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MASTER

Exploring the Effectiveness of Immersive Virtual Environments for Co-Design in the Built Environment

Akkers, Sem J.

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Exploring the Effectiveness of Immersive Virtual Environments for Co-Design in the Built Environment

Sem Akkers

Colophon

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Author	Sem Akkers
ID number	1024169
TUE email	s.j.akkers@student.tue.nl

Institute	University of Technology Eindhoven
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Address	Den Dolech 2 - 5612 AZ Eindhoven

Chairman (USRE)	Prof Dr. Theo Arentze
Chairman (CME)	Ir. Aloys Borgers
Graduation supervisor (USRE)	Dr. Gamze Dane
Graduation supervisor (CME)	Dr. Qi Han

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Preface

The following report is the finalization of my master's program in Urban Systems and Real Estate (USRE) and Construction Management and Engineering (CME) at the Eindhoven University of Technology. It explores the effectiveness of immersive virtual environments for co-design in the built environment, with a specific focus on urban design, simultaneous immersion, and communication. I found Virtual Reality within the context of the built environment a fascinating technology, which spared my interest to start this overall research.

A special thanks to my supervisors Gamze Dane, Aloys Borgers, Theo Arentze, and Qi Han, who helped me throughout the entire process of my graduation. The initial challenge for me was a lack of clarity on how to delve into the topic and transform it into a structured research, encompassing findings that actually contribute to the progression of the subject. My supervisors guided me through this challenging initial process.

I also want to thank my friends and family who supported me, helping me complete the overall research. Without them, I would have never been able to complete such an endeavor. A special thanks to Iris and my parents, who were there for me during the highs and lows of the overall process, following me closely every step of the way. Additionally, a heartfelt thanks to everyone who participated in the workshop. Your enthusiasm allowed me to delve further into the topic, and during the workshops, we had a good laugh.

Sem Akkers
Eindhoven, 2024

Summary

The Netherlands is facing a housing shortage of approximately 248,000 houses by 2025 (Van Loon & Hochstenbach, 2019), leading to challenges for students and starters to enter the housing market. Brownfield development, involving the redevelopment of existing buildings and public spaces, is considered crucial to address this shortage. The recently enacted Environmental and Planning Act in the Netherlands advocates stakeholder participation to accelerate urban development (Den Boer, 2022) and alleviate the housing shortage, although challenges persist in engaging citizens due to traditional top-down procedures. In addressing the complexity of urban design, characterized by social, physical, and economic intricacies, a lack of participatory roles for end users and stakeholders in conventional practices leads to policy gaps. To bridge this divide, the development of methodologies and tools facilitating collaboration from an early phase between non-experts and experts becomes imperative, given the ongoing trend of urbanization. Co-design with Immersive Virtual Environments gives non-experts access to a platform to voice their opinion from an early design stage. The study focuses on the redevelopment of Eindhoven's public square near the train station, underscoring the importance of collaboration and negotiation in the urban design process (McKercher, 2020), aiming to answer the following research question:

How can IVE play a role to improve and stimulate participation in the built environment?

This study is designed to unfold in three stages: literature research, experimental setup, and the actual experiment. These stages collectively contribute to the findings that will form the basis for the conclusion and discussion. The paper aims to assess participant preferences for co-design through Immersive Virtual Environments (IVE), exploring what end-users appreciate or dislike about co-design, IVE, and participation in the built environment, using a combination of survey and experimental research. The study addresses the top-down nature of urban design, introducing co-design to incorporate non-professional stakeholders early on, thereby allowing community perspectives and needs to shape tailored urban solutions. The primary focus is on exploring the impact of group immersion in co-design using IVE, providing valuable insights into user engagement, interaction, and feedback in addition to existing literature on solo immersion.

According to literature findings, integrating IVE into co-design processes in the built environment has potential. The willingness of non-experts to participate in such projects depends, however, on project scope and personal factors. Appropriate tools are crucial to attract participants to these events. Co-design, as a collaborative method, actively involves non-designers throughout the design process, leveraging diverse perspectives to address challenges and generate innovative solutions. Principles such as participation, development, ownership, and focus on outcomes guide this approach. IVE complements co-design through a user-cantered approach, visual communication, an iterative process, and collaboration, resulting in increased user engagement and a sense of ownership in the design process.

A workshop was organized with the objective of involving participants in an urban development process using the co-design methodology with Immersive Virtual Environments. In preparation, specific attributes—trees, parking, seating, and shelter/landmark—were designated for participants to manipulate within the existing model. The workshop employed two Oculus Quest 2 devices running the Arkio program, chosen based on its use in previous literature for individual immersion in urban design processes. The configuration, inspired by literature, allowed two participants to fully immerse in the IVE, while the researcher monitored activities via a connected PC for technical assistance or addressing attributes. Ten workshops, involving a total of 20 participants, were conducted with the goal of collaboratively designing a public square in

Eindhoven within a 30-minute timeframe. Subsequently, participants completed a survey encompassing topics such as personal background, prior experiences, confidence in design, learning experience, the integration of IVE and co-design, communication, and future use of the method.

The workshops yielded results in the form of transcribed conversations and responses to survey questions. A protocol analysis was conducted to assess the communication flow and topics discussed by non-experts throughout the design process. Open-ended survey questions provided detailed insights into the aforementioned subjects. Additionally, a Spearman's Rank Correlation and Binary Logistic Regression analysis were executed to identify any significant correlations between personality traits, socio-demographics, and the willingness of participants to engage again in this method.

Survey responses indicated participants' enthusiasm to engage in urban design as non-experts, particularly in their immediate surroundings, although scepticism existed regarding the design's alignment with built environment standards. Protocol analysis revealed active participant engagement in the design process, emphasizing scenario-related discussions, design choices, and tool-related communication. Communication between participants and researchers was generally positive, with few interruptions. The collaborative immersive experience increased engagement, fostering confidence through interactive discussions on design decisions. Contextual understanding of attributes was highlighted, with discussions on shading, location within the city, and suggestions for improvement, such as incorporating lampposts. The Binary Regression analysis identified age and openness as significant predictors, indicating potential connections between personality traits and socio-demographics with participants' willingness to engage in urban design using Virtual Reality. There is a need for further research, however, due to the small sample size and limited variability in the independent variables.

In summary, this study revealed that a youthful audience demonstrated enthusiasm for participating in urban design as non-experts if implemented in their immediate environment. The collaborative approach empowered non-experts to actively contribute their preferences and needs for the designated area, evident in the survey and protocol analysis. The flexibility of the tool, accommodating multiple perspectives and facilitating an interactive design process, enhanced participants' ability to conceptualize the overall square. Simultaneous immersion with vision and verbal communication boosted confidence, and the expert's facilitative role proved crucial in guiding participants through thoughtful design choices. A 30-minute time limit is emphasized to prevent fatigue, highlighting the need for expert guidance with both tool and design knowledge. The methods application should occur during the early initiative, and throughout the feasibility phases to shape the structural vision, aligning with municipal requirements for citizen engagement in the area structure vision creation. Design communications consistently emphasized the importance of contextual information for informed decision-making, stressing the need for knowledge-building workshops covering various aspects, including area context, goals, attributes, other participants, and the VR tool, to enhance the effectiveness of this approach in real-life applications.

Samenvatting

Nederland staat voor een huisvestingstekort van ongeveer 248.000 huizen tegen 2025 (Van Loon & Hochstenbach, 2019), wat leidt tot uitdagingen voor studenten en starters om de huizenmarkt te betreden. Een cruciale ontwikkeling om dit tekort aan te pakken is de herontwikkeling van industriegebieden en dergelijke, waarbij de herontwikkeling van bestaande gebouwen en openbare ruimtes betrokken is. De recentelijk aangenomen Omgevingswet in Nederland pleit voor participatie van burgers om stedelijke ontwikkeling te versnellen (Den Boer, 2022). Dit zorgt voor verlichting in het huisvestigingstekort. De traditionele top-down benadering van stedelijk ontwerp is om de complexiteit van het proces te beheersen. Deze complexiteit omvat sociale, fysieke en economische belangen van meerdere partijen. Eindgebruikers hebben binnen deze top-down werkwijze een gebrek aan inspraak, wat leidt tot gebreken in het beleid. Ontwikkelingen in methodes and instrumenten maken samenwerking vanaf een vroeg stadium mogelijk tussen niet-experts en experts. Dit is noodzakelijk gezien de voortdurende trend van verstedelijking. Co-ontwerp met Immersive Virtual Environments (IVE) biedt niet-experts toegang tot een platform om hun mening te uiten vanaf een vroeg ontwerpstadium. Deze studie richt zich op de herontwikkeling van een plein in het stadscentrum van Eindhoven, waarbij het belang van samenwerking en onderhandeling in het stedelijk ontwerpproces wordt benadrukt (McKercher, 2020), met als doel de volgende onderzoeksvraag te beantwoorden:

Hoe kan IVE een rol spelen om participatie aan de gebouwde omgeving te verbeteren en stimuleren?

Dit onderzoek is ontworpen in drie fasen: literatuuronderzoek, experimentele opstelling en het experiment. Deze fasen dragen gezamenlijk bij aan de bevindingen die de basis zullen vormen voor de conclusie en discussie. Het doel is de ervaring van deelnemers voor co-ontwerp via IVE te achterhalen. Het co-ontwerp betrekt de niet-experts al vroeg in het proces, waardoor gemeenschapsperspectieven en behoeften op maat gemaakte stedelijke oplossingen vormgeven. De nadruk ligt op het verkennen van de impact van groepsimmersie in co-ontwerp met behulp van IVE, wat waardevolle inzichten biedt in gebruikersbetrokkenheid, interactie en feedback in aanvulling op bestaande literatuur over individueel IVE gebruik.

Volgens literatuuronderzoek heeft het integreren van IVE in co-ontwerpprocessen in de gebouwde omgeving potentieel. De bereidheid van niet-experts om deel te nemen aan dergelijke projecten hangt echter af van de projectomvang en persoonlijke factoren. Geschikte instrumenten zijn cruciaal om deelnemers aan te trekken voor deze sessies. Co-ontwerp, als een collaboratieve methodologie, betrekt actief niet-experts gedurende het ontwerpproces, waarbij diverse perspectieven worden benut om innovatieve oplossingen te vinden. Principes zoals participatie, ontwikkeling, eigendom en focus op eindresultaten leiden deze aanpak. IVE vult co-ontwerp aan door een op de gebruiker gerichte aanpak, visuele communicatie, een iteratief proces en samenwerking, resulterend in verhoogde gebruikersbetrokkenheid en een gevoel van eigendom in het ontwerpproces.

Een workshop werd georganiseerd met als doel deelnemers te betrekken bij een stedelijk ontwikkelingsproces met behulp van de co-ontwerpmethodologie met IVE. Ter voorbereiding werden specifieke attributen - bomen, parkeergelegenheid, zitplaatsen en schuilplaats/herkenningspunt - aangewezen voor deelnemers om te verplaatsen binnen het bestaande model. De workshop maakte gebruik van twee Oculus Quest 2-apparaten met het programma Arkio. Deze is gekozen op basis van het gebruik in eerdere literatuur voor individuele immersie in stedelijke ontwerpprocessen. De configuratie, geïnspireerd door literatuur, stond toe

dat twee deelnemers volledig immersief waren in de IVE, terwijl de onderzoeker activiteiten controleerde via een verbonden pc voor technische ondersteuning of hulp bij attributen. Tien workshops, met in totaal 20 deelnemers, werden uitgevoerd. Hier was het doel om in een tijdsbestek van 30 minuten gezamenlijk een openbaar plein in Eindhoven te ontwerpen. Vervolgens vulden deelnemers een enquête in over onderwerpen als persoonlijke achtergrond, eerdere ervaringen, zelfvertrouwen in ontwerp, leerervaring, de integratie van IVE en co-ontwerp, communicatie en toekomstig participeren aan deze methode.

De workshops leverden resultaten op in de vorm van getranscribeerde gesprekken en antwoorden op enquêtevragen. Een protocolanalyse werd uitgevoerd om de communicatiestroom en besproken onderwerpen door niet-experts gedurende het ontwerpproces te beoordelen. Open vragen in de enquête gaven gedetailleerde inzichten in de eerder genoemde onderwerpen. Daarnaast werden een Spearman's Rank Correlation en een Binary Regression-analyse uitgevoerd om eventuele significante correlaties te identificeren tussen persoonlijkheidskenmerken, sociaal-demografische gegevens en de bereidheid van deelnemers om opnieuw deel te nemen aan deze methode.

Enquêteresultaten gaven aan dat deelnemers enthousiast waren om als niet-experts te participeren in stedelijk ontwerp, maar alleen als dit in hun directe omgeving plaatsvind. Protocolanalyse onthulde actieve betrokkenheid van deelnemers bij het ontwerpproces, met nadruk op discussies over scenario's, ontwerpkeuzes en communicatie over tools. Communicatie tussen deelnemers en onderzoeker was over het algemeen positief, met weinig onderbrekingen. De collaboratieve immersie verhoogde de betrokkenheid en bevorderde het vertrouwen door interactieve discussies over ontwerpbeslissingen. Discussies over schaduw, locatie van het plein binnen de stad en suggesties voor verbetering van het model, zoals het opnemen van lantaarnpalen, laten de nadruk op het contextuele kenmerken van het model zien. De Binair Regressieanalyse identificeerde leeftijd en openheid als significante voorspellers. Dit wijst op mogelijke verbanden tussen persoonlijkheidskenmerken en sociaal-demografische gegevens met de bereidheid van deelnemers om deel te nemen aan stedelijk ontwerp met behulp van Virtual Reality. Er is echter verder onderzoek nodig vanwege de kleine steekproefgrootte en beperkte variabiliteit in de onafhankelijke variabelen.

Samengevat onthulde deze studie dat een jong publiek enthousiasme toonde om als niet-experts deel te nemen aan stedelijk ontwerp, mits geïmplementeerd in hun directe omgeving. De collaboratieve aanpak gaf niet-experts de kracht om actief hun voorkeuren en behoeften voor het aangewezen gebied bij te dragen, zoals blijkt uit de enquête- en protocolanalyse. De flexibiliteit van de tool, die meerdere perspectieven toelaat en een interactief ontwerpproces vergemakkelijkt, verbeterde het vermogen van deelnemers om het plein te ontwerpen. Gelijktijdige immersie met visuele en verbale communicatie verhoogde het vertrouwen van niet-experts. De begeleidende rol van de expert bleek cruciaal bij het leiden van deelnemers voor doordachte ontwerpkeuzes. Een tijdsbeperking van 30 minuten wordt benadrukt om vermoeidheid te voorkomen, waarbij de behoefte aan deskundige begeleiding met zowel kennis van de tool als het ontwerp wordt benadrukt. De toepassing van de methode moet plaatsvinden tijdens het vroege initiatief en gedurende de haalbaarheidsfasen om de structurele visie vorm te geven. Dit is in lijn met de gemeentelijke eisen voor burgerbetrokkenheid bij het creëren van de visie voor het gebied. Communicatie omtrent het ontwerp benadrukte consequent het belang van contextuele informatie voor geïnformeerde besluitvorming. Dit benadrukt de noodzaak van kennisopbouwende workshops die verschillende aspecten behandelen, waaronder de context van het gebied, doelen, kenmerken, andere deelnemers en de VR-tool, om de effectiviteit van deze benadering in praktijksituaties te verbeteren.

Abstract

The Netherlands is grappling with a housing shortage of 248,000 homes by 2025, creating challenges for prospective homeowners, especially students and starters. Involving the ramping of existing structures and public spaces, is considered essential to combat this shortage. Despite the enactment of the Environmental and Planning Act, citizen engagement remains challenging due to top-down procedures in the urban development sector. To bridge this gap, methods facilitating collaboration between non-experts and experts are necessary given the ongoing urbanization trend.

The study centres on the redevelopment of a public square next to the train station in Eindhoven's city centre, highlighting the crucial role of collaboration in the urban design process. The primary research question revolves around how technology can enhance and promote the involvement of non-experts in the built environment. The study unfolds in three stages: literature research, experimental setup, and the actual experiment. The study aims to examine participant preferences for co-design through IVE, utilizing surveys and experimental research.

