Data-Informed Built Environment Design Democratization through Location-Based Augmented Reality

by

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Abstract

The adoption of democratic and participatory design processes involving community members can lead to the creation of better and more livable environments. This thesis examines the potential of location-based augmented reality (L-AR) as a system solution for engaging the public in evaluating design proposals, intending to contribute to democratizing built environment design. I introduce a mobile L-AR prototype, D-ARE, which leverages mobile devices' capabilities to allow interactive and in-situ visualization of design proposals, along with features like interactive AR form views, performance data displays, and interfaces for facilitating discussion threads. The thesis also discusses challenges in transforming complex design data into understandable formats for non-specialist users. It presents insights gathered from D-ARE's user evaluation with 20 participants, highlighting promising engagement possibilities and identified challenges. The findings emphasize the transformative potential of in-situ AR applications and the importance of fostering informed dialogue between designers and community members to ensure that built environments reflect their needs and perspectives.

Keywords: Location-based Augmented Reality; public engagement; built environment design; design analytics; design democratization; data-informed decision making

Dedication

To the child within, whose dreams I’ve silenced.

Acknowledgments

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Table of Contents

List of Tables

List of Figures

List of Acronyms

AR	Augmented Reality
BIM	Building Information Model
D-ARE	**D**esign Democratization through **AR-**based **E**valuation
GIS	Geographical Information Systems
L_AR	Location-Based Augmented Reality
MR	Mixed Reality
VR	Virtual Reality

Chapter 1. Introduction

Augmented Reality's (AR) roles continue to grow in architecture and urban design, from creating initial concept designs (Milovanovic et al., 2017) to reviewing digital twins as in the Building Information Model (BIM) (Ratajczak et al., 2019), It can also enhance making design proposals more accessible and democratic by allowing a wider group of stakeholders to see and understand the potential changes proposed to their built environments (Reaver, K., 2023; Boos et al., 2023) and provide their feedback to decision-makers.

In this thesis, I explore location-based (or in-situ) Augmented Reality (D-ARE) as a medium to improve public participation in built environment design processes. Built environments are human-made structures, such as buildings, parks, bridges, and roads, that alter our surroundings to accommodate human needs while considering their impact on nature. By overlaying a virtual view of the proposed design (i.e., augmenting the real-world view with virtual models and data), AR can present the stakeholders of such designs with what is being proposed, how it may change the environment, and what kind of impact it can cause, both negative and positive, in the world they live in. I argue that AR can enable the stakeholders to visualize proposed designs within the context of their realization, and it can improve their understanding and evaluation of these proposals while discussing their opinions with other stakeholders in the same medium. They can offer a unique experience with real-time and location-based visualization of proposed design alternatives. I assert that such technology can enhance the accessibility and understandability of design data, making it more engaging for stakeholders with varying design or data literacy levels. To provide a testing ground for the argument, I developed prototype AR systems to explore how such tools can be created and adapted to inform and receive stakeholders' feedback on future projects.

Public engagement in built-environments encompasses the diverse processes and methodologies employed to actively involve stakeholders in creating built environments, including residents, designers, planners, and other community members. This engagement may ensure that developments are more functional, socially acceptable, sustainable, and responsive to the community's needs. As a conceptual approach, we call engaging the stakeholders when developing design ideas. By informing design stakeholders about alternative solutions on a platform for discourse around such alternatives, we can enable them to share their questions, concerns, and opinions as '*design democratization*.' When meaningful and useable data support the discourse, the process becomes '*data-informed design democratization'* (Erhan, 2024), leading to better-communicated design ideas beyond their form, and the stakeholders can participate by more transparently accessing relevant data.

In the next section, I will outline the research objectives and questions guiding this thesis and explain how my two research papers comprehensively address the core questions of this thesis.

1.1. Research Objectives

This research aims to enhance public engagement through *data-informed design democratization* and explore how Location-Based Augmented Reality (AR) can bridge the gap in the built environment's design process, better involve the community, and make more informed data-driven decision-making processes. Further, I aim to investigate how in-situ AR can complement existing methods to make built environment design proposals easier to understand by its stakeholders.

Based on the current state of research, I present three research objectives:

- To develop an Augmented Reality (AR) system that seamlessly integrates and displays multiple design alternatives and associated data (performance data) in their intended physical environment, enhancing stakeholder engagement through immersive augmented, contextual visualizations.

- To design AR interfaces that support in-situ feedback from diverse stakeholders, focusing on ease of use, clarity of design information presented, and accessibility.
- To assess the practical implementation of an in-situ AR system in built environment design projects, identifying its strengths in improving public participation and transparency and addressing challenges related to technology adoption and equitable access.

To achieve these research objectives, I proposed and implemented one low-fidelity and one high-fidelity prototype and conducted user evaluations on the high-fidelity prototype. This study is designed to answer the following research questions derived from research objectives:

RQ1. How can multiple design alternatives and their associated data be shared in an in-situ AR environment to enable and enhance stakeholders' engagement?

RQ2. What are the characteristics of interfaces that could be used to engage design stakeholders in in-situ feedback sharing?

RQ3. When reviewing built-environment design proposals, what opportunities and challenges may an in-situ AR system exhibit in real-world scenarios?

RQ1 examines how AR can show different design options and their data in where they are proposed to be built, helping stakeholders see and understand potential changes in an immersive environment. Immersion refers to the users feeling a presence in an environment through sensory engagement with physical and virtual spatial or interactive elements. In virtual reality (VR) and augmented reality (AR) applications, immersion influences the quality of user engagement (Interaction Design Foundation, 2023). An immersive environment is a simulated or virtual space that creates a sense of being fully engaged or involved in its activities or context. It can be physical, virtual, or a combination of both, designed to replicate a real or virtual world. Immersive environments are often used in virtual reality (VR), augmented reality (AR), and mixed reality (MR). RQ2 looks at making AR tools user-friendly so people can give feedback effectively. RQ3 checks how well these AR tools may work in real situations, looking at the positive gains, like participant engagement and openness, and the challenges, such as technology limits, accessibility, and usability of the product for all users. Overall, the insights discussed in chapters 3 and 4 enable me to address each research question.

1.2. Research Overview

This cumulative thesis includes one published peer-reviewed research paper by my research group and another under review. I am the main contributor and the first author of both papers. Following my supervisor's support, I developed the prototype systems (D-ARE.v1 and D-ARE.v2) (Table 1.1).

1. Behrouz, T., Erhan, H., & Abuzuraiq, A. M. (2024). D-ARE: A Location-Based Augmented Reality Tool for Public Engagement in Design of Built Environments. Presented at CAADRIA 2024, Singapore (10 pages).
2. Behrouz, T., Yagmur Kilimci, E. S., Erhan, H. (2024). D-ARE: Data-Informed Built Environment Design Democratization through Location-Based Augmented Reality. In Review for ACADIA 2024 (10 pages).

In this thesis, I present each of these papers and their contribution to answering my research questions. The thesis structure is as follows:

Chapter 2 reviews the background that this work is built on. I first review the tools and previous research that aimed to enhance public engagement in the context of built environments. I will then discuss how these tools are made to demonstrate the benefits of combining different tools and approaches for improving public engagement. Following this, I explore how visual analytics tools were utilized and identified as key strategies to manage numerous design alternatives and enhance decision-making.

Table 1.1 The overall contribution of each paper in answering the research questions.

	RQ1: Present data and design alternatives	RQ2: Engage stakeholders in-situ	RQ3: Implication of using in-situ and data
D-ARE.v1 (Paper 1 – CAADRIA 2024-Published)	How can multiple design alternatives and their associated data be shared in an in-situ AR environment to enable and enhance stakeholders' engagement?	What are the characteristics of interfaces that could be used to engage design stakeholders in in-situ feedback sharing?	
D-ARE.v2 (Paper 2, ACAADIA 2024-In review)		How do AR technology and its affordances influence user engagement and feedback sharing when public opinion is needed in built-environment design?	When reviewing built-environment design proposals, what opportunities and challenges may an in-situ AR system exhibit in real-world scenarios?

Chapter 3 presents the first article, 'D-ARE.v1' D-ARE: Data-Informed Built Environment Design Democratization through Location-Based Augmented Reality. In this paper, we explore the potential of augmented reality (AR) to democratize the design process of built environments by enhancing public engagement. Initially, I introduce a low-fidelity prototype mobile AR called D-ARE. We developed D-ARE to enable users to view, interact with, and directly provide feedback on design proposals within a real-world context. I conducted a literature review to define the research scope and surveyed the existing methods and tools used in public engagement within build-environment design. The D-ARE prototype is envisioned as a platform to collect structured or unstructured feedback on the design proposals, which can constitute the public opinion to be considered in the following design decisions, addressing RQ1 and RQ2.

Chapter 4 introduces the second paper, 'D-ARE.v2'. This study builds upon the initial research by further developing its findings and incorporating necessary features using Unity (Unity, n.d.) and ARCore (Google for Developers, n.d.). Subsequently, we carried out user testing to address Research Question 3.

Chapter 5 reported the result of user study that I did not cover on chapter 4 because of the page limitation that we had for conference submission. Finally, in Chapter 6, I conclude the thesis by summarizing the research conducted and the findings based on chapters 3 and 4. I also report on planned future studies following the research's limitations.

Chapter 2. Literature Background

Integrating Augmented Reality (AR) into planning and designing built environments requires examining and questioning how such integration may enhance public participation and engagement and promote democratic practices (in design). I organized my findings into three main categories. Initially, the literature tracks the evolution of public engagement strategies, moving from traditional methods to innovative, technology-based approaches that may effectively address earlier limitations. Subsequently, the review focuses on the fundamental democratic principles, e.g., transparency, inclusivity, and equity. It discusses how technological advancements like web platforms, digital games, and wearable gadgets like smartwatches can support these principles in design practices. Finally, the review concentrates on AR's specific contributions to creating liveable built environments by enhancing the stakeholders' interaction to make the design decision-making processes more accessible and engaging for diverse community members.

2.1. Public Engagement in Built Environments Design

Arnstein (1969) proposed "A Ladder of Citizen Participation," which states that public participation can be segregated into eight concrete levels. In lower participatory levels of the spectrum, manipulation and therapy, participation is minimal where citizens do not influence decisions. Further up the ladder are informing, consultation, and placation, where the public can have a significant impact. However, their ability to see their ideas acted upon is still constrained. It is only at the top levels-partnership, Delegated Power, and Citizen Control-that there is power-sharing where citizens strive for the direct management of specific programs or community-based projects and hence for real decision control.

Today's designers and urban planners work with social, technological, and environmental issues that challenge their design processes and require adaptive and inclusive engagement strategies. It is imperative to involve all community members regardless of their acquaintance with the technology in use (Slotterback & Lauria, 2019). This concentration on the upper rungs of Arnstein's ladder is indicative that it is a must that planners not merely participate in communities but should empower them, a way to bridge the gap from consultation to what it means by collaborative governance.

Traditional methods of public participation, such as public hearings, review, and comment procedures, open meetings laws, elite citizen committees, and voting, often fail to engage a broad range of the community and rarely influence actual decision-making (Innes and Booher, 2000; Kingston et al., 2000). Several challenges would be observed during town hall meetings and often need to be revised. For example, due to time constraints, the limited number of specialists available, or personal reticence, participants may struggle to ask detailed questions or express their views (Kingston et al., 2000). These methods typically attract those directly affected or with interests, leading to polarized discussions and little constructive dialogue, which diminishes the effectiveness of public feedback. For example, the City of Burnaby conducted a public participation exercise to gather stakeholder opinions on the location of the new city hall. They proposed three different locations, each with three distinct design alternatives. They used a web platform, presented these options through basic sketches and descriptions, and facilitated an online survey to gather preliminary feedback. Subsequently, a public session was organized where these proposals were presented in person to greatening stakeholders' opinions. During this session, attendees were encouraged to provide their feedback by placing comments on sticky notes alongside the displayed sketches (Figure 1). This approach allowed for a structured yet accessible method for community input, reflecting a commitment to inclusive and transparent decision-making processes.

Procedural complexities and inflexible regulations can even obscure the process, sometimes pushing discussions out of public view and making participation futile for many. Furthermore, groups like elite citizen committees often don't represent the wider community, particularly marginalized or less active groups, limiting the diversity of input in planning and decision-making processes. This results in public disenchantment and a disconnection from the political process (Innes & Booher, 2000). These challenges can significantly impede stakeholder participation and engagement, leading to built environment developments that may not fully consider or meet the community's diverse needs and preferences. The main problem, therefore, lies in the limitations of conventional engagement tools to bridge the substantial communication gap between technical design data and community stakeholders (Khan et al., 2024; Behrouz et al., 2024). This gap often results in disconnection in visualizing and understanding the impacts of proposed designs on their lives and environments.

Figure 2.1 Public engagement session with the city of Burnaby (British Colombia, Canada) June 25, 2023 (picture by Tina Behrouz)

To address these barriers, Hanzl (2007) highlights the potential of IT tools like GIS, 3D models, virtual reality, and collaborative software. Hanzl suggests that these tools can foster more inclusive and effective public engagement by enabling remote participation and better managing the participatory planning process.

Moreover, effective public engagement is crucial for integrating stakeholders' needs and values into decision-making processes. This inclusive and participatory approach ensures community members can actively influence design outcomes through diverse communication methods (Cascetta & Pagliara, 2013; Enwereji & Uwizeyimana, 2020). With the rising importance of social and ethical considerations in design, there is a pressing need to reassess public engagement tools—including print, digital, and in-person meetings—to ensure they efficiently disseminate design data and engage the public in the design process (Verbeek, 2009; Keh et al., 2021). By refining public engagement methods, we can work towards a more democratic and sustainable urban future where community feedback is collected, truly valued, and acted upon.

2.2. Democratic Design Principles

Data democratization ensures that data is accessible to everyone involved, helping all participants to make informed decisions based on clear and comprehensive information (Khan et al., 2024). This practice is crucial in various fields, including big data, business, healthcare, and information systems (Wang et al., 2021; Knudsen et al., 2018; Hyun et al., 2020; Samarasinghe et al., 2022). However, discussions about data democratization in built environment design are notably absent. Making data more accessible democratizes information so that everyone, regardless of their role or level of expertise, can work with the data to the best of their ability. It promotes transparency and collaboration—a unique environment where diverse opinions can come together to ensure better decision-making and innovation. By reducing barriers to access, we empower data use by an increasing range of stakeholders to produce outcomes that have more meaning and better information in a wider array of application areas. (Hyun et al., 2020; Awasthi & George, 2020; Lefebvre et al., 2021).

Data democratization encourages the inclusion of non-specialist stakeholders in decision-making, not just analysts and decision-makers (Khan et al., 2024). By making it accessible and understandable for all Stakeholders, they would be encouraged to participate meaningfully. They can participate in planning discussions and decisions and provide valuable local insights and preferences that might be overlooked. This contribution can create a sense of ownership and empowerment amongst citizens. This approach promotes fairness in the design and planning processes and supports a more informed and active community. Enabling individuals to view, examine, and use selective data empowers them to contribute effectively to discussions and decisions, enhancing community engagement and participation (Awasthi & George, 2020).

Promoting data accessibility in this area could foster a collaborative environment where more acceptable choices by the communities are the norm. This can enhance transparency and accountability across organizations.

2.3. Augmented Reality as a Tool for Democratic Urban Design: Enhancing Visualization, Interaction, and Accessibility

Augmented Reality can blend digital content seamlessly with the real-world environment, enhancing the user's perception and interaction with their physical context. This immersive experience created through AR may give the user the ability to explore the proposed changes in a live context, distinguishing it from other forms of digital and virtual experiences. Various tools and approaches have been proposed to enhance public engagement and data-informed decision-making in built environment design, especially for non-expert stakeholders. These include web applications, games, and social media. Using Augmented Reality (AR) shows the potential to influence several fields, including business, marketing, tourism, gaming, human-computer interface, and manufacturing (Rauschnabel et al., 2024). Previous research showed that in situ public engagement using AR technology helps stakeholders better understand complex design information. Geertman (2001) argues that planning support systems can bridge the gap between spatial planning and geographical information systems (GIS) by improving democratic planning processes and making spatial data more accessible and useful in interactive planning environments.

Augmented Reality (AR) would be an effective and engaging tool for designing and planning built environments, as it allows a personal interactive experience exploring changes that could happen in the surrounding environment. This can be effectively achieved by providing the public with selectively chosen data, which may be meaningful and understandable to each project. The simplicity of the data presentation and simple sharing methods are maintained so as not to overwhelm the participant and to enhance understanding and involvement. The latter interaction strategy will bring about greater community engagement and further emphasize a sense of linkage to the project. Ultimately, improved participation results in a sense of ownership and satisfaction with the ultimate outcomes of the urban development process.

In this thesis, I developed a system integrating design form and data visualizations on location-based AR. I explored how such integration can enhance public engagement by examining the potential of AR to make the built environment planning and designing process more inclusive and effective. This study proposes innovative solutions for more dynamic and responsive design decision-making processes. Through detailed analysis and evaluation, the thesis explores the capabilities of AR to complement current public engagement methods, aiming to provide substantive contributions to public engagement. This exploration is expected to offer valuable insights into the potential of AR technologies in making design proposals more accessible, engaging, and inclusive, thus leading towards more sustainable and community-focused environments.

Chapter 3. D-ARE.v1 (Paper 1 – CAADRIA 2024)

3.1. Research Summary

The first section of this thesis introduced a comprehensive literature review of public engagement, examining the current tools and methodologies in the field. This exploration is crucial for identifying the gaps in stakeholders' engagement with built environment design alternatives. The thesis analyzes these gaps and proposes new solutions to enhance stakeholder involvement in discourse.

Building on the findings from the literature review, the thesis proposes the initial version of D-ARE as a low-fidelity prototype. This prototype aims to bridge the gaps identified. To refine this initial proposal, the prototype undergoes an expert review process, incorporating feedback from seasoned professionals. This iterative process ensures that the prototype meets theoretical expectations and is practical, usable, and effective in real-world applications.

D-ARE leverages location-based augmented reality to enhance communication between designers, planners, and stakeholders. By integrating AR technology, D-ARE provides an interactive platform that presents design data within its actual environmental context. This approach enhances stakeholders' understanding and lets them visualize the potential impact of different design alternatives directly within their surroundings. The AR interface particularly excels in making complex design data more accessible and comprehensible to all non-expert stakeholders. This paper has been accepted, published, and presented at the CAADRIA 2024 (Computer-Aided Architectural Design Research in Asia) conference. Experts from the field come together to discuss the most recent advancements in this field of study.

3.2. My Contributions

As the first author of this work, I worked with my supervisor to establish the research objectives and conducted the literature review. Based on these, my supervisor and I established the higher system requirements for D-ARE. I developed the system architecture and outlined use cases and corresponding user interfaces. I then designed the prototype. I wrote the initial draft of the paper, edited mainly by my supervisor and the other co-author. This approach ensured a clear and structured development process from ideation to prototyping to documentation.

3.3. Paper: D-ARE: A Location-Based Augmented Reality Tool for Public Engagement in Design of Built Environments

Authors

Tina Behrouz, Halil Erhan, and Ahmed M. Abuzuraiq

Abstract

In this paper, we explore the systems for engaging the public in evaluating the design proposals by questioning means to improve the democratization of designing built environments. We argue that a democratic and participatory design can be achieved when community members are motivated to contribute actively to the design process of shaping their environment. Our goal is to provide a critical understanding of how existing tools have integrated or failed to motivate the public to be part of design decision-making and collect feedback effectively. Grounded in our literature review, we propose a location-based mobile-AR prototype to create an inclusive, data-informed design process. The mobile platforms are suitable for an AR application because of their accessibility, familiarity, and ability to support in-situ awareness notices. The tool features include interactive and in-situ form views in AR, performance data views, and interfaces for sharing insights through discussion threads. A challenge for such solutions is transforming complex design

data for different non-specialist users through an interactive AR experience. The proposed AR interface is a step towards bridging the gap between designers and community members, ensuring that built environments are created with the perspectives of those for whom they serve.

Keywords

Location-based AR, design data democratization, public engagement, built environment design, urban design, and design analytics.

Introduction

Public engagement involves various activities and strategies to gather input, share information, and foster dialogue for inclusive decision-making. The term refers to the process of engaging a community as stakeholders in the planning and decision-making through, e.g., meetings, workshops, surveys, focus groups, and online platforms. As an umbrella term, it constitutes approaches for understanding the opinion of a community toward finding solutions for the problems that will impact their lives (Nabatchi and Amsler, 2014; Chow and Leiringer, 2020). The objective is to address shared challenges, meet individual needs, enhance outcomes, and foster social cohesion between planners, designers, policymakers, and the community (Cascetta and Pagliara, 2013). In the context of built environment design, the term typically entails collective decision-making wherein diverse stakeholders, serving as community representatives, actively engage across various project phases. As defined by Næss (2016), the built environment encompasses more than the physical buildings and urban spaces. It also involves the interactive dynamics between these physical elements and how they influence and are influenced by human behavior and social interactions.

Public engagement in built environment design faces various challenges, including reaching and maintaining engagement with a distinct and often diverse audience. Designers must navigate communication barriers and ensure representation from different demographic groups, considering age, socioeconomic status, and cultural backgrounds. Balancing competing interests and opinions within the community poses another challenge, as well as managing expectations and potential conflicts. Limited resources can hinder engagement efforts in terms of time and budget. Additionally, there might be skepticism or distrust among the public regarding the impact of their input on the final decisions, requiring efforts to build transparency and credibility (Konsti-Laakso and Rantala, 2018). Overcoming these challenges is crucial to realizing the benefits of public engagement in creating more responsive, inclusive, and successful designs (Cascetta and Pagliara, 2013).

Web applications can be a means to reach a wider and diverse audience, enabling virtual participation for those who may be excluded otherwise. Increasing participation can promote equality and inclusion while creating connections between stakeholders and decision-makers (Hovik and Giannoumis, 2022). For example, social web applications tailored for design reviews can allow stakeholders to assess the proposed design ideas from their perspectives while seeing and replying to others' (Alsalman and Erhan, 2022). Augmented with data analysis, identifying patterns in comments can guide the decision-makers when reviewing opinions (Leyden et al., 2017; Katika et al., 2021; Alissandrakis and Reski, 2017; Awang et al., 2020; Wu et al., 2021).

Immersive Virtual (VR) or Augmented Reality (AR) environments have been increasingly used throughout the design and planning phases, enabling designers to visualise their design and allowing the stakeholders to experience higher levels of engagement (Saßmannshausen et al. 2021; Kayla et al., 2021; Farshid et al., 2018; Boos et al. 2023). We explore tool features that can motivate and engage design stakeholders in a built-environment project based on AR methods for in-situ design visualization and assessment. For this purpose, our study seeks to answer the following questions:

- How can multiple design alternatives and their associated data be shared in an in-situ AR environment to enable and enhance stakeholders' engagement?

- What tools are used for public engagement relevant to the built environment's design, independent from their solution platform?

- What are the characteristics of interfaces that could be used to engage design stakeholders in in-situ feedback sharing?

Building on a literature review and investigating the existing digital solutions, we present requirements for system features addressing design democratization through AR. We developed D-ARE, an AR-based social web tool prototype, demonstrating how AR-driven, data-informed design democratization can be realized. We also reflect on our experiences and share the lessons learned for others.

Tools for Engaging Public

Effective public engagement can lead to successful and sustainable built environments by considering diverse perspectives, addressing community concerns, and creating a sense of ownership among the stakeholders. One of the goals is to ensure that the decisions made address the needs of the people, promoting a sense of place and enhancing the overall quality of life (Konsti-Laakso and Rantala, 2018). Below, we summarise and compare four public engagement systems: ChangeExplorer (Wilson, Tewdwr, and Comber, 2019), Metropolis (Aguilar et al., 2021), D-ART (Alsalman and Erhan, 2022), and #MySydney (Williamson and Ruming, 2020). We aim to propose system ideas to improve public engagement based on our findings from analyzing these tools.

CHANGEEXPLORER

ChangeExplorer, a public engagement application for smartwatches, tracks the users' location and notifies them when they are near new urban changes (Wilson, Tewdwr, and Comber, 2019). The notifications ask the users to provide feedback by responding to a short on-screen questionnaire. Notifications and in-situ interactions helped engage citizens to share their immediate but less informed reactions. Its evaluation revealed a tension between the opportunity for a quick interaction and the need to access detailed information about the changes for those interested in an in-depth engagement. For the latter, ChangeExplorer running on a smartwatch was unsuitable, e.g., for written comments with pictures and annotations. It highlights that while the participants responded positively to in-situ reviews, the platform's form factor constrained a deeper interaction for personalized feedback.

METROPOLIS

Aguilar et al. (2021) studied urban patterns and citizen behaviors within the context of a smart city through a mobile app called Metropolis. Their research demonstrated how a collaborative approach influences urban planning and citizen satisfaction. Metropolis is a serious game application that allows users to decide about city development based on their preferences by presenting two distinct cases: one involving social communities with similar interests and another requiring collaboration among individuals with different characteristics. The findings of this study showed that Metropolis is effectively used to form urban zones and patterns based on collective player decisions. The positive impact of collaboration resulted in higher satisfaction among the users, positioning the serious game approach as a contender for participation, collaboration, and democratic decision-making. However, it lacks in-situ and comparative review features of different scenarios.

D-ART

D-ART, developed by Alsalman and Erhan (2022), is a web-based platform for supporting collaborative and data-driven design reviews of design alternatives. D-ART integrates customizable and interactive visualizations augmented by feedback sharing about and comparative analytics of form, performance, and design objectives data. By presenting the design alternative through five main views—namely projects browser, project view, alternatives and comparison view, and building block view—D-ART enables the design stakeholders to share their feedback in a discussion thread, typically seen in social web applications. The stakeholders can interact with each other while commenting on the proposed designs. Feedback sharing is limited to textual and outside of the visualizations, which detaches comments from context. Although alternative comparison features were considered valuable, the evaluation of the system revealed the difficulty in developing a mental model of the flow due to the modal navigation between views, interrupting the flow.

#MYCYDNEY

Williamson and Ruming (2020) analysed the #MySydney campaign by Sydney's Department of Planning and Environment, which aimed to involve citizens in district planning through social media channels as part of an overarching digital marketing strategy. Their study pointed out that despite the broad outreach, the engagement was predominantly one-directional, with the department collecting data without resulting in significant interactive dialogue. They identified issues with data representation linked to privacy settings and low engagement. A particular issue was using a generic hashtag, #MySydney, which was quickly co-opted by single-issue groups, diverting attention from the intended dialogue. As they concluded, the campaign showed a lack of genuine engagement and suggested that the planning agencies be responsive and prepared for unexpected concerns brought up by citizens. The researchers also stressed the need for a multidisciplinary team to engage the public.

SUMMARY OF TOOL ANALYSIS

The comparison of the public engagement tools reveals distinct features and functionalities (Table 1). ChangeExplorer stands out for its emphasis on quick and in-situ feedback, making it a valuable approach for understanding design implications within specific environments. In contrast, #MySydney, aimed at encouraging public engagement in urban planning through commonly used social media, fell short in being focused and collecting relevant or meaningful consensus.

D-ART, with its unique focus on design review focusing on data of alternative solutions, proves particularly useful for projects requiring a detailed evaluation by its stakeholders. On the other hand, Metropolis distinguishes itself by combining engagement and fun, appealing to users seeking an enjoyable experience while contributing to design decision-making. Both ChangeExplorer and Metropolis have dedicated mobile applications, enhancing accessibility and user reach. Each tool caters to different aspects of the design decision process, offering diverse features that can be strategically chosen considering the project characteristics and the goals for public engagement.

Data-informed and AR-Based Design Democratization

We aim to create an engaging and inclusive AR application for mobile platforms where design proposals can be shared with their stakeholders in situ to engage them in sharing their insights and feedback by reviewing design data. This choice is deliberately based on mobile platforms' potential for immediate availability. Drawing insights from literature, we assert that people are more likely to share their opinions when present in the same context. Mobile platforms are a practical choice because of their in-situ awareness and notification capability.

Table 3.1 A comparison of the four systems for public engagement (3, 5) helps public participants make informed judgments (1, 2, 4) or leads to reaching a wider audience (6).

