−0.13	0.90
	Lay people	15	14.17	212.50				
S1_Understanding	Experts	12	12.88	154.50	76.50	154.50	−0.76	0.45
	Lay people	15	14.90	223.50				
S2_Engagement	Experts	12	12.25	147.00	69.00	147.00	−1.10	0.27
	Lay people	15	15.40	231.00				
S3_Interest	Experts	12	12.21	146.50	68.50	146.50	−1.013	0.26
	Lay people	15	15.43	231.50				
S4_C. feedback	Experts	12	13.54	162.50	84.50	162.50	−0.29	0.78
	Lay people	15	14.37	215.50				

2.3), the Mann-Whitney *U* test for gender differences was performed. No significant differences between male and female participants were found, all *p*-values >0.05.

4. Discussion

4.1. Limitations and future work

The present study focused on exploring whether an AR application can be a useful tool for increasing citizen engagement in sustainable architecture. Although the findings suggest that there are positive associations between the technical aspects of the AR app and the understanding, engagement and interest of people, there are still some limitations of the study that need to be discussed.

The sample size can be considered small. However, it is to be noted that this paper reports a pilot study, and as such the sample size fulfils its role for providing initial insights for the studied topic, and to continue the technical development of the AR application. Yet, further research efforts focusing on studying this topic with larger sample sizes are encouraged.

Although the correlation analyses indicate positive association between the studied variables, it is to be remembered that correlation does not infer causality. Although the findings of this study are valid in terms of the strength and direction of association that exists between the variables, the study has not proven that the use of AR, compared to other methods or approaches, can in fact increase citizen engagement. More research to study different approaches (e.g. a comparison study between the use of AR, VR, workshops and/or seminars, or comparisons between a group of people using AR and a control group without use of AR) should be undertaken to determine whether any of those approaches have a direct effect on citizen engagement and if so, to what degree they have an effect.

4.2. Discussion of the findings

Considering the aims of the present paper, the analyses of the results focused on answering the research questions: (RQ1) *Can AR technology increase people's understanding, interest and/or engagement in sustainable architecture?* And (RQ2) *Are there any difference between people working with sustainable architecture and lay people on how engaged they become after using AR technology?*

To address the first research question, correlation analyses were performed. The statistical analyses by using Spearman's rho revealed that in particular 2 technical aspects directly related to the AR application could increase the understanding, engagement and interest of people in sustainable architecture. These two technical aspects refer to the perceived user-friendliness and the usefulness of the application. The fact that user-friendliness and usefulness are the aspects that have shown relevance in this study is in accordance with the "Technology Acceptance Model" (TAM) postulated by Davis (1989), who clearly indicated that the perceived usefulness and the perceived ease-of-use (related to the user-friendliness) are determinant aspects for the users' intentions to use any technology. The findings are also in line with more recent research studies, such as the one conducted by Cabero-Almenara et al. (2019), who also found that the perceived usefulness of AR technology increased the learning motivation of university students.

Discussing these results further, the user-friendliness of the AR app in this study entailed that the participants considered the application easy to understand and to operate. The findings indicating that as user-friendliness is evaluated higher so does the evaluation of the sustainability aspects are in line with previous studies. For example, the study by de Olde et al. (2016) emphasised, among other aspects, the importance of user-friendliness as a practical requirement for technological tools used in sustainability evaluations. Naturally, if people find any tool challenging to use, the motivation and interest to use it may decay, thus neglecting to continue its use. Likewise, the positive association found in this study between the perceived usefulness of the AR app and the sustainability aspects is in accordance with the findings of Lo and Lai (2021), who found in their research study that students who evaluated the perceived usefulness of a AR app higher, had more positive attitudes towards using the app and were more interested to keep using it, increasing then their environmental education.