Literature findings suggest appropriate tools are crucial for attracting non-experts in the urban design process. Co-design actively involves non-designers, leveraging diverse perspectives to address challenges. IVE complements co-design by enhancing user engagement, visual communication, and collaboration, fostering a sense of ownership. Therefore, there is potential for integration of IVE into the co-design process of urban design.

A workshop involving 20 participants, utilizing Oculus Quest 2 devices with the Arkio program, was organized to collaboratively design a public square in Eindhoven. Results from conversations, surveys, and analysis revealed participants' enthusiasm for engaging in urban design as non-experts. The collaborative immersive experience increased engagement, fostering confidence and contextual understanding of design attributes.

In summary, the study showcased the enthusiasm of a youthful audience to participate in urban design as non-experts, emphasizing the importance of a collaborative approach and the flexibility of IVE. The findings suggest the need for expert guidance, contextual information, and knowledge-building workshops to enhance the effectiveness of this method in real-life applications, particularly during the early stages of urban development initiatives.

Key words

Co-design, Immersive Virtual Environment, Participation, Urban Design Process, Virtual Reality

List of Abbreviations

Abbreviation	Meaning
BLR	Binary Logistic Regression
IVE	Immersive Virtual Environment
PD	Participatory Design
UCD	User-Centered Design
VR	Virtual Reality
UI	User Interface

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1. Introduction

The Netherlands suffers from a housing shortage. It is estimated that around 248.000 houses are short by the year 2025 (van Loon & Hochstenbach, 2019). The housing shortage resulted in students and starters being unable to join the market. Brownfield development is important to tackle the housing shortage in the Netherlands. By redeveloping existing buildings and public spaces for housing and other facilities, the government tries to solve the housing shortage. The densification of inner cities aims to minimize greenhouse gases while being one of the solutions for the housing shortage. For example, people use more sustainable modes of transport (e.g. public transport, walking) in dense urban areas, reducing greenhouse emissions (Lu et al., 2018). A factor adding to the housing shortage is the urbanization of cities, people are moving from rural areas to cities (NOS, 2017). Therefore, the densification of cities is needed to supply the demand.

Large amounts of problems in the urban environment can be conquered via appropriate technical solutions. Co-design can form an interesting solution for potential social conflicts. Involving end users during the design process could help maintain the local urban identity. The method of involving people during the design process is via co-design. A new trend is to integrate the end user into the process (McKercher, 2022). Not only people who move into the new area are the end users, but the existing inhabitants are end users as well. They come in contact with the redeveloped area daily. The book by McKercher (2022) on co-design describes the concept as follows. The approach of co-design is to design with users, not for users. The concept works best when professionals, communities, and people with lived experience work together for a common goal of improving their living environment. There are four key principles to co-design. The first principle is to share power. It is important to share the power in research, decision-making, design, delivery, and evaluation regardless of experience or knowledge. The second principle is to prioritize relationships. Relationships, trust, and social connection are vital for conversations about the design process. The third principle is the use of participatory means. Co-design aims to facilitate people from simple participants to active partners, expression through visual and oral approaches is therefore a key factor in the concept. And the final principle is to build capability. Learning and teaching are important for the concept to succeed, and assessing the different methods and tools for co-design are therefore important (McKercher, 2022).

Participation of the end user during the design process of urban development is an important topic in the Netherlands. A new Environmental and Planning Act came into effect around Januari of 2024 (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022; Minnisterie van Binnenlanse Zaken en Koningkrijksrelaties, 2023). Participation of stakeholders (including end users) is a key component of this act. Here municipalities are promoted for the participation of stakeholders from an early stage of decision-making and project activity. The goal is to accelerate the process of urban development via cooperation (den Boer, 2022). The acceleration of the overall process could help with the housing shortage. A good example of the need for participation and success of large-scale urban development is in Germany. A large number of cities use participation due to the severe public response to existing controversial large-scale urban development. This created the demand for the participation of the end user (Stelzle & Noenning, 2017).

However, there is difficulty in attracting citizens to participate and involve them equally in the process (den Boer, 2022). There are a large number of factors contributing to the low willingness for participation. Communities are unwilling to participate due to strictly determined top-down procedures, low community capacities, lack of participatory attitude (public and practitioners), and ill-defined processes (Geekiyanage et al., 2020). Personal characteristics are influential when

it comes to the willingness to participate. Two different types could be categorized as “engaged citizens” and “passive citizens”. Engaged citizens preferred more interactive participation, with feedback on outcomes and the decision-making process as the overall highest determining factor in determining the preferred method of participation. Passive citizens preferred to minimize their participation to just one session of only 15 minutes. Another important fact is that the preference of participants differed depending on the scale and level of complexity of the project (den Boer, 2022). This is supported by the before mentioned studies of Geekiyange et al. (2021) and Stelzle & Noenning (2017).

Co-design can be implemented using a variety of tools, and immersive virtual environments (IVE) is among these tools. A study by Chowdhury and Henegraaf (2022) shows how an immersive virtual environment can be created for a co-design purpose. According to the study, “an immersive co-design environment supports an active and real-time experience with the design, therefore presenting a sense of being in the environment.”. They achieved this via a tool called Arkio. This tool allowed participants to freely interact with the virtual environment for architectural and urban design purposes, and even see each other’s actions in a collaborative environment. The tool offers several 3D artifacts to be placed within the environment creating the interaction desired for co-design. Other participants could see in real time the actions via a computer screen and communicate with the participant who was in the virtual environment. With this method, Arkio is used in a multimodal communication system. The study concludes that Arkio has the potential as a co-design method in the future where non-expert participants collaborate with experts in remote VR environments. There is also potential to further develop knowledge on the subject via immersive virtual environments. Immersive virtual environments allow for the advanced implementation of behavioral and physiological measurements that go beyond self-reporting (Birenboim et al., 2021). A study by Chowdhury (2021) involved citizens from a community to design their neighborhoods. With the help of virtual environments, these citizens were allowed to “express, explore and convey their imagination easily”. The combination of the immersive virtual environment and verbal communication allowed these non-experts to “produce meaningful urban design outcomes”. Therefore, co-design helped with the overall quality and the result of the urban design creating a meaningful result.

When projects undergo a participatory process, this process is usually during the pre-design analysis stage (concept development). And methods that involve interactive participation of the end user are under-represented during this stage as well (Geekiyanage et al., 2021). Therefore, IVE could still be an interesting development for both participants during the conceptual development and in the later stages of the project. Most studies on QoL and the built environment focus on understanding the relationship between the two subjects. These studies use literature reviews, surveys, and other tools. This current study will focus on involving people in the co-design process of dense inner cities on top of understanding the subject.

The area of development for this paper is the city center of Eindhoven. The center of Eindhoven is due for a large amount of redevelopment according to the municipality (2022). The area of the central station is redeveloped as well as the city center (Eindhoven municipality, 2022a). Currently, the area has around 200 residents, after the renovation they expect around 15,000 residents. The focus of the renovation is on public transport, connecting the area and the city to the rest of the Netherlands (KnoopXL, 2022). The municipality of Eindhoven wants to increase the QoL of citizens in dense urban development. They want to achieve this via collaboration and negotiation between experts, government, and citizens (Eindhoven municipality, 2022b). Collaboration and negotiation enhance the transparency of the decision-making processes. This

increases public trust in the municipality. More trust creates a stronger connection between end users and their environments and therefore enhances QoL.

QoL is an important subject in the modern built environment. QoL is defined as "Quality of life is the degree to which an individual is healthy, comfortable, and able to participate in or enjoy life events" (Britannic, n.d.). The term QoL is a subjective attribute on the individual level. Research is conducted on the QoL in combination with the built environment. According to a study by Pelczynski & Tomkowicz (2019), a risk of densification is potential social conflicts, e.g. loss of local identity. The municipality of Eindhoven aims to enhance the connection between citizens and their environments via transparency of the decision-making process. This is via the already mentioned method of negotiation and collaboration between end users, experts, and the municipality (Eindhoven municipality, 2022b).

1.1 Problem Analysis

Urban design is a complex process with social, physical, and economic issues. End users and other stakeholders are lacking a participatory role within the design ideas of conventional urban design. Organizations and systems fail to listen to citizens who experience their environment daily. This failure in communication leads to policy gaps where professionals' understanding of what people want and need is different from the end user's experience (Mckercher, 2020). Due to the complexity of the process of urban design, extensive tools need to be created to allow nonexperts to be involved and collaborate with experts in the early design stage. With the current trend of urbanization and the problems that come with this, end users do not have access to a platform to voice their opinion from an early design stage.

This research aims to answer the following research question: *How can IVE play a role to improve and stimulate participation in the built environment?*

The sub-questions below aim to address various facets of the main research question.

1. How should new technology be introduced to participants and what makes a good tool?
2. How can information best be communicated to the end user during the co-design process?
3. What information is important to be communicated with the end user and the designer?
4. Are people interested in the concept of co-design with Immersive Virtual Environments?
5. What are the pros and cons of IVE as a tool to involve end users in the design process?
6. Where does this method fit within the process of urban design?

1.2 Research Design

Figure 1 illustrates the overall structure of this paper. The initial section comprises the literature review, which centres on topics such as IVE, co-design, and participation within the built environment. This review aims to investigate both the integration of tools with IVE and the methodology of co-design, exploring the potential amalgamation of this methodology with IVE. Additionally, it examines the current low participation rate in the Netherlands and explores the role of technology in enhancing participation. The findings from the literature review lay the foundation for the experiment conducted in the latter parts.

The second part aims to set up an experiment focused on IVE and co-design. This phase consists of creating the 3D IVE, finding participants, and informing these participants about the methodology of co-design. There are existing 3D immersive virtual environments based around the station area of Eindhoven through ongoing research by CoHeSIVE (an alliance between the universities of Eindhoven, Utrecht, and Wageningen) (EWUU, 2022). These environments are

altered and imported to Arkio to fit this experiment (Arkio, n.d.b). Participants are recruited during this phase, focusing specifically on individuals between the ages of 20 and 30. Potential participants are contacted through the researcher directly via word-of-mount, email, or text messages.

A co-design experiment is implemented in the third part. Participants are informed about the experiment and the concept of co-design before they enter the IVE. This paper intents to use the immersive 3D environment of the Arkio tool mentioned in the article by Chowdhury and Henegraaf (2022). Participants are immersed in the IVE in pairs, creating a collaborative immersive experience for the experiment. The aim is to have at least 16 to 20 participants, this should be able to create eight to ten pairs. All participants can interact with the design simultaneously, engaging in communication within the virtual environment while immersed. Key attributes of the built environment related to QoL are allowed to be altered by the participants. These attributes are determined from existing research of the CoHeSIVE project by the coalition of universities in the Netherlands (Dane & Evers, 2023). A qualitative survey is distributed to the participants of the experiment after they come out of the IVE. This qualitative survey is focused on the main research question and sub-questions. Questions on the following criteria are mentioned in the survey; usability, ease of use, communication process, complexity, level of comfort, willingness to participate in this format in the future, and overall confidence in their design. These criteria come from the following papers; Venkatesh & Davis (2000) and Lee et al. (2003).

The concluding section of the paper involves summarizing the data collected during the experiment. A protocol analysis is conducted on the audio recorded during the workshop, and the responses from the qualitative survey are processed in this phase. Using this data, an overall opinion on the concept of co-design with IVE in a group immersion setting is determined, thereby addressing the research questions outlined in section 1.1.1.

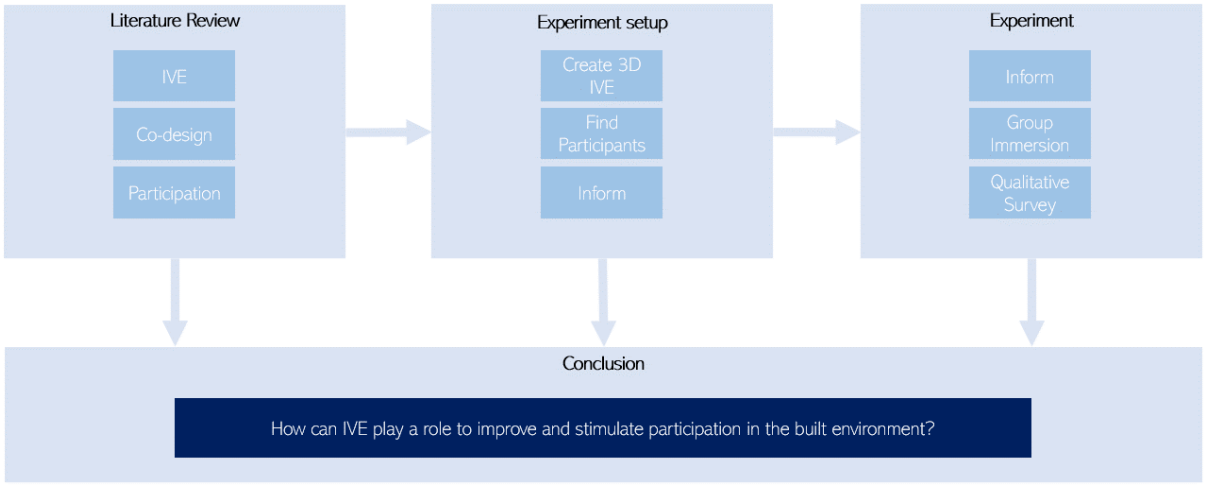


Figure 1: Research design of the thesis.

1.3 Scientific and Practical Relevance

The main goal of this paper is to find out if co-design through immersive virtual environments is a concept preferred by participants over traditional methods such as PowerPoint and 2D drawings and to indicate what end-users do or do not like about co-design, immersive virtual environments, and participation. This is achieved by combining both survey and experimental research on the subject of IVE, co-design, and participation in the built environment.

In practice, urban design is a top-down approach where large institutions and municipalities are stakeholders. With the help of co-design, 'non-professional' stakeholders could be incorporated from an early design phase. Inhabitants of the area could therefore voice their perspectives and needs, leading to more tailored urban solutions. Notably, the Environmental and Planning Act, stimulates municipalities to explore new innovative methods for participation. For municipalities, co-design offers a deeper understanding of community needs and fosters a sense of ownership. Designers benefit from diverse insights, resulting in higher-quality solutions, while investors experience reduced risks and increased market appeal, as co-design aligns projects more closely with user expectations.

The scope of this study includes a large number of cross-disciplinary fields. The urban design process, immersive virtual environmental tools, and communication.

The research on co-design in the built environment using immersive virtual environments is relevant due to the lack of studies exploring the impact of multiple participants immersed in the virtual environment at the same time. Previous research mainly focused on the individual experience of immersion in a virtual space. The impact of the change from solo immersion to group immersion could have a significant impact on the overall preference of the method. By exploring the effect of group immersion, the research can provide valuable insight into the co-design process, and what can be observed in terms of user engagement, interaction, and feedback in comparison to solo immersion.

1.4 Reading guide

This thesis consists of five chapters. The first chapter provides an overall introduction to the research, explaining the relevance of the topic and presenting the different research questions associated with this thesis. The second chapter explores the literature to establish a baseline knowledge of the overall topics of participation, co-design, and VR. This is followed by an elaboration on the various research methodologies employed in this thesis, explaining the VR tool, attributes, survey, protocol analysis, and the overall workshop structure. Chapter four presents the results, encompassing the overall findings of the protocol analysis, design choices, design approach, survey, and a brief analysis. Finally, the results of the literature research and the workshop are discussed in the conclusion chapter.

2. Literature research

This chapter delves into the underlying determinants that influence individuals' decisions to engage or abstain from participation in the urban design and planning processes. The first section examines citizen participation in the urban development initiatives in the Netherlands. Subsequently, the second section elaborates the co-design methodology. This chapter explores its definition, historical origins, essential components, and added benefits. The third section concentrates on IVE technology as an instrumental tool in the domain of urban design. This section provides information on the concept and user interface aspects of this technology. In the fourth section, attention is directed towards the combination of the co-design methodology and the IVE tool. The chapter emphasizes their complementary attributes and the benefits derived from their merge. Finally, the literature concludes by drawing insights from the research conducted.

2.1 Participation in Urban Design & Planning Processes

Before exploring participation in urban design, it is essential to examine the overall urban design process in the Netherlands. Figure 2 illustrates the four distinct phases of urban design: initiative, feasibility, realization, and exploitation, including the products generated during each phase. In the initiative phase, the project explores fundamental elements and initial aspects, establishing a hierarchy for these elements based on their importance. This exploration encompasses various locations and is documented in the municipal structure vision, providing a framework for development (Den Boer, 2022).