System Features	ChangeExplorer (Wilson, 2019)	#MySydney (Williamson, 2020)	D-ART (Alsalman, 2021)	Metropolis (Aguilar, 2021)
1. Design comparison	no	no	yes	no
2. Provide detailed data	no	--	yes	yes
3. Collaboration	no	yes	no	yes
4. In-situ/contextual feedback	yes	no	no	no
5. Engagement and Fun	yes	yes	--	yes
6. Working prototype system	yes	no	yes	yes

We developed D-ARE as a low-fidelity prototype to explore features for location—and AR-based public engagement tools. D-ARE stands for Design Democratization through AR-based Evaluation. It aims for in-situ feedback sharing through interfaces for viewing design proposals, their data on demand, and feedback sharing on mobile platforms (Figure 3.1).

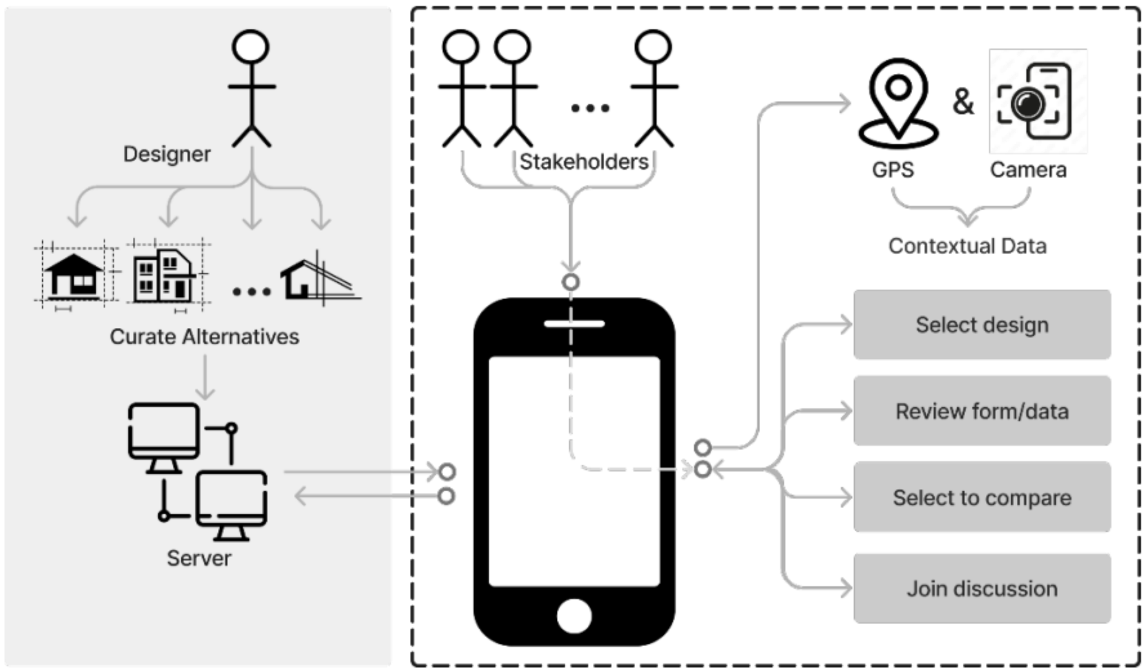

Figure 3.1 The D-ARE components and information exchange schema.

THE PREMISE OF D-ARE FOR IN-SITU PUBLIC ENGAGEMENT

AR applications on mobile platforms show potential for collaboration among various design stakeholders due to their accessibility and features for combining the physical and virtual views augmented by rich interaction affordances. Overlaying the views into the real context offers an advantage for immersion (Shin, 2019). On mobile devices, they can provide first-hand user experience for reviewing proposals viewed virtually, imposed on physical real-time views. They can also offer a perspective closer to the final appearance of a project, even in its conceptual development, incorporating subtle factors like sky, light, and movement, which are often overlooked in traditional methods. Another advantage lies in the replaceability and repeatability of AR content, enabling continuous design adjustments, risk reduction, and conflict resolution in the decision-making phases, potentially saving effort and cost (Wang and Lin, 2023). Therefore, an AR experience becomes more relevant, offering a clear vision for evaluating and reflecting on how design proposals could affect their environment.

SYSTEM REQUIREMENTS ELICITATION

We developed D-ARE through iterative and incremental phases. In the initial phase, we conducted a focus group study involving six architects to define the high-level system requirements by asking them to consider specifically the potential of AR combined with mobile platforms for a location-based application. As part of this inquiry, the focus group was instructed to express their opinion on how stakeholders could use their current location to explore and compare different design proposals. The group discussed the tool's features for engaging individuals with varying experience levels and interests to foster active participation.

The focus group inquiry led us to develop user stories as small testable parts of potential use cases capturing the functional requirements for the D-ARE's design. The user stories evolved through two-week sprints spanning over three months, as in Scrum methodology, and parallel to user interface design. Each sprint concluded with a formative evaluation of the research team; due to time constraints, running evaluation sessions with participants was impractical. The following section presents the system features we developed following this iterative process.

AR-BASED SYSTEM FEATURES

Interactive engagement level

In terms of interaction, we offer stakeholders varying levels of engagement with design data. D-ARE tracks the location of its users. It can present design proposals on-demand or through in-situ notifications in an interface similar to social media applications. The designs can be in any environment at any scale (Figure 3.2-left).

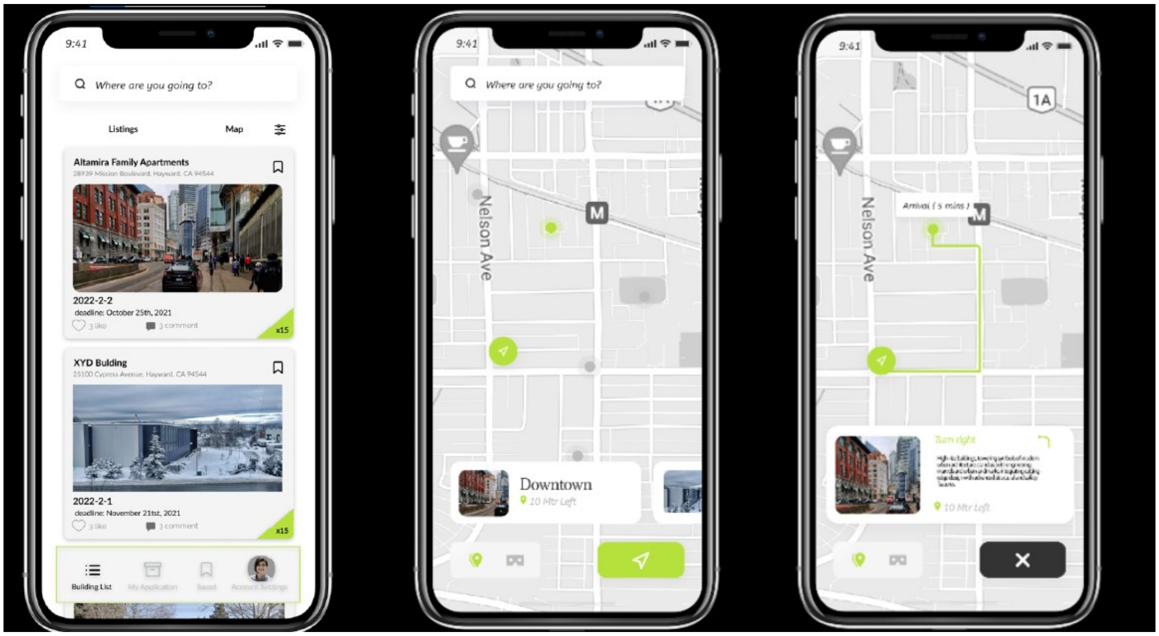

Figure 3.2 DARE interfaces include a social-media-like view (left) of existing projects in situ (centre) and the ways to reach them through path suggestions (right).

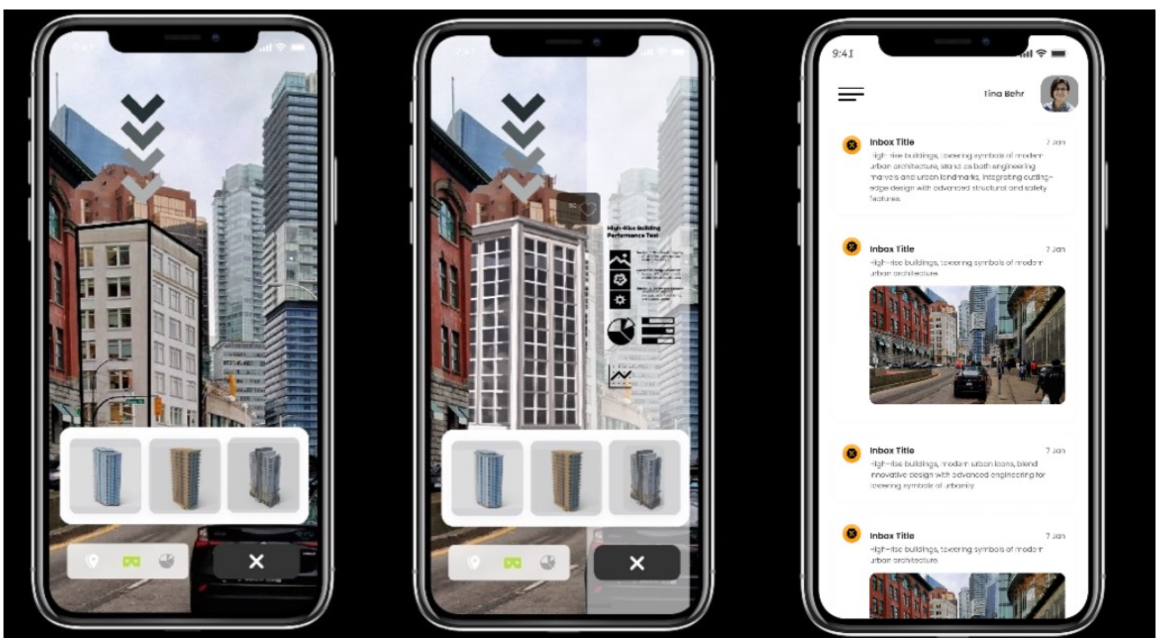

Figure 3.3 An In-situ virtual view of a design proposal can be viewed from different angles (left). In contrast, an on-demand view of relevant data summary can be shown as expandable data visualization (centre). The stakeholders can share their comments on a social-media thread in D-ARE (right).

Switching to the map view, the users can identify the location of the new proposals around their vicinity and see the paths to reaching the sites (Figure 3.2-centre, right). The design proposals can be viewed overlayed on their proposed physical location with a close-to-realistic scale and view while presenting access to any other data the design team shares. Such data can be numerical, such as cost, usable area, occupancy load, or categorical, such as function, style, and options. The users can navigate between views by translucent overlayed interfaces, e.g., for revealing geometric form data on graph visualizations. This multi-level interaction aims to cater to diverse user preferences.

Design Data Presentation

D-ARE presents curated design data in two main categories: form and performance data. The 3D models are embedded in the view of the surroundings, allowing individuals to explore various perspectives by walking around the proposals. Additionally, it can provide on-demand data specific to each project through simple charts and text, engaging stakeholders to choose the aspects of design they wish to review and comment on. It is not uncommon to have multiple proposals presented when engaging the public. Therefore, the D-ARE users can switch between different alternatives within the context. The designers curate alternatives and their relevant data to determine how the stakeholders respond to the proposals (Figure 3.3-left, centre).

Feedback and Insight Sharing

D-ARE provides a social-media-like interaction for the users to give feedback and engage in conversations. They can share their comments with the option to upload pictures and add annotations (Figure 3.3-right). We envision this feature will help gather diverse perspectives from stakeholders informed by assessing how the proposed built environment can exist within the physical structure, contributing to a richer and more informed design discourse.

Design Review and Updates

We conducted continuous and formative in-team evaluations as we developed system ideas on the low-fi prototype. A recurring theme in these reviews emerged towards developing simplified views and interactions for comparative analysis of the proposals, possibly on a side-by-side, juxtaposed view, while providing affordances for accessing their form and performance data. Two critical challenges to achieving these goals are information overload and interaction (e.g., navigation) on small-screen mobile devices. Although we have yet to address these challenges, we updated the D-ARE comparison view (Figure 3.4). Another theme for improving design democratisation centred around feedback collection. The interfaces must be inclusive so diverse users can express their opinions through 'ranking', 'liking', or 'voting' rather than writing comments. We experimented on how this can be achieved on an updated D-ARE (Figure 3.4).

Figure 3.4 Proposed changes for reviewing alternatives side-by-side. The discussion interface includes feedback sharing while enabling responses by commenting and annotation input in situ.

Discussions and Conclusion

We presented a study questioning how to improve public engagement when evaluating and deciding on built environment design proposals. Our literature review and analysis of four tools demonstrated a consensus on the importance of public engagement and the need for novel tools for inclusive and engaged participation. However, it also revealed that there are challenges for public participation, such as reaching and maintaining engagement with diverse stakeholders with competing interests, reaching out to different groups to ensure equal representation, limited resources, and distrust. Overcoming such challenges is not trivial, requiring efforts to build transparency and credibility.

As part of our research, we propose partially addressing some of these challenges through a location-based augmented reality (AR) application called D-ARE. Among our goals, first, we aim to provide 'transparency' for the design decisions that will affect the public through in-situ and data-informed evaluation of design proposals. Secondly, we demonstrate accessibility to information on-demand without any formal, scheduled, or biased public gathering and enable the public to interact with each other and the design decision-makers by sharing their feedback. Third, tools like D-ARE should be 'fun' or 'inviting' to encourage evaluating the proposals and building a community.

D-ARE has four distinct interface features: an in-situ AR view of the design form providing an immersive experience, design-data visualizations familiar to non-specialists, a comparison view (if applicable) to see proposals juxtaposed and a social interaction view where the public can share their feedback. We refined the feedback-sharing features by providing the stakeholders with focused and in-depth feedback mechanisms and quick responses using 'Like', 'Rate', and 'Rank' options. To initiate a rich feedback-sharing experience, we aim to motivate dialogue among the stakeholders is necessary. On D-ARE, the stakeholders can access, read, and interact with each other, ensuring consensus and satisfaction of the final design decision.

Users of D-ARE are expected to have a basic understanding of their surroundings, be able to use smartphones, and interpret basic graphs like bar charts or line graphs. While smartphones are suggested for convenience, we understand that certain demographics may not have access to them or cannot use all their features. Additionally, individuals less familiar with digital technology may find such systems overwhelming, and those with cognitive, visual, or motor control impairments may need help navigating mobile interfaces. To ensure inclusive engagement in built environments, alternative systems must be developed to cater specifically to the needs of diverse user groups. To promote inclusive engagement in built environments, alternative systems must be explored to cater to the specific needs of diverse users.

As a future study, we will implement a minimally viable version of D-ARE to study its potential for increasing public engagement and meaningful feedback sharing by acknowledging the social and personal challenges. Emerging technologies, such as AI-based discourse analysis, can reduce the labour for feedback assessment. Next, we will focus on compiling, summarising, analyzing and reporting the stakeholders' feedback through another system tailored for designers.

Chapter 4. D-ARE.v2 (Paper 2- ACAADIA 2024)

4.1. Research Summary

My second paper introduces D-ARE.v2, a high-fidelity prototype of D-ARE. The study, "D-ARE: Data-Informed Built Environment Design Democratization through Location-Based Augmented Reality," explores the potential of augmented reality (AR) to enhance public engagement in urban design. By developing the D-ARE prototype, we sought to make design proposals more accessible and understandable to people without specialized knowledge, thus broadening participation in built environment design. The research involved evaluating the prototype's usability and effectiveness by collecting data through screen recordings, surveys, and interviews with participants at a public site.

The paper opens by emphasizing the critical role of public engagement in built environment design. It then questions how AR technology could impact user interaction and feedback when reviewing urban design proposals. It suggests that AR could provide non-expert stakeholders with a more intuitive and engaging way to understand and evaluate urban designs, proposing that this technology could democratize the design process by allowing more comprehensive community input.

The paper details the methodology and describes the technical framework of D-ARE, which leverages advanced AR functionalities facilitated by Unity and Google's ARCore. This setup overlays 3D models of design proposals onto the actual environment, enhancing the relevance and utility of stakeholder feedback. We meticulously analyzed how participants interact with the system, aiming to assess its features' user-friendliness and practical value.

The conclusion reflects on the findings from the user study, discussing the application's potential to transform public engagement in urban design and acknowledging challenges such as precision in 3D model placements and the need for enhanced safety measures. It suggests future improvements, including more interactive features and better data visualization tools, to make the system more effective and engaging. This narrative, from conceptualization to prototype testing, illustrates the promising role of AR in making built environment design more inclusive and responsive to public needs, setting the stage for further research and development in the field.

This paper is submitted to ACADIA 2024 (Association for Computer-Aided Design in Architecture), an international blind peer-reviewed conference. ACADIA supports critical exploration of computational applications in architecture, planning, and building science, promoting advancements in design creativity, sustainability, and educational practices with a focus on the role of computation.

4.2. My Contributions:

As the first author of this paper, my responsibilities included developing the conceptual framework in collaboration with my supervisor, defining the study's scope and objectives, developing the system architecture, and implementing the prototypes of D-ARE as an AR application using front-end interface and server-side software technologies. I also designed and conducted the user studies under Dr. Erhan’s supervision and with the help I received from Dr. Yagmur-Kilimci.

4.3. Paper: D-ARE: Data-Informed Built Environment Design Democratization through Location-Based Augmented Reality. In Review for ACADIA 2024, Calgary

Authors

Tina Behrouz, Elif Sezen Yagmur-Kilimci, and Halil Erhan

Abstract

This paper argues for integrating in-situ Augmented Reality (AR) in the toolset for public engagement within built environment design. We aimed to enhance receiving feedback from the public and allow non-expert stakeholders to access design proposals with their relevant data in situ. To experiment with the AR possibilities, we developed D-ARE as a functional prototype and evaluated its usability, effectiveness, and ability to support informed design discourse. The study used a mixed methods approach to collect data through screen recordings, surveys, and interviews with twenty participants at a public site. The findings revealed significant engagement with the AR features and challenges, such as data integration and user safety. The results underline the potential of in-situ AR applications to democratize built environment design processes, making them more inclusive and accessible. Suggestions for future enhancements include improving the precision of 3D placements and enriching interactive elements to increase the immersive experience of such applications. This study contributes to the growing body of knowledge on digital engagement tools in built-environment design, emphasizing the transformative potential of AR technologies through a user study.

Keywords

Location-based Augmented Reality, public engagement, built environment design, design analytics, design democratization, data-informed decision making

Introduction

This study investigates the application of mobile augmented reality (AR) technologies in built environment design contexts through a series of integrated research questions formulated to examine the multifaceted impact of AR on public engagement. The primary research questions addressed include:

- How do AR technology and its affordances influence user engagement and feedback sharing when public opinion is needed in built-environment design?
- When reviewing built-environment design proposals, what opportunities and challenges may an in-situ AR system exhibit in real-world scenarios?

The research further explores the possibility of non-expert stakeholders using AR tools effectively to understand and evaluate urban design proposals. Finally, it identifies the requisite AR application improvements to enhance public participation in built-environment development projects. These questions are essential for assessing the potential of AR technologies to democratize and improve the inclusivity and effectiveness of built environment design processes.

Engaging the public in the planning and decision-making on the developments to be made in the built environment is essential to developing livable, socially acceptable, and environmentally conscious built environments. One of the common practices carried out with this objective is to involve the public in evaluating design alternatives for the built environment, i.e. the buildings and urban spaces, through various means such as meetings, workshops, surveys, and online platforms. Like all other forms of public engagement in built environment design, this practice faces the challenges of reaching a diverse audience from different demographics and motivating the engagement of people with differing interests. Distinct from some others, it also faces the challenges of conveying the data associated with the design alternatives to individuals with varying backgrounds and experiences for all participants to make data-informed decisions (Khan et al. 2024) and providing them with means through which they can easily and if necessary, privately share their insights, concerns, and opinions (Behrouz et al,2024). How can we address these challenges and improve public engagement in evaluating alternative designs to improve the built environment and the people?

Digital technologies can promote more participatory forms of democracy (e.g., Helbring et al., 2022; Carver et al., 2001). Reaching a broader and more diverse audience could be achieved by using digital technologies such as online platforms/web applications, enabling virtual participation for those who may be excluded otherwise. Until now, various efforts have been made to develop online platforms to support public engagement practices. The platforms aimed at the engagement of the public in built environment design have mainly focused on the planning phase of the urban development projects (e.g. Change Explorer, metropolis, my Sydney, PublicInput, Citixenlab, Social, Pinpoint, and Granicus) (Khan et al., 2024, Behrouz et al., 2024). Only a few of these platforms focused on engaging the public in the review of design alternatives (Boos et al., 2023; Wang and Lin, 2023). Thus, the issue of conveying 3D built-environment design data to the public so they can make data-informed decisions has yet to be given much attention within the context of the efforts aimed at developing platforms for public engagement. This issue has primarily been focused on in efforts aimed at developing stand-alone or specialized tools and in research that explores the potentials of existing 3D modeling and visualization tools or technologies (BIM, VR, AR) for supporting participatory planning-design processes (Ehab, Burnett, & Heath, 2023).

One potential means for improving participants' (a stakeholder with no design background) understanding of the form and spatial composition of alternative design proposals could be to provide participants with an opportunity to view and explore the designs in their context using mobile-AR technologies. Virtual reality (VR) or Augmented Reality (AR) environments have been increasingly used throughout the design and planning phases, enabling designers to visualize their design and allowing the stakeholders to experience higher levels of engagement (Saßmannshausen et al., 2021; Farshid et al., 2018; Boos et al., 2023). AR technologies enable users to experience proposals firsthand by overlaying virtual elements onto real-time physical views. This approach provides a more accurate preview of a project's final appearance during the conceptual phase, capturing subtle factors such as sky, light, and movement frequently missed with traditional methods (Behrouz et al., 2024).

We developed a prototype mobile-AR application, D-ARE (Behrouz et al., 2024), to gather public opinion on design alternatives, considering the potential of digital platforms and AR technologies in addressing the challenges inherent to these practices. By enabling stakeholders to view the design proposals in their physical context, we believe that AR can facilitate stakeholders' understanding of design data and their making of data-informed decisions. By enabling interaction with design alternatives in the context, AR may also increase participant's interest in the review process and enrich contributions to the design review process. The mobile platform, through its in-situ awareness, can also motivate participation and support access to a broader audience (Boos et al., 2023, Wilson et al., 2019).

D-ARE has four main features that aim to allow non-experts to explore and interact with built environment design proposals, helping them make informed decisions about their surroundings. The first feature enables users to explore architectural forms using augmented reality (AR), integrating design data directly within their physical context. Two additional features allow users to view and compare performance data, enhancing their understanding of different design aspects. The final feature facilitates user engagement by allowing them to share feedback and select their preferred design proposals directly through the platform.

Here, we provide an overview of our system and report the findings of a user study to explore the extent to which the features we incorporated in the system fulfill their intended purposes.

Background

Public engagement is fundamental in governance, serving as a conduit for incorporating diverse community perspectives into decision-making processes. It employs various strategies, from workshops to advanced online platforms, to broaden inclusivity and ensure community voices are integrated into impactful solutions (Nabatchi and Amsler, 2014; Chow and Leiringer, 2020). Over time, advancements in information and extended reality technologies, such as online platforms, social media, Virtual Reality (VR), and Augmented Reality (AR), have transformed traditional engagement practices, like town hall meetings, into more accessible and engaging experiences. These technologies not only facilitate real-time interactions but also enhance the comprehension and participation of a broader audience through superimposed or simulated environments, allowing stakeholders to visualize potential changes vividly and contribute more effectively to urban planning and design discussions (Ehab, Burnett, & Heath, 2023; Wilson, Tewdwr-Jones, & Comber, 2019).

In one instance, AR was used to engage youth in the urban planning process in Oslo, Norway to place 100,000 new trees around the city. This AR application allowed participants to overlay digital simulations of these trees onto actual locations using smartphones and tablets, making urban planning concepts more tangible and understandable. The real-time visualizations provided by AR enhanced participants' understanding of urban design and boosted their confidence in expressing their ideas (Reaver, K., 2023). In another example, using AR in a public artistic exhibition demonstrated how AR could enhance visitor engagement by overlaying digital information on physical objects and environments. This technique allowed visitors to interact with the exhibition more immersive, making the displayed content more engaging and comprehensible by augmenting physical objects with digital information, which could be viewed through devices provided at the exhibition (Reeves et al., 2005).

However, incorporating AR into public spaces presents challenges, including synchronizing physical and digital realms, addressing social dynamics, and ensuring system reliability. Despite challenges such as imprecise location tracking, AR's potential to enhance public participation remains substantial, especially among younger, tech-savvy populations. AR enhances public exhibitions' interpretative and educational functions, allowing for deeper visitor involvement and reaching a broader audience (Reeves et al., 2005; Reaver, K., 2023).

Further studies, such as those by Boos et al. (2023), have highlighted AR's ability to enhance understanding of urban projects through immersive experiences, where users can interact with the model at different layers of detail, facilitating informed decision-making. Additionally, museums and educational settings have adopted AR to enable interactive and educational engagements with artifacts, providing personalized learning experiences that transcend physical museum spaces (Woolley et al., 2020).

Innovations like the mobile AR platform introduced by Wang and Lin (2023) emphasize the importance of superimposing urban designs over real environments, clarifying complex planning concepts, and enhancing community responsiveness to proposed urban changes. Comparative studies by Alissandrakis and Reski (2017) and Ehab et al. (2023) have explored how AR and VR can be tailored to enhance civic engagement and participatory processes in different contexts, pointing to a promising future for these technologies in creating more inclusive and engaging public spaces.

Methods

We designed and developed D-ARE, a high-fidelity prototype that we built to investigate system features for location-based AR applications for public engagement. D-ARE, which stands for Design Democratization through AR-based Evaluation, operates on mobile devices. It is designed to support the in-situ exploration of design proposals on interfaces that allow users to view and access design forms and other relevant data, compare alternatives, and share feedback (Figure 4.1) (Behrouz et al.2024).

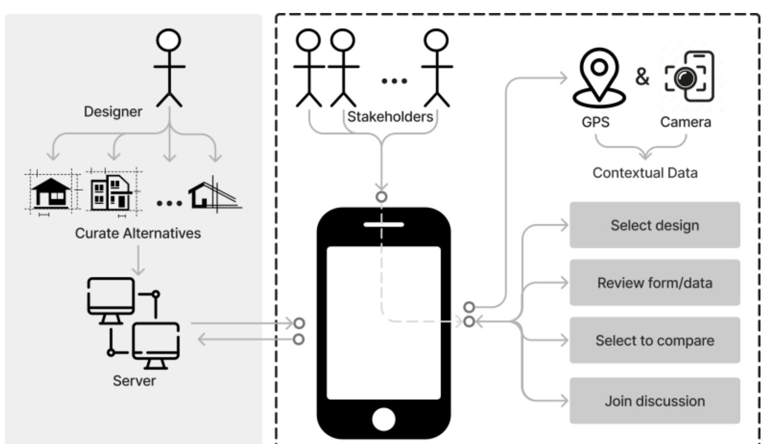

Figure 4.1 D-ARE system design and information exchange schema (Behrouz et al., 2024).

Our review of previous research on different systems for enhancing public engagement and data-informed decision-making for stakeholders revealed a structured method divided into three main functional feature categories:

- Presentation, Exploration, and Comparison features allow stakeholders to explore design alternatives viewing their form as data, interact with 3D views in contextual settings, and compare proposed forms by switching between alternatives.
- The performance evaluation features involve presenting and comparing performance data of design alternatives.
- The feedback integration provides users a platform for discourse around the alternatives and collecting stakeholder feedback using discussion threads, surveys, and comment fields.