Furthermore, the results of this study also revealed that as the interest in sustainable architecture increased so did the engagement and the willingness to provide feedback as a citizen. This is also true in the other direction, meaning that as people's engagement level increases, so does the level of interest. These findings are similar to the ones obtained by McDonald (2011), whose findings emphasised that people are more motivated to engage in activities that are related to their own interests. This seems logical, as it is expected that as people have more interest in a topic, there is a higher probability that they will get engaged in activities related to their topic of interest. Thus, increasing the interest in a topic that may be considered boring, tedious or that it is considered unknown, should be among the first actions to increase engagement. On the other hand, and as mentioned earlier, the results of this study are based on association and not causality, meaning that the results do not infer that interest has an effect on engagement. Although the findings suggest that interest and engagement could be seen as complementary, interest alone does not secure that people get engaged in activities. People can hold a high degree of interest in a specific activity, and yet perceive that they do not have the means or possibilities to get engaged. This was discussed for example by Chryssochoou and Barrett (2017), who suggested more actions to pass from interest to engagement to engage young people in civic and political activities. This is particularly relevant for the discussion of sustainable architecture and climatic awareness as these can be considered as civic engagement. Thus, despite that the findings of this study show promising results suggesting that AR could contribute into increasing both interest and engagement in sustainable architecture, other approaches should be developed to create a deeper link between both. This means that researchers, organizations and/or communities interested in engaging citizens in sustainable architecture can use AR as a tool, but still need to propose complementary and meaningful activities around the use of AR that can lead the way into bridging interest and citizen engagement.

Moreover, the results of this study suggest that AR could directly address the challenges in participatory processes as given by Elelman and Feldman (2018), see Section 1.1. Specifically, from the challenges given by Elelman and Feldman (2018), AR could redirect the attention from people's personal interests to large common issues (e.g. CO2 emissions of buildings, as tested in this study), and provide enough information for sustainability to not be seen as fraught (e.g. increasing the interest in the topic). The findings of this study also seem to be aligned with the studies by Katika et al. (2021, 2022), who found that AR was successful in delivering information about circular economy and increased public's attention.

Regarding the second research questions, the results revealed no significant differences in the evaluations of the AR app and the sustainability aspects between the group of experts and the group of lay people (non-experts). These findings are dissimilar to the results of other research studies that have discussed the differences in knowledge, opinions and views between experts and lay people in topics related to sustainability (Koizumi & Yamashita, 2021; Riechers et al., 2017; Whitmarsh et al., 2009). Moreover, while the findings of this study regarding the increase of people's engagement using AR were in accordance with the findings of Katika et al. (2022), when it comes to the second research question, both studies' results are different. In this study, lay people referred to people without previous training in architectural or sustainability issues, whereas experts referred to people with such training (see Section 2.3). Katika et al. (2022) found that people with limited understanding of circular economy and sustainability concepts (equivalent to lay people) had higher engagement levels and higher interest in the topic, whereas this study found no differences in interest or engagement between lay people and experts. A possible reason for these results could be due to the nature of the study. Being a pilot study the sample size was limited, and thus significant effects could not be found. As discussed in Section 4.1, further research efforts with a larger sample size are encouraged by the authors.

5. Conclusions

This paper presents the results of an experimental pilot study designed to explore whether an AR application developed by the authors could be a useful tool to increase people's understanding, interest and engagement in sustainable architecture. The findings showed that the perceived user-friendliness and the perceived usefulness of the AR app (as two aspects of the TAM model) were evaluated higher so did the understanding, interest and engagement of people in sustainable architecture. The findings also showed that as the interest was rated higher, the willingness to get more engaged also increased. This suggests that AR tool could be a useful tool to inform people (both experts and lay people) about energy issues related to architecture, aiming to increase their awareness and interest in climatic topics. Much as interest and engagement were also positively associated, increasing interest is only the first step. Clear actions need to be planned and performed to advance from interest to real citizen engagement.

Although technology is advancing at a large pace in recent years, offering technological tools as means to be used in engaging citizen in sustainability topics needs to be a reflected and well-planned process. This will ensure that the technical aspects, such as the amount of information, user-friendliness and usefulness of the tool can meet the needs of citizen awareness actions. The findings presented in this paper contribute to the discussion of selecting appropriate approaches and methods for citizen engagement in sustainable architecture.

CRediT authorship contribution statement

Claudia Moscoso: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Roya Morad:** Writing – review & editing, Investigation. **Andreas Oksvold:** Writing – review & editing, Software. **Olav Dimmen:** Writing – review & editing, Software. **Jo Skjermo:** Writing – review & editing, Software, Methodology. **Kristoffer Tangrand:** Writing – review & editing, Software.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Claudia Moscoso reports financial support was provided by Horizon Europe. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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