This is followed by the feasibility phase of the project, which can be categorized into definition, design, and preparation. In the definition phase, the project explores its objectives, scope, and constraints. The design phase involves creating plans and blueprints for the development, while the preparation phase focuses on readying for the actual implementation of the project through activities such as acquiring permits and funding. The documents produced during this phase include the area structure vision, a plan outlining the intended structure and development of the entire area. This plan incorporates goals and requirements defined in the definition phase and integrates the design elements developed in the design phase. Additionally, the zoning plan is produced, specifying how different parcels within the area will be used. It defines permissible land uses, building sizes, and other regulations for each zone (Den Boer, 2022; Franzen et al., 2011).

The realization phase comes after the zoning plan is produced. During this phase, the urban design plan is executed, and agreements made in previous phases guide the implementation. Builders and contractors are actively involved in bringing the development into existence during this phase (Den Boer, 2022; Franzen et al., 2011).

Moving on to the exploitation phase, which is the final stage in the overall process, it involves ongoing care and management with a distinction between building and public space maintenance. Building maintenance encompasses activities to keep individual buildings in good condition, while public space maintenance involves the management of shared open areas within the urban environment, such as parks, streets, sidewalks, and other public amenities (Den Boer, 2022; Franzen et al., 2011).

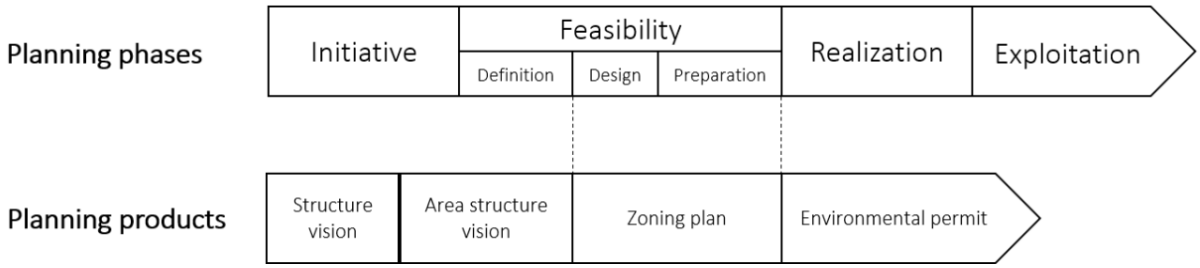


Figure 2: Phases of urban planning with accompanying planning products (Den Boer, 2022).

Citizens in the Netherlands wield significant influence in (re)shaping the built environment. They have the ability to formally respond to plans presented by private and governmental stakeholders (Den Boer, 2022). An urban design project consists of multiple phases (figure 2), spanning from initiative to exploitation. During the feasibility phase, developers or municipality craft a zoning plan, which is subsequently (dis)approved by the municipality. At the start of the realization phase, citizens are presented with the environmental permit. Citizens can formally object within the conforms of the law to both the zoning plan and environmental permit (Den Boer, 2022; Netherlands Enterprise Agency, RVO, 2021).

There is also a more informal form of citizen participation in urban development. Informal participation seeks to involve stakeholders, including citizens, businesses, civil society organizations, and other governing bodies, in decision-making from the early stages of the design process. Incorporating new points of view, interests, and experiences, as noted by Den Boer (2022), can contribute to a more streamlined design process. As mentioned, the emphasis is placed early in the overall planning process, with participants able to join workshop, fill out surveys, or use other methods to participate (Den Boer, 2022; Geekiyanage et al. 2021). The municipality is obliged to involve citizens under the new participation law from an early stage in the urban design process (Den Boer, 2022). Motivation obligation is a required document from the municipality included in the planning products. This entails how citizens, business, societal organizations and governing bodies were involved in the participation process, and what the result of this cooperation entails. This document is attached to the products of area structure vision, zoning plan, and environmental permit products (Den Boer, 2022; L'Ortye & Van Brunschot, 2019). It therefore illustrates that the municipality is required to have citizen participate within the urban project from the initiative phase throughout the entire feasibility phase.

In short, formal participation is characterized by a more regulatory and legal framework, providing citizens with specific rights and channels to voice objections. Informal participation, meanwhile, focuses on fostering a collaborative process where citizens actively contribute to shaping decisions and generating innovative solutions. Both approaches complement each other, contributing to a more inclusive urban design process. For this thesis, informal participation is further explored, and the impact of new technology on the overall willingness to participate is examined.

2.1.1 Willingness to participate in the Netherlands

The concept of participation has gathered significant attention and discussion within the built environment. Willingness to participate shows how much individuals and communities engage in decision-making, planning, and development. It is a measure to assess inclusivity and democratic aspects of urban design. Citizen participation methods have been developed for urban development practices in the Netherlands since the 1970s, as noted by Edelenbos et al. (2006). According to the government, too many citizens of the Netherlands have insufficient influence on

decisions that affect them (Ministerie van Algemene Zaken, 2023). Consequently, the Dutch government has made a collective effort to increase citizen participation in urban development via a new environmental act introduced in January of 2024. This act mandates citizen involvement in urban development projects (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022; Den Boer, 2022).

Citizens' preferences for participation in urban planning vary, and effective participation processes should be tailored to meet the preferences of different citizen groups. This customization enhances their willingness to engage in the urban development process, which can be challenging (Den Boer, 2022). Difficulties stem from a lack of knowledge, limited time, low awareness, and communication barriers, all of which can hinder people's willingness to participate (Den Boer, 2022; Geekiyanage et al., 2021). Process and personal characteristics such as the context of the project, how citizens are invited to participate, the intensity of participation, the level of involvement, the level of communication during and after the process, the chosen participatory methods and tools, external rewards, and access to information and technology are influencing factors for attracting citizens to participate in urban design and planning processes (Den Boer, 2022). Geekiyanage et al. (2020) mention multiple contributing factors lowering citizens' willingness to participate. This is due to strictly determined top-down procedures, low community capacities, lack of participatory attitude (public and practitioners), and ill-defined processes. Integration of technologies presents possibilities to enhance citizen participation and engagement in the Dutch urban planning landscape (Den Boer, 2022).

2.1.2 Participation Methods and Tools

The paper by Den Boer (2022), describes how new technologies can facilitate participation in urban planning. These technologies increase accessibility, convenience, time- and cost-efficiency, inclusivity, diversity, creativity, innovation, and transparency within the process. At the same time, potential risks and pitfalls of the use of technology, such as unequal access to information and participation, technological barriers, digital exclusion, reduction of opportunities for face-to-face communication, lack of trust, false expectations, data ethics and privacy. These factors should be addressed to prevent negative consequences.

Geekiyanage et al. (2021) conducted a systematic review of community engagement methods, where they described the tools, strengths, and limitations of these methods. Their research identified 34 available community engagement methods. In this paper, 10 of them are presented as examples of participation methods and tools, as shown in Table 1. An example given by Geekiyanage et al. (2021) is: 'if focus groups are chosen to gather data from selected individuals, they may conduct discussions via face-to-face meetings or using remote meeting tools. Thus, the procedure to be used to conduct the discussions may vary based on the tool selected'.

*Table 1: Classification of participatory methods for different community engagement purposes in urban development (*Geekiyanage et al. 2021).

Method	Tools	Strengths	Limitations
	Presentation and dissemination of information		
Printed material	• Newsletter • Letters • Posters • Fact sheets • Reports • Brochures	• Easy to use • Low costs	• limited reach to the younger generation

Displays/Exhibits	• Set up at relevant public locations (e.g., libraries)	• Provides project information and raises awareness about particular issues • Can be personalized and interactive • Can be readily accessible	• Brief attention spans • Limited amount of information that can be conveyed • Competition for attention at events
Presentations, live streaming videos	• PowerPoint • Visme • Haiku Deck • Canva • YouTube Live	• A creative and attractive way of engaging people • A great tool to convey messages quickly and succinctly	• Need creative knowledge and skill in designing • Need specific software in designing
Public awareness			
Public meetings	• Presentation followed by questions and answers • Town-hall meeting • Panel/roundtable • Large group/small group	• Relatively easy to convene, familiar procedures can involve a wide range of stakeholders • Provides an opportunity to relay information, explain processes and gather feedback with a large group of people	• Discourages those not used to speaking in large groups • Can be difficult to control • Attendance levels can be low unless people feel deeply connected to the issue and / or make the time to attend
Opinion collection from a selected group of general public			
Interviews	• Face to face • Using virtual tools such as Microsoft Teams • Telephone	• Generate in-depth information on a specific topic	• Time-consuming • Should continue until a data saturation point is reached
Focus groups	• Face to face • Virtual tools such as Microsoft Teams • Virtual Reality	• Can explore different perspectives of small groups of people of a common issue/goal	• Not effective for providing information to the public
Opinion collection from a large body of the general public			
Polls	• Physical polling booths • Postal vote • Online vote	• Are highly representative nature • Using scientifically developed techniques, samples from polls generate an accurate match of the population • Allow issue specific with immediate feedback	• Measure an immediate response to a question, thereby granting little opportunity for informed opinions or discussion of issues • Polling information is meaningless if it is not statistically valid
Surveys	• Paper survey • Postal survey • Email survey • Online survey	• Provide a baseline for measuring changes in people's views • Inform people about the project that is taking place • Prompt further involvement by asking if people would like to receive information or	• Time-consuming process • Results may be statistically incorrect if a large sample is not involved

		invitations to future events	
Bring deliberation and public participation into public policy decisions			
Citizen juries	• Round tables • Virtual meeting tools	• Bring new thinking to the issue at hand • Develop a deep understanding of an issue • Help build participant capacity through involvement and increased knowledge • Can dispel misinformation • Could build credibility	• Group selection may be mistrusted • Participants may not show up on the day • Sessions can lose focus • The costs can be expensive • Time-consuming for all involved • The sample of the community is small
Creating solutions			
Workshop, open space events	• Physical workshop • Remote workshops using Menimeter, Slido, Go Create	• Help to translate detailed discussions into action plans • Provide an opportunity to bring together the knowledge of all participants and is attractive because they set the workshop agendas	• Participants attending may have very disparate skills and knowledge • Logistics-It can be difficult to arrange meetings and workshops for different geographical locations and time zones

2.2 Co-design Methodology

Co-design and participation in the scope of urban development are closely related. Both emphasize inclusivity, shared decision-making, community empowerment, and better alignment with the needs of the people living in the urban areas (Cook, 2011; Den Boer, 2022; McKercher, 2022). Co-design is a specific method within the scope of participation in urban development. While participation involves a large variety of methods (section 2.1.2), co-design specifically focuses on collaborative and inclusive design processes where non-experts are actively involved throughout the design phase (McKercher, 2022). Co-design, as described in McKercher's book (2022), emphasizes designing with users rather than for them, fostering collaboration among professionals, communities, and individuals with lived experience to enhance their living environment. The principle of the methodology "shifts the balance from designer as judge, arbiter, and auteur to the designer as guide, facilitator and producer" (Cook, 2011). In the following subchapters, the definition, history, key elements, and added value of the co-design methodology is explored.

2.2.1 Definition of Co-design

Co-design is a relatively new methodology with no clear consensus on the definition due to practitioners and academics partitioning it differently (Cook, 2011). Different definitions are explored and eventually, a definition for this thesis is formed.

The first definition provided is from Sanders and Stappers' (2008) article, 'Co-creation and the New Landscapes of Design', which explores co-design and the evolution of design research over the past six decades. In this article, co-design is defined as part of an umbrella term of co-creation. Co-creation refers to any act of collective creativity, encompassing physical to metaphysical and from material to the spiritual. This term is not limited to the physical, tangible, or material aspects

of a project; it also extends to more abstract, intangible, and subjective dimensions. Therefore, co-creation recognizes that development process is not only for the physical environment but also in the cultural, social, and emotional dimensions. Co-design, as a specific instance of co-creation, involves applying collective creativity across the entire span of the design process. In broader sense, co-design includes the collaborative efforts of both trained designers and non-designer working together throughout the design process.

Cook (2011) explores the emergence and practice of co-design as a method for social sustainability under new labor in the UK from 1997-2010. As outlined in a survey conducted in 2010 by the Design Council, involving around 100 participants, co-design can be characterized as a methodology employed by designers to collaborate with the individuals they are creating for. This democratic approach centers on the methodologies and protocols of design, fostering cooperative engagement, consultation, and the generation of problem-solving solutions. It's important to note that co-design is not synonymous with a particular design aesthetic.

The third definition is from a paper by Antonini (2021). The article discusses the shift in focus from products/services' features to users' reactions and expectations for the design product in the last three decades, and how co-design reflects this shift. According to Antonini (2021), co-design represents a collaborative design methodology encompassing users and stakeholders in the design process. Its objective is to blend the insights, contributions, and expertise of individuals from various backgrounds to tackle specific challenges and devise fresh, inventive resolutions for various facets of daily existence. Co-design's rising prominence in the design sphere stems from its recognition and prioritization of end-users' and stakeholders' insights and perspectives, affording them a broader role in shaping knowledge, fostering idea inception, and refining concepts. This cooperative approach yields design outcomes that are more impactful and purposeful, catering not only to user requisites but also exhibiting social conscientiousness and sustainability.

A definition for use in this paper yields the following: co-design in urban planning is a collaborative design approach that involves the active participation of both trained designers and non-designers. This (i) including end-users which are living in and using the environment and (ii) stakeholders which are developers, municipality, designers, and more, throughout the entire design process. Its primary goal is to harness collective creativity, insights, and expertise from diverse backgrounds to address specific challenges and generate innovative solutions, ultimately resulting in more impactful and socially conscious design outcomes.

2.2.2 History of Co-design

The co-design methodology originates from two approaches, participatory design (PD) and user-centered design (UCD) (Antonini, 2021). Participatory design approaches have been applied in various design fields since the 1970s (Antonini, 2021; Sanoff, 2011; Sanoff, 2022). Social empowerment and emancipatory purpose are at the core of the PD design approach. It was formulated as a framework with the objective of exploring, comprehending, contemplating, setting up, advancing, and fostering reciprocal learning among numerous participants engaged in collective reflection-in-action (Antonini, 2021). The main purpose of PD is to involve citizens in decision-making processes, improve the quality of the environment, and various methods to raise awareness and facilitate creative thinking (Sanoff, 2022). Increased social capital, a sense of community, and citizen empowerment are all strengths of the methodology (Sanoff, 2011). The approach originated in Europe from the Scandinavian area. Only during de late 1980s was an approach adopted in North America under the mantra UCD (Caroll, 1996). UCD aims to increase the strength of the design based on needs and desires from users. Designers make decisions based

on user feedback and insight. UCD has a strong emphasis on end users, however they do not always actively participate in the design process but are consulted at various stages to provide feedback (Antonini, 2021).

There is a difference between PD and UCD methodology (Antonini, 2021; Caroll, 1996). The most fundamental difference is the level of involvement of end-users. PD actively engages the end-users in the decision-making process. UCD on the other hand involves studying and considering user needs, this does not always entail active participation in the design decisions. (Antonini, 2021; Caroll, 1996). Both methodologies typically undertake the roles of designers and users. In this context, the designer strives to forge a more robust connection between technical expertise and an understanding of the users' anticipations, while the user's goal is to articulate their objectives and grasp technological methods to achieve them (Antonini, 2021). The current co-design methodology is based on years of building on these two approaches of involvement of users during the design.

2.2.3 Tools and Techniques of Co-Design

Co-design tools and techniques can be broadly categorized into three activities (Akach et al., 2021). These activities can be described as "Talking, Telling and Explaining", "Making Tangible Things", and "Acting, Enacting and Playing" (Sanders et al., 2010). Talking, Telling and Explaining refers to techniques that support verbal expression. Tools include diaries, logs, and card sorting. Making Tangible Things refers to tools and techniques for production. Tools include collages, maps, models, and mock-ups. Acting, Enacting and Playing refers to imagination of act out possible futures by trying things out in setting that resemble, or in locations, where future activities are likely to take place (Akach et al., 2021).