System Architecture

We composed four core technologies in D-ARE's development: Google Cloud and Maps, Cesium for rendering, Google ARCore for geospatial visualization in AR, and Unity for modeling and integration (Figure 4.2). We used Unity because of its robust support for 3D modeling and augmented reality functionalities. Further, it enables the integration of Google's ARCore (2024) and Geospatial API, allowing the application to overlay 3D models of urban design proposals directly onto the real-world environment as seen through the device's camera. This integration is vital for the real-time interaction and visualization of design alternatives within their intended physical locations, providing a seamless user experience in augmented reality.

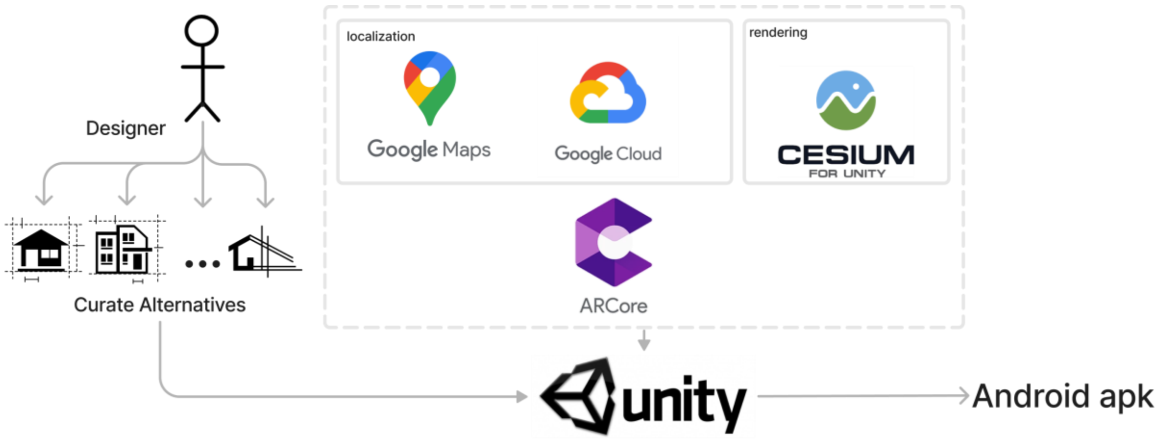

Figure 4.2 Alternative design models are shared by integrating the four core technologies into D-ARE's overall system architecture. Google Cloud and maps are used to locate and visualize the design form in situ. Cesium helps with precise location and view identification connected with ARCore.

For AR features, the application uses ARCore, an API supporting tracking a device in its surroundings and recognizing real-world elements through its environmental recognition features. Connecting ARCore's Geospatial API within Unity allows AR content to be placed at precise geographic coordinates across Android and iOS devices. This is achieved by using earth-localized anchors that bind AR objects to latitude, longitude, and altitude coordinates, ensuring they remain persistently in place despite the user's movement around the site. This precise localization is crucial for accurately comparing and evaluating design proposals in the context where they are planned to be built, enhancing both the relevance and the impact of the stakeholder feedback collected. We tested the application's stability and accuracy outdoors to ensure the optimization of locating designs using the GPS data received.

User Study Design

D-ARE enables users to view design proposals, access data on demand, compare designs, and share their feedback. Our primary goal in the user study was to evaluate the usability of our system, observe user behaviour, and determine how well the D-ARE features meet their intended purposes. During the study, we assigned participants a task that evaluated three alternative large-scale sculptures proposed to be placed in a public outdoor space (Figure 4). Project scales in building environment design can vary widely, from small objects like urban furniture or sculptures to large-scale structures such as buildings or bridges. For user testing, we selected three different sculptures designed to be located at the entrance of Surry Central Mall during the Christmas holiday (Figure 4.3). Using a simple and easy-to-understand example of a design proposal helped us focus mainly on evaluating the system by reducing the possible design confounds that more complex structures might have caused and enabled us to run the study within a reasonable time (10-15 minutes for each interaction).

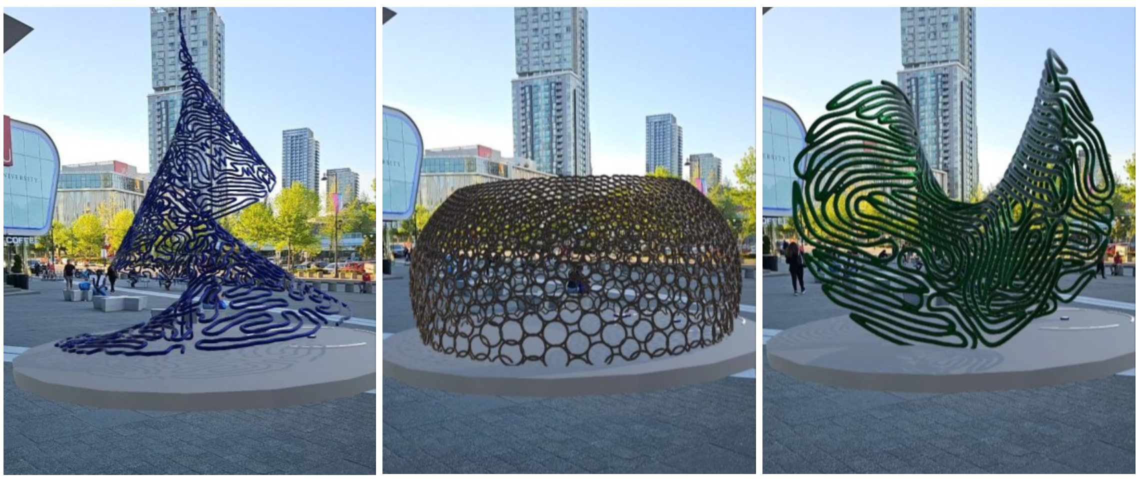

Figure 4.3 During the user evaluation on D-ARE, the participants were shown three sculpture design alternatives (helix-cone, sliced-torus, and **multi-curve). Each sculpture's characteristics, e.g., material to cost, were also shared as 'design data.'**

We invited 20 participants to use the prototype to compare and analyze the design alternatives and to provide feedback through the prototype's feedback-sharing section (Figure 4.3). We conducted the study at the entrance to the Surry Central Mall and the SFU's Surrey Campus, where the participants were randomly approached to ensure the study's objectivity and to gather unbiased feedback across a diverse demographic spectrum. By removing any possibility of selection bias, this random selection method provides a sample that is more typical of how the broader public could perceive or use the system. We collected screen recordings of participant interactions with the system during the user study. Additionally, we conducted a post-study questionnaire to assess the system's usability and features' effectiveness and a semi-structured interview to gather feedback about the user experience of our application.

We developed a survey to assess the effectiveness of our system, incorporating insights from our six use cases (Figure 4.5). This survey comprises 24 rating questions designed to evaluate various aspects of system performance. Figure 5 shows the mapping we used in developing the study to ensure that each system use case is addressed by one or more questions to gather detailed feedback on user satisfaction and the system's efficiency in accomplishing use cases. Additionally, we prepared five open-ended questions to gather further insights from participants and identify areas of importance. For Example:

> *“Were there any features or aspects of the Application that you found particularly challenging or confusing?"*
>
> *" In what ways do you think this application could support or enhance your decision-making process on choosing the best design proposal?"*
>
> *" Are there other tools you are familiar with that have similar or different features supporting the tasks you performed? If yes write their names?"*

These questions are designed to allow participants to express their thoughts and experiences in detail, providing us with valuable qualitative data that might not be captured through the structured rating questions. This approach helps us understand the nuances of user interactions and perceptions, enabling an assessment of the system's impact and areas for enhancement. In the semi-structured interview, we asked participants questions such as describing their overall experience of using D-ARE and the other features they expected to have to collect detailed feedback on the user experience and the future development of our application.

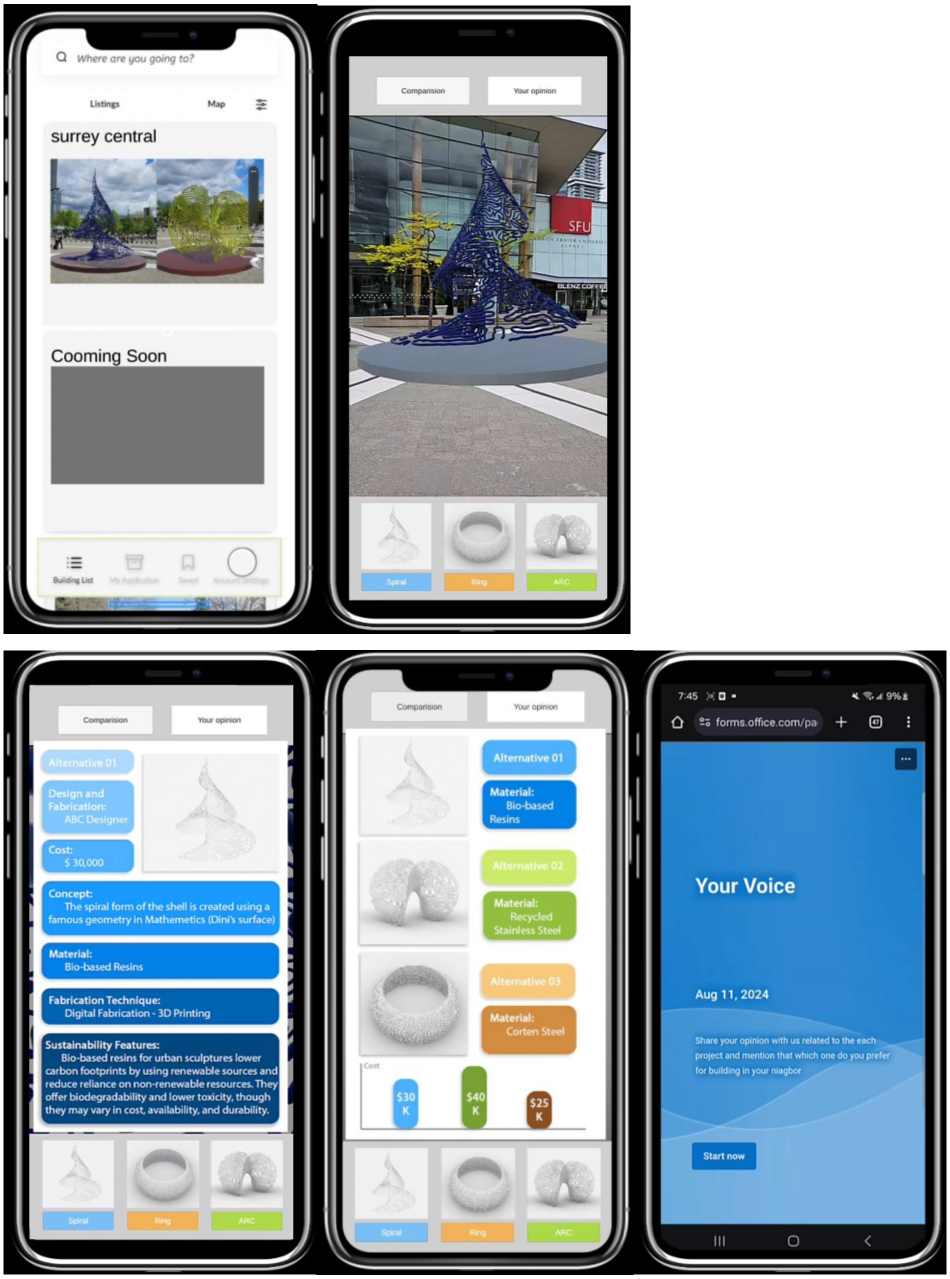

Figure 4.4 D-ARE Interfaces: (left to right, top to bottom, 1-5) (1) a social-media-like interface for stakeholders seeing proposed projects in particular geographic area, (2) In-situ virtual rendering of a design proposal, viewable from multiple perspectives, (3) an on-demand view of summary of select data, (4) Comparison view enabling to assess data through expanding visualizations, and (5) Interaction view for commenting and sharing feedback and interacting with other stakeholders.

The study began with a pre-task survey to assess participants' background and familiarity with public engagement methods. Following this, participants were invited to interact with the D-ARE (Figure 4.4), which displayed sculpture alternatives proposed to be displayed in the courtyard. This setup enabled users to view the alternatives within the context of the courtyard and their associated data, such as cost, allowing for their meaningful comparison beyond form. For instance, participants could compare two sculptures in their actual settings and analyze the cost estimate, material, and other data to determine which suits their preferences and interests better. Additionally, participants had access to preset comparison options to aid in understanding data visually and its relation to the form data. After engaging with the prototype, users were prompted to share their experiences, including their emotional response to the interface, any challenges encountered, and their overall assessment of the user experience through a post-task survey. Finally, we conducted a post-task interview and recorded the session. Each session, including introducing D-ARE, reviewing alternatives, feedback, or presentation, lasted between 30 and 45, an average of 40 minutes.

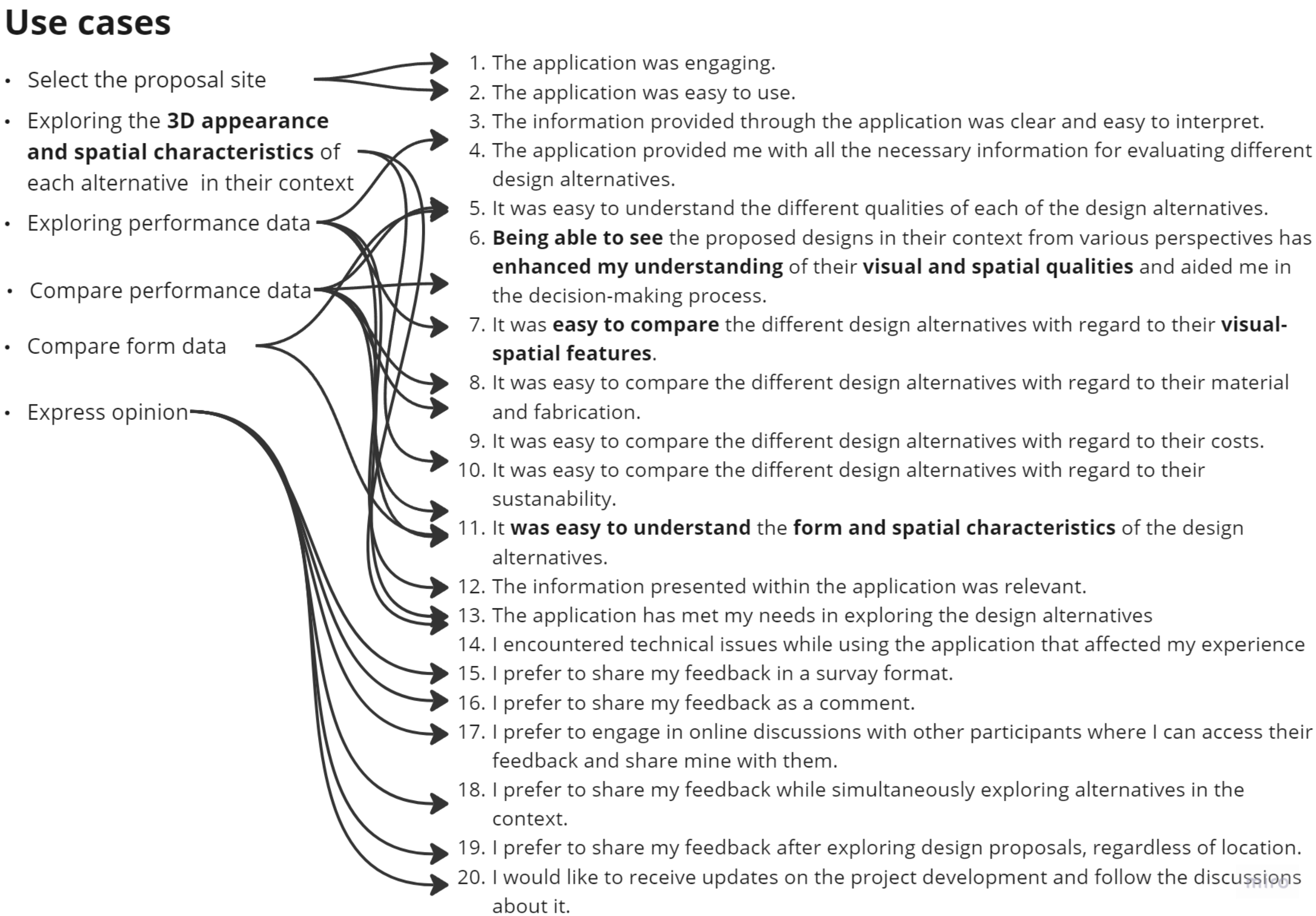

Figure 4.5 Development of post-task survey

Results and Reflection

We collected quantitative and qualitative data from our participants, including screen recordings of participation sessions, rated responses to the survey and open-ended questions about likes, challenges, comparisons with other tools, and desired future features, and voice recordings from semi-structured interviews. The qualitative analysis focused on the survey and interview transcriptions, observations, and smartphone screen recordings of participants' interaction with D-ARE.v2. The open-ended responses provided insights into user experiences and their satisfaction levels. We examined the screen recordings from two perspectives to understand real-time usage patterns (Figures 6 and 7) and identify usability issues. We determined the timing and number of clicks for the usage patterns. For usability, we looked at whether all features were used during task completion and whether there were any difficulties during the prototype's exploration of the features. The application's post-task survey data revealed user experiences and expectations. Participants provided detailed feedback on several aspects of the prototype, offering both quantitative ratings and qualitative suggestions that highlight areas of strength and opportunities for improvement.

Based on participant interactions we observed through recorded video, we identified six distinct patterns, three popular among participants (n=16) (figure 4.6). One hundred percent of participants clicked on all form data buttons, and based on the post-task survey, we were notified that it was the most interesting and engaging part of the application for all participants. On the other hand, 15 participants did not show any interest in the overall design data, such as performance data; the ones who checked the data related to the design form found them appealing before making any decision. The interaction patterns with the application varied significantly (Figures 4.6 and 4.7), except for two participants who neither explored the performance data nor used the comparison feature. However, nearly all participants reviewed the comparison feature, often before making their final decision.

Regarding the presentation of performance data, a participant mentioned:

> *"I would like to see information about the material of the structure and their level of environmental friendliness in a more visually appealing way. That way, I could receive information by seeing an image or chart instead of reading a paragraph."*

This shows that presenting the data more visually may increase users' engagement.

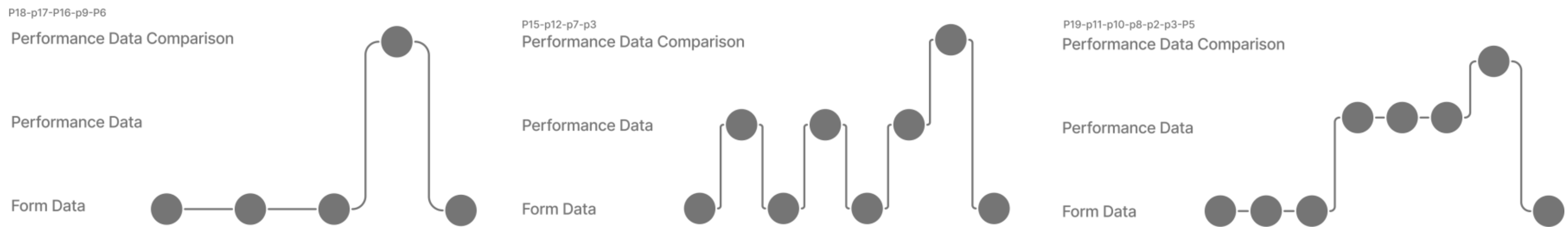

Figure 4.6 Diagram illustrating three popular patterns of participant interaction with different features of D-ARE.

Figure 4.7 Diagram illustrating three other patterns of participant interaction with different features of D-ARE.

One limitation of our system was the inability to compare form data directly, as we could only set one 3D model per geographical coordinate. However, participant feedback indicated that toggling between different forms of data allowed stakeholders to make comparisons and better understand the models. Our survey and analysis revealed that stakeholders who clicked fewer times but spent more time exploring had a grasp of the form data, like those who clicked frequently but spent less time exploring and demonstrated a good understanding of the data. Integrating quantitative assessments and qualitative observations helped identify user interaction challenges and preferences, guiding actionable improvements for the application's future development. Regarding feedback sharing, 9 participants commented on design alternatives, and 15 preferred a survey format feedback collection rather than commenting. An example of a comment is:

> *"I liked the spiral design the most, however, the others were more justified in terms of sustainability. I would design the spiral one with the new material that matches the trees'"*

D-ARE has been highly rated for its usability, with an impressive average score of 4.75 out of 5 for ease of use, showcasing its intuitive and user-friendly interface. Regarding this, participant 2 mentioned:

> *"I think having a few options and limited functionalities made it easy to use, which I think is good for the urban design since people are from different backgrounds and they don't necessarily have the knowledge about AR or these applications."*

Also, the P6 mentioned that:

> *"It was very simple to use. It didn't rely on spatial imagination of the user, as opposed to traditional sketches or physical architecture modeling."*

P7 noted:

> *" Switching between the alternative designs provides a clear image of the characteristics of the design and makes it really engaging."*

However, its engagement score of 3.9/5 suggests there's potential to make the application more engaging. Participant 3 mentioned that

> *"This was awesome. Being able to see how it is going to look like by being able to walk around it was incredible. At some points, I was completely immersed and didn't realize this was a fake."*

The clarity of the presented information scores well at 4.5/5, indicating that users generally find the content clear, though there's scope for simplifying complex information. The information's relevance to evaluating design alternatives received a score of 4.3/5, suggesting that while the data provided is mostly adequate, enhancing the evaluation tools could improve user experience. However, some of the participants wanted to see more data about design proposals, as Participant 12 mentioned.

> *"I would like to know about the designer and more analytical info like carbon footprint for all designs. It was mentioned in one of the designs that the carbon footprint is lower and in the other recyclable materials and in the other biodegradability of the material. I would prefer to have the exact info(number) for each that would help better compare. Or, knowing a bit about the company and the designers"*

The participants showed interest in clear features that could enhance engagement, such as game-like elements and virtual instructions explaining D-ARE functionalities. Such additions could make the application more interactive and enjoyable. Popular suggestions also included integrating social media features to allow users to share designs and connect with a community, adding a valuable social dimension to the app. Others suggested more advanced analytical tools, like timeline charts for deeper comparison of design elements, and support features like live chat and voice assistance to accommodate users with different needs, emphasizing the importance of inclusive design.

The likelihood of continued use is promising, with most users indicating they would continue using the application (the average score is 8/10). This feedback emphasizes the application's potential to engage the design stakeholders to evaluate proposed built environments and suggests that incorporating the recommended features could improve user satisfaction and acceptance. Simplifying the application's interactivity and enhancing the sense of social connectedness and inclusivity can contribute to the D-ARE's increased use in various scale built-environment design projects.

Conclusions

Our study highlighted several areas for improvement in public engagement in the context of the built environment. One critical issue identified was the accuracy of the 3D model placements. While this did not impact the user study due to the small scale of the objects used, it could pose significant limitations in larger-scale projects or those requiring more precise location settings. Potential solutions include integrating Visual Simultaneous Localization and Mapping (VSLAM) and Google Street View (GSV) to enhance location precision (Brata et al., 2024). Another concern was user safety; participants were so immersed in using the application that they occasionally neglected their surroundings. For instance, two participants accidentally collided with a bench near our virtual object display area. Future developments should address this by marking real-world boundaries or restricting the viewing angles to ensure users are aware of their environment while interacting with the application. These adjustments aim to enhance the AR experience's functionality and safety.

For future development, enhancing the immersive experience of our system is a primary focus. One proposed enhancement is the introduction of interactive features such as haptic feedback (vibrations) or auditory cues when a user interacts with a virtual structure or even real-world objects. This addition could deepen the engagement and provide a more tactile and auditory dimension to the AR environment. Also, based on the result of our study, some participants suggested maintaining the visibility of the design while exploring its details and characteristics; we are considering integrating performance data and form data within the same visual field in our future work. This overlay could facilitate more seamless evaluation and improve the efficiency of interactions with the feature, potentially enhancing user comprehension and satisfaction. These enhancements may refine the system’s utility and user experience, guided by user feedback and observed interaction patterns.

Chapter 5. User Study Details

The chapter presenting D-ARE.v2 (Chapter 4) summarizes the qualitative findings from the post-task interviews. In this chapter, I expand the findings from this formative evaluation study, including the survey results, which we opted to exclude from the paper due to page limitations in the conference requirements.

5.1. Participants

We recruited participants using a convenience sampling method (n=20) in the courtyard shared by Simon Fraser University Surrey Campus and the Central City shopping mall. Their ages ranged between 20 and 40 (μ=30, Mdn=31, Mo=31). To reduce the pressure on the participants, we did not ask gender questions. All participants self-reported professions requiring higher or post-graduate education (Table 5.1).

Table 5.1 Participants' age distribution and background.

ID	Age	Profession
P1	37	Creative AI
P2	31	Computer science (VR/AR)
P3	34	Researcher (VR and HCI)
P4	32	Bio-Signal Processing
P5	27	Sociotechnical Systems Engineering
P6	29	Pharmacy
P7	33	Software engineering (Technology-assisted learning)
P8	28	Biomedical engineering, VR, AI, and Machine Learning
P9	38	Architecture
P10	32	Architecture
P11	24	Computer Engineering
P12	28	Software Engineer (VR)
P13	32	Mechatronics Engineering
P14	24	Computer Engineering (Machine Learning)
P15	40	Civil Engineering

P16	31	Automotive and Mechatronics Engineer
P17	31	Polymer Engineering
P18	29	Electrical Engineering
P19	26	Computer Science (Machine Learning)
P20	20	Psychology

The participants (n=20) rated their expertise in related fields to the D-ARE on a 5-point Likert scale (Table 5.2). Only P9, P10, and P15 (n=3) identified themselves as highly familiar with architecture or urban design. The majority (n=14) reported no experience in these fields. The participants were almost evenly split in terms of familiarity with AR/VR technologies, with 6 participants indicating some prior experience. Additionally, 12 participants were familiar with data visualizations. The low familiarity with data visualizations was somewhat unexpected given the participants' educational background. Only P6 noted prior participation in a public urban development meeting. None of the participants have expressed opinions or engaged in a discourse about urban or architectural proposals on any platform.

Table 5.2 Self-rating of participants' familiarity (experience level) in related fields.

(n=20)		Architecture/Urban Design	AR/VR	Data Visualization
Not at all familiar	1	14	6	5
Slightly familiar	2	2	3	3
Somewhat familiar	3	1	6	6
Moderately familiar	4	0	3	4
Highly familiar	5	3	2	2
	μ	1.8	2.6	2.8
	σ	1.5	1.4	1.3

The participants selected did not represent a diverse population. Given the study location (university entrance), it was expected to see demographics with higher education. Therefore, the findings might have been limited to the opinion of a small group. On the other hand, it gave us a consistent group of participants regarding educational background to compare their feedback to the others in future user studies. We also believe that the 'sculpture' proposed will be in the environment of the population represented by the participants. Therefore, the user study served the purpose of 'engaging' the stakeholders that could be directly affected by the proposed changes, which was consistent with the thesis objectives.

5.2. Post-Task Survey

The post-task survey covers in-depth user feedback gathered regarding the D-ARE performance. It sought to assess users in four key dimensions: engagement, ease of use, clarity of information, and completeness. Participants (n=20) rated their agreement on 5-point Likert scale questions: 1 (Strongly Disagree) to 5 (Strongly Agree) (Table 5.3). Fourteen participants agreed about the D-ARE's engaging characteristics (μ=3.9, σ=0.9); almost all participants agreed about the ease of use and ease of interpreting presented design data (μ = 4.8, σ=0.4 and μ = 4.5, σ=0.6 respectively). User engagement with the application, however, shows a more mixed profile. While 14 participants frequently found the application engaging, five only sometimes felt engaged, and only one rarely found it engaging. In general, to raise the user engagement rate, the data point to the fact that the application can receive good attention from a few users and bring improvement through interactive elements or improving user experience through personal perspectives.

Table 5.3 D-ARE's engagement, ease of use, and interpretation of designs.

(n=20)		Engaging	Easy to use	Easy to interpret
Strongly disagree	1	0	0	0
Disagree	2	1	0	0
Neither agree nor disagree	3	5	0	1
Agree	4	9	5	8
Strongly agree	5	5	15	11
	μ	3.9	4.8	4.5
	σ	0.9	0.4	0.6

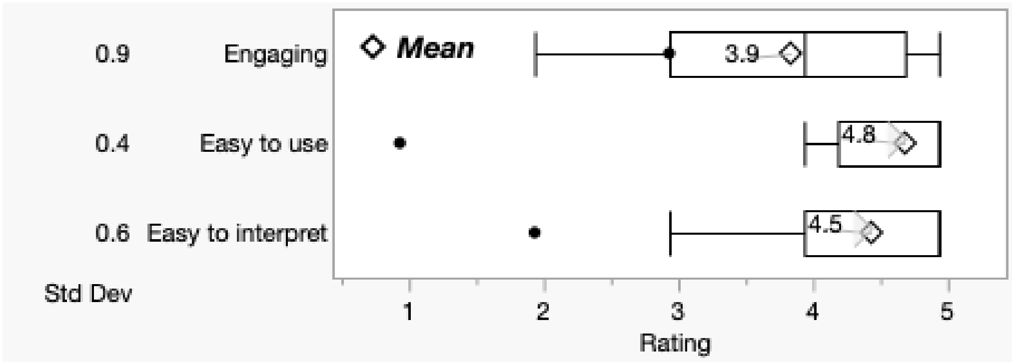

Figure 5.1 Rating of Engagement, ease of use and interpretation.

We further asked about other characteristics, such as understanding and comparing design alternatives considering form (aesthetics), non-spatial data, or other properties, such as material (Table 5.4) (Figure 5.1). Most satisfaction (n=18, $\mu = 4.7$, σ=0.8) ratings were on the features for comparison of alternatives by form (aesthetics) and the understanding of spatial characteristics (n=19, μ=4.4, σ=0.8). The least satisfaction was on comparing alternatives by non-spatial properties (n=8, μ=3.15, σ=0.9); One participant rated their experience with evaluating non-spatial properties as below average, and eight above average.

The high agreement with understanding and comparing form and spatial characteristics shows that the participants didn't have significant difficulty reviewing proposed sculptures in situ. This is expected as spatial perception may demand less cognitive load than reviewing and understanding the non-spatial data, such as cost or environmental impact. Further, such non-spatial data may not be of direct interest to the participants; for example, material choice may be less important than form, affecting the rating.

Table 5.4 Responses to system characteristics for 'easiness.'

(n=20)		compare alternatives by form	compare alternatives by non-	compare alternatives by cost	compare alternatives sustainability	understand design qualities	understand spatial characteristic
Strongly disagree	1	0	1	0	0	0	0
Disagree	2	0	3	0	3	0	1
Neither agree nor disagree	3	2	8	1	5	4	0
Agree	4	2	8	6	9	11	9
Strongly agree	5	16	0	13	3	5	10
	μ	4.7	3.2	4.6	3.6	4.1	4.4
	σ	0.7	0.9	0.6	0.9	0.8	0.8

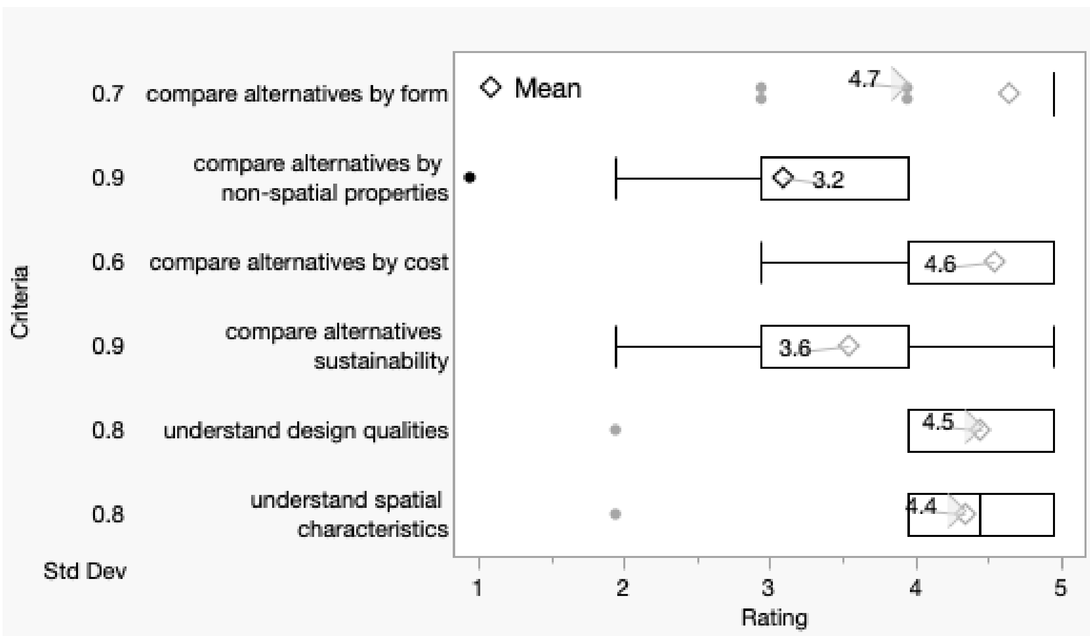

Figure 5.2 Rating of system characteristics for 'easiness.'

Again, the participants' interest in seeing the alternatives in their physical context is consistent with our research goals (Table 5.5) (Figure 5.2). The participants were almost evenly split in preferring functions that enable exploring designs' visuospatial features in context (μ=3.0, σ=1.2), where 8 participants definitely or probably preferred, six as 'probably not' or 'definitely not'. The remaining 6 rated this feature as neutral. However, the highest preference (n=15, μ = 4.3, σ=1.1) was for the features for sharing feedback in survey format, while the lowest was for sharing feedback as a comment (n=5, μ=2.6, σ=1.2). The distribution of preferences on the other features, such as engaging in discussions, in- or off-situ review of alternatives and feedback sharing, and receiving updates on proposals, were ranked as close to neutral (between μ = 3 and 3.6); 11 participants preferred to share their feedback in-situ as the alternatives are reviewed (μ = 3.6, σ=1.1). The participants preferred less demanding ways to share their opinions, such as in surveys by marking rather than writing comments. However, there was still interest in participating in discussions (n=11, μ=3.0, σ=1.0).

Table 5.5 Responses to preferences for features supporting engagement in D-ARE.

(n=20)		Explore spatial features	Share feedback in survey	Share feedback as comment	Engage in online discussions	Share feedback as alternatives	Share feedback after	Receive updates on a project and
Definitely not	1	3	1	3	3	0	1	0
Probably not	2	3	0	3	5	4	3	6
Neutral	3	6	4	7	4	5	6	3
Probably	4	7	3	3	4	5	5	9
Definitely	5	1	12	2	4	6	5	2
	μ	3.0	4.3	2.9	3.1	3.7	3.5	3.4
	σ	1.2	1.1	1.2	1.4	1.1	1.2	1.0

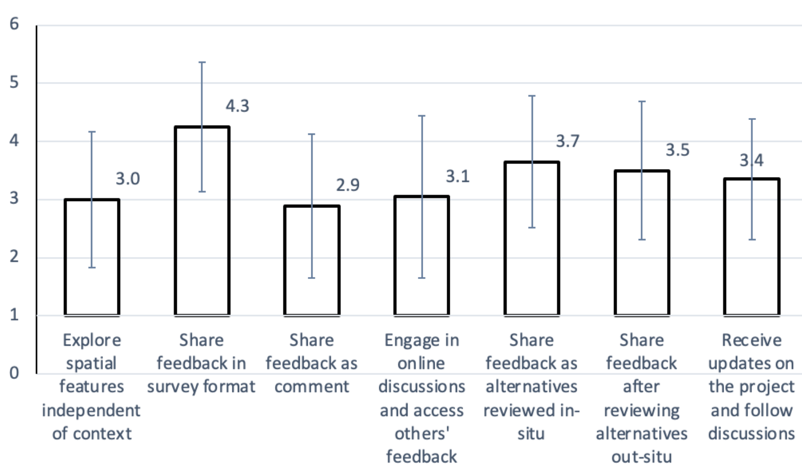

Figure 5.3 Mean values of responses to preferences for features supporting engagement in D-ARE.

The survey results indicate that D-ARE was well-received, particularly for its real-time presentation of alternatives within the given context (n=19 positive feedback, μ = 4.7, σ =0.6) (Table 5.6) (Figure 5.3). Similarly, the feature for comparing alternatives was rated as useful (n=18, μ = 4.3, σ =0.6). These findings highlight the significant role of Augmented Reality (AR) components in the D-ARE interfaces, or AR in general, in enhancing the comprehensibility of proposed alternatives. While ranked lowest among the features, the design data presentation feature was still considered useful, with a mean rating of 3.6 (n=13 positive feedback, σ=0.7). This result may be influenced by how the data presentations were introduced in D-ARE and potential biases in data selection. For future projects, it is crucial to carefully select the data shared with stakeholders to ensure it is meaningful for them.

Table 5.6 Rating of the usefulness of each functional feature of D-ARE in decision-making.

(n=20)		Real-time presentations of alternatives in their	Comparing different alternatives	Data presentation related to each alternative	Method of feedback sharing
Strongly disagree	1	0	0	0	0
Disagree	2	0	0	2	2
Neither agree nor disagree	3	1	2	5	2
Agree	4	4	11	13	11
Strongly agree	5	15	7	0	5
	μ	4.7	4.3	3.6	4.0
	σ	0.6	0.6	0.7	0.9

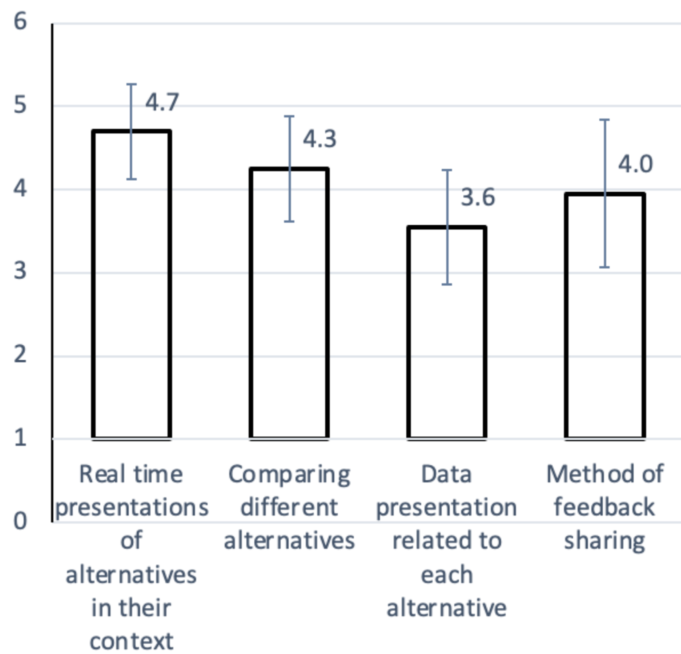

Figure 5.4 Mean values of rating of the usefulness of each functional feature of D-ARE in decision-making.

Additionally, the participants valued the feedback-sharing features (n=16, μ=4.0, σ=0.9). This positive response encourages the further development of D-ARE, as it suggests a potential for increased stakeholder engagement in data-informed discussions. The participants' interest in the feedback-sharing features is particularly significant given their reported lack of experience participating in public forums related to built environment projects.

At the end of the survey, participants (n=20) were asked whether they would like to receive updates on the proposed project and be involved in further changes. Based on the responses, all participants are interested in receiving updates. The updates are categorized into six different areas. Among these, two categories attracted the highest demand: first, updates on the project progress and design changes; second, on community impact and feedback (n=12). Subsequently, participants showed interest in receiving updates on construction timelines, logistics, and news about the project's completion and opening (respectively, n=11 and n=10). There was less interest in the other categories, specifically budget and funding details (n=5) and detailed design and technology updates (n=2) (Figure 5.4).

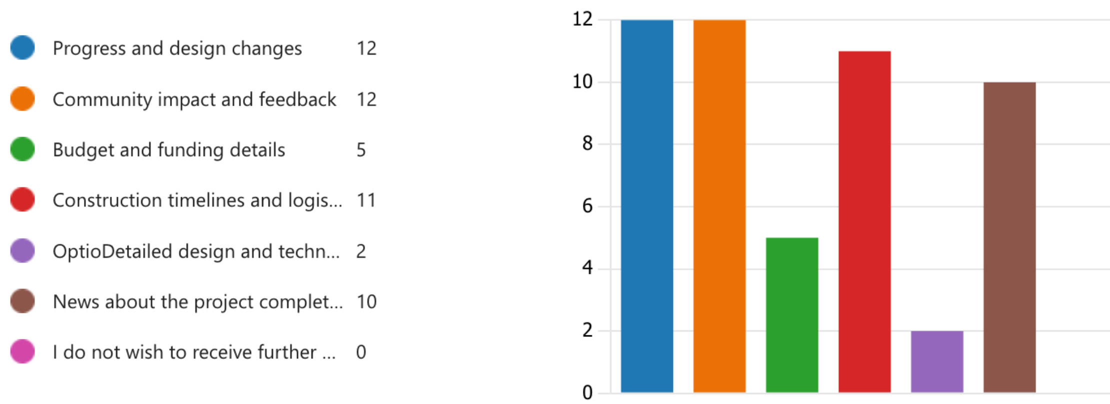

Figure 5.5 What updates about this project would you like to receive? Survey Results on Participant Interest in Project Updates.

Also, participant feedback underscores a clear demand for more comprehensive and detailed information to make informed decisions about the design alternatives. Key areas of concern include the practicalities and structural integrity of the designs. For instance, respondents express a need for specifics on how long it takes to build and the model's resistance to corrosion, which is essential for assessing their longevity and feasibility. Environmental impact is another significant factor; there is a call for details on how constructions will affect surrounding areas and for exact numbers regarding the carbon footprint of each design option.

There's a keen interest in understanding the rationale behind each design choice on the cultural and aesthetic front—questions like the "*reason for selecting this shape*" and its relevance to the region are highlighted (Table 5.7). Although the AR application provided an immersive experience, some found the presentation of cultural impacts lacking, suggesting an area for improvement in how information is conveyed. Safety features, especially concerning children, also emerged as a priority, with inquiries about how child-friendly the installations are. Overall, the feedback indicates a desire for a deeper, more analytical look at the designs' creative and practical elements, including insights into the designers and the materials used.

5.3. Post-Task Interview Notes

At the end of the user study, I asked participants to share their overall feedback on the D-ARE application, discussing their expectations and their views on what they would like to see in the future and the opportunities and limitations they perceive in this application. I present below some of the excluded observations from the post-task interview, presented in detail in the paper on D-ARE.v2.

Table 5.7 What additional information would help you make a more informed decision about the design alternatives?

Artist info and timeline
It seems the information about the cultural impact was in the app but I missed it. Maybe it's because of the presentation.
This was awesome. Being able to see how it is going to look like by being able to walk around it was incredible. At some points, I was completely immersed and didn't realize this was a fake.
The provided information was sufficient in my case!
How long does it take to build? How resistant the model is to corrosion in time
Information about the time it takes to construct the design and how it affects the surroundings and buildings.
Safety with regard to children interacting to them (for example climbing them)
Third one doesn't block circulation in area
How much time needed to build the structure? How would it effect the children's life because there was no information about that.
The reason of selecting this shape, why it's good for this region, the connection between the architecture of mall building and the sculpture
I would like to know about the designer and more analytical info like carbon footprint for all designers. It was mentioned in one of the designs that the carbon footprint is lower and in the other recyclable materials and in the other biodegradability of the material. I would prefer to have the exact info(number) for each that would help better compare. Or, knowing a bit about the company and the designers
Others' opinion on each of designs
Weight, structural design
The purpose of this design

P6, P11, and P14 mentioned that the application was easy to use but requested the addition of a guide instruction for the first use. Regarding support and enhancing informed decision-making, P5 mentioned that "*presenting information on* *alternatives in a more structured view would be beneficial,*” such as using a tabular format for comparison.

P19 mentioned expecting more interaction in AR, for example, having multiple layers in AR for presenting data instead of only providing forms (geometry/rendering). P19 also mentioned that adding more graphs and charts could improve the comprehensibility of the data instead of presenting them in sentences. Additionally, P19 mentioned that adding terminology definitions can help understand the differences between the materials mentioned in the application and make an informed decision. P3, an expert in developing extended reality applications, emphasized the role of the immersive experience in AR in mobile platforms but also mentioned that in crowded areas, it would be dangerous for the users because they may be disconnected from their surroundings, posing a risk to their safety. This can be partially avoided by adding viewpoints on AR views.

5.4. Results and Conclusions

The survey's findings confirm that the D-ARE.v2 may bring stakeholders into the conversation through immersive augmented reality experiences. Still, they also point out important areas that need to be improved to increase user satisfaction and engagement. Enhancing D-ART’s functional features to clearly and interactively show design choices will help us promote a more informed and collaborative decision-making process. This research demonstrates the significant influence of AR-based and in-situ media on public opinion and built environment development decision-making. We find the input from participants in the user study highly valuable for developing the next version of D-ARE to ensure inclusion and encourage participation.

The participants expressed that D-ARE’s strengths are its simplicity and clarity in presenting design projects in situ and through AR views, two critical factors for user satisfaction and engagement. However, the feedback on engagement and design data presentation indicates further considerations to increase D-ARE’s usefulness and foster stakeholders' participation in reviewing build environment data, sharing feedback, and being part of the discourse. Considering the overall satisfaction from the user study, future developments will focus on interactivity and design data selection and presentation.

Chapter 6. Conclusions, Limitations, and Future Work

In this thesis, we explored the potential of a location-based AR (D-ARE) application in improving public engagement in the design of built environments. Design alternatives presented in a physical context with their form and performance data may foster discussions and feedback sharing by the stakeholders and, in turn, improve design decisions to create more liveable and responsible environments.

The development and iterative testing of D-ARE prototypes have shown that it can potentially increase the democratization of built environment design processes by making design data more accessible and understandable for all stakeholders, irrespective of their type or level of expertise. We have also explored the challenges and extracted potential considerations for designing future AR-based applications in built environment design and democratization.

Through this study, we have seen how AR can be useful for gaining insight into proposed changes within actual environmental contexts and simultaneously foster an active and informed community dialogue. Augmented reality overlays form and interactive visualizations of design proposals onto the physical world. Thus, they reduce the gap between abstract planning and tangible outcomes to a minimum, allowing stakeholders to view, experience, and possibly critique proposed designs from their perspectives.

Therefore, we addressed our main objectives as follows:

> *RQ1: How can multiple design alternatives and their associated data be shared in an in-situ AR environment to enable and enhance stakeholders' engagement?*

Our findings show that D-ARE (particularly in-situ AR) may have the potential for effectively presenting multiple design alternatives and associated data within a context. D-ARE allows the stakeholders to visualize and interact with design alternatives superimposed on their proposed physical environment. In addition, such immersive experiences may empower the stakeholders to make more informed decisions through real-time contextual data visualization. It can foster participation and engagement in the process of built environment design.

RQ2: What are the characteristics of interfaces that could be used for engaging design stakeholders in in-situ feedback sharing?

The D-ARE system interface emphasized which characteristics are most important for effective stakeholder engagement; however, we realized them through an extensive literature review of related studies. These include, for instance, intuitive navigation, real-time visualization of data, and easy access to information, which are critical in reaching people with a diverse range of technical knowledge. The user-friendly interface can help in trouble-free interactions with complex design data so stakeholders can provide feedback in an informed manner directly within the design context. We tested this aspect by conducting a user study on D-ARE.

RQ3: What opportunities and challenges may an in-situ AR system exhibit in real-world scenarios during the review process of built-environment design proposals?

Significant findings from implementing the D-ARE system under real-world conditions suggest that this method holds many potentials related to the transparent and inclusive development of built environment design. Stakeholders had a chance to see and evaluate the potential impacts of the design proposals within context. However, this also evidenced issues of technological reliability, data privacy, and accessibility. These issues support the need for strong system design and equal access to technologies that would benefit AR tools across diverse stakeholders.

The thesis has explored how D-ARE may enhance public engagement in design, as demonstrated by the deployment of the D-ARE. While the clear benefits of using online mediums in engaging and decision-making have been presented, it also comes with several challenges that must be addressed to realize the real potential.

The usability and access of AR technology, for instance, must be improved so that the processes involved in building environment design can be turned into more participatory activities and more reflective of community needs. This may enrich the information in the design process and make built environments more livable and responsive.

A critical limitation of the study was that some stakeholders found D-ARE difficult in how they could share open feedback, such as comments, which could restrict expression or impose extra cognitive effort. Some participants preferred not to provide free-form answers. This limited the reach and level of feedback that could be obtained. Moreover, the social media-like features can introduce biases, creating situations in which design stakeholders may feel pressured to conform to the majority view, thus hindering the expression of an authentic, objective individual perspective. Therefore, there is a risk of agreeing with the preferred popular opinion over real and diverse input, thereby impacting how AR tools may foster the engagement of a wider population. The challenge was designing mechanisms that could provide objective and unbiased feedback enabled by an AR solution that embraces inclusivity and representation.

6.1. Limitations

In this study, I identified several potential limitations that provide a foundation for future improvements in AR design for built environment design aimed at enhancing data democratization.

One technical challenge involves the need for precise geo-localization and high-performance hardware required to implement AR platforms, potentially limiting accessibility. However, advancements in processor technology are expected to overcome these barriers over time. For larger projects such as urban-scale structures like bridges or stadiums, the small screen size of smartphones and the processing constraints for rendering large-scale 3D models can pose limitations.

Adopting AR glasses, such as HoloLens or Apple Vision Pro, offers some solutions by providing natural central and peripheral views augmented with visualizations.

User testing revealed difficulties in integrating and comparing two distinct types of data: 3D forms displayed through AR and design information shown as data, descriptions, and pictures in separate views. Future design should consider techniques to present design form and data considering user preferences such as superimposed or side-by-side, enhancing comprehension and interaction.

Our findings underscore the need to balance technological solutions with user needs and characteristics in AR systems. Overly complex systems can deter non-technical users, thus defeating the purpose of inclusive engagement. Simplifying the interface to accommodate a broader user base will ensure that AR technologies are both advanced and accessible, supporting effective participatory built environment design.

6.2. Future Work

Based on the lessons learned from this study, future research in this area should consider continuing the progress of visualization in AR applications and improving non-form data presentation to stakeholders. There is a potential way to improve the feedback collection process by introducing the levels of stakeholder participation. A possible enhancement is a tiered feedback system that allows for user engagement and expertise differences. For example, this application may begin with basic rating scales with pre-defined questions that can be answered easily. It may then advance to more complex commenting features such that those who desire to articulate a more subtle opinion are also allowed to do so.

Likewise, moderated discussion boards where experts within the stakeholders deliver their learned opinions and advice to relatively novice or unaware users can facilitate a much more balanced discourse. Encouraging broader participation, the setup allows even less confident users to present their views and helps reduce the impact of biases by promoting informed discussions. Such forums could also serve as good platforms for educational purposes, improving the general understanding of the issues at hand and resulting in more informed choices by the community.

Lastly, there's the potential bias introduced with social media-like engagement platforms. It is critical to explore how these biases could be managed or counteracted. These biases would be assessed one way or another toward favoring them or against them. For example, representing expert stakeholders in driving community opinion could lead to better decisions; however, an excess of powerful voices might alienate the weaker and minority ones. This suggests further research to investigate mechanisms that will balance these effects through increased engagement while at the same time ensuring that all community voices are heard and valued.

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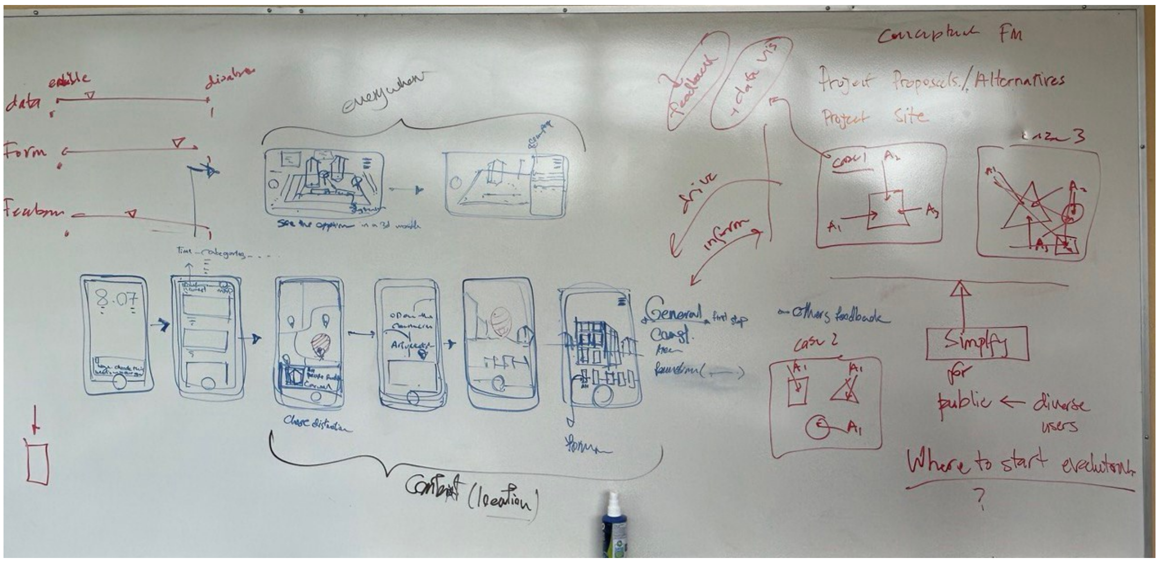
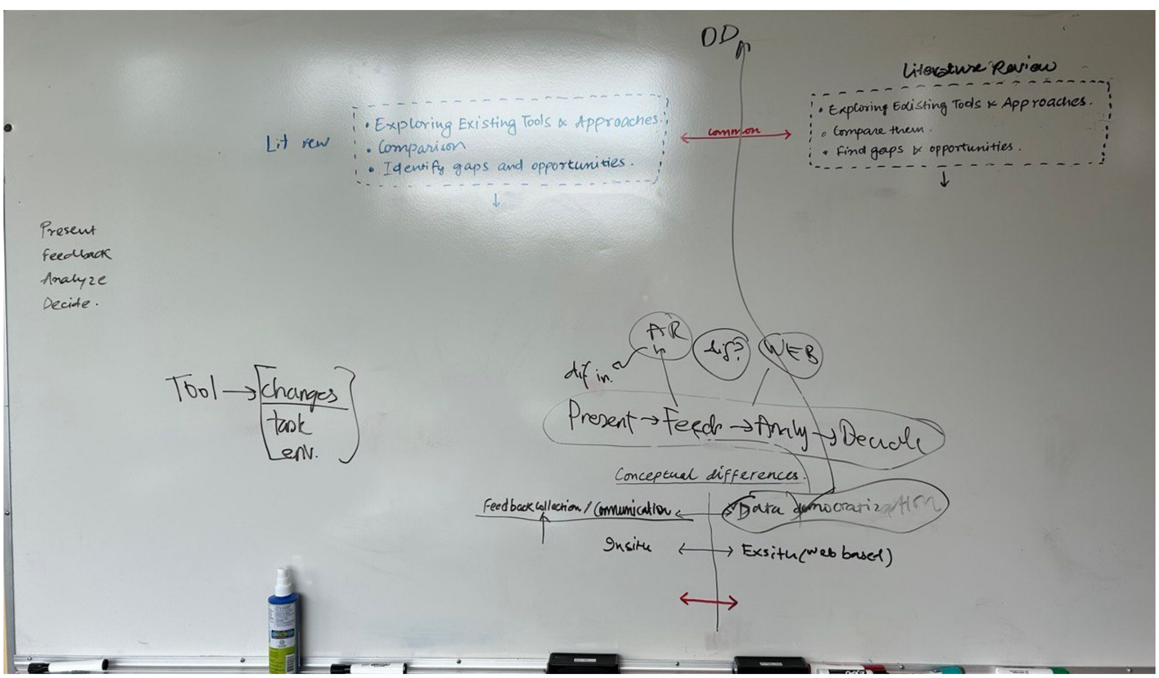
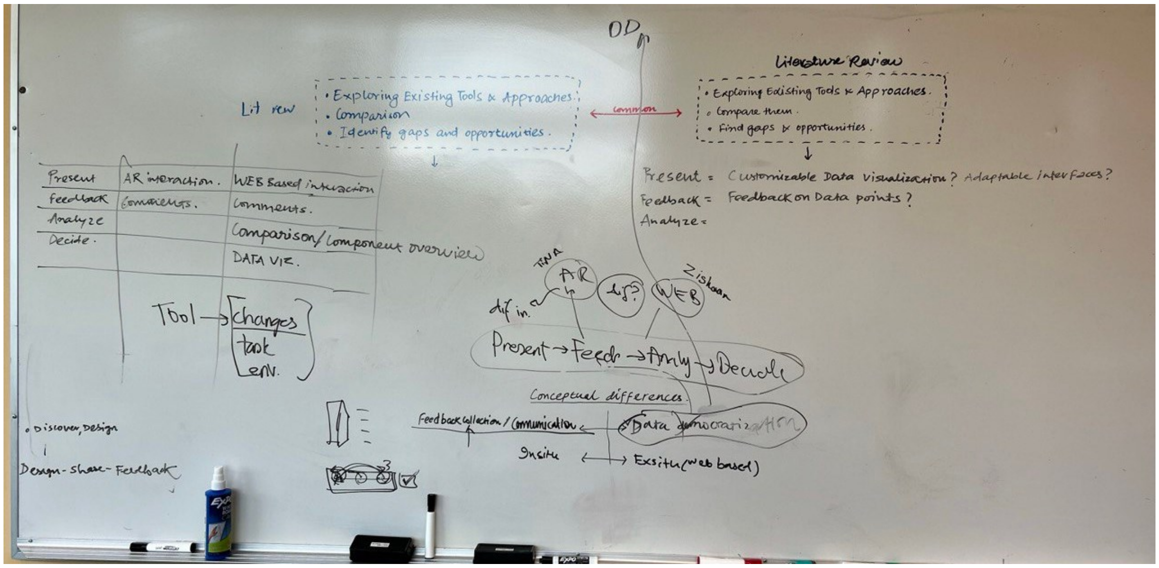
Appendix A.   Early Sketches of D-ARE