Table 2 shows the purpose of these different activities via examples of tools, each tool or technique may be applicable to one or more of these purposes, as indicated by the table. The four purposes are probe, prime, understand and generate. Probing involves the utilization of tools and techniques to gather information and insights from participants. Priming, on the other hand, employs these tools and techniques to prepare participants for specific activities or tasks. Understand is to harness these tools and techniques to achieve a deeper grasp of participants' experiences, while generate involves their application in the process of generating ideas or solutions (Akach et al., 2021; Sanders et al., 2010).

Table 2: Purpose of the tools and techniques used in PD (Sanders et al. 2010).

Tools and techniques	**Probe**	**Prime**	**Understand**	**generate**
Making tangible things				
2D collages using visual and verbal triggers on background with timelines, circles, etc.	X	X	X	X
2D mappings using visual and verbal components on patterned backgrounds.		X	X	X
3D mock-ups using foam, clay, Legos or Velcro-modeling.			X	X
Talking, telling and explaining				
Stories and **storyboarding** through writing, drawing, blogs, wikis, photos, video, etc.	X	X	X	
Diaries and daily logs through writing, drawing, blogs, photos, video, etc.	X	X	X	
Cards to organize, categorize and prioritize ideas. The cards may contain video snippets, incidents, signs, traces, moments, photos, domains, technologies, templates, and what if provocations.			X	X
Acting, enacting and playing				
Game boards and **game pieces and rules** for playing.		X	X	X
Props and **black boxes.**			X	X
Participatory envisioning and **enactment** by setting users in future situations.				X
Improvisation			X	X

Table 3 illustrates how these tools and techniques are applied within the context of a PD setting. The first consideration is group composition. Sessions can be conducted either individually or in group settings involving two or more participants. The second factor is the choice between a face-to-face or online context. While, face-to face is more often the preferred method, it is worth noting that this approach can be time-consuming and costly. Notably, probing and priming activities have been successfully conducted in an online environment (Sanders et al., 2010).

The success of participatory design relies on a thorough understanding of the tools and techniques' purpose and context, and the need to customize them accordingly. Therefore, each dimension of both context and purpose must be balanced (Akach et al., 2021).

Table 3: Tools and techniques used in PD described in context (Sanders et al. 2010).

Current applications of the tools and techniques	Individual	Group	Face-to-face	Online
Making tangible things				
2D collages using visual and verbal triggers on background with timelines, circles, etc.	X	X	X	X
2D mappings using visual and verbal components on patterned backgrounds.	X	X	X	
3D mock-ups using foam, clay, Legos or Velcro-modeling.	X	X	X	
Talking, telling and explaining				
Stories and **storyboarding** through writing, drawing, blogs, wikis, photos, video, etc.	X	X	X	X
Diaries and daily logs through writing, drawing, blogs, photos, video, etc.	X		X	X
Cards to organize, categorize and prioritize ideas. The cards may contain video snippets, incidents, signs, traces, moments, photos, domains, technologies, templates, and what if provocations.	X	X	X	
Acting, enacting and playing				
Game boards and **game pieces and rules** for playing.	X	X	X	
Props and **black boxes.**	X	X	X	
Participatory envisioning and **enactment** by setting users in future situations.	X	X	X	
Improvisation	X	X	X	

2.2.4 Key Elements of Co-Design

The Co-design Approach embodies several essential principles according to Cook (2011). First, is participation, prioritizing the inclusion of people in the design process to ensure that solutions are developed in collaboration with them rather than being imposed upon them. Second, is the concept of development. Co-design is evolving through continuous self-learning and improvement. This means the approach is not static; it adapts to changing needs, feedback, and evolving contexts. Practitioners of the methodology are open to learning from their experiences and refining their methods. Third is the notion of ownership and power dynamics in co-design. This principle addresses the issue of power dynamics within the traditional design process. It acknowledges that traditional design processes may concentrate power among a few individuals or groups. In Co-design, there is a deliberate shift in power dynamics, creating a structured framework of rights and freedoms among all participants. This ensures that the design process is more equitable and that no single group dominates the decision-making. Lastly, the emphasis on outcomes and intent. Co-design operates based on tangible results and clear objectives. This is to keep the design process focused and aligned with the needs of the people it serves. By keeping the end goals in sight, co-design can continuously evaluate their progress and make informed decisions to steer the project in the right direction, yielding more effective and practical results.

In the co-design methodology, three distinct roles come into play: the user, researcher, and professional designer. The role of the user is part of the design team as an expert in their experiences (Akach et al., 2021; Sanders & Tappers, 2008). As stated by Akach et al. (2021), 'The shift is then from 'designing for the user' to 'designing with the user.' This change reflects one of the core elements of co-design. The effectiveness of the methodology however relies on the

utilization of appropriate tools, so users can express themselves (Sanders & Tappers, 2008). Examples of these tools are; visual facilitation, prototyping, workshops, storytelling, and more. Interest in tools and technologies for co-design is growing rapidly (Akach et al., 2021; Geekiyanage et al., 2021; Sanders et al., 2010). The role of the designer changes from translator between users and designer to facilitator. The designer provides a platform for the user to express their creativity (Akach et al., 2021; Sanders & Tappers, 2008). Sanders and Tappers (2008) argue for the importance of the professional designer in co-design. In essence, professional designers bring essential skills and expertise to co-design efforts. They excel in managing complex design challenges, fostering generative design thinking, and seamlessly integrating into co-design teams. Their adaptability, holistic vision, and ability to harness generative tools make them indispensable in the evolving landscape of design practices.

2.2.5 Added Value of Co-design for Urban Development Projects

Co-design has added benefits to the overall design process and outcome within urban development projects. Firstly, co-design raises the quality of fundamental characteristics that an urban environment should have. This leads to a superior design that aligns better with the needs and requirements of the community. Therefore, user satisfaction is elevated, culminating in a more gratifying experience of their living environment (Antonini, 2021). Additionally, it fosters the development of innovative services with unique benefits that resonate with people. This drive towards differentiation is coupled with a reduced development timeline, ensuring a timely process (Antonini, 2021). Moreover, co-design in urban planning acts as an educational tool for community members. Residents and stakeholders gain insights into the complexities, attributes, and specifications of novel urban design developments. This collaborative learning process not only enhances the understanding of urban planning concepts but also fosters a sense of ownership and engagement within the community. As a result, it is expected that the acceptance of new urban design initiatives in the market is increased, leading to improved public relations and strengthened long-term relationships between urban planners and the residents (Antonini, 2021). And finally, the capacity to tap into users' creativity. This allows users to contribute ideas for innovation that might not be considered by professionals (Antonini, 2021).

However, the success of the co-design methodology does depend on the utilization of appropriate tools (Akach et al., 2021; Sanders & Stappers, 2008; Sanders et al, 2008). A process must be effective for all team members, especially those who may be less familiar with the design process itself. Therefore, a variety of communication tools should be employed to provide a range of communication options (Dahlstrom-Hakki et al., 2021).

2.3 Immersive Virtual Environments for Urban Design Planning Processes

There is a large variation of tools used for citizen participation in the urban design and planning process. Notably, the tool of VR has been absent from literature until now. This is due to the fact this tool is relatively unexplored in the context of urban development, participation, and co-design. As stated by Den Boer (2022), new technology could be a contributing factor in enhancing individuals' willingness to participate. VR and IVE could be a new technology people are willing to adopt for participation in urban design. VR teleports users into digital realms, engaging their senses and perceptions with the virtual environment. These virtual environments are created through utilizing advanced technologies to replicate real-world scenarios or construct entirely new and imaginative worlds, captivating users in ways that blur the lines between physical and digital reality.

2.3.1 The Concept of Immersive Virtual Reality

VR offers users the opportunity for active, real-time interactions with designs, consequently fostering a tangible sense of presence (Chowdhury, 2021; Tham et al, 2018). VR serves as a powerful medium for human communication, enabling the exchange of information and experiences among individuals. By facilitating such interaction, VR transcends conventional communication methods and engenders deeper engagement and interaction among users (Chowdhury, 2021).

Figure 3 illustrates a scale of different realities, ranging from reality to virtuality (Schnabel, 2009). These seven concepts of reality can be categorized in three main forms of reality, where first is reality itself. Real Reality encompasses the real and physical world, this term in context of urban design encompasses everything, whether it is naturally occurring, designed, observable, or understandable. Second is so called mixed realities (MR), which refers to the merging of real and virtual environments, creating a mixed environment (ME). Within MEs, digital and physical elements co-exist and interact. Therefore, a large spectrum of environments on the reality-virtuality scale are based in MEs. In the context of urban design, MEs enable creative collaboration throughout the life cycle of facilities, facilitating a smooth transition between digital and physical realms and resulting in alternative design outcomes. The final category is virtuality, encompassing an environment that is entirely computer-simulated, therefore there is no need for a real artifact. Immersive Virtual Environments (IVEs) offer a high degree of sensory immersion, enabling real-time interaction with virtual designs. New opportunities combating design problems arise when using IVE.

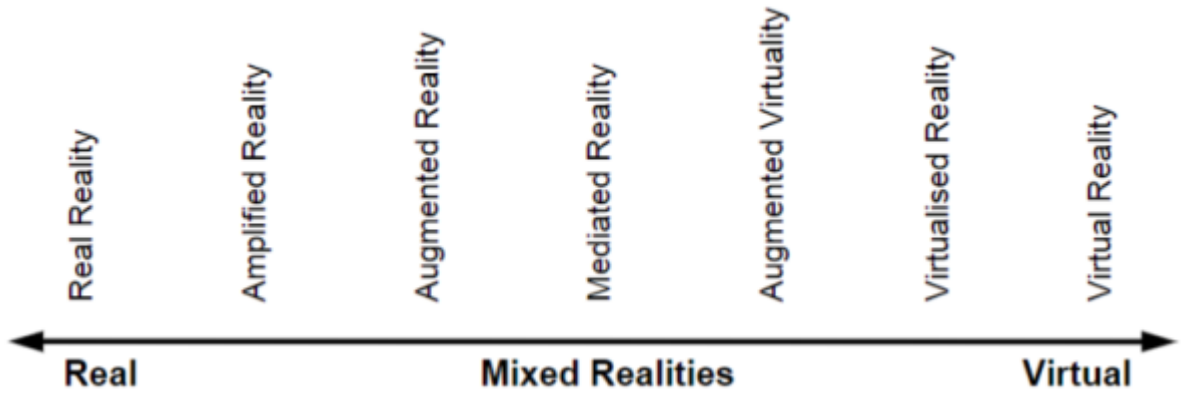


Figure 3: Order of reality concepts ranging for reality to virtuality (Schnabel, 2009).

In the study conducted by Fuchs et al. (2011), the foundational concept of VR is explored. Figure 4 illustrates this concept. Within the IVE, users engage via user motor interfaces, capturing their actions. Computational processing of these actions culminates in alterations within the IVE, conveyed through sensorial interfaces such as glasses. This causes an interaction between perception, cognition, and action. This interaction is an interactive loop. A downside of the VR application is the existence of latency between user action and the subsequent perception. The mitigation of latency, coupled with the improvement of sensorimotor disparities is a measurement for the overall quality and immersive fidelity of the VR tool. Latency refers to delays in information processing or response times, which can impact real-time interactions. Sensorimotor disparities involve mismatches between sensory input and motor output. Minimizing latency is one way to reduce sensorimotor disparities in such systems (Chowdhury, 2021).

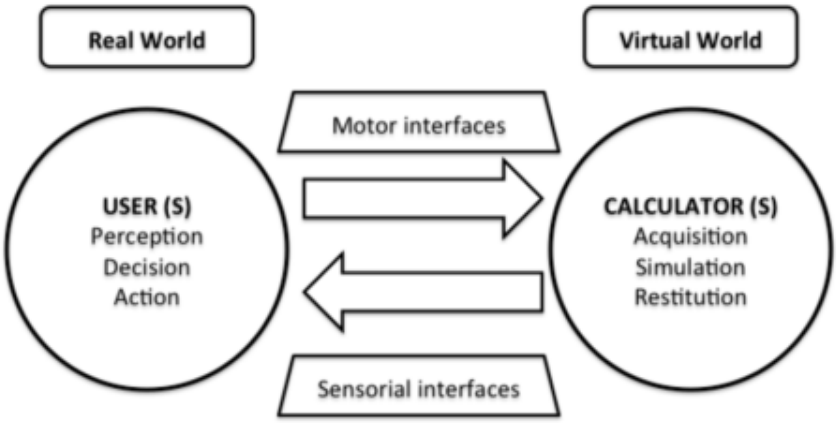


Figure 4: 'Perception, cognition, action loop (Fuchs et al., 2011)'.

2.3.2 Interface of Virtual Reality

The interface offers information from the artifact that participants can act upon (Chowdhury, 2021). There are 4 key elements to a user interface within VR according to Bowman (1995). These elements are affordance, mappings, feedback, and constraints. Affordances, in the context of human-computer interaction, pertain to the inherent perceptible attributes of an object or tool (Bowman, 1995). For instance, the design features of a chair inherently facilitate a seated posture. Therefore, the chair is affording a seating function. The incorporation of affordances is crucial to enabling users to instinctively engage with digital environments, minimizing the likelihood of errors during interaction. Mappings, as described by Bowman (1995), involve the input provided by the user through the interface that should yield a proportionate and coherent response within the system (Bowman, 1995). For example, a user's hand reaching out could be mapped to the virtual hand in the VR environment, allowing them to interact with virtual objects by touching or manipulating them based on the real-world hand movements. The element of feedback, as explained by Bowman (1995), pertains to the process of relaying information back to the user concerning executed actions. In complex systems such as IVE, a higher amount of feedback is required to sustain user awareness of the VE. The last and most important element is Constraints. This element shapes the potential actions of an object or system by imposing limitations. An example of a real-world instance of a constraint is gravity. Constraints are necessary to create a realistic IVE (Bowman, 1995). The domain of input devices connects users to virtual realms. Implementing constraints in both input devices and the virtual environment is crucial for enhancing user experiences and maintaining realism in immersive virtual settings. An excess of constraints may limit the versatility and reusability of a tool, while conversely, an insufficient number of constraints can detrimentally impact its usability. Therefore, VR controllers and headsets are the preferred tools, while alternatives like gloves and voice recognition can be less usable due to their low amount of constraints (Bowman, 1995).

One could therefore conclude that a successful user-friendly UI in VR involves careful consideration of four key elements: affordances, mappings, feedback, and constraints, as outlined by Bowman (1995). Without a successful UI, users will not utilize the tool effectively, therefore eliminating the positive elements of the VR tool.

2.4 Combining Co-design and IVE

Digital technology can be employed in the urban design process, by combining VR technology with the methodology of co-design. First the complementary attributes are explored and then the added benefits of the combination.

2.4.1 Complementary Attributes of Co-design and IVE

There are complementary attributes in co-design and IVE that can enhance the planning and design process of urban development projects. These shared attributes are: user-centered approach, visual communication, an iterative process, collaboration (Chowdhury, 2021; Cook, 2011).

Both tool and methodology place an emphasis on user-centered design approach. Co-design involves engaging end-users and stakeholders in the design process, ensuring their needs and preferences are considered (Antonini, 2021; Cook, 2011). Immersing participants in a virtual environment enhances this characteristic. Both co-design and VR emphasize visual communication (Koutsabasis et al., 2012; Sanders et al., 2010). Workshops in the co-design methodology typically rely on sketches, and other visual tools to convey design ideas among participants and professional designers (Akach et al., 2021; Sanders et al., 2010). VR, on the other hand, emphasizes visualization through specialized VR glasses. Participants can see and experience designs using VR technology (Chowdhury, 2021; Koutsabasis et al., 2012). In urban design, the project is developed and refined through a cycle of repeated evaluation and feedback. Co-design encourages this ongoing feedback and refinement of concepts (Cook, 2011). VR allows for rapid change in the virtual environment, which can be assessed immediately (Tham et al., 2018). Collaboration is a fundamental aspect of co-design. The methodology brings together experts and non-experts to collaborate on design decisions (Antonini, 2021; Cook, 2011; Stappers, 2008). Multiple participants are able to interact within the same virtual environment (Chowdhury, 2021), making VR a collaborative tool. Table 4 illustrates these complementary attributes.

Table 4: Complementary attributes of co-design and IVE.

Attribute	Description
User-centered approach	Designer focus on users and their needs in each phase of the design process.
Visual communication	The use of visual elements to convey ideas and information. Examples are symbols, models, and drawings.
Iterative process	An approach to continuously improving a concept, design, or product.
Collaboration	Collaboration is the process of two or more people, entities or organizations working together to complete a task or achieve a goal.

2.4.2 Added Benefits of Combining Co-design and IVE

The concept of co-design involves non-designers in the participatory role which have different backgrounds, experiences, interests and roles (Sanders et al., 2010). This is a strength of the methodology, where designers can tap into a wealth of ideas and perspectives they may not have considered otherwise (Chowdhury et al., 2023). However, the challenge is to find appropriate ways to engage and involve these non-designers in the design activities (Sanders et al., 2010). One of the most prominent benefits of co-designing in VR is the increased user engagement (Chowdhury et al., 2021; Koutsabasis et al., 2012). With VR, users feel a sense of ownership and belonging to "their" design. Therefore, users are more interested in the outcome and more likely to participate (Chowdhury et al., 2023). In short, 3D artefacts in IVE in co-design allows non-designers to initiate new design ideas (Chowdhury, 2021). Besides, more extensive citizen involvement in the virtual decision-making process is needed to deal with complex urban issues (Von Heland et al., 2015).

2.5 Conclusion of the Literature Research

In summary, the concept of integrating VR in co-design within the context of the built environment holds the potential to make an impact in the field. Citizens could be involved from an early phase in the design and planning process through the new Environmental and Planning Act. The willingness of non-experts to participate in these projects, however, depends on both the scope of the project and the personal factors of the individual. Therefore, the use of appropriate tools is necessary to attract participants to these participatory events.

Co-design emerges as a powerful and collaborative design methodology that actively engages non-designers, or end-users, through the entire design process. Its central aim to leverage the collective creativity, insights, and expertise stemming from diverse backgrounds to address specific challenges and cultivate innovate solutions. This goal is achieved via the principles of participation, development, notion of ownership, and emphasis on outcomes and intent.

In this context, IVE can support the co-design methodology via its complementary attributes of a user-centered approach, visual communication, an iterative process, and collaboration. The synergy between IVE and co-design leads to increased user engagement by fostering a sense of ownership in the design process, ultimately encouraging more active participation.

3. Methodology

The case area under consideration originates from the redevelopment project of the Eindhoven station area, namely KnoopXL. It seeks to transform the urban environment of Eindhoven city center adjacent to the train station. The project seeks to mix the functions of work, leisure and living together. A residential change in population of 200 to 15,000 will take place (KnoopXL, 2022). With more people living in the area, there is more pressure on existing public space. In this context, participants are tasked with configuring the public space of the urban landscape based on a role assigned at the start of the session. Central to these considerations are creating a healthy public space and enhancements in connectivity between the city center and the broader urban scope, aligning with the core objectives of the ongoing urban initiative of the KnoopXL project (KnoopXL, 2022). This chapter explores how the participants achieve their goal within the IVE by addressing the attributes for public space, Arkio tool, workshop structure, and data collection methods.

3.1 Attributes for in the IVE

As mentioned in chapter 2.3.2, constraints in the IVE are needed for comfortable use. This section explores possible attributes for citizens to use in their design choices for the urban environments within the VE. According to (Dane & Evers, 2023), public spaces play a vital role in facilitating connections among individuals, fostering self-awareness, and nurturing a relationship with the surrounding environment. They serve as dynamic platforms for communal engagement, enabling people to establish meaningful bonds, develop a sense of identity, and contribute to the collective well-being of their communities.

3.1.1 Attributes From the CoHeSIVE Research

Building on insights from the CoHeSIVE project, a collaboration involving TU/e, Wageningen University, and Utrecht University, a workshop conducted on July 9th, 2022, aimed to pinpoint attributes in the built environment beneficial to fostering healthy public spaces. From the workshop, 27 attributes were identified and subsequently categorized into green, building, land-use, pedestrian facilities, leisure, and social and safety within this thesis (as presented in Table 5). It is worth noting that not all attributes from Table 5 translate into the VR technology of Arkio, as explained in more detail in section 3.2. Considering usability constraints in VR, the selection for this workshop was confined to four attributes: Trees, seating, parking, and shelter/landmark. The decision to limit the number of attributes was influenced by the importance of maintaining good usability in VR. These four attributes were specifically chosen based on guidance from the CoHeSIVE (Dane & Evers, 2023) project and insights from literature by Gomes (2017), Efe (2016), Rašković & Decker (2015), and Ibrahim (2017).

Table 5: Categorization of attributes based on research by Dane & Evers (2023).

Category	Attribute
Green	Presence of trees Size of trees Presence of vegetable garden Vertical greening
Building	Monotonous or diversity among facades Presence of historic buildings Building height Presence of active plinth Colors among facades
Land-use	Pavement or grass surface Presence of fountain(s) Size of urban public space Amount of parked cars Different levels of surface Mixed land-use
Pedestrian facilities	Designated or shared paths Width of paths Direct routes of paths
Leisure	Presence of canopy Presence of benches Presence of sculptures Presence of drinking fountain
Social and safety	Amount of driving cars Amount of people Presence of lighting posts Presence of bollards

3.1.2 A deep dive into the attributes used for the workshop

This section dives into the different attributes used for the workshop. Participants can move these attributes within the model to their liking. The potential positives and negatives of each attribute are discussed in this section.

Presence of Trees

From a literature and VR standpoint, the presence of green within the public space is one of if not the most impactful attribute. First start with the positive influence of green. The aesthetics amenities, green can be viewed as beautiful and a nice change of scenery in an urban environment (Rašković & Decker, 2015; Song et al, 2018). Trees increase the willingness to stay, sit, or shop, and enhance the city image (Rašković & Decker, 2015). Shading, often overlooked in the context of trees, in turn promoting leisure activities (Song et al, 2018). Trees are used as a regulator for water (Song et al, 2018). Urban heat island refers to the elevated temperature in urban areas compared to their rural counterparts, primarily caused by human activities and the built environment trapping heat. Green amenities cool down the city, minimizing these urban heat islands (Grylls & Van Reeuwijk, 2020; Rahman et al., 2020). By providing shade and reducing temperatures, trees also contribute to the reduction of ground-level ozone formation, thus helping to improve air quality in urban areas. Trees also play a crucial role in enhancing air quality in various ways. Harmful pollutants are absorbed during the photosynthesis process (Grylls & Van Reeuwijk, 2020).

It is not all positive, however. Tree amenities need a high level of maintenance to keep a positive impact on the environment. As mentioned by Lee and Maheswaran (2010), low-maintained green

can have negative influence on perceived safety. Roots can destroy pavement, pipes, or other infrastructure. This need for maintenance can therefore be seen as a high cost in comparison to simple (concrete) pavement (Lee & Maheswaran, 2010). These findings are summarized in Table 6.

Table 6: Overview of the impact of trees on public space and the VR environment.

Positives	**Negatives**
Aesthetics amenities	High maintenance
Shading	Medium costs
Water regulation	
Heat regulation	
Air quality	

Presence of seating opportunities

Benches are not just for sitting but also for watching, reading, and parenting (Rishbeth & Rogaly, 2017). The positives of these seating opportunities are the promotion of social interaction, comfort and resting, position from where to watch the scene, and sense of direction. Sociability can be improved by the correct placement of seating opportunities (Oram et al., 2018; Gomes, 2012; Southey, 2020). Small conversations and interactions are more likely to happen on these seating locations. Comfort and resting are important to a public space (Dane & Evers, 2023). People tend to seek appropriate locations within public spaces to observe activities or scenes, this is called passive engagement. Passive engagement entails interaction with the environment however, no direct participation or active involvement (Gomes, 2012). Southey's study (2020) exemplifies that seating arrangements are influenced by various activities, such as sporting events and children's playground activities. Residents are therefore passively engaging with these activities through seating. Seating locations such as benches are then used for this. Through proper placement, seating can also give a sense of direction through pathways or designated areas for people to follow (Efe, 2016).

Placement of seating opportunities needs to be carefully considered otherwise negatives could arise. For example, bad placement could disrupt existing walking lines. Poor positioning of seating can create bottlenecks or disrupt the flow of pedestrian traffic (Oram, 2018). Large or improperly placed seating elements might obstruct visibility, creating blind spots that compromise safety and security within the space. This obstruction can potentially hide undesired activities or hinder surveillance. This gives the last negative which is unwanted loitering around these locations. Loitering refers to lingering or hanging around in a place without a specific purpose. This occurs due to the before-mentioned seating that is placed in locations that are hidden. Table 7 illustrates these findings.

Table 7: Overview of the impact of seating opportunities on public space and the VR environment.

Positives	Negatives
Promote social interaction	Disrupting continuity of walking lines
Comfort and resting	Obstruct visibility
Position from where to watch the scene	Unwanted loitering
Sense of direction	

Access to car parking

The findings are summarized in table 8. There is often problems with car parking in urban areas. Especially within city centers, car parking has often a shortage. With a shortage of car parking, drivers cannot find a place to park their cars. Drivers therefore circle nearby areas for a parking spot. This phenomenon is called cruising, and has an impact on the overall urban design (Ibrahim,

2017). People who cruise have already arrived at their destination. Cars during cruising make streets overcrowded, consume more fuel, emitting extra pollution and forming hazards for people using the same street just for moving (Ibrahim, 2017).

Parking, however, has to take into account some negative aspects. Parking takes up a large amount of land, this in turn lowers walkability and aesthetics. Increasing the number of off-street parking spaces near buildings pushes building apart from each other and increases the distance between buildings. Therefore, making walking distances longer, decreasing the overall walkability. Curb parking could also disrupt walking paths (Ibrahim, 2017). Aesthetically speaking, parking is seen as a negative impact on the surrounding area. Curb parking for example could disrupt building facades while off-street parking lots could be bland (Ibrahim, 2017). Replacing vegetation and soil with asphalt and concrete for parking purposes has an impact on the direct environment. This is known as the heat island effect, leading to an increase in temperatures in the area (Onishi et al., 2010).

Table 8: Overview of the impact of car parking on public space and the VR environment.

Positives	Negatives
Combat shortage	Not aesthetics
Connectivity	Decreased walkability
Decrease cruising	Heat islands
	Consume large amount of land

Presence of shelters/landmark

Table 9 shows the overall positives and negatives. Shelters provide shade, promote social interaction and increases comfort (Gomes, 2012). Comfort, both physical and psychological are important to promote social activities within a public space. Weather is one factor that relates to physical comfort. Protection from unpleasant weather conditions are therefore important (Gomes, 2012). Shelters and landmarks have other influences to public space as well. Landmarks can give a sense of direction and identification to a space (Sorrows & Hirtle, 1999). As for navigation, Landmarks act as reference points to help individuals make navigational decisions such as where to turn. They could also act as origin and destination identification. Spatial reference points, like landmarks, help organize our memory of space by being familiar, visually dominant, and visible from a distance. When recalling space, we tend to remember objects based on their proximity to these points. These points serve as central markers in our mental map, shaping how we organize and recall spatial relationships between objects or locations (Sorrows & Hirtle, 1999).

Some landmarks or shelters can attract attention or foot traffic, which might compromise the privacy of nearby residences. Big crowds, noise, or increased activity due to landmarks could therefore compromise the privacy of the area. Shelters and landmarks occupy physical space, potentially limiting available land within the park for other purposes.

Table 9: Overview of the impact of shelters and landmarks on public space and the VR environment.

Positives	Negatives
Shade	Reduced privacy of residents
Social interaction	Takes up land
Comfort	
Sense of direction/identification	

Summary of Attributes
Having at least an understanding of the dynamic between attributes helps participants design their public space within the IVE during the workshop. Car parking has a competing relationship with the three other attributes of trees, seating, and shelter. This arises from the space allocation within the restricted research area. Car parking takes up a large amount of space, so the choice is between city centre infrastructure and attributes that make the park more enjoyable experience.

The other three attributes of trees, seating, and shelter all have a complementary relationship with each other. Integrating green and seating arrangements amplifies the appeal of public areas. Trees also offers natural backdrop and physical comfort to seating locations due to shade and shelter. Physical comfort is also the reason shelter and seating have a complementary relationship. Trees can provide a natural form of shelter and shade, therefore complementing the shelter attribute.

3.2 Arkio as a VR Tool for Urban Development Projects

Arkio is the tool used for the VR experience during the workshop. This application was conceived and developed by Haraldur Thorvaldsson, Hilmar Gunnarsson, and Johan Hanegraaf, founding the company in 2017. Embracing the slogan of "design, mix & share realities" (Arkio, n.d.a). Arkio is a versatile software instrument, with support of a number of applications. These are virtual reality (VR), desktop, and mobile. The feature most important for this paper is its capacity to facilitate collaborative engagement. Arkio supports up to 25 participants concurrently within the VR environment. Furthermore, integration with various 3D applications such as Rhino, Unity, SketchUp, and Revit, are supported. Thereby creating more utility within the field of urban development (Arkio, n.d.).

3.2.1 A Deep Dive into Arkio

Arkio mentions multiple components of the tool that are relevant to the workshop. First is so-called fast solid modeling. Parametric volumes can be created, with the additional functionality of slide, snap, glue, and stack. This gives the tool an overall easy learning curve to start with creating adjustments. The second important component is cross-platform collaboration. This allows for the tool to be used on desktops, tables, or phones where it is accessible to the average user. Third is workflow integration. 3D models and scenes from various external programs (e.g., Rhino, Revit, etc.) can be imported and explored within Arkio (Arkio, n.d.b). These can be exported back to their original program. This is great for creating detailed models of the project area beforehand, allowing participants a more immersive experience during the workshop due to a more detailed model, which could not have been achieved in Arkio itself. Fourth is the Arkio cloud, which allows for this interaction with other programs. 3D models and images can be uploaded and downloaded from the cloud on any device, no manual transfer of files are therefore needed. Fifth is the possibility to model at any scale from scale models to human scale (Arkio, n.d.b).

3.2.2 User Interface of Arkio

The User Interface (UI) varies depending on the application, it differs between laptop and mobile devices compared to VR application. In this paper, the VR UI is explored since it is used during the workshop. Figure 5 illustrates the possible design functionality within the UI circle of Arkio.

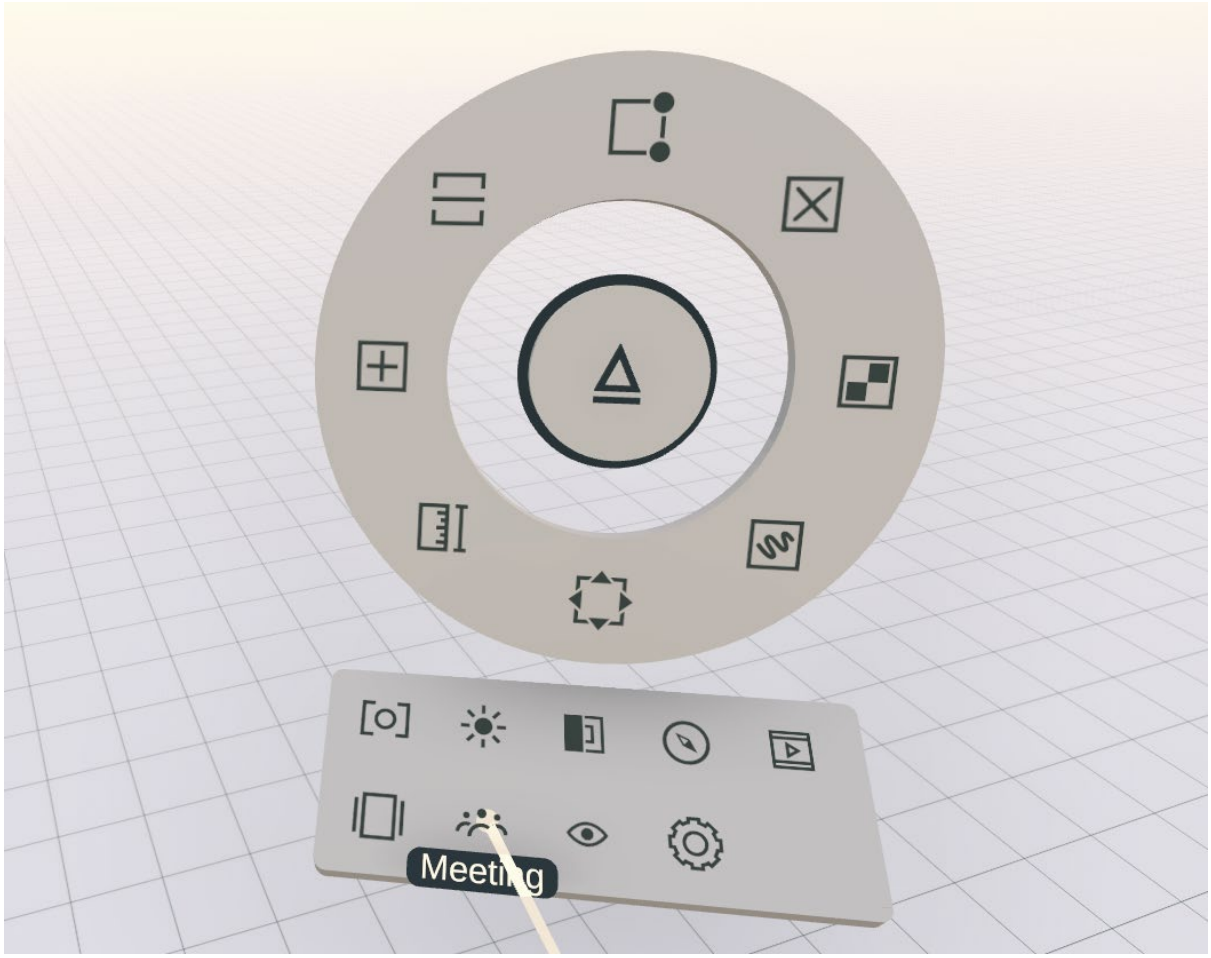
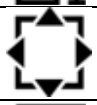


Figure 5: Illustration of UI circle in Arkio VR (Arkio, 2023).