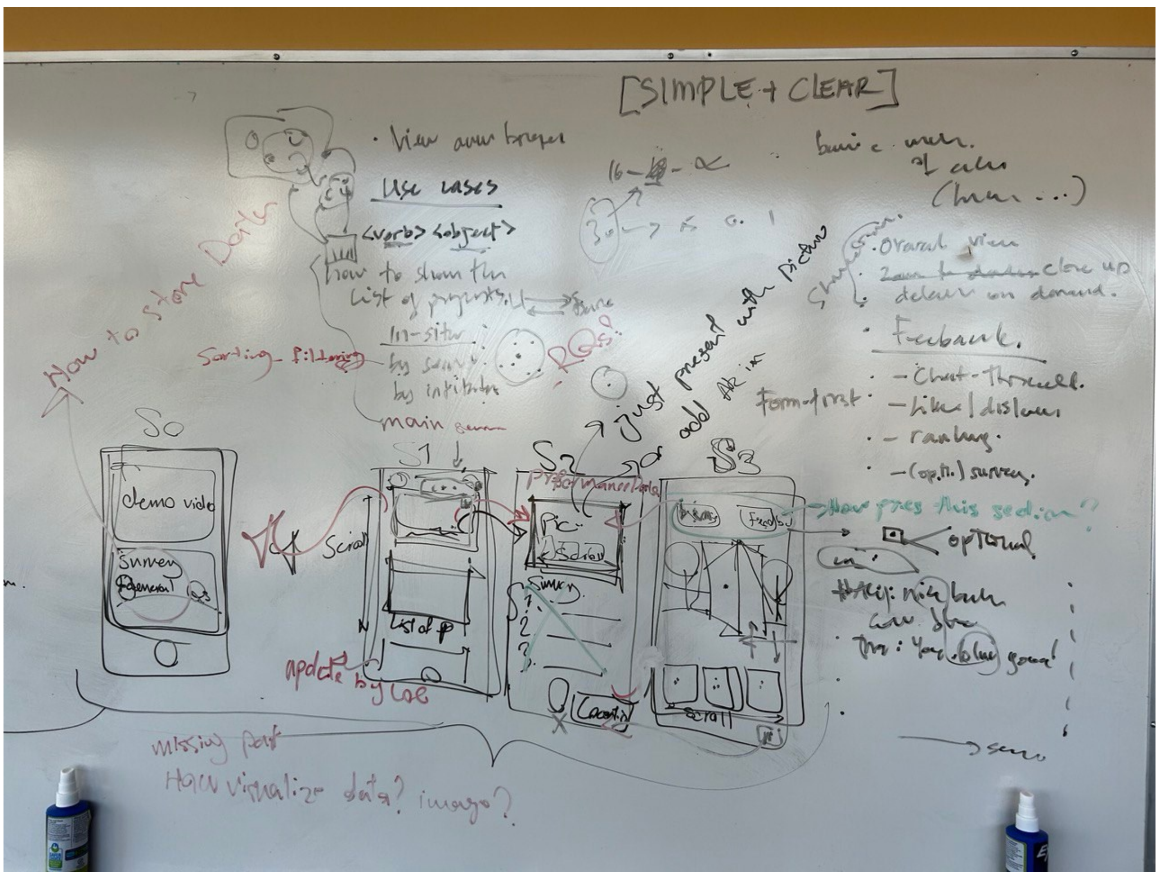
Design sketches:

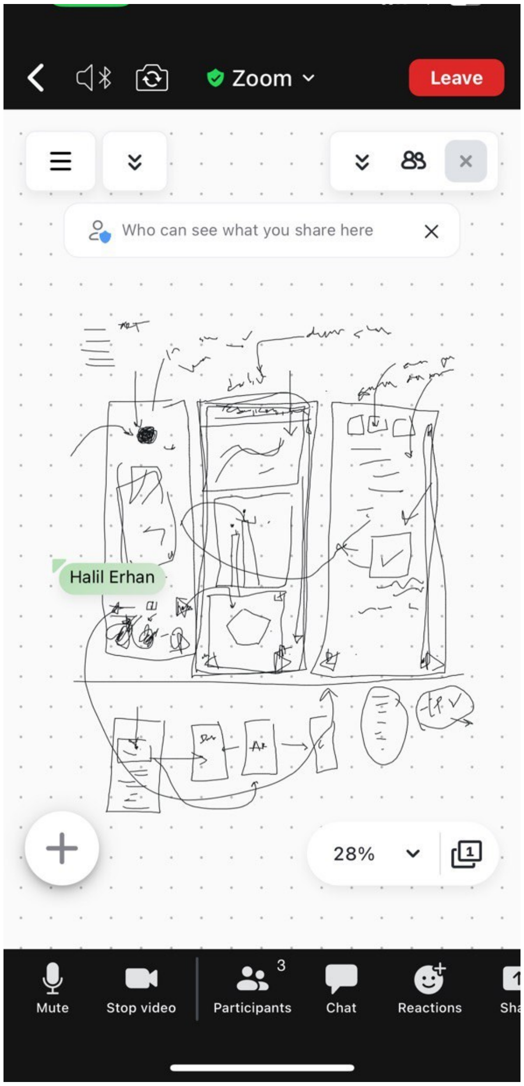
The following images are the initial design sketches for different sections of the D-ARE prototype.






Lit rew
Exploring Existing Tools & Approaches
Comparison
Identify gaps and opportunities
Literature Review
Exploring Existing Tools & Approaches
Compare them
Find gaps & opportunities
Present
Feedback
Analyze
Decide
AR interaction
WEB Based interaction
Comments
Comparison / Component overview
DATA VIZ
Tool
changes
task
env.
Present = Customizable Data visualization? Adaptable interfaces?
Feedback = Feedback on Data points?
Analyze =
AR
WEB
Conceptual differences
Feedback collection / Communication
Data democratization
Insitu
Exsitu (web based)
Discover, Design
Design - Share - Feedback


[SIMPLE + CLEAR]
Use cases
<verb> <object>
How to store Data
just present with picture
Feedback.
optional
demo video
Scroll
missing part
How visualize data? image?


Zoom
Leave
Who can see what you share here
Halil Erhan
28%
Mute
Stop video
Participants
Chat
Reactions

question

How does the use of AR applications in the interior design process impact customer satisfaction, design efficiency, cost-effectiveness, and creative design possibilities compared to traditional design methods?

Definition of the creative (design) domain and list of activities concerning CSTs
The creative (design) domain is defined as a space where people engage in activities that require original thinking, such as generating novel ideas, exploring possibilities, and synthesizing information. Shneiderman suggests that a wide range of creative activities can be supported by Creativity Support Tools (CSTs), including brainstorming, sketching, prototyping, and collaborating. He emphasizes that CSTs should not replace human creativity but rather serve as tools to enhance and augment it. Shneiderman concludes that HCI researchers have a grand challenge to create effective and usable CSTs that can support the diverse needs of creative professionals across various domains.(1)

Definition of the users (actors/personas)

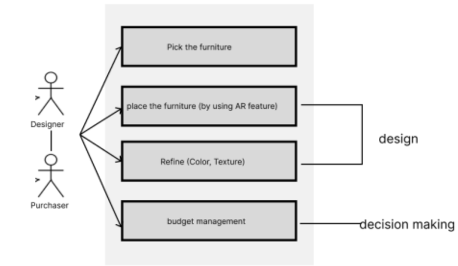
purchaser: the tool to visualize and experiment with different interior design options before making renovation or remodeling decisions
interior designers: use it to create and present design concepts to clients

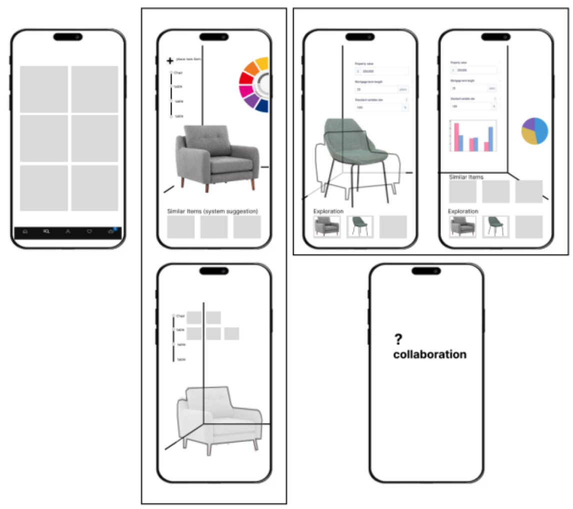
CST problem definition concerning the creative (design) activities and users
the problem definition concerns the lack of technology tools that can support the complex and non-linear processes of creativity.(1)

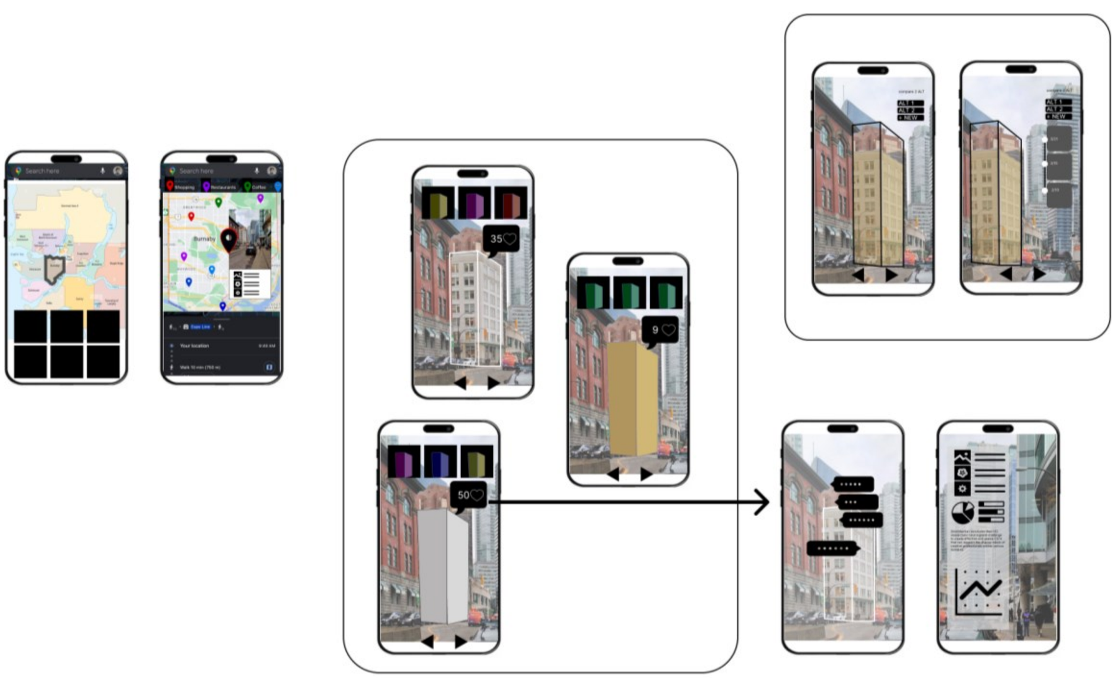
references

1. Shneiderman B. (2009) Creativity Support Tools: A Grand Challenge for HCI Researchers. In: Redondo M., Bravo C., Ortega M. (eds) Engineering the User Interface. Springer, London.

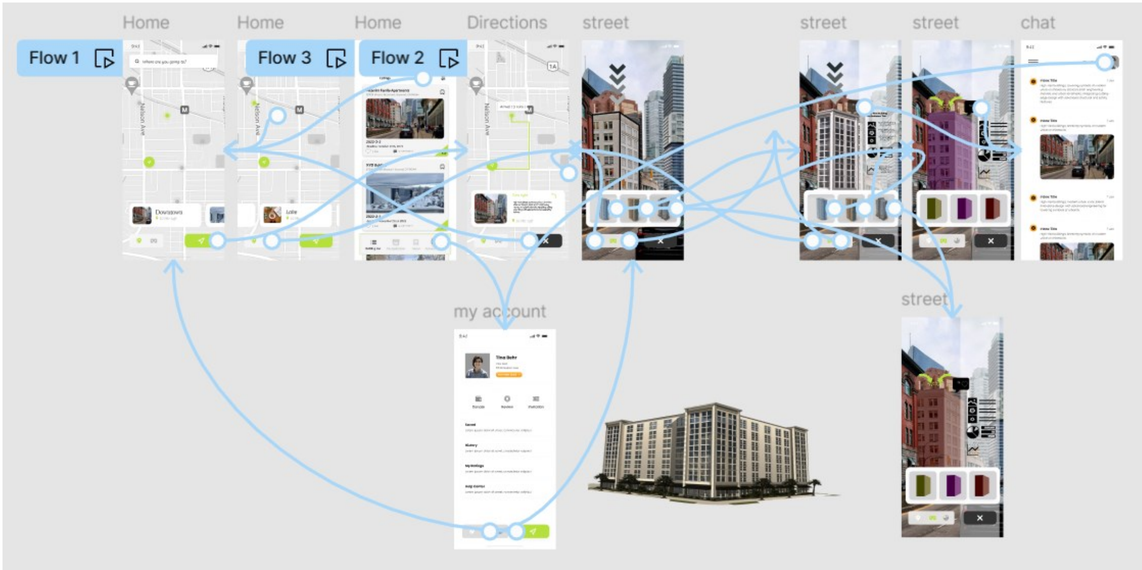
Use case diagram



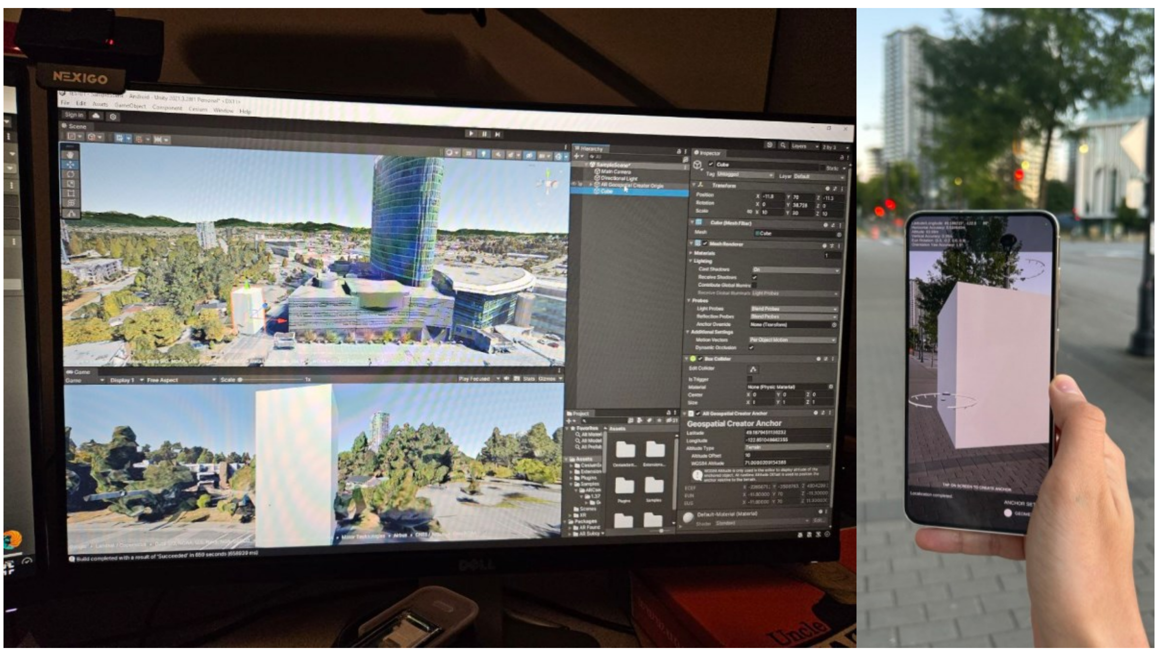




for safety in some location like street the ar feature does not work



First sketch's of Lo-Fi prototype on Figma



The initial phase of implementation of the prototype and testing the application by using Unity and ARCore.

Appendix B. User Study Documents

SIMON FRASER UNIVERSITY
ENGAGING THE WORLD

Application Number: 30002151

Participant Informed Consent Form

Study Title: Data-Informed Built Environment Design Democratization through Augmented Reality
Grant: NA
Principal Investigator: Dr. Halil Erhan, Associate Prof., SIAT, SFU
Collaborators: NA
Research Assistant: Tina Eslami Behrouz, MSc Student, SIAT, SFU

Study Goals: This proposal investigates the possibility of utilizing Augmented reality platforms to enhance public engagement in the decision-making process regarding built environment design. The objective is to provide citizens with access to design data and design alternatives, enabling them to review design proposals and give feedback. The research team mentioned above will gather data for the research, including a participant study. The objectives are to identify methods for making it understandable to the public and to determine media features that encourage dialogue among stakeholders and inform design. We aim to create a collaborative environment where diverse perspectives are considered, bridging the gap between design professionals and the public. By democratizing design data, the decision-making process can be more inclusive and reflective of stakeholder needs. The user studies will evaluate the effectiveness of the prototype tool in engaging stakeholders and empowering them to participate in decision-making. The specific goals of the study are:

1. Explore ways to help people filter and share important information from complex data on design options created by professionals. Ensure that even those without technical expertise can understand and benefit from this information.
2. To identify media features /interaction techniques that can be appealing to non-specialist users when they interact with design data.

Qualification: To take part in this study, the Principal Investigator or Research Assistant must invite you, and you must choose voluntarily to participate in this project.

Study Procedure: This research will employ a case study and mixed methods research to investigate the effectiveness of Augmented Reality platforms in making design form and performance data accessible to diverse stakeholders.

In this study, we will start by a pre-task interview and after that we will be inviting participants to interact with a prototype. The prototype will display design data in the form of data visualization, and users will be able to see different design options on the context of built environment along with their associated data. This will allow users to compare different design options based on their existing data. For example, they can compare two buildings side by side and analyze the data to determine which one suits their needs best.

Additionally, users will be given the option to filter data attributes and select only the relevant ones. They will also be able to choose from preset data visualization options to help them better understand complex data visually and see how it relates to other factors. After interacting with the prototype, users will be asked to share their experiences about how they felt while using it, what challenges they faced, and how

Version 4: May 2, 2024 Page **1** of **3** they found the user experience overall. We will ask users to complete the following tasks while they interact with the prototype–

- compare and analyze different design options from the prototype and provide feedback in the comment section of the prototype.

At the end, we will conduct a post-task interview with participants to gather their feedback about the user experience of our application and the participants will have the chance to win one of the three 50 CAD gift cards through a lottery. The odds of winning the lottery is 1 of 7 (assuming 20 participants approximately).

We will record the session using video recording devices that can capture both video and audio. All parts of session that includes meeting, feedback, or presentation will take 60 to 90 minutes and all session will be recorded. If more time is needed, we will schedule another session.

Benefits of Study to Participants: The participants will develop a sense of responsibility as citizens by participating in this study and being part of the research. The SFU student participants will have an option to receive 1 credit point for participating in the study.

Risks of Study: The study process has a 'minimal risk.' There are no foreseeable physical or psychological risks for participating in this study, nor are there risks associated with the distribution of data.

Confidentiality: All the data related to the study will be kept confidential, and only the researchers listed above of this form will have access to it. On the consent form, participant will write their names and do a signature. The participants will be assigned aliases, eg, participant 1, participant 2 and more. The name and signature on the consent form will be kept confidential and will be only accessible to the research team. Our research documents will be stored on password-protected computational design lab computers at SIAT, SFU, which can only be accessed by the researchers. The study files will be kept until we analyze the qualitative data. The video recordings will be only seen by the research team listed above, If the participant provides a consent for recording the session. All records either in paper or electronic format from the study will be kept secure in a locked cabinet in SIAT, SFU Surrey Campus. The digital files will be stored in password-protected hard disks. The digital files will be permanently erased, and sketches and prototypes will be shredded permanently after the life cycle of this study in five years. If needed, the recordings will be reviewed by the members of this research team to answer emerging questions in this period for publication and validation. If segments of videos or snapshots from the videos to be shared by others for academic purposes, all the features revealing your identity (e.g. face, unique hairstyle, tattoos etc.), your projects, or information marked as confidential will be redacted by covering the image/video areas with black digital markers; sounds will be muted or replaced by captions. If any unsolicited information is shared, please inform the research team at any time to extract this information from the records permanently. If publishing the results, note that some journals require uploading the data to online repositories for this purpose. For journals, requiring uploading data to online repositories, confidentiality of the participants will be maintained by strictly maintaining their privacy and not disclosing any personal information. We will use aliases for the participants, and any video/image will be kept confidential by hiding any personal information (as mentioned above).

Contact for information about the study: If you have any questions or desire future information with respect to the study (e.g. research results), you may contact Dr. Erhan .

Contact for concerns or complaints about the study: If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, please contact the Director, SFU Office of Research Ethics

Consent: Your participation in this study is voluntary and you may refuse to participate or withdraw from the study at any time. Refusal to participate or withdrawal/dropout after agreeing to participate will not have an adverse effect or consequences on you, your employment, or services. You may withdraw from the study without any penalty at any time during or after the study by notifying one of the researchers. Please send an email to Prof. Erhan (xxx@xxx) expressing your withdrawal if you decide it after the study. In this case, your personal data will be removed from study. We will shred or erase the digital and analog documents you shared with us. Your signature below indicates that you have received a copy of this form for your own records and that you consent to participate in this study. However, please note that once the results are published or submitted for publication, withdrawal will not be possible.

By consenting to participate in this research, participants will not waive any rights to legal recourse in the event of research-related harm.

☐ I give my consent to participate in the study.

☐ I am invited to work with the research team voluntarily and qualify to take part in this project.

☐ I give my consent to be re-contacted by email after the experiment.

☐ I consent to the recording of activities.

☐ I do not consent to the recording of activities.

____

Print Name Date (MM/DD/YYY)

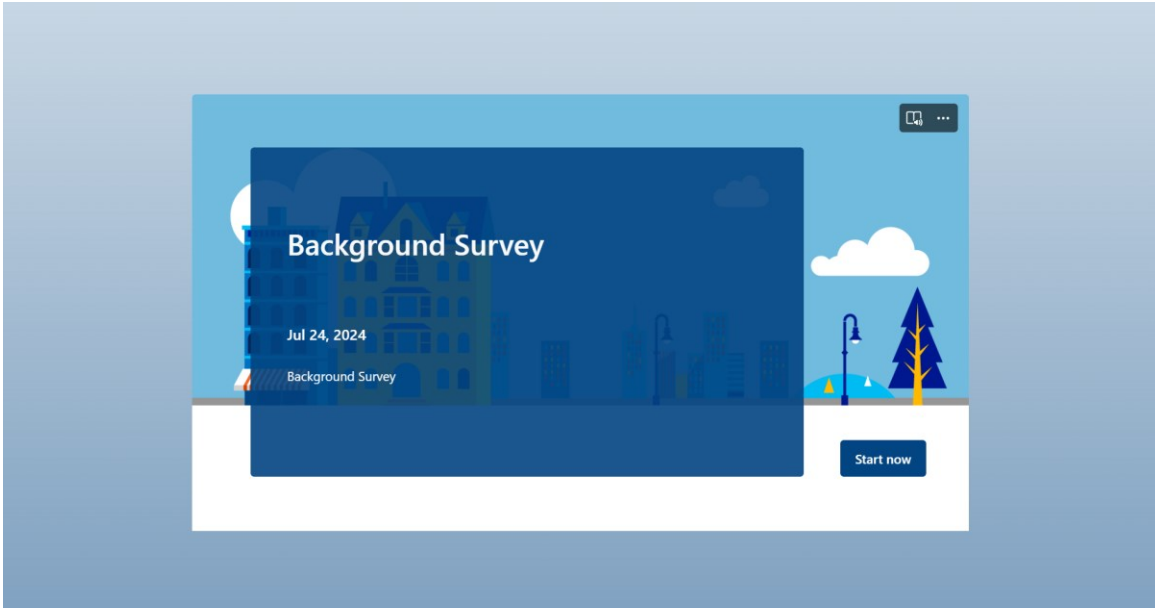
____

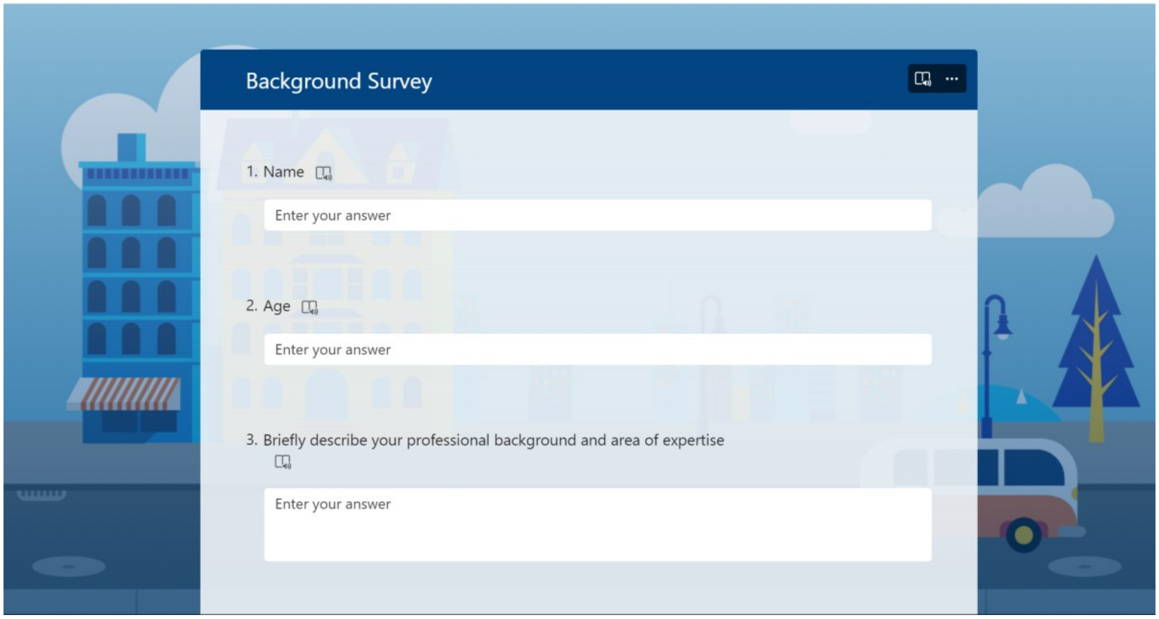
Signature

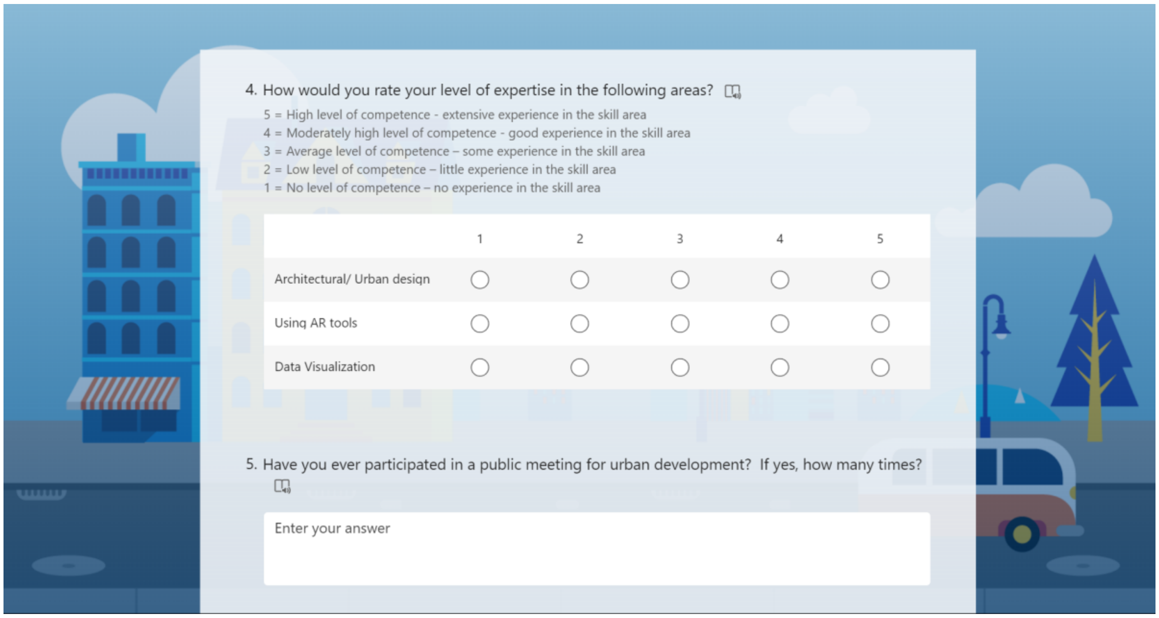
Appendix C. Forms and questioners

Background Survey

This initial survey was designed to gather information about participants' backgrounds, including their age and their expertise. It also asked whether they have any experience attending public meetings or participating in surveys related to the development of built environments.







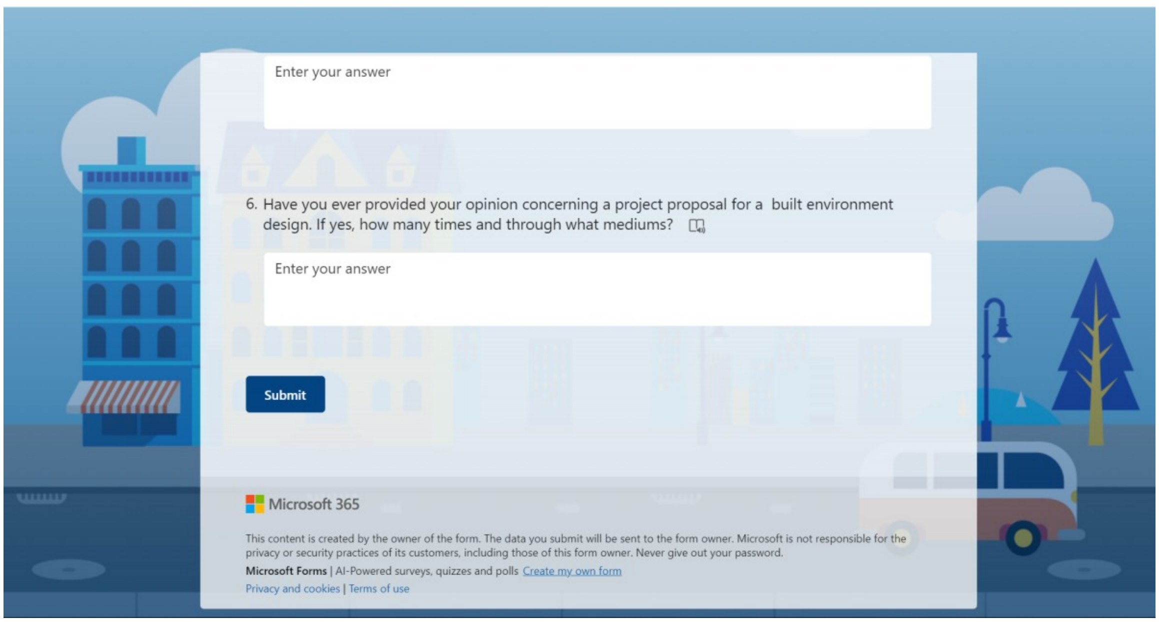
4. How would you rate your level of expertise in the following areas?

5 = High level of competence - extensive experience in the skill area
4 = Moderately high level of competence - good experience in the skill area
3 = Average level of competence – some experience in the skill area
2 = Low level of competence – little experience in the skill area
1 = No level of competence – no experience in the skill area

	1	2	3	4	5
Architectural/ Urban design	○	○	○	○	○
Using AR tools	○	○	○	○	○
Data Visualization	○	○	○	○	○

5. Have you ever participated in a public meeting for urban development? If yes, how many times?

Enter your answer



Enter your answer

6. Have you ever provided your opinion concerning a project proposal for a built environment design. If yes, how many times and through what mediums?

Enter your answer

Submit

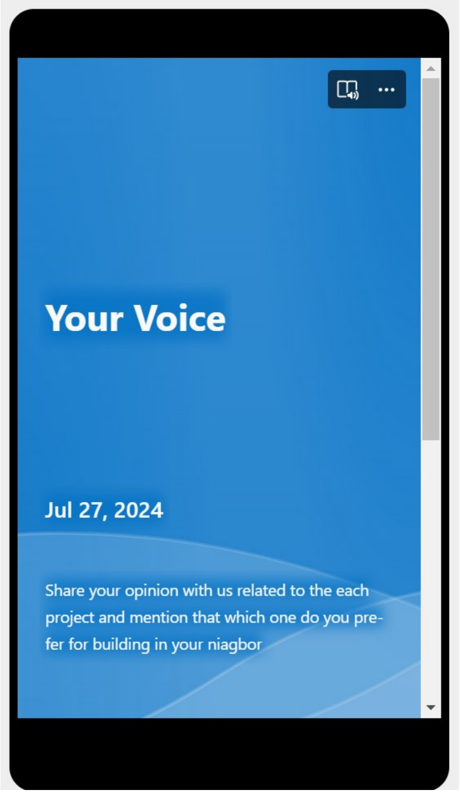
Microsoft 365

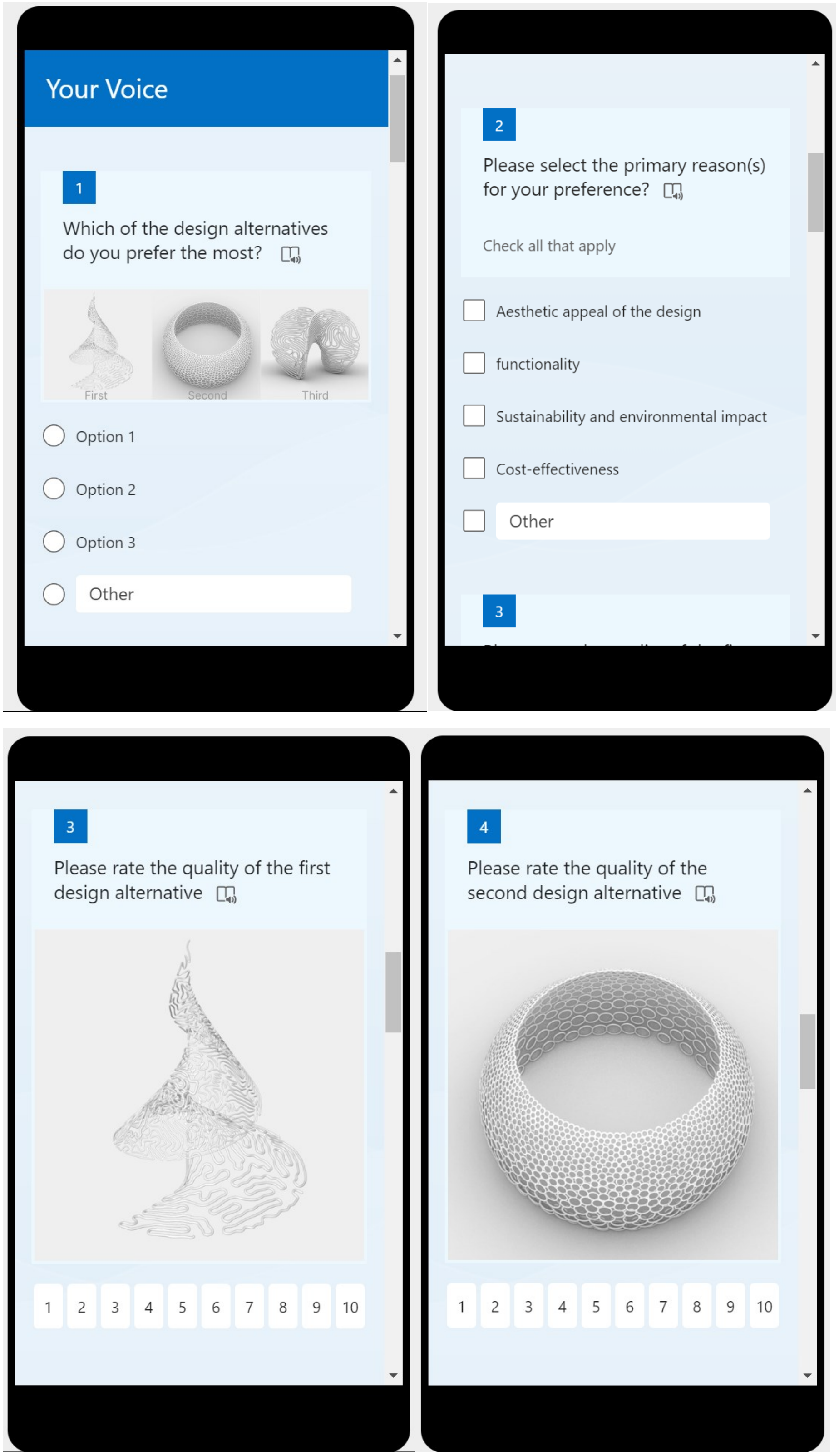
Results

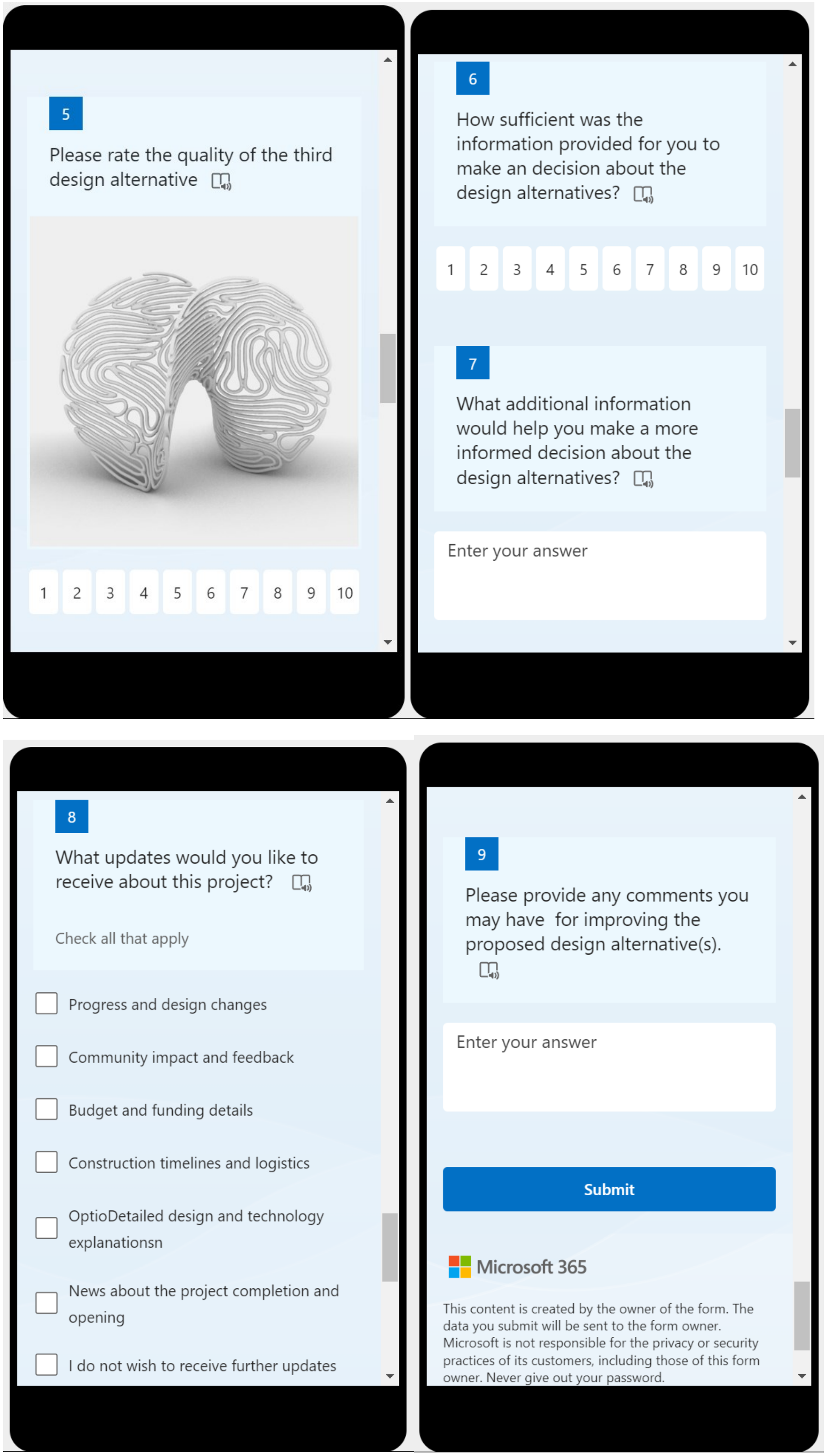
Id	Start time	Completion time	Email		A	Briefly describe you	I	H	H	Have you ever partic	Have you ever provi
1	5/9/2024 12:51	5/9/2024 12:53	anonymous	Ar	37	Creative AI, Design mn	1	3	2	no	no
2	5/9/2024 13:28	5/9/2024 13:30	anonymous	Mc	31	Computer science and	1	5	3	No	No
3	5/10/2024 14:24	5/10/2024 14:26	anonymous	Au	34	Mostly in academia. A I	1	3	3	No	No
4	5/10/2024 18:43	5/10/2024 18:45	anonymous	An	32	Bio-Signal Processing	1	2	5	No	No
5	5/10/2024 19:26	5/10/2024 19:29	anonymous	Me	27	Sociotechnical Systems	1	2	4	No	No
6	5/10/2024 19:30	5/10/2024 19:36	anonymous	Mc	29	Pharmacist	2	4	2	1 time	No
7	5/11/2024 13:16	5/11/2024 13:19	anonymous	Ar	33	I have Ms.c. degree in s	1	3	3	No	No
8	5/11/2024 15:43	5/11/2024 15:57	anonymous	Ar	28	I am coming from Biom	1	4	3	NO	NO
9	5/11/2024 18:16	5/11/2024 18:24	anonymous	Fat	38	I hold a master's degre	5	3	4	never	never
10	5/12/2024 13:10	5/12/2024 13:22	anonymous	Ma	32	Master degree in archit	5	2	1	no	no
11	5/12/2024 13:22	5/12/2024 13:28	anonymous	Elh	24	I have Bachler Degree i	2	1	3	No, unfortunately I hav	No.
12	5/12/2024 13:41	5/12/2024 13:44	anonymous	Pe	28.5	Software Engineer, Virt	1	4	4	no	no
13	5/12/2024 16:28	5/12/2024 16:30	anonymous	Asl	32	PhD in Mechatronics Er	1	1	1	NA	NA
14	5/12/2024 17:09	5/12/2024 17:10	anonymous	Mc	24	Background in Comput	1	1	2	No	No
15	5/12/2024 18:15	5/12/2024 18:50	anonymous	Em	40	Civil Engenering	5	1	1	No	Yes, For privet company
16	5/13/2024 11:16	5/13/2024 11:35	anonymous	Ar	31	Automotive Engineer (E	1	5	5	No	No
17	5/13/2024 11:26	5/13/2024 11:36	anonymous	Ma	31	master of polymer engi	1	3	1	NO	NO
18	5/13/2024 12:23	5/13/2024 12:27	anonymous	An	29	I'm currently a PhD stu	3	1	1	No	No
19	5/13/2024 18:12	5/13/2024 18:17	anonymous	Ma	26	Computer Science - Ma	1	1	3		
20	5/13/2024 19:47	5/13/2024 19:59	anonymous	Ta	20	Studing psychology anc	1	3	4	no	no

Your Voice

This survey was conducted to gather participants' feedback on design proposals while they were using the application. Participants completed the survey on the smartphone.




Your Voice
1
Which of the design alternatives do you prefer the most?
First
Second
Third
Option 1
Option 2
Option 3
Other
2
Please select the primary reason(s) for your preference?
Check all that apply
Aesthetic appeal of the design
functionality
Sustainability and environmental impact
Cost-effectiveness
Other
3
3
Please rate the quality of the first design alternative
1 2 3 4 5 6 7 8 9 10
4
Please rate the quality of the second design alternative
1 2 3 4 5 6 7 8 9 10


5

Please rate the quality of the third design alternative

1 2 3 4 5 6 7 8 9 10

6

How sufficient was the information provided for you to make an decision about the design alternatives?

1 2 3 4 5 6 7 8 9 10

7

What additional information would help you make a more informed decision about the design alternatives?

Enter your answer

8

What updates would you like to receive about this project?

Check all that apply

- [ ] Progress and design changes
- [ ] Community impact and feedback
- [ ] Budget and funding details
- [ ] Construction timelines and logistics
- [ ] OptioDetailed design and technology explanationsn
- [ ] News about the project completion and opening
- [ ] I do not wish to receive further updates

9

Please provide any comments you may have for improving the proposed design alternative(s).

Enter your answer

Submit

Microsoft 365

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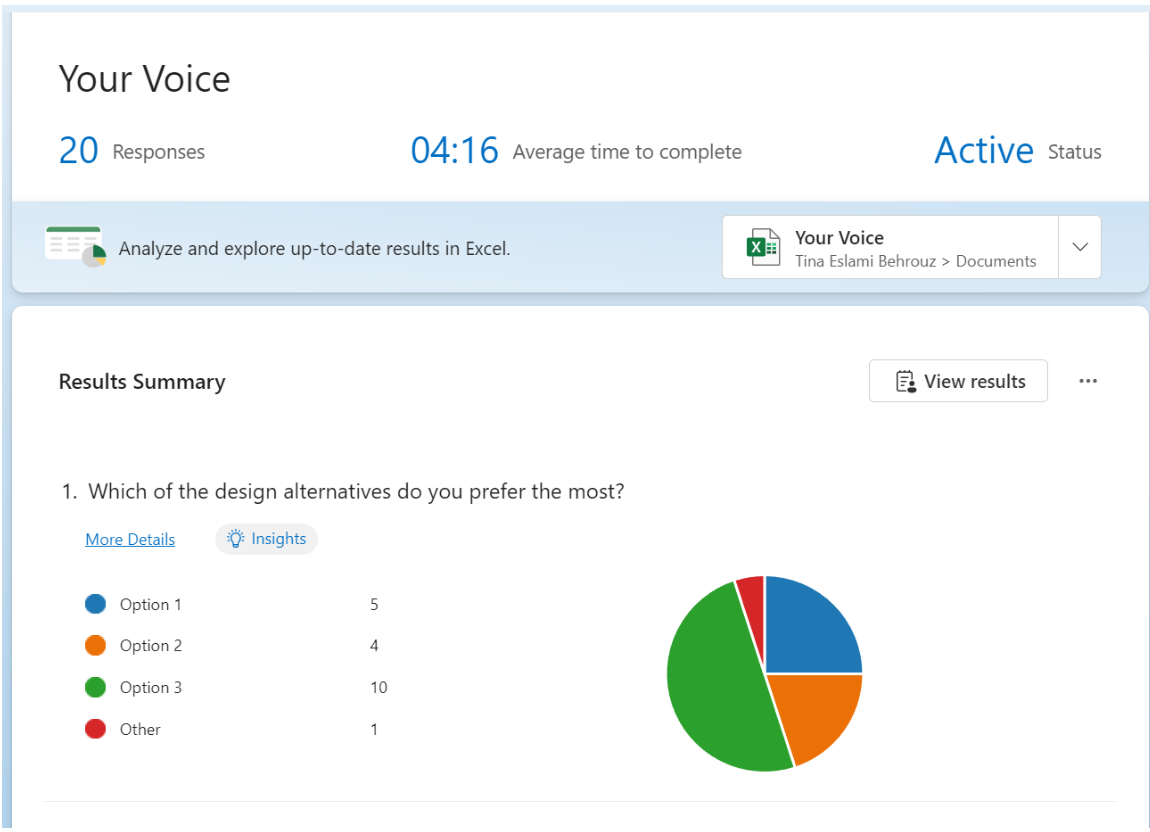
Results

	Id	Start time	Completion time			Which	Please select the primary reason(s) for your preference?
2	1	5/9/2024 12:57	5/9/2024 13:00	ano		Option 3	Aesthetic appeal of the design;
3	2	5/9/2024 13:41	5/9/2024 13:45	ano		Option 3	Aesthetic appeal of the design;
4	3	5/10/2024 14:34	5/10/2024 14:36	ano		Option 1	Aesthetic appeal of the design; Sustainability and environmental impact;Cost-effectiveness;
5	4	5/10/2024 18:32	5/10/2024 18:35	ano		Option 1	Aesthetic appeal of the design; Sustainability and environmental impact;
6	5	5/10/2024 19:18	5/10/2024 19:20	ano		Option 2	Cost-effectiveness; Aesthetic appeal of the design;
7	6	5/10/2024 19:47	5/10/2024 19:52	ano		Option 3	Sustainability and environmental impact;Cost-effectiveness;
8	7	5/11/2024 13:33	5/11/2024 13:39	ano		Option 2	Aesthetic appeal of the design;
9	8	5/11/2024 16:07	5/11/2024 16:13	ano		Option 3	Aesthetic appeal of the design;
10	9	5/11/2024 18:34	5/11/2024 18:38	ano		Option 3	functionality;
11	10	5/12/2024 12:57	5/12/2024 13:01	ano		Option 3	Sustainability and environmental impact;
12	11	5/12/2024 13:34	5/12/2024 13:45	ano		Option 3	Aesthetic appeal of the design; Sustainability and environmental impact;
13	12	5/12/2024 13:55	5/12/2024 14:01	ano		Option 2	Sustainability and environmental impact; Aesthetic appeal of the design;
14	13	5/12/2024 16:39	5/12/2024 16:41	ano		Option 2	Aesthetic appeal of the design;
15	14	5/12/2024 17:17	5/12/2024 17:20	ano		Option 1	Aesthetic appeal of the design;
16	15	5/12/2024 19:01	5/12/2024 19:13	ano		Option 1	Cost-effectiveness;functionality;
17	16	5/13/2024 11:45	5/13/2024 11:46	ano		Option 1	Aesthetic appeal of the design;
18	17	5/13/2024 11:51	5/13/2024 11:56	ano		Option 3	functionality;
19	18	5/13/2024 12:06	5/13/2024 12:09	ano		Option 3	Aesthetic appeal of the design;Cost-effectiveness;
20	19	5/13/2024 18:26	5/13/2024 18:28	ano		Option 3	Aesthetic appeal of the design;
21	20	5/13/2024 20:04	5/13/2024 20:07	ano		All of the	Sustainability and environmental impact;Cost-effectiveness;functionality;

Ple	Ple	Ple	How	What additional information would help you make a more informed decision about the design alternatives?
5	4	8	8	Artist info and timeline
8	3	9	7	It seems The information about the cultural impact was in the app but I missed it. Maybe it's because of the presentation.
8	5	6	8	This was awesome. Being able to see how it is going to look like by being able to walk around it was incredible. At some points, I was completely immersed and didn't realize this was a fake.
8	3	7	9	N/A
7	7	5	8	The provided information was sufficient in my case!
7	6	8	7	How long does it take to build? How resistant the model is to corrosion in time
7	8	5	7	Information about the time it takes to construct the design and how it affects the surrounding environment and buildings.
6	5	7	7	Safety with regard to children interacting to them (for example climbing them)
6	7	8	8	Third one doesn't block circulation in area
6	8	8	9	-How much time needed to build the structure?- How would it effect the children's life because there was no information about that.
4	6	8	7	The reason of selecting this shape, why it's good for this region, the connection between the architecture of mall building and the sculpture
7	8	5	8	I would like to know about the designer and more analytical info like carbon footprint for all designers. It was mentioned in one of the ddesigns that the carbon foot print is lower and in the o
8	10	10	10	NA
8	7	6	6	Others opinion on each of designs
8	7	8	8	Weight, structural design
8	7	9	8	The purpose of this design
4	6	8	5	Have wider lanse
6	4	9	5	N/A
3	7	9	6	Time needed for construction
9	7	6		

What updates would you like to receive about this project?
Progress and design changes;News about the project completion and opening;
Progress and design changes;Community impact and feedback;Construction timelines and logistics;News about the project completion and opening;
Progress and design changes;Community impact and feedback;Construction timelines and logistics;Budget and funding details;News about the project completion and opening;
Community impact and feedback;News about the project completion and opening;Progress and design changes;
Community impact and feedback;Budget and funding details;Construction timelines and logistics;
Progress and design changes;Budget and funding details;News about the project completion and opening;
Progress and design changes;Construction timelines and logistics;
News about the project completion and opening;Construction timelines and logistics;
Community impact and feedback;OptioDetailed design and technology explanationsn;
Community impact and feedback;Progress and design changes;Construction timelines and logistics;
Community impact and feedback;Progress and design changes;
Community impact and feedback;Construction timelines and logistics;Progress and design changes;News about the project completion and opening;
News about the project completion and opening;
Community impact and feedback;Construction timelines and logistics;
Construction timelines and logistics;Budget and funding details;
Progress and design changes;Community impact and feedback;
Progress and design changes;OptioDetailed design and technology explanationsn;
Community impact and feedback;News about the project completion and opening;Construction timelines and logistics;
Community impact and feedback;Budget and funding details;Construction timelines and logistics;
Progress and design changes;News about the project completion and opening;

Please provide any comments you may have for improving the proposed design alternative(s).
N/a
N/A
Using local resources and designers
I chose this design because it had a simple and appealing design. However, the design is hand made and I liked the alternative construction options more.
Just take into account safety, being environmentally friendly, and anesthetics.
No
What are the light sources for the design?What is the night view ?
It could be interactive which makes it more interesting and appealing for people walking around it.
I liked the spiral design the most, however the others were more justified in terms of sustainability. I would design the spiral one with new material it matches the trees:D
colors
Nothing.Good job.
What is your purpose for this design?Why do you use onley curve member?What is the specification of those models(mesurment)?
Na
I'd rather to have more options to choose.
NA
Love all the projects, great work



2. Please select the primary reason(s) for your preference?

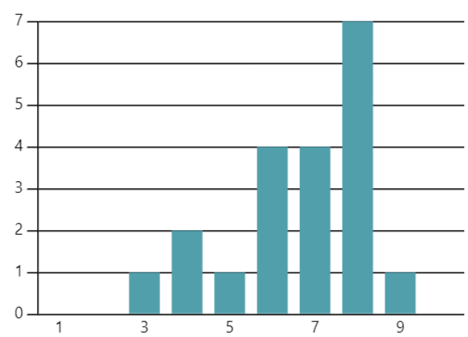
More Details

Aesthetic appeal of the design	14
functionality	4
Sustainability and environmenta...	7
Cost-effectiveness	6
Other	0

3. Please rate the quality of the first design alternative

More Details Insights

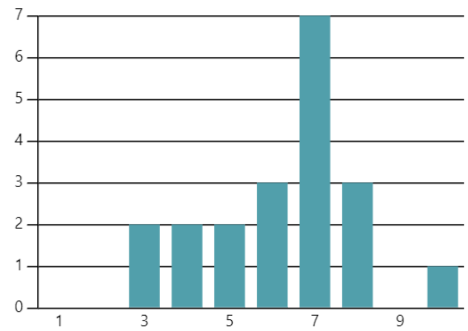
6.65
Average Rating



4. Please rate the quality of the second design alternative

More Details Insights

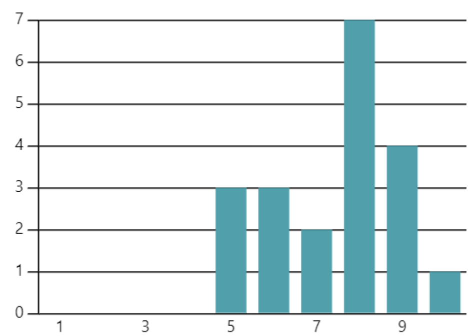
6.25
Average Rating



5. Please rate the quality of the third design alternative

More Details Insights

7.45
Average Rating

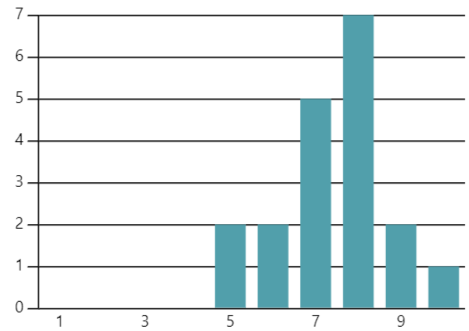


6. How sufficient was the information provided for you to make an decision about the design alternatives?

More Details   Insights

7.42

Average Rating



7. What additional information would help you make a more informed decision about the design alternatives?

More Details   Insights

19

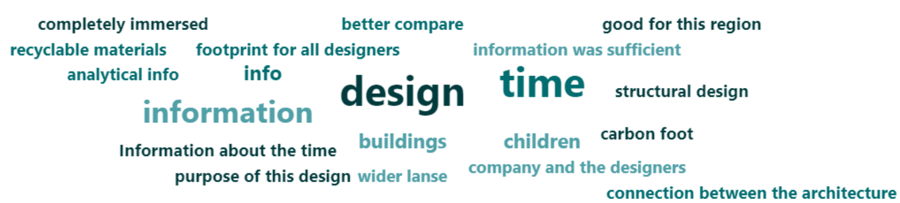
Responses

Latest Responses

"Time needed for construction "

"N/A"

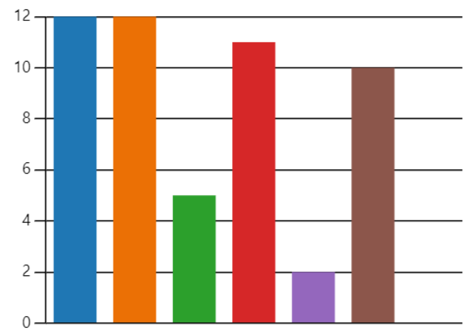
4 respondents (**21**%) answered **design** for this question.