As mentioned in the literature, giving participants constraints within the VR environment is important for ease of use. Arkio has a large number of functions as seen in Table 10, however for this paper, only the move and delete function are important.

First is the create function. This function allows the designer to create new elements within the model. Elements that can be added via the create function are basic forms, trees, landscaping elements, people, cars, and furniture. The second functionality is delete, which deletes the elements from the model. Third functionality is Edit. This allows the designer to change existing shapes within the model. Examples of this are increasing the size of a tree or editing the shape of a building. The fourth functionality is split. This allows the participant to split a shape into floors. The fifth functionality is color. Elements created in Arkio all have neutral coloring as a standard function. This functionality allows the designer to make trees green for example. The measure function is relatively straightforward. This allows the designer to measure elements within the model, for example the height of a tree or building. The move function allows the designer to move existing elements to a new location within the model. And the sketch function allows the designer to make notes within the model.

Table 10: Different functions within the Arkio Tool (Arkio, n.d.a)

Pictogram	Name	Function
	Create	Creates elements within the model
	Delete	Deletes elements from the model
	Edit	Edits existing shapes
	Split	Splits existing shapes into floors
	Paint	Colors different elements
	Size	Measures elements within the model
	Move	Moves elements within the model
	Sketch	Creates notes within the model

Another function that is really important for participants to understand is how to navigate the model within the VR environment. The participant has two different states when navigation the model. State 1; the participant in the IVE navigates the model with his or her right joystick. Holding a thumb forward allows the participant to see a blue line, when letting go the participant teleports to the location the blue line indicated (Figure 6). The designer could also turn around via right thumb turning left or right. The participant can enter another state of the model by pointing the blue line strait up. State 2; the model is shown in an AR environment. This indicates that the participant sees the model in scale format and their surroundings of real life. In this state it is important for participants to know how to move, rotate and scale the model to their liking. This is done via the side buttons on the controllers of the Oculus quest 2, shown in figure 7. Pressing one button allows the participant to move the model. Pressing two buttons allows the participant to rotate and scale the model via movement of the arms. Closing the arms increases the scale, widening the arms decreases the scale while rotation of the arms rotates the model.

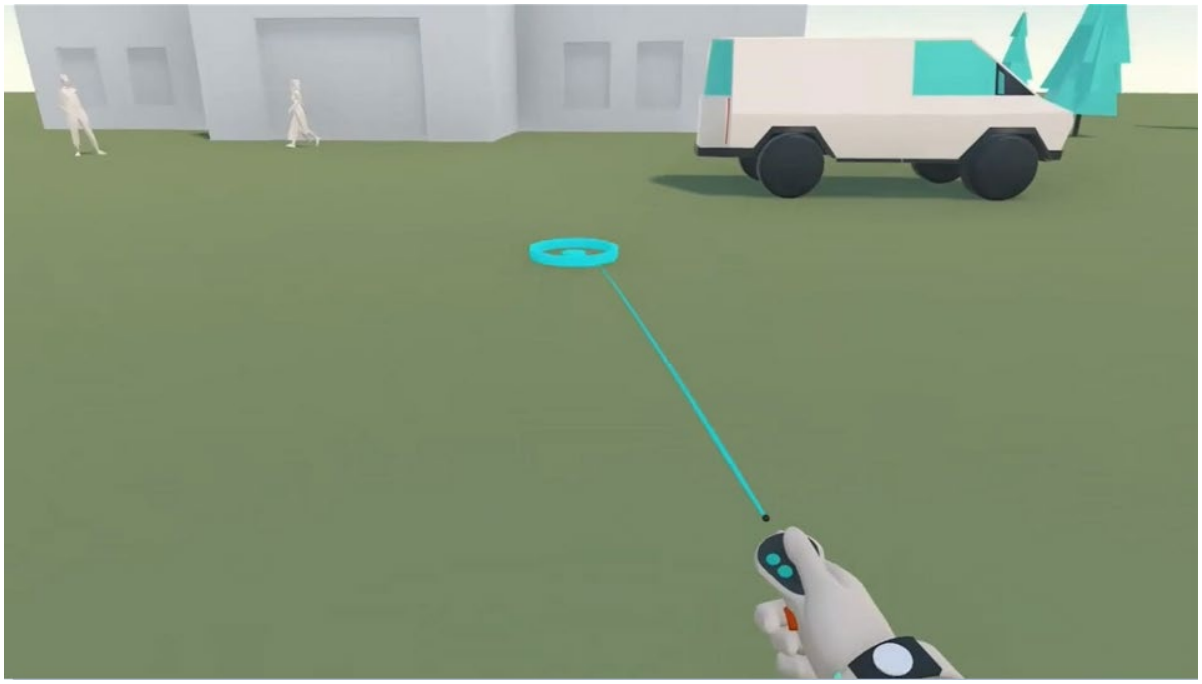


Figure 6: Navigation within the Arkio IVE (Arkio, 2020).

Figure 7: Controllers of the Oculus Quest 2.

3.3 Workshop

This chapter endeavors to provide an elucidation of the workshop, offering details that can facilitate replication of the outcomes. It encompasses an examination of various key facets, including participants, workshop's location, configuration of the session, scenario presentation, questionnaire design, and the ensuing transcription methodology.

3.3.1 Participants

The objective of this workshop is to ensure simultaneous immersion. Due to the limited availability of only two VR headsets within the scope of this research, the workshop will be conducted in pairs. Pairs facilitate the desired level of communication and discourse within the VE. For statistically robust qualitative research outcomes, a minimum of ten participants are engaged in the workshop (Creswell & Creswell, 2018). Since there can only be two participants immersed at the same time, this will take at least 5 sessions. The participants are between the age of 20 to 30. As mentioned in the literature review section, it is important to acknowledge that younger individuals are comparatively less inclined to partake in the participation process. Consequently, the workshop focuses on the student demographic to assess their interaction with emerging technology and gauge their willingness to potential future participation opportunities (Den Boer, 2022; Herring, 2007). Potential participants are contacted through the researcher directly via word-of-mount, email, or text messages. The workshop was approved by the ethics commission associated to the TU/e before recruitment of participants commenced.

3.3.2 Location

The venue for the session is situated on the campus of the TU/e. The Vertigo building is equipped with multiple reservable rooms. To adhere to the spatial requirements outlined by Atkinson (2022), in accordance with established guidelines, a minimum spatial allocation of 2x2 meters per individual (equivalent to 4 square meters) is required. Consequently, a spatial allocation of no less than 20 square meters, ensuring ample room for both immersive experiences and the accommodation of research personnel should be used.

3.3.3 Setup

During the workshop, Arkio serves as the designated tool for facilitating participants' within the VE. This tool uses specialized VR headsets and controllers, allowing individuals to immerse themselves in the IVE. Consequently, a minimum of three sets of glasses and controllers is required. The specific brand of glasses and controllers employed in the workshop is denoted as "Oculus" and is purchased as part of the research project CoHeSIVE (Dane & Evers, 2023). Establishing a connection between the Arkio system and a personal computer is an important factor to the workshop. This facilitates the researcher's ability to monitor and analyze participant interactions within the IVE without the need for direct immersion in the virtual environment.

Notably, Arkio possesses the capability to capture and archive sessions within the VE. The recorded data is transferable to a personal computer via a link cable. Nonetheless, it is important to supplement these recordings with additional voice recording devices. This is due to the importance of audio data in contributing to the overall research outcomes.

Figure 8 presents an illustration of the experimental configuration, adapted from Chowdhury (2021). Within this setup, a group of (2-4) participants are fully immersed within a virtual environment. Here they engage with a three-dimensional (3D) model. Subsequent modifications to the 3D model are reflected in the visual output through the participants' virtual reality glasses. This immersive context facilitates intra-designer communication for collaborative decision-making. The virtual environment is also connected to a personal computer or laptop. The

researchers can therefore monitor the ongoing activities within the virtual environment. This allows researchers to offer assistance to the designers in the event of technical challenges, inquiries pertaining to given attributes, or any other questions. A casting device enables the headset to project an image of what the participant sees onto another device. This could be achieved via the app on a mobile device or Google Chromecast connected to a TV for example. The casting functionality allows the researcher to view the scenario from the participant's perspective, allowing for fast and accurate assistance if needed.

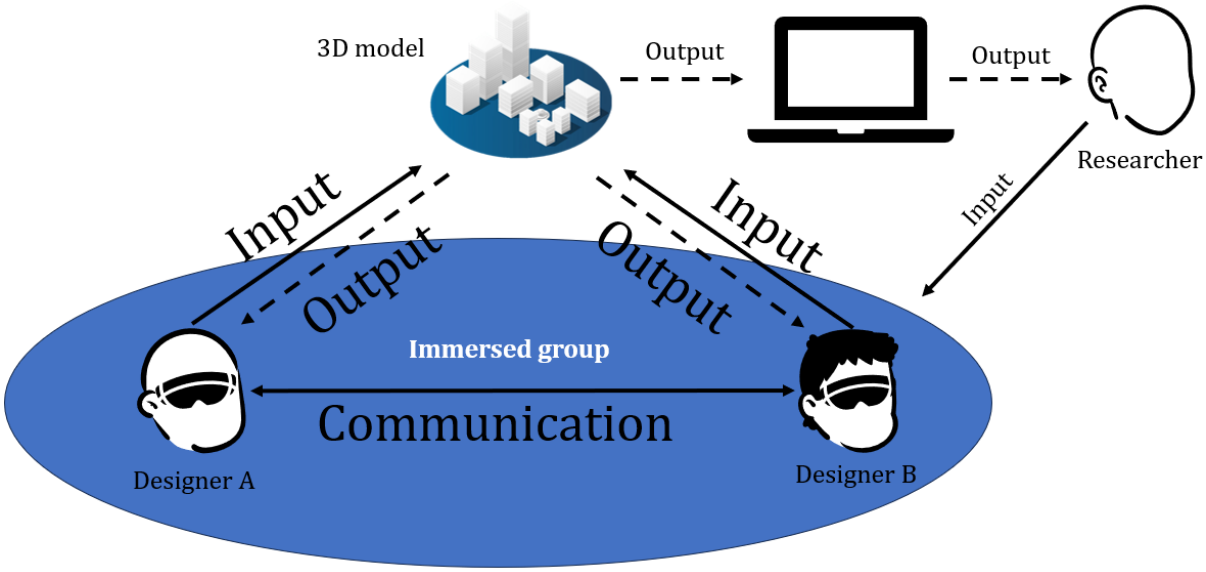


Figure 8: Illustration of the setup for the workshop

Illustrated in Figure 9 are the spatial confines designated for the participants. As mentioned in Section 3.3.2, each participant is afforded a minimum of 2x2 meters of space (Atkinson, 2022). It is worth noting that participants are individually confined to their designated boundaries. This is a precautionary measure aimed at preventing any potential collusion. These spatial boundaries are set by the research team before the immersion of the participants.

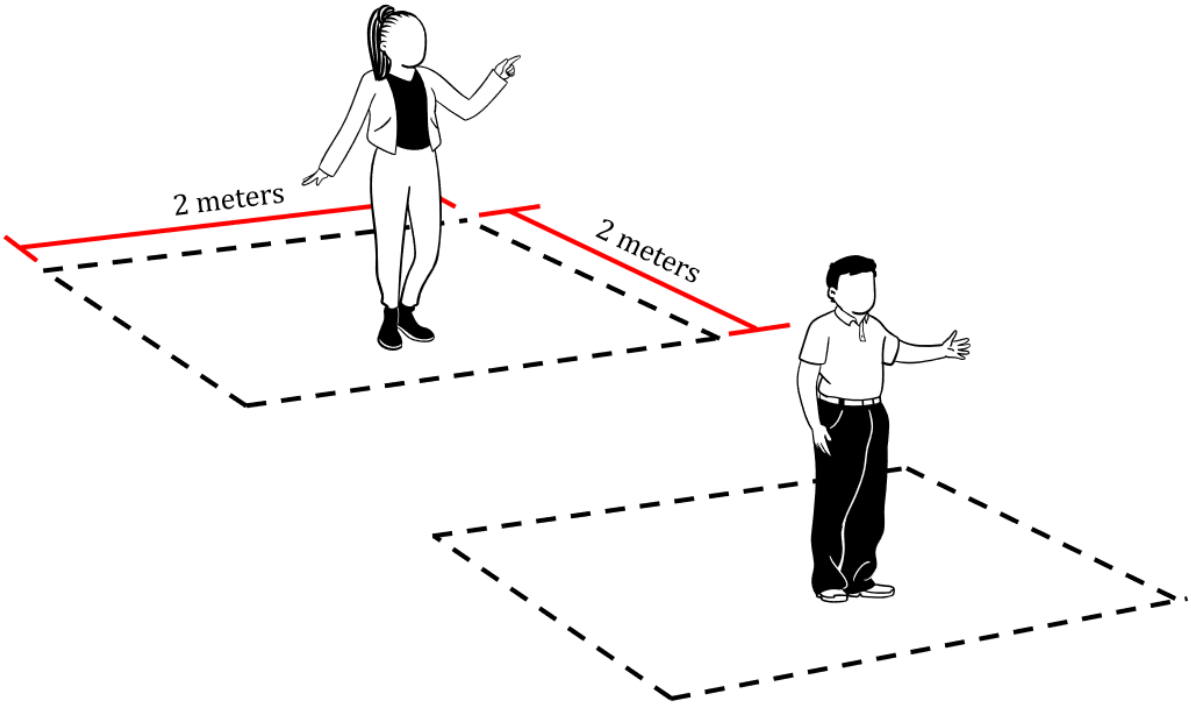


Figure 9: Illustration of boundaries for participants.

3.3.4 The Session

This subsection explores the overall session of the workshop in further detail. Table 11 shows an overview of the session.

The session starts with a PowerPoint presentation, elucidating the workshop's purpose and the broader research context. Firstly, it explains the co-design methodology and the underlying concept of IVE, including the overarching research objectives. Subsequently, the presentation transitions to an elucidation of the Arkio tool, its UI and assorted functionalities. This kickoff presentation has a timeframe of 10 to 15 minutes.

Following the introductory presentation, participants gain access to the virtual environment. A trial session designed to familiarize them with the Arkio tool. This phase is about exploration of fundamental functions, such as creation, deletion, and navigation within the IVE. For this purpose, a designated test IVE is provided. During the trial phase, participants are immersed in pairs, and the exploratory IVE experience is to be contained within a maximum timeframe of 15 to 30 minutes.

Subsequently, a break is afforded to the participants, instituted to mitigate VR sickness. During this interlude, a secondary presentation is administered. This elucidates the research area of Eindhoven Central Station. Participants are allowed to manipulate the design during the second IVE session. This presentation explains the different attributes delineated in the preceding chapter, delving into their effects on the environment. The presentation culminates with a scenario, featuring diverse participant roles. The duration of the overall break period is approximately 20 minutes. This permits participants a respite before the second IVE session.

Participants assemble within the IVE in the pre-defined area of Eindhoven central station. Here they enact the scenario described in section 3.3.5. Throughout this phase, conversational interactions and visual focal points are captured via recording devices. This session extends for a total duration of approximately 30 minutes. Participants are able to take breaks, assume seated positions, or discontinue their participation at their discretion. A brief cumulative break of 5-10 minutes may also be incorporated.

Upon completion of the final IVE session, participants are directed to complete a survey. This survey centers on the theme of tool integration. It is designed to take no more than 15 minutes to complete. Subsequently, participants engage in a collective discussion, to reflect upon their workshop experiences, delve into design decisions, and more. The overall duration of the workshop is within a time frame not exceeding 120 minutes.

Table 11: Summary of the workshop session.

Part of the session	Goal	Duration
Introductory presentation	Introduce: • The goal of the research. • The tool used in the session. • The concept of co-design.	10-15 minutes
Trial VR session	Get an understanding of: • The tool. • The UI.	15-30 minutes
Scenario presentation	• Give participants a break from the VR environment. • Explain the scenario and attributes	20 minutes
VR scenario	• Allow participants to design a public space based on the pre-described scenario. • Monitor communication between participants	30 minutes
Survey	Give answers to the following subjects: • Personal background • Prior experience • Learning experience • Usability • Communication • End result • Future use	15 minutes

3.3.5 Scenario

The scenario revolves around the central station of Eindhoven. The model is based on a preliminary design by Dane & Evers (2023) and serves as a starting point for participants (Figure 10). Within this framework, participants are encouraged to propose alteration and refinements that would render the proposed new plan acceptable to them based on a role assigned at the start of the session. The first role is as if he or she were a newly arrived inhabitant of the area. The second role is to look at the design throughout the scope of the municipality. This participatory engagement is structured to immerse individuals in the scenario and spark discussion. However, the goal remains consistent for both parties: creating a healthy public space and aligning with the core objectives of the KnoopXL initiative on connectivity.

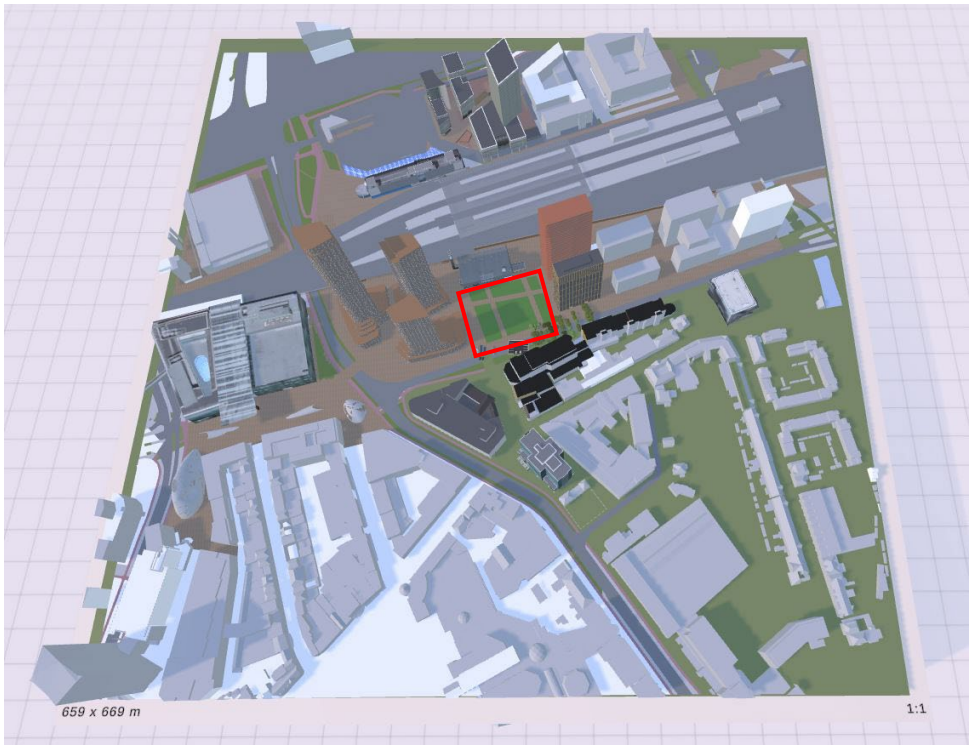


Figure 10: Base model of Eindhoven central station.

During the workshop, participants do not create their own attributes. These attributes already exist within the model, and participants only need to move them to their desired locations. The use of attributes is optional, and it is not mandatory to apply all attributes. Figure 11 illustrates a close view of the model with the starting positions of the attributes.

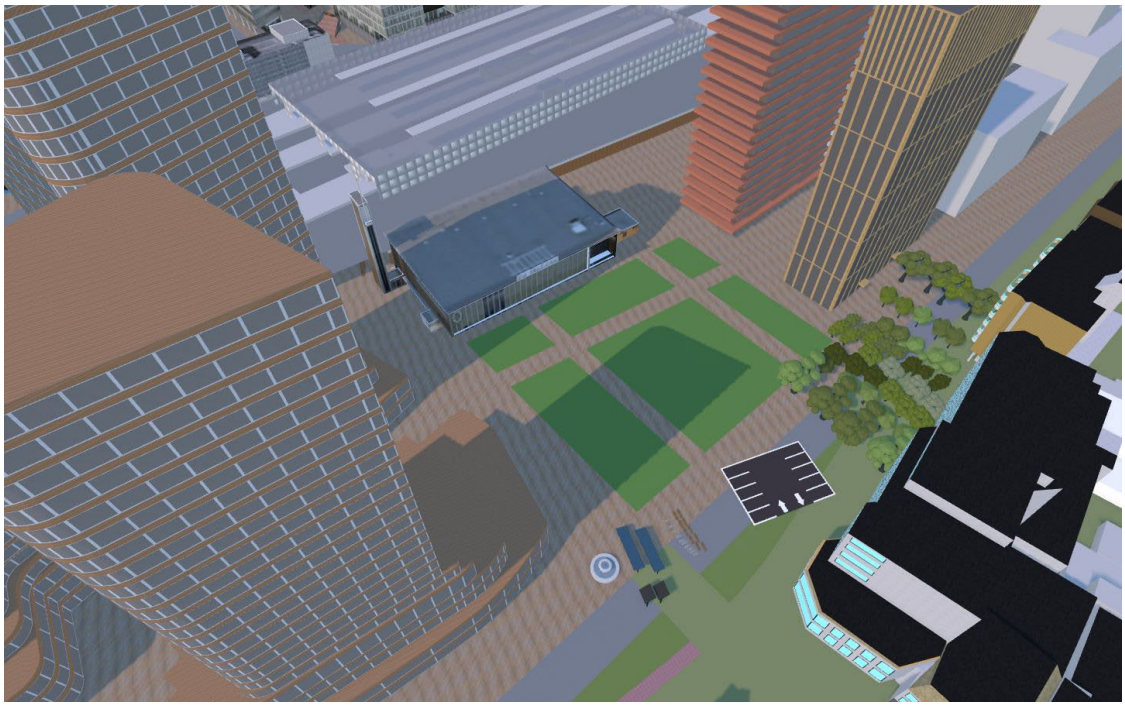


Figure 11: Public square to be designed by participants and attributes starting locations.

Defining the attributes before organizing the workshop enables the expert to guide participants throughout the process. Non-experts may not have a comprehensive understanding of all the

elements involved in designing a public space. When participants have a clear understanding of the attributes they need to address within the public space, it encourages a more thoughtful decision-making process.

3.3.6 Questionnaire

A concluding survey is administered at the end of the workshop and encompasses six different categories. Appendix A shows the question format of the survey. Firstly, it involves a personal background assessment. Respondents provide answers to socio-demographic information such as age, study direction, their living environment, and to a few questions aimed at determining their personality traits. The personality traits are determined using the "Ten Item Personality Measure (TIPI)". This test establishes fundamental baseline characteristics (Gosling et al., 2003). As mentioned in the literature (Den Boer, 2021), it is noteworthy that the willingness to engage in participation in urban development is influenced not solely by the scope and intricacy of the project but also by sociodemographic and personal variables. Therefore, it is suggested that diverse personality traits could yield different outcomes within the experimental framework.

The second section of the survey delves into participants' previous encounters with the tools and methodologies employed during the workshop. This part of the survey assesses participants' familiarity with co-design, VR technology, and their involvement in urban development initiatives. Prior experience with VR, co-design, or participation in such contexts can exert an influence on the design process and its outcomes. This could impact aspects like user comfort, efficiency, creativity, and the adept utilization of VR tools and functionalities.

The third section of the survey is dedicated to assessing the participants' learning experience during the workshop. It includes questions related to participants' comprehension of the workshop's objectives and attributes. Additionally, there is a query regarding the overall duration of the workshop.

The fourth section of the questionnaire is dedicated to evaluating the usability of the VR tool within the framework of co-design. This section seeks (i) to ascertain whether the utilization of the VR tool enhances the overall user experience, promotes a sense of safety (if the participants feel safe within the IVE), identify potential drawbacks, and (ii) opinions on the perceived ease of use of the VR tool.

The fifth section of the questionnaire centers on the examination of the communication experience during the workshop. Within this section, attention is directed towards analyzing the quality of communication among participants immersed within the IVE, assessing the interactions between participants and the researcher, and exploring the advantages and disadvantages associated with group immersion in the IVE.

The sixth section of the questionnaire addresses participants' willingness towards future utilization of the VR tool. Specifically, it seeks to gauge participants' preferences for employing this tool in public design assignments within the context of urban development, relative to more conventional methodologies and tools such as surveys, face-to-face meetings, and public hearings. Additionally, this section elicits feedback about the experimental process itself.

3.3.7 Protocol Analysis

Protocol analysis, employing a predefined coding scheme, serves as a methodological approach for various design activities (Chowdhury, 2020). This approach primarily relies on the collection of qualitative observational data, as highlighted by Kan and Gero (2017). It serves as an empirical

research technique for probing into the cognitive behaviors and thought processes commonly embraced by individuals engaged in problem-solving activities (Chowdhury, 2020; Lister & Hurst, 2020). Within the realm of collaborative design endeavors, researchers frequently opt to employ protocol analysis techniques as a means of investigation (Chowdhury, 2020). The concept of "thinking aloud" during problem-solving signifies that individuals verbally articulate their thoughts while actively addressing the design problem. Notably, this approach does not involve the interpretation of the expressed thoughts. It is important to acknowledge that protocol data may not always be comprehensive, as participants may only verbalize a subset of their cognitions. Therefore, protocol analysis possesses inherent limitations, particularly in its capacity to capture non-verbal thought processes during the design process. Consequently, the realm of non-verbal communication often remains underexplored within this methodology.

In the context of protocol analysis, a crucial element is segmentation, referring to the procedure of partitioning spoken text into discrete segments (Lister & Hurst, 2020). Table 12 employs coding inspired by Chowdhury's (2020) research, which shares a similar investigative scope. Four primary communication facets are identified. The first pertains to communication control, wherein the monitoring of conversational flow is undertaken. This includes instances of tool-induced interruptions, interruptions from other design team members, or conversational shifts driven by questions. The second category encompasses design communication. Discussions concerning design-related tasks within the given scenario, such as ideas or the positioning of a 3D object within the environment. The third category, social communication, encapsulates exchanges unrelated to scenario-related matters. Lastly, communication technology encompasses dialogues related to tool usage, encompassing discussions regarding the instrument's utility or actions performed using the tool.

Table 12: Coding for communication control during the workshop used in protocol analysis.

Communication	**Code**	**Description**
Communication control		Flow of conversation
Interruption by member	IBM	When a design member interrupts another member.
Interruption by instrument	IBI	When a design member is interrupted by instrument functioning. E.g. wrong button, instrument shutdown.
Handing-Over the conversation	HOC	Handing over the conversation from a design member to another member, possibly through questions or by specifically naming the next speaker. E.g. “You know?”
Pause	PAU	Pausing during the communication.
Design communication		Design related interaction
Scenario-related communication	SRC	When design members talk about scenario-related things.
Social communication		Social interaction
Non-scenario-related social communication	NSRSC	When design members talk about non-scenario-related things.
Communication technology		Tool related
VR instrument	VI	When design members discuss the use of tools for design in the VR environment.
Examining	EXA	When a design member examines what has been done by using the instrument.

3.3.8 Analysis

Both Spearman's Rank Correlation and Binary Logistic Regression analysis methods are employed in this thesis. Spearman's Rank correlation analysis is utilized to determine the correlation between the independent and dependent variables outlined in Table 13. This method assesses the strength and direction of the association between these variables, at least on an ordinal scale (Field, 2013; Laerd Statistics, n.d.a). The analysis is conducted using the SPSS software, employing a two-tailed test to determine if a significant correlation exists in either direction. The calculation involves ranking the data, determining the differences between ranks, and applying Spearman's Rho formula (Field, 2013; Laerd Statistics, n.d.b).

The results are represented by the symbol ρ (rho), ranging from -1 to 1. A result of -1 indicates a perfect negative monotonic relationship, 1 indicates a perfect positive relationship, and 0 indicates no monotonic relationship (Field, 2013; Laerd Statistics, n.d.b). The significance level determines whether the relation is statistically significant. If the significance level is above 95% certain ($p<0.05$), the null hypothesis of 'no correlation between the variables' can be rejected, suggesting a significant correlation exists (Field, 2013).

Table 13: Variables for Spearman's Rank Correlation analysis.

Independent variable	**Variable type**
Extraversion	Interval
Openness	Interval
Agreeableness	Interval
Conscientiousness	Interval
Emotionality	Interval
Age	Ratio
Living environment	Ordinal
Dependent variable	**Variable type**
Likelihood of participation	Ordinal
Confidence in the final design	Ordinal

The Binary Logistic Regression (BLR) is used to predict the probability of an event with two possible outcomes. These outcomes are as follows: (i) the participant would not partake in the method employed during the workshop again if organized by their local municipality, or (ii) the participant would engage in the method employed during the workshop under the same circumstances. The variables predicting this outcome include the big five personality traits, prior experiences, study background, and age. The formula used to predict to what category the dependent variable belongs to is shown below.

$$P(participate) = \frac{e^{(\beta_0+\beta_1 X_{1i} + \beta_2 X_{2i}+\cdots)}}{1 + e^{(\beta_0+\beta_1 X_{1i} + \beta_2 X_{2i}+\cdots)}}$$

$P(participate)_i$ represents the probability that individual *i* will participate. The coefficients β_j are estimated through the Maximum Likelihood Estimation (MLE). Finally, X_{ji} is the score on independent variable *j* for individual *i*, see also Field (2013).

Each independent variable has a coefficient (β) as can be seen in the formula. This coefficient indicates the direction of the correlation, this could be positive or negative. For this analysis, the utility of no participation is set as the base value (0, exp(0)=1). Therefore, a positive coefficient indicates if the predictor variable increases in value, the odds of the participant being likely to participate again in this method increases and a negative coefficient indicates if the predictor

variable increases in value, the odds of the participant being likely to participate again in this method decreases. The magnitude of the coefficient indicates the strength of the relationship and is used to calculate the odds ratio (Field, 2013). Table 14 illustrates the variables used in the Binary Logistic Regression Analysis.

Table 14: Variables used in the Binary Logistic Regression Analysis.