8. What updates would you like to receive about this project?

More Details

- Progress and design changes 12
- Community impact and feedback 12
- Budget and funding details 5
- Construction timelines and logis... 11
- OptioDetailed design and techn... 2
- News about the project complet... 10
- I do not wish to receive further ... 0



9. Please provide any comments you may have for improving the proposed design alternative(s).

More Details Insights

16
Responses

Latest Responses

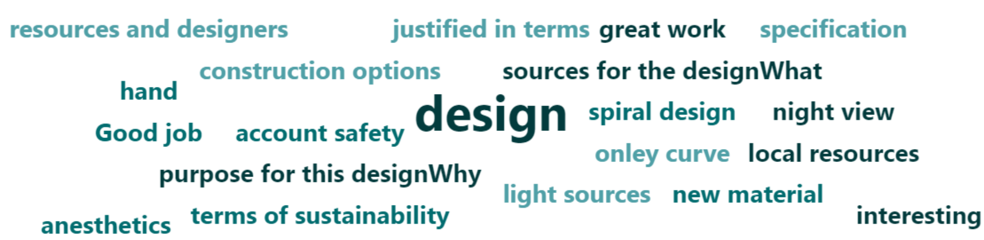
"Love all the projects, great work "

"NA"

"I'd rather to have more options to choose."

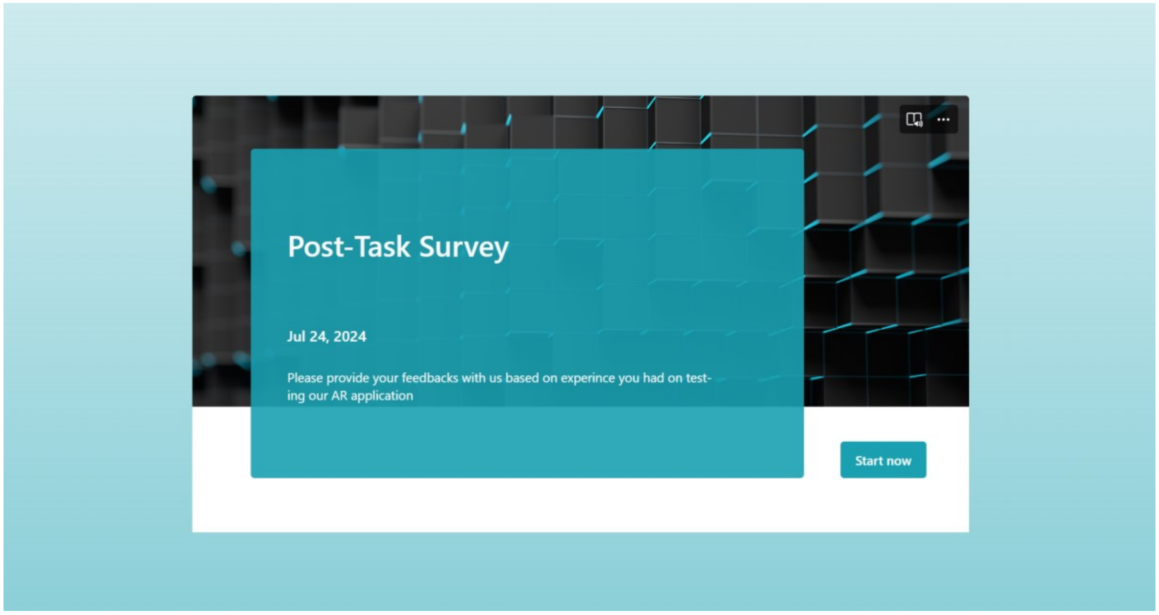
...

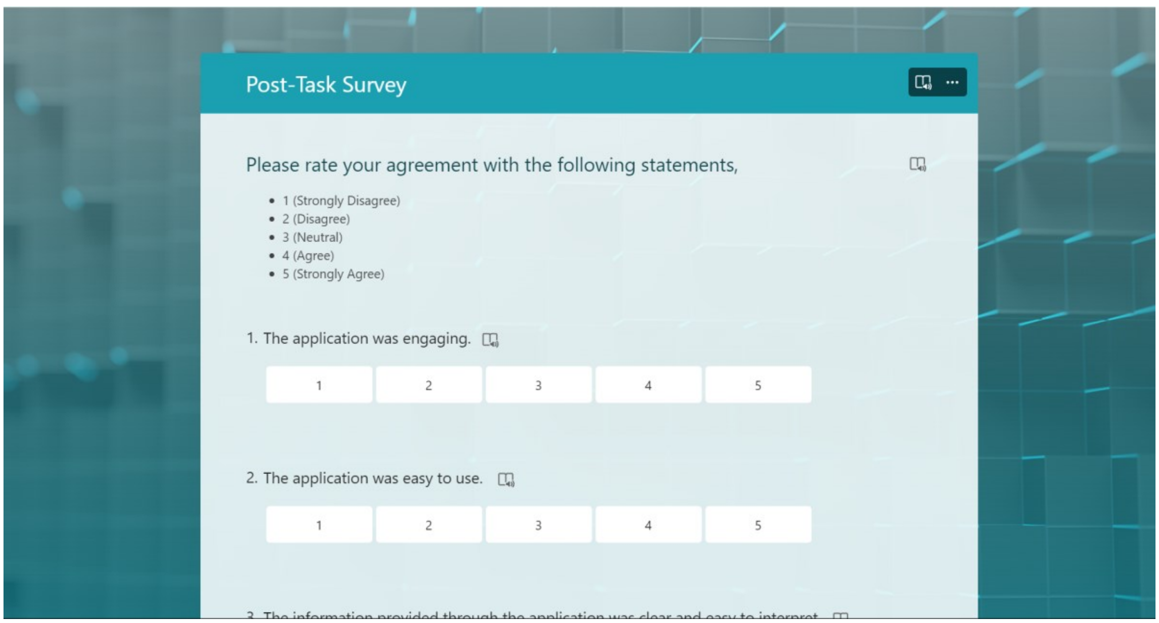
2 respondents (**13**%) answered **design** for this question.

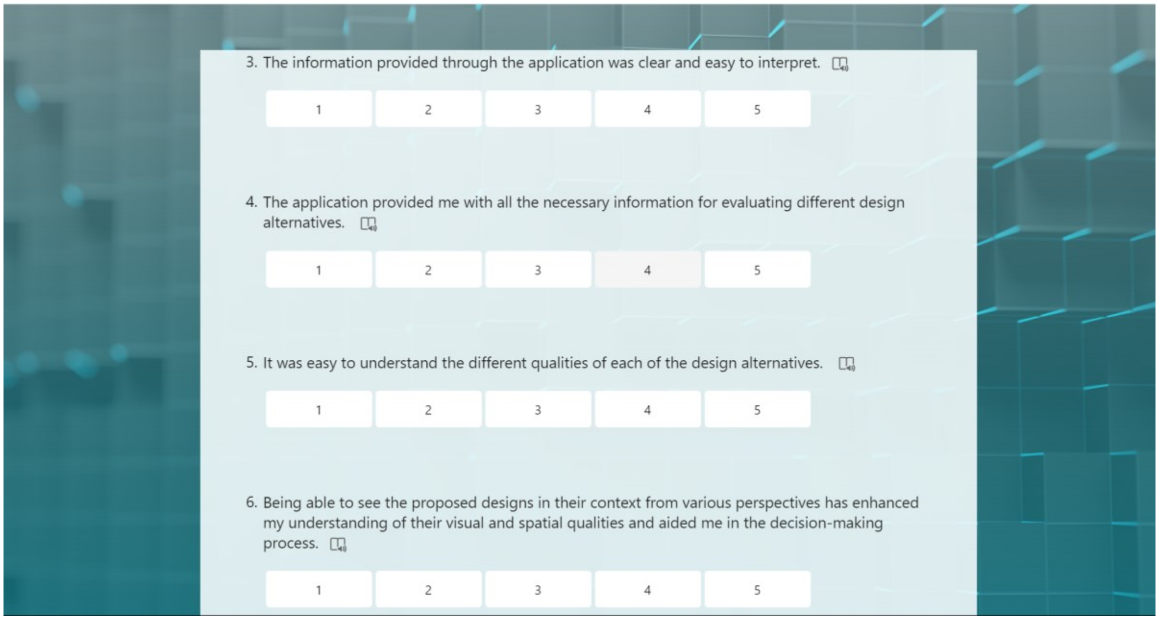


Post task survey

Final Survey: This is the concluding survey given to participants after they have tested the application. It seeks feedback on different aspects of the D-ARE prototype.


Post-Task Survey
Jul 24, 2024
Please provide your feedbacks with us based on experince you had on testing our AR application
Start now


Post-Task Survey
Please rate your agreement with the following statements,
1 (Strongly Disagree)
2 (Disagree)
3 (Neutral)
4 (Agree)
5 (Strongly Agree)
1. The application was engaging.
1 2 3 4 5
2. The application was easy to use.
1 2 3 4 5



3. The information provided through the application was clear and easy to interpret.

1 2 3 4 5

4. The application provided me with all the necessary information for evaluating different design alternatives.

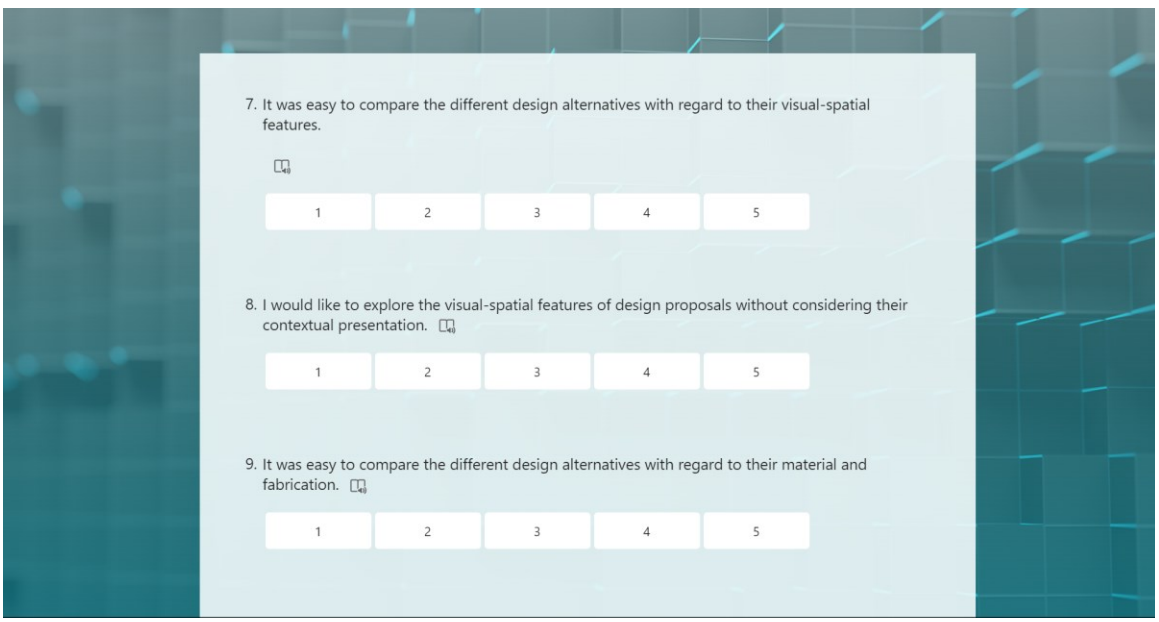
1 2 3 4 5

5. It was easy to understand the different qualities of each of the design alternatives.

1 2 3 4 5

6. Being able to see the proposed designs in their context from various perspectives has enhanced my understanding of their visual and spatial qualities and aided me in the decision-making process.

1 2 3 4 5



7. It was easy to compare the different design alternatives with regard to their visual-spatial features.

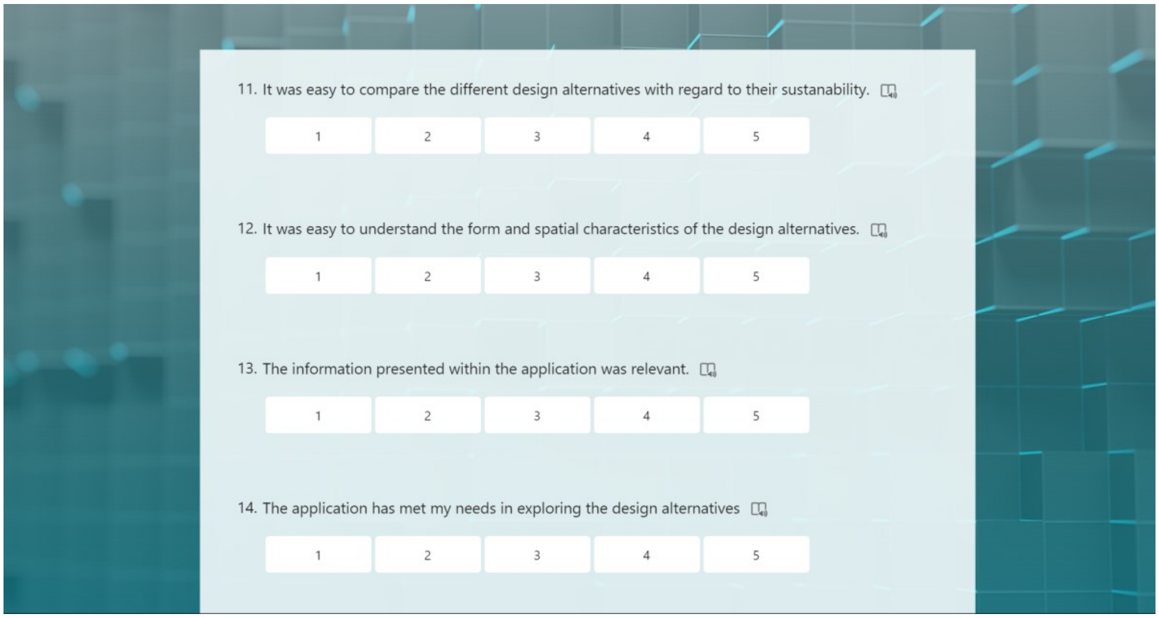
1 2 3 4 5

8. I would like to explore the visual-spatial features of design proposals without considering their contextual presentation.

1 2 3 4 5

9. It was easy to compare the different design alternatives with regard to their material and fabrication.

1 2 3 4 5



11. It was easy to compare the different design alternatives with regard to their sustanability.

1 2 3 4 5

12. It was easy to understand the form and spatial characteristics of the design alternatives.

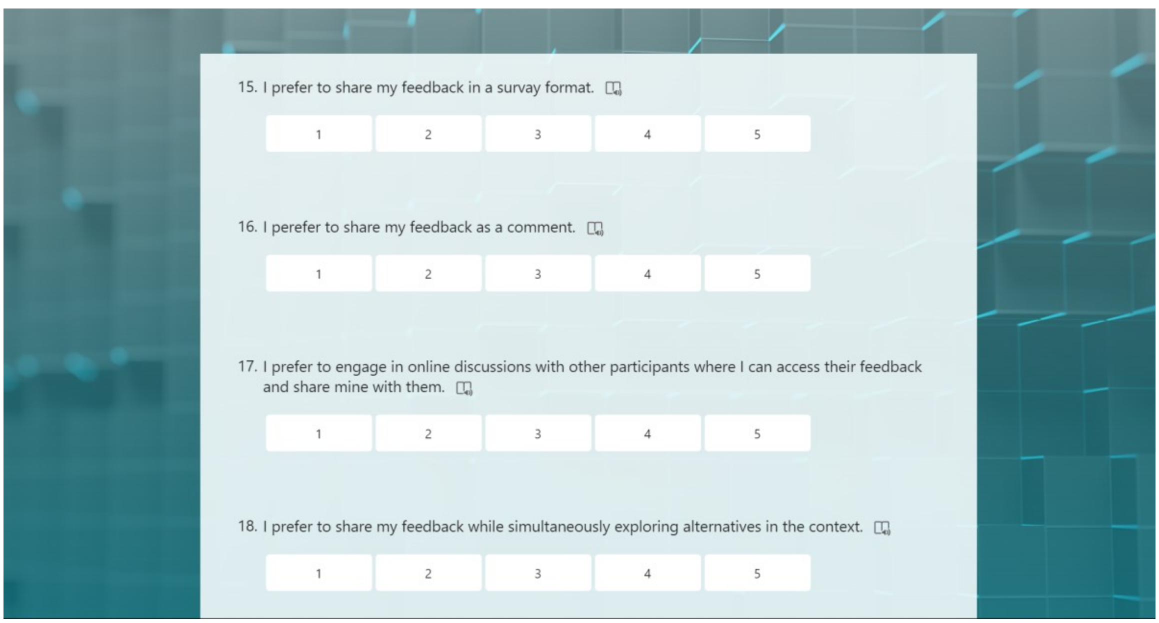
1 2 3 4 5

13. The information presented within the application was relevant.

1 2 3 4 5

14. The application has met my needs in exploring the design alternatives

1 2 3 4 5



15. I prefer to share my feedback in a survay format.

1 2 3 4 5

16. I perefer to share my feedback as a comment.

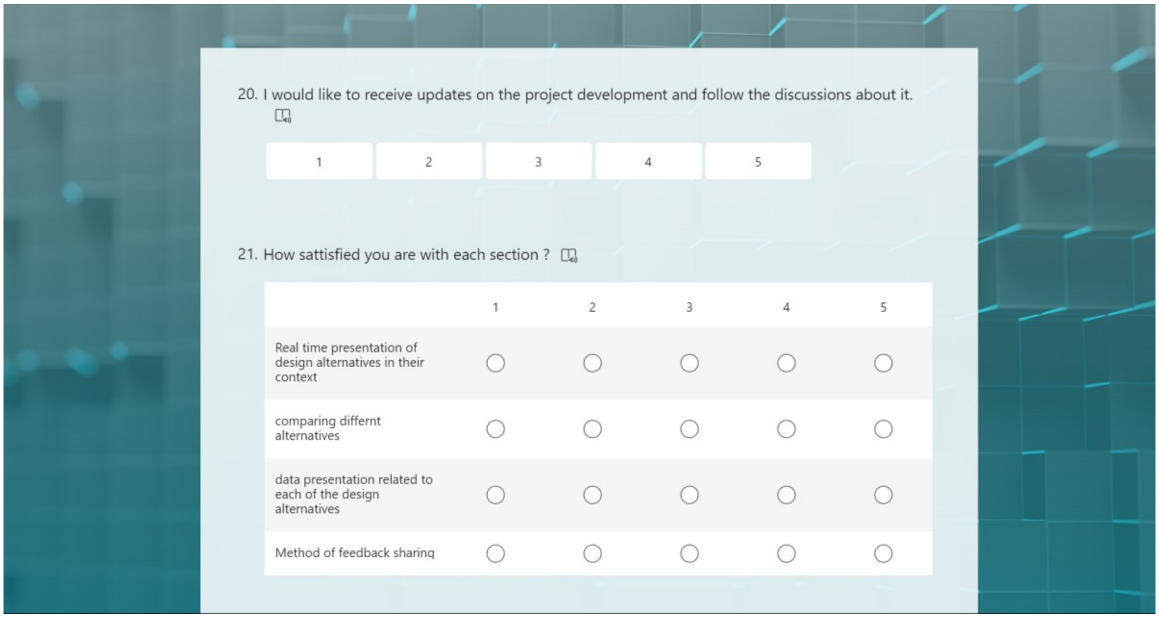
1 2 3 4 5

17. I prefer to engage in online discussions with other participants where I can access their feedback and share mine with them.

1 2 3 4 5

18. I prefer to share my feedback while simultaneously exploring alternatives in the context.

1 2 3 4 5

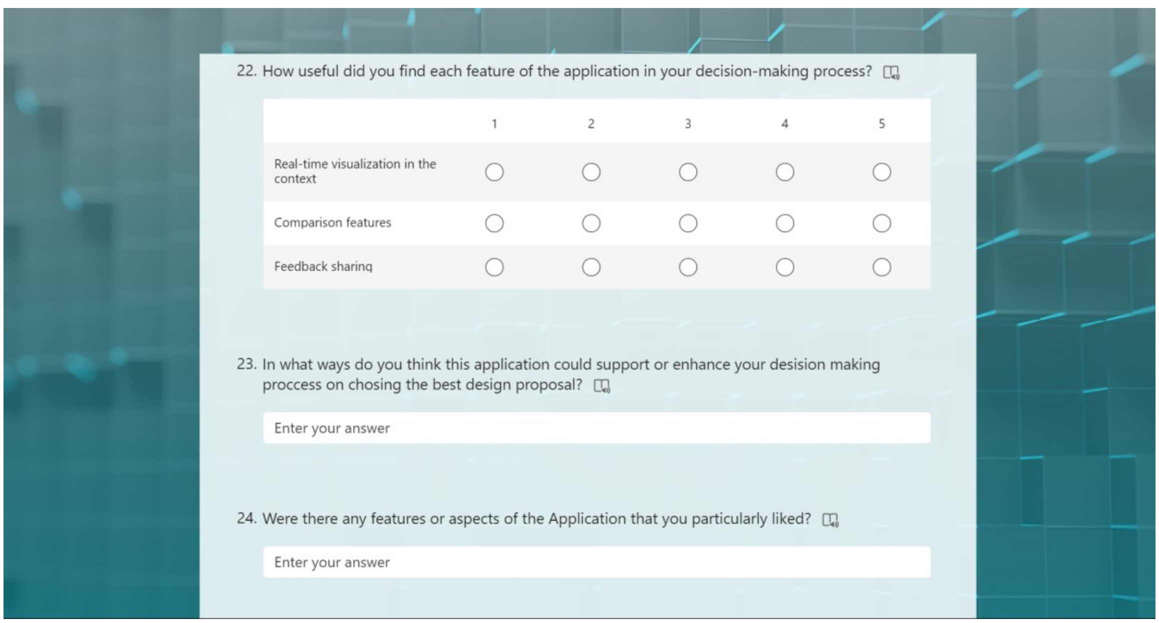


20. I would like to receive updates on the project development and follow the discussions about it.

1	2	3	4	5

21. How sattisfied you are with each section ?

	1	2	3	4	5
Real time presentation of design alternatives in their context	◯	◯	◯	◯	◯
comparing differnt alternatives	◯	◯	◯	◯	◯
data presentation related to each of the design alternatives	◯	◯	◯	◯	◯
Method of feedback sharing	◯	◯	◯	◯	◯



22. How useful did you find each feature of the application in your decision-making process?

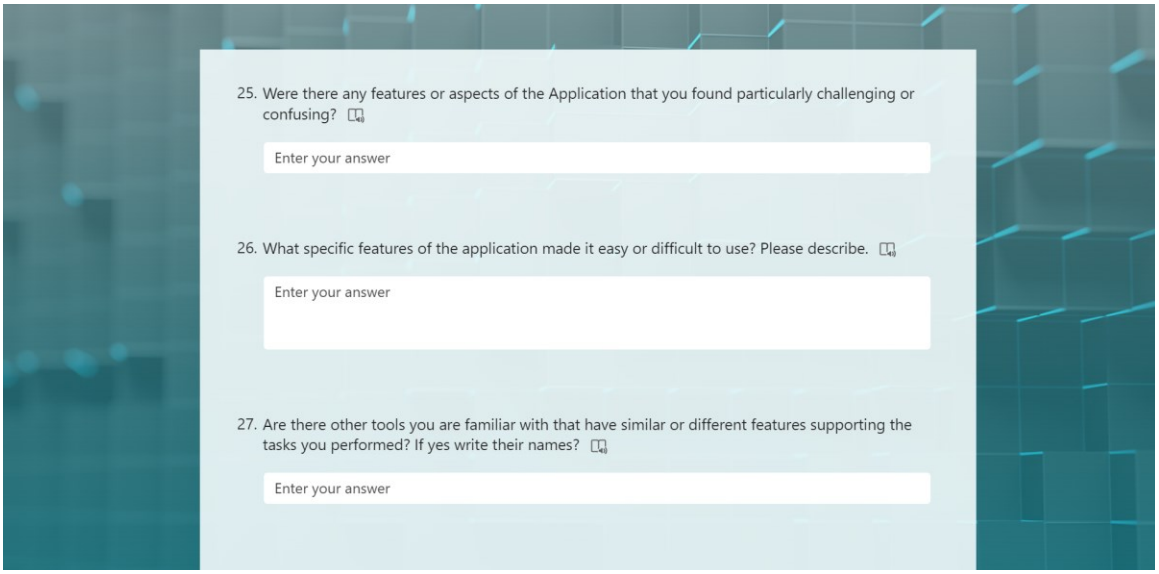
	1	2	3	4	5
Real-time visualization in the context	◯	◯	◯	◯	◯
Comparison features	◯	◯	◯	◯	◯
Feedback sharing	◯	◯	◯	◯	◯

23. In what ways do you think this application could support or enhance your desision making proccess on chosing the best design proposal?

Enter your answer

24. Were there any features or aspects of the Application that you particularly liked?

Enter your answer



25. Were there any features or aspects of the Application that you found particularly challenging or confusing?

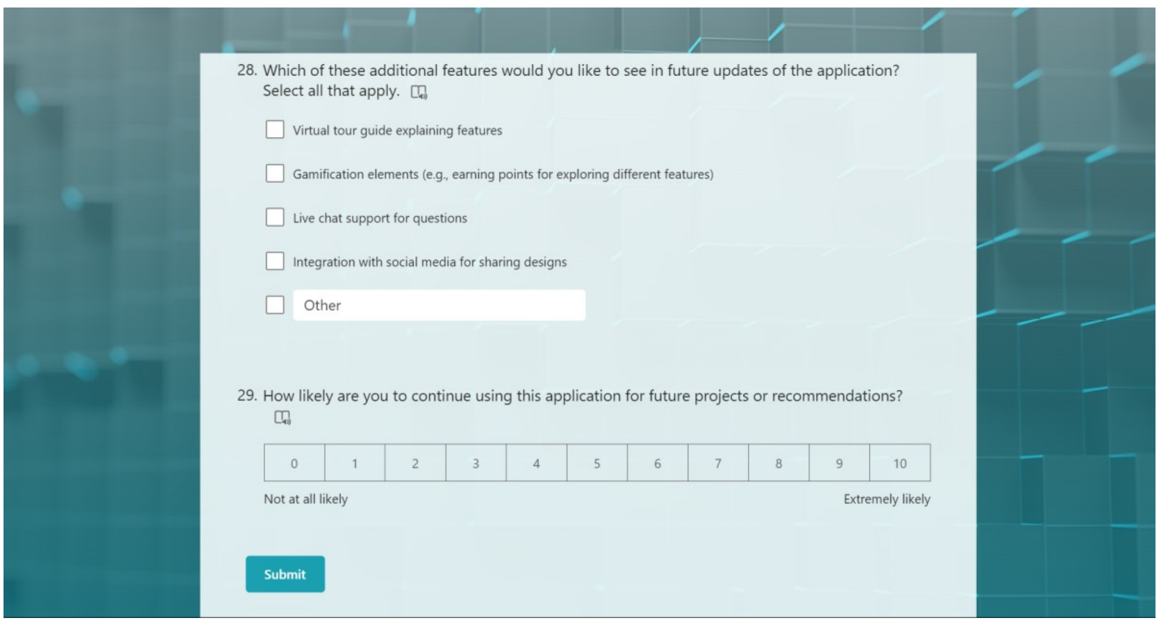
Enter your answer

26. What specific features of the application made it easy or difficult to use? Please describe.

Enter your answer

27. Are there other tools you are familiar with that have similar or different features supporting the tasks you performed? If yes write their names?

Enter your answer



28. Which of these additional features would you like to see in future updates of the application? Select all that apply.

- ☐ Virtual tour guide explaining features
- ☐ Gamification elements (e.g., earning points for exploring different features)
- ☐ Live chat support for questions
- ☐ Integration with social media for sharing designs
- ☐ Other

29. How likely are you to continue using this application for future projects or recommendations?

0	1	2	3	4	5	6	7	8	9	10

Not at all likely — Extremely likely

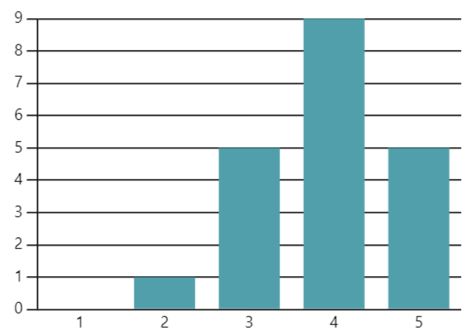
Submit

Results

1. The application was engaging.

More Details | Insights

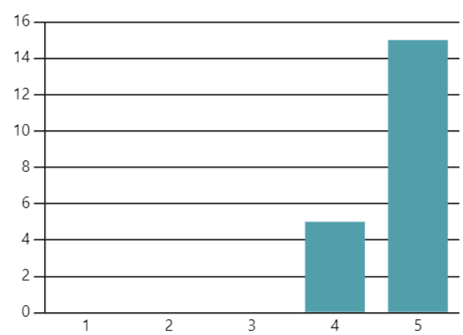
3.90
Average Rating



2. The application was easy to use.

More Details | Insights

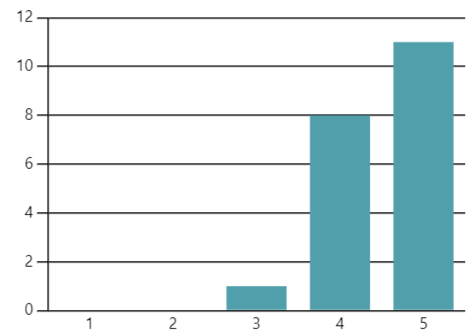
4.75
Average Rating

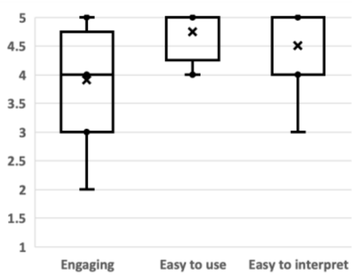


3. The information provided through the application was clear and easy to interpret.

More Details Insights

4.50
Average Rating

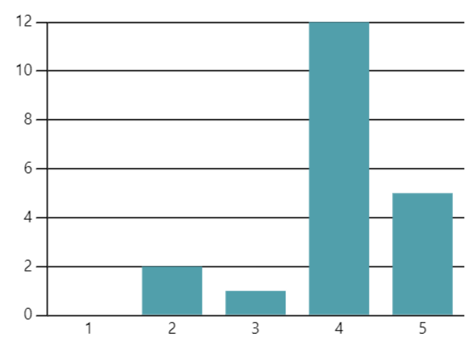




4. The application provided me with all the necessary information for evaluating different design alternatives.

More Details Insights

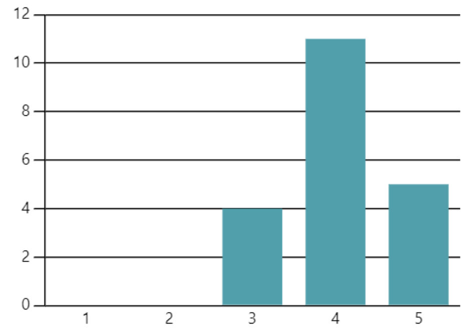
4.00
Average Rating



5. It was easy to understand the different qualities of each of the design alternatives.

More Details Insights

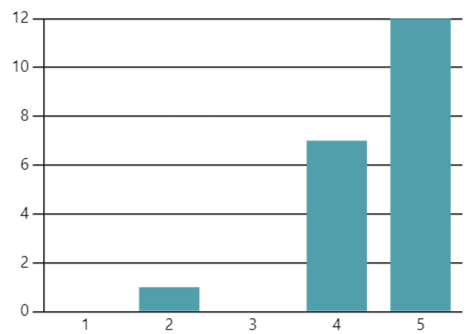
4.05
Average Rating



6. Being able to see the proposed designs in their context from various perspectives has enhanced my understanding of their visual and spatial qualities and aided me in the decision-making process.

More Details Insights

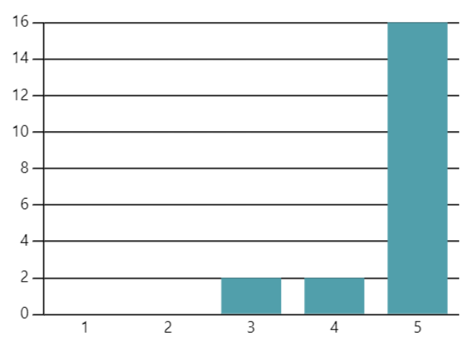
4.50
Average Rating



7. It was easy to compare the different design alternatives with regard to their visual-spatial features.

More Details Insights

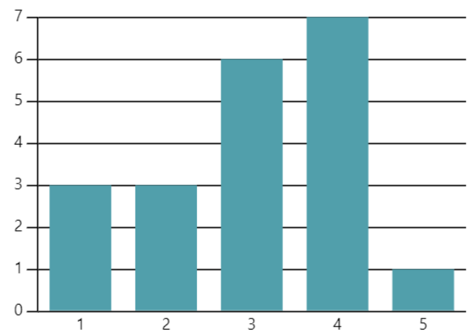
4.70
Average Rating



8. I would like to explore the visual-spatial features of design proposals without considering their contextual presentation.

More Details Insights

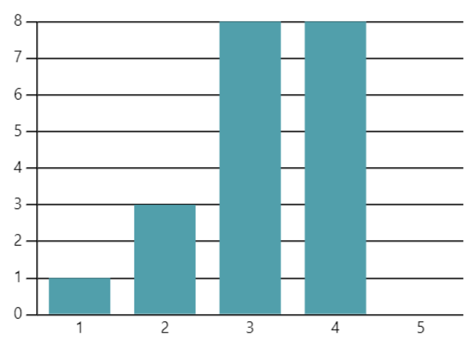
3.00
Average Rating



9. It was easy to compare the different design alternatives with regard to their material and fabrication.

More Details Insights

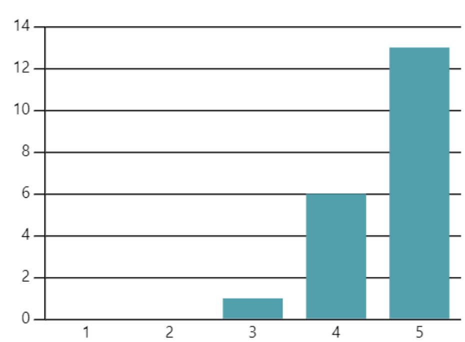
3.15
Average Rating



10. It was easy to compare the different design alternatives with regard to their costs.

More Details Insights

4.60
Average Rating

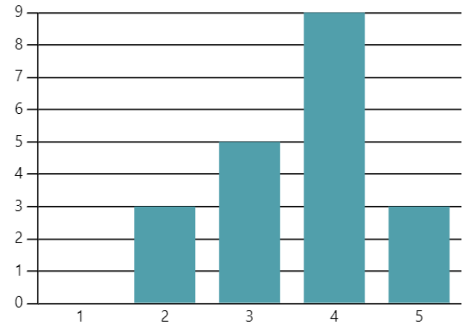


11. It was easy to compare the different design alternatives with regard to their sustanability.

More Details

Insights

3.60
Average Rating

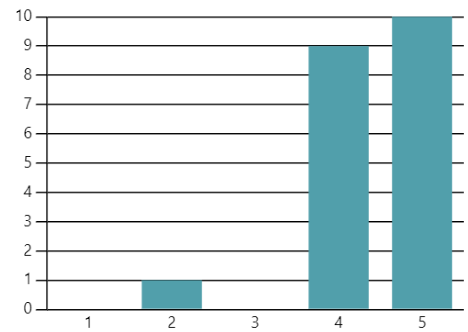


12. It was easy to understand the form and spatial characteristics of the design alternatives.

More Details

Insights

4.40
Average Rating

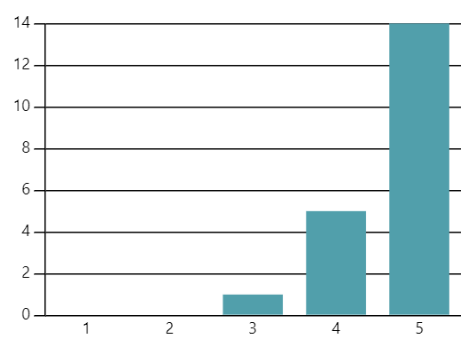


13. The information presented within the application was relevant.

More Details

Insights

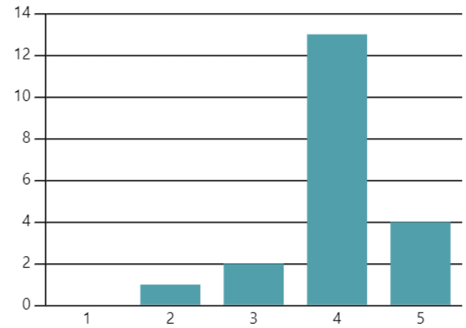
4.65
Average Rating



14. The application has met my needs in exploring the design alternatives

More Details Insights

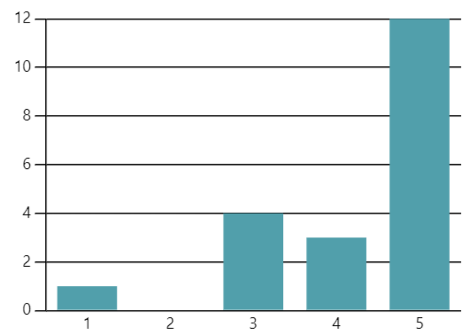
4.00
Average Rating



15. I prefer to share my feedback in a survay format.

More Details Insights

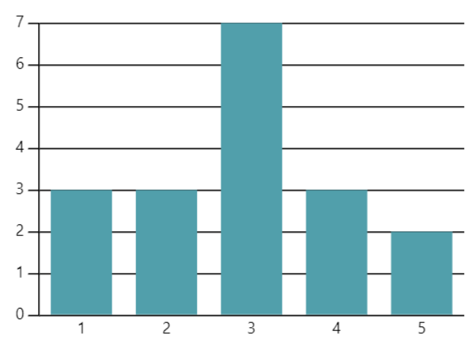
4.25
Average Rating



16. I perefer to share my feedback as a comment.

More Details Insights

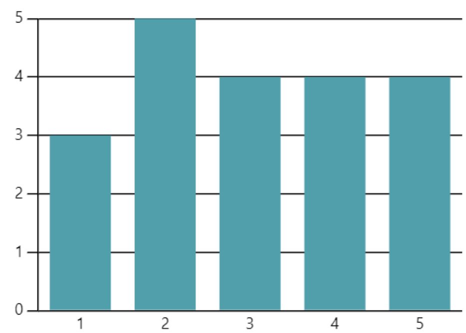
2.89
Average Rating



17. I prefer to engage in online discussions with other participants where I can access their feedback and share mine with them.

More Details Insights

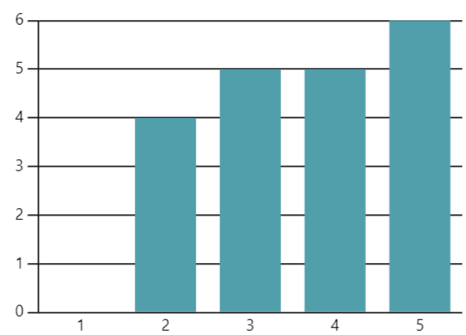
3.05
Average Rating



18. I prefer to share my feedback while simultaneously exploring alternatives in the context.

More Details Insights

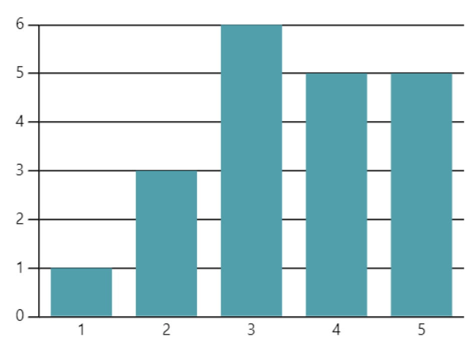
3.65
Average Rating



19. I prefer to share my feedback after exploring design proposals, regardless of location.

More Details Insights

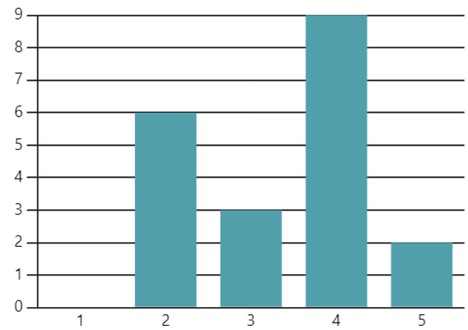
3.50
Average Rating



20. I would like to receive updates on the project development and follow the discussions about it.

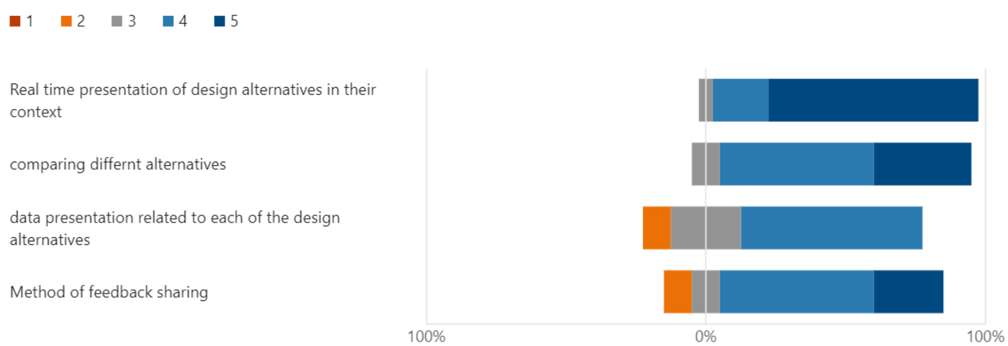
More Details Insights

3.35
Average Rating



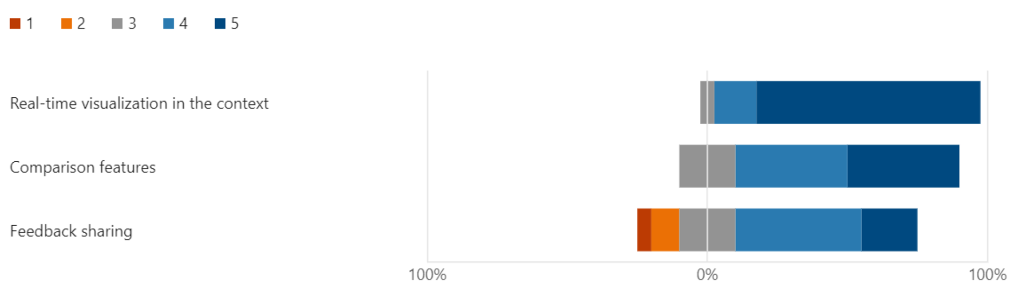
21. How sattisfied you are with each section ?

More Details



22. How useful did you find each feature of the application in your decision-making process?

More Details



23. In what ways do you think this application could support or enhance your desision making proccess on chosing the best design proposal?

More Details   Insights

19
Responses

Latest Responses

"Having guidance for the AR - Showing related information real time while y...

"The option to change the desgin color."

...

7 respondents (**37**%) answered **designs** for this question.

24. Were there any features or aspects of the Application that you particularly liked?

More Details   Insights

20
Responses

Latest Responses

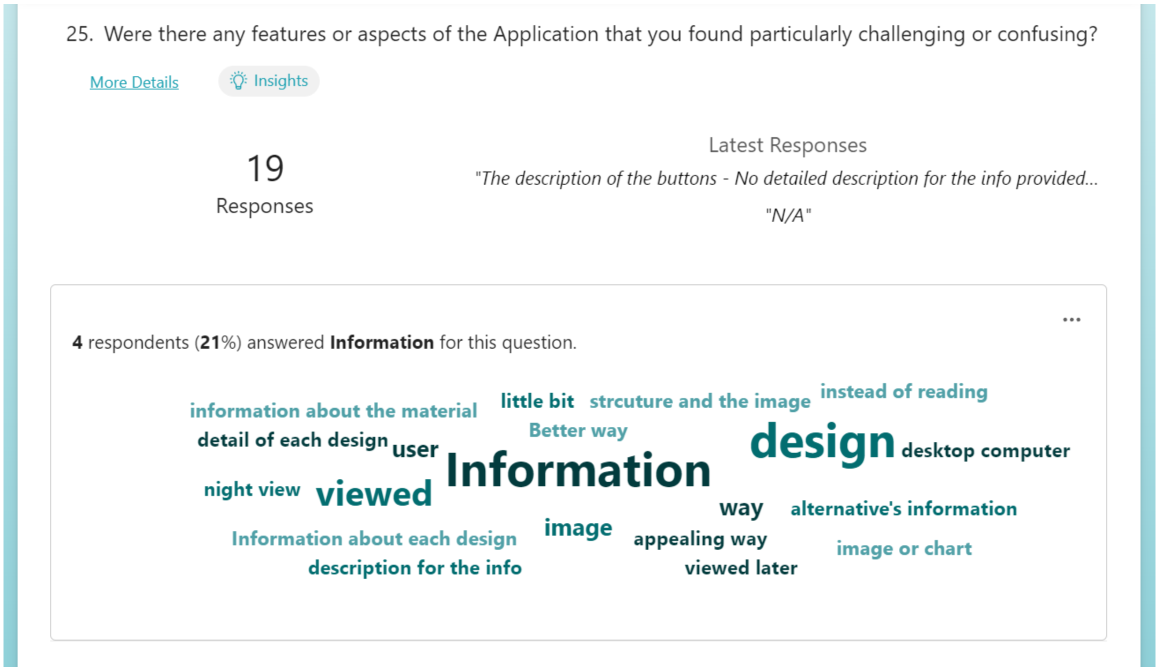
"camparison and the way it describe "

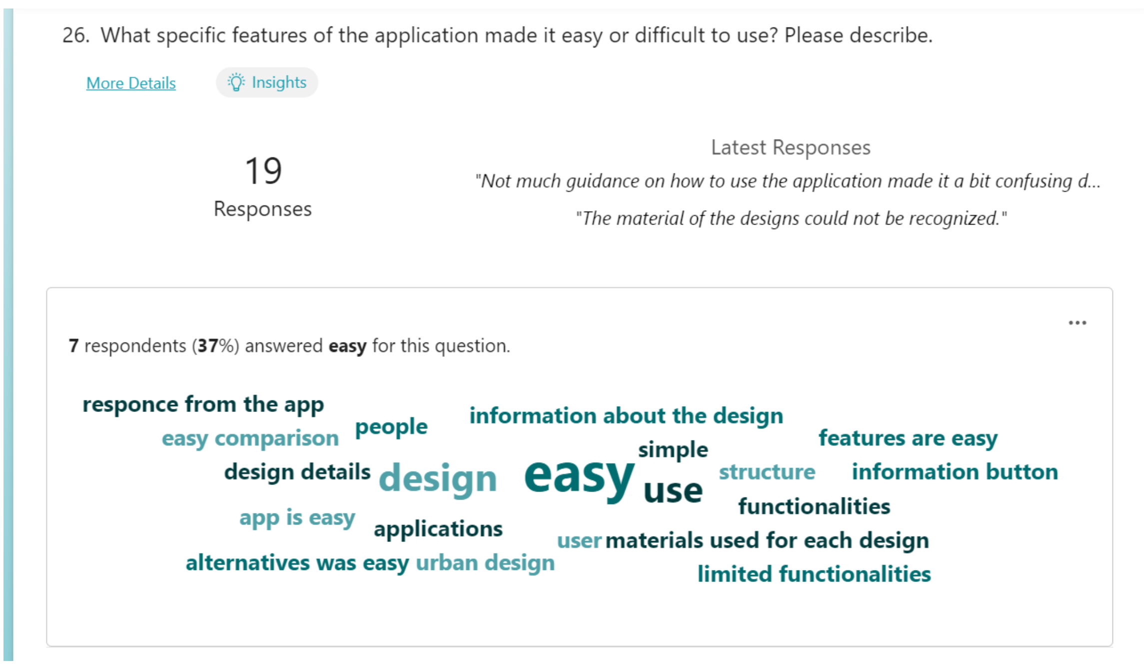
"Being able to visualy see the alternatives"

"Real time visualization"

...

7 respondents (**35**%) answered **Design** for this question.


25. Were there any features or aspects of the Application that you found particularly challenging or confusing?
More Details
Insights
19
Responses
Latest Responses
"The description of the buttons - No detailed description for the info provided...
"N/A"
4 respondents (21%) answered Information for this question.
information about the material
little bit
strcuture and the image
instead of reading
detail of each design
user
Better way
design
desktop computer
Information
night view
viewed
way
alternative's information
Information about each design
image
appealing way
image or chart
description for the info
viewed later


26. What specific features of the application made it easy or difficult to use? Please describe.
More Details
Insights
19
Responses
Latest Responses
"Not much guidance on how to use the application made it a bit confusing d...
"The material of the designs could not be recognized."
7 respondents (37%) answered easy for this question.
responce from the app
people
information about the design
easy comparison
simple
features are easy
design details
design
easy
use
structure
information button
functionalities
app is easy
applications
user
materials used for each design
alternatives was easy
urban design
limited functionalities

27. Are there other tools you are familiar with that have similar or different features supporting the tasks you performed? If yes write their names?

More Details | Insights

17
Responses

Latest Responses
"easy to use and accessable ,everyone can use "
"N/A"

2 respondents (**12**%) answered **similar** for this question.

28. Which of these additional features would you like to see in future updates of the application? Select all that apply.

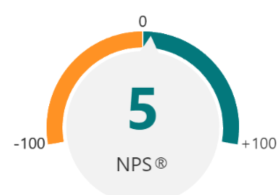
More Details

Virtual tour guide explaining fea...	14
Gamification elements (e.g., ear...	10
Live chat support for questions	4
Integration with social media fo...	8
Other	6

29. How likely are you to continue using this application for future projects or recommendations?

More Details | Insights

Promoters	6
Passives	9
Detractors	5



Appendix D. Results (Observation)

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Participa		cheack				click		tima		perspective			
		3d		3d	Data	comparision	3d	P data	COMP		Using Features	feedback	totall
1	Ar	3	1	10	3	2	01:50	00:06	00:11	yes	02:07	02:27	04:34
2	M	3	3	3	5	2	04:16	00:30	00:16	yes- no zoom	05:02	03:53	08:55
3	ar	3	3	6	4	1	01:04	00:38	00:20	high-zoom	01:59	02:34	04:33
4	ar	3	1	10	1	1	02:19	00:05	00:20	yes	02:44	02:33	05:17
5	M	3	3	7	3	2	01:32	00:50	00:25	yes	02:47	02:22	05:09
6	m	3	0	12	0	1	02:16	0	00:28	yes	02:44	04:43	07:27
7	Ar	3	3	5	5	1	05:39	01:52	00:40	yes	08:11	06:31	14:42
8	Ar	3	3	16	6	4	01:51	00:29	00:23	yes	02:33	06:05	08:38
9	Fa	3	0	9	0	2	02:09	0	00:20	yes	02:29	03:57	06:26
10	El	3	3	5	5	1	01:47	01:04	00:35	yes	03:26	03:58	07:24
11	M	3	3	9	5	2	05:49	00:45	00:33	yes	07:07	11:14	18:21
12	Pe	3	3	11	12	2	02:00	00:30	00:13	no	02:43	05:42	08:25
13	As	3	0	10	0	0	02:29	0	0	yes	02:29	01:59	04:28
14	M	3	0	4	0	1	01:33	0	00:16	yes	01:49	02:45	04:34
15	Er	3	3	8	3	1	03:44	00:55	00:35	yes/no	05:14	11:09	15:23
16	Ar	3	1	9	1	0	02:23	00:13	0	yes	02:39	01:30	04:09
17	M	3	0	19	0	1	02:06	0	00:18		02:24	05:22	07:46
18	Ar	3	0	15	0	1	01:14	0	00:23	no	01:37	03:11	04:48
19	M	3	3	8	8	1	01:51	00:36	00:12		02:39	01:38	04:17
20	Ar	3	1	10	1	4	01:30	00:05	00:30	no	02:05	02:07	04:12