Dependent variable
Likelihood of participation
Predictor variable
Extraversion
Openness
Agreeableness
Conscientiousness
Emotionality
Co-design experience
VR experience
Participation experience
BE study background
Age

3.4 Conclusion of the Methodology

In summary, this thesis employs a workshop where 20 participants aim to design the public square of Eindhoven Central Station in a Virtual Environment as duos within a 30-minute time limit. Before entering this design scenario, participants receive context on the method, tool, and model, allowing them time to adapt to the attributes, controls, and overall goals of the workshop. A protocol analysis is performed to determine the overall flow of conversation and discussion topics, exploring the overall communication of participants. This is complemented by a survey, which is examined on an individual question basis, alongside a Spearman's Rank Correlation Analysis and Binary Logistic Regression Analysis. These analyses aim to determine whether personality or socio-demographic traits have any influence on participants' willingness to engage in this format again.

4. Results

The results derived from the 10 workshops involving a total of 20 participants. Given that there was no minimum required time, participants had the flexibility to conclude the activity at their discretion. This arrangement was implemented to address the potential of VR sickness. The timer would only cease once both participants confirmed they had completed the design. It's noteworthy that no workshop concluded prematurely due to VR sickness; rather, the conclusion was determined by participants' confidence in their final designs. Consequently, this caused a variety in the duration of workshops, ranging from 18 to 31 minutes. In this chapter, communication throughout the workshops is analyzed through protocol analysis. Following that, the design approach of the participants is examined, the survey responses are investigated, and finally, the results are analyzed via Spearman's rank correlation and Binary Logistic Regression analysis.

4.1 Protocol Analysis

The protocol analysis investigated two points of communication which are communication control and conversation topics. Communication control pertains to the overall flow of conversation, trying to answer questions such as how are people moving the conversation forward? Are participants interrupted by others or the instrument? And is there any pause in the conversation? Conversation topics aim to answer what participants are talking about during the workshop. This is categorized into three sections design, social, and tool communication. Table 15 shows the counted events.

4.1.1 Communication Control

Interruptions by a member (IBM) and instrument (IBI) were not common apart from workshops one and three. Participants were usually talking calmly, letting each other finish sentences. Interruptions caused by the instrument occurred due to accidental movement of attributes, changes in the size of attributes, entering of the IVE model, color change, and model deletion. Overall, the communication felt natural, people used questions, names, etc. regularly to hand over the conversation (HOC). A pause in conversation (PAU) was unusual, so there was a lot of communication during the workshops. Notably, workshop five had the largest total pause in conversation with 6 out of 30 minutes being a pause. Even in this case, there was an ongoing conversation for 24 out of 30 minutes. Moreover, a pause in conversation was not always detrimental to communication; pauses usually occurred due to activity within the VR model, such as moving attributes to their desired location.

4.1.2 Conversation Topics

The predominant focus of the workshop's discourse revolved around the scenario (SRC). Participants expressed design ideas, examples are preferences for an open area near the station, and a desire to place parking close to the established road. Conversation on context such as questions on the location of the city center or the sunlight distribution on the public square. Dialogue also covered different attributes, among them conversation on unidentified attributes, the purpose of attributes, and revisiting positives and negatives associated with attributes. Overall SRC was the most common topic throughout all workshops.

Examining (EXA) was the second most discussed topic. Two different design methodologies were frequently conducted. These are (i) tackling the design completely together, either attribute or area-related, or (ii) individual design choices and reviewing these together afterward. Even when duos did not design the complete square together step by step, examining still occurred regularly. This indicated that collaborative efforts were prevalent during the square's design. Participants

expressed enjoyment in exchanging ideas with each other, which could explain why the SRC and EXA were the most common conversation topics.

Conversation on tool use (VI) occurred throughout the workshop, typically the focus on immersion came before any other topic. Examples included discussions about their immersion in the model, recognizing connections between the model and the real environment, and observing the other participant's simultaneous immersion. Over time, discourse on the tool shifted to a more question-oriented discussion. These questions revolved around assisting with forgotten functions, such as navigation in the model (e.g., how do I enter the IVE again?), operations (e.g., how do I rotate the parking lot again?), and directions (e.g., I think I am lost, can you help me?). Also questions on functionality inquiry, such as if it was possible to change the paths of the park, copy-paste elements, group elements, and create more attributes. Despite the recurrence of this topic, such discussions were typically brief.

As for non-scenario-related social communication (NSRSC), it was non-existent within the workshops, usually not more than one sentence if it occurred at all. Small jokes or real-life experiences from the area occurred, however, these interactions were limited to just one sentence.

Table 15: Count of communication events and topics happening in the workshop.

Communication	Code	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Duration (minutes)											
		28	28	30	28	30	20	18	29	30	31
Communication control											
Interruption by member	IBM	4	4	6	1	1	1	3	3	1	2
Interruption by instrument	IBI	15	5	17	6	2	5	5	6	4	5
Handing-Over the conversation	HOC	20	13	13	21	7	18	12	14	14	20
Pause	PAU	0	7	1	5	8	0	2	2	3	0
Design communication											
Scenario-related communication	SRC	49	41	47	32	33	39	36	40	38	36
Social communication											
Non-scenario-related social communication	NSRSC	0	1	0	2	1	0	3	1	0	0
Communication technology											
VR instrument	VI	26	12	17	12	12	11	12	11	10	16
Examining	EXA	29	24	25	11	10	16	16	21	18	19

4.2 Design Approach Within the Workshop

Designs differentiated from each other, however, participants tackled attributes in a consistent order. Initially, parking was tackled, followed by the placement of the fountain. Subsequently, the area was designed with trees, benches, and a shelter. Participants started with parking due to the size of the attribute, dominating the overall design of the square. The fountain followed, emphasizing the center point of the square and countering the dull parking location. After this, participants usually designed the square either based on location (e.g., left to right) or based on attributes (e.g., trees followed by benches and finally shelter). Cooperation occurred throughout all workshops, as evidenced by the high occurrence of SRC and VI. Important to note is that even

if a participant had less of a grip on the Arkio tool, they actively participated to the best of their ability by providing design ideas, and feedback, and joining in on the discussion. Typically, the participant with a better understanding of the tool played a more active role in designing, placing the attributes, and assisting their partner. This highlights that a cooperative immersive experience enhanced the overall workshop experience.

Regarding the working environment, the majority of participants opted to remain seated throughout the workshop, with only two exceptions. One participant began the session standing but transitioned to a seated position after 18 minutes, ultimately completing the workshop while seated. Conversely, another participant initially sat but stood up after 15 minutes, concluding the workshop in a standing position.

Even though the design was not the primary focus of this thesis, examining recurring design decisions could strengthen the overall results and contribute to future research. Appendix B shows the results of each workshop. Design decisions during the workshop should be considered in a more general sense. Participants had only 30 minutes to design an entire public square, which is not enough time to create a final detailed design, including the exact location of attributes. It is more important to capture general design preferences and understand why participants made these design choices. Table 16 illustrates these recurring preferences, as attendees during the square design process indicated the reasons behind their choices.

Table 16: Reoccurring design decisions.

Design choice	**Why**
The parking lot is located close to the main road	• Easy access to parking • Leaving more room on the square for other functions • Ability to hide parking from the rest of the square
The fountain forms a centerpiece of their surroundings, including bench placement around the fountain	• Counteract the parking • Focal point of the design • Chill area
Shelter placed close to the parking lot	• People could be dry while waiting to get picked up • Payment point for parking
Low number of trees close to the station	• Give people entering the city a better orientation of their surroundings
Benches chosen based on their location (e.g., wooden benches more inside park, aluminum benches close to the station)	• Divide the overall space into functional zones

A thesis by a fellow student of the TU/e researched the influence of presentation mode on individual choice behaviour (Pagie, 2024). This research aimed to find user preferences for a healthy public space design. Findings show that users preferred to have a fountain present, maximizing the number of lampposts (9), the number of trees (15), and the number of benches (15). The final designs from the workshop show some comparable results to the thesis by Pagie (2024). In all designs, the fountain was incorporated. Users showed a preference for a high number of trees, with the minimum number of trees in a design being 13. In the survey conducted after the design phase, participants indicated a preference for the inclusion of lampposts in the model. Finally, users expressed a preference for a large number of benches.

4.3 Survey findings

After the design scenario concluded, participants completed a survey. This section explores the overall survey responses, divided into the following topics: personal background, prior experience, confidence in the final design, learning experience during the workshop, VR as a tool for co-design, communication and teamwork, and finally, the future use of VR in co-design for urban design.

4.3.1 Personal Background of Participants

Personal information, including age, gender, living environment, and study details, was compiled through the survey. Table 17 summarizes these findings. Later, these attributes are utilized for analysis to determine if any socio-demographic factors influence participants' willingness to engage in co-design with VR.

Table 17: Personal background information of participants.

Question	Answer
Age	• Range from 21 to 29 • Average of 25
Gender	• 15 Male • 5 Female
Living environment	• 1 Rural (0-3,000 inhabitants) • 1 Small town (3,000-10,000) • 2 City (10,000-100,000) • 16 Large city (100,000+)
Built Environment-related study	• 5 Yes • 15 No

4.3.2 Prior Experience with the Tool or Methodology

The survey consisted of mandatory questions to be answered on a Likert scale of 1-7, chosen for consistency with the TIPI test. Per question, participants were asked to elaborate on their answer for the previous question. For instance, if the initial question was, 'How confident are you with your final design?' and the participant responded with high confidence, the subsequent follow-up question would be, 'Could you describe why you have high confidence in your final design?' This format was selected to accommodate the intensity of the VR workshop.

The majority of participants lacked familiarity with co-design, VR, and participation in urban design projects (UDP). Notably, none of the participants responded with yes to all three aspects, making the combination a novel experience. Those acquainted with co-design primarily had a study background in BE. Previous VR experiences varied, ranging from gaming to participation in other research studies. Remarkably, only three attendees had prior experience in public urban project participation. Figure 12 illustrates the prior experience of the participants.

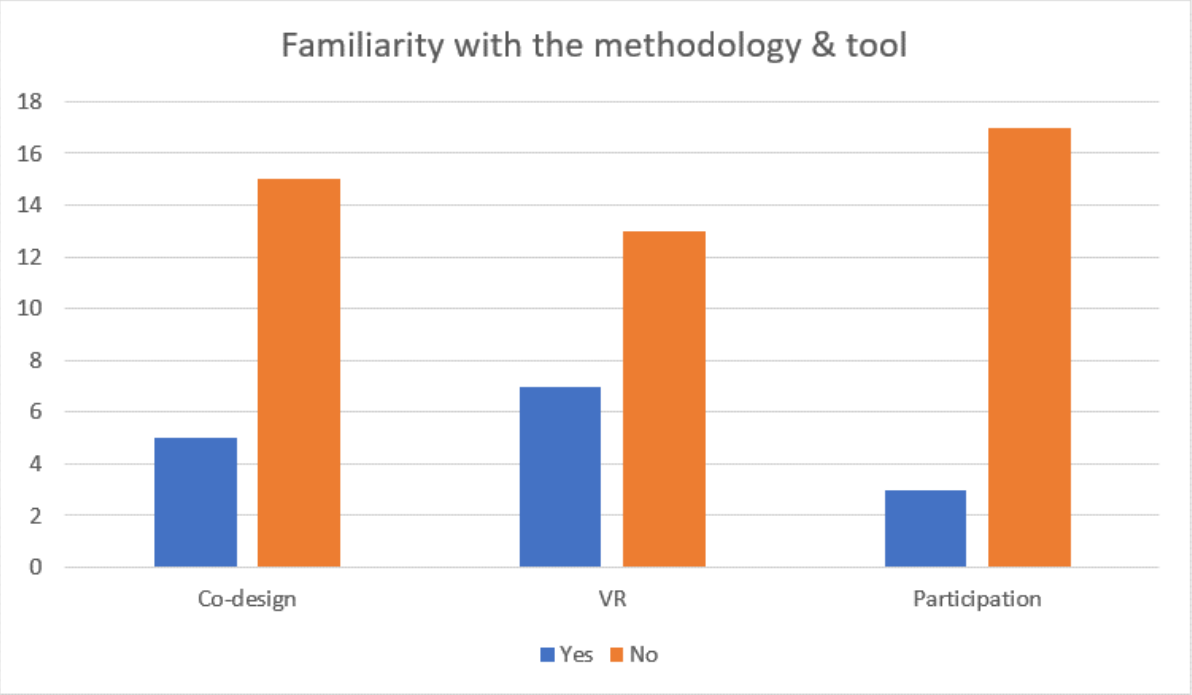


Figure 12: Familiarity of participants with the methodology of co-design and the tool of VR.

4.3.3 Confidence in the Final Design

Participants were questioned about their confidence in the design (Figure 13). Seven participants rated their confidence as neutral or lower. While all participants liked their final design, they were unsure if it met 'good' design standards in BE. They expressed uncertainty about municipal approval but were personally satisfied with the creation. One participant mentioned that 30 minutes is insufficient for creating a realistic design, as it doesn't allow enough time for thorough consideration, hence the low confidence level.

High confidence in the design typically resulted from attendees liking their final design. Cooperative efforts during the design process, the significant number of trees placed in the square, and the overall balance of attributes generally resulted in their high confidence in the design.

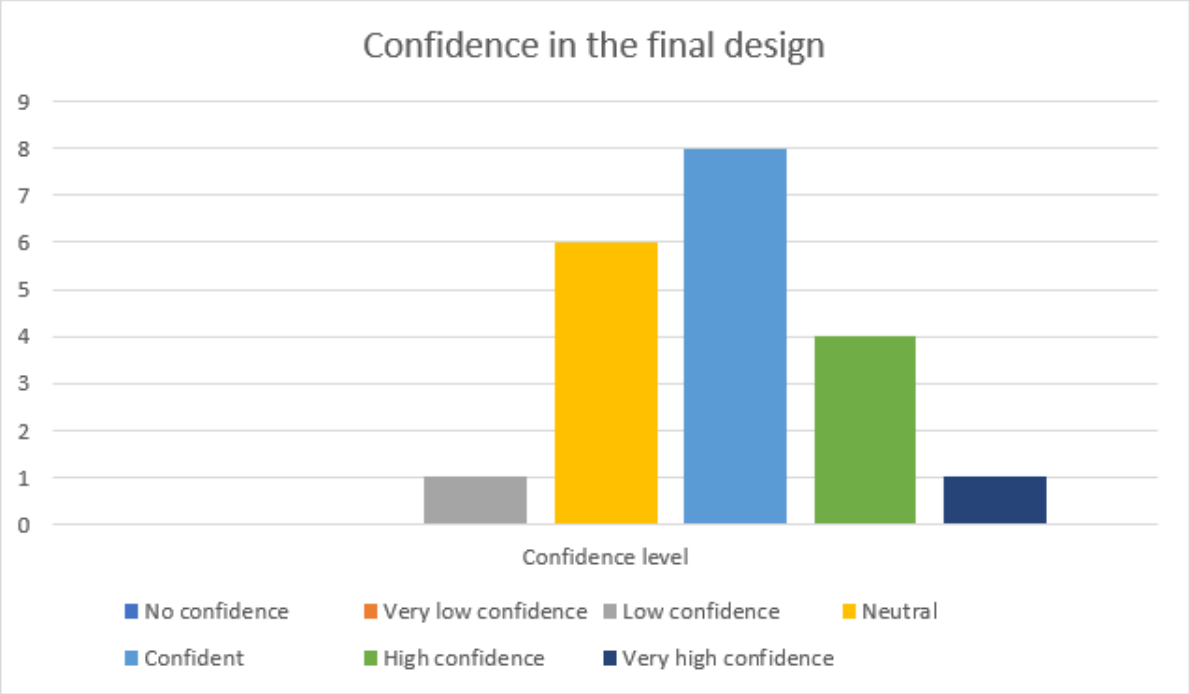


Figure 13: Confidence of participants in their final design.

4.3.4 Learning Experience During the Workshop

The following subsection focuses on the learning experiences participants gained during the workshop. These experiences are related to attributes, roles, goals, and time allocation for exploring and designing.

Attributes within the model were adequately explained during the workshops (Figure 14). For each attribute, a mood board was presented, followed by a discussion on the positives and negatives, before delving into the final design scenario. Two participants rated clarity of attributes as below average to poor. Unfortunately, due to time constraints, this workshop skipped the discussion of positives and negatives before participants entered the VR model. This highlights the importance of providing context to the model and its attributes. Interestingly, attendees reacted positively to the presentation of attributes beforehand, expressing that this discussion helped with their decision-making during the scenario.

Attendees were asked about attributes that were missing during the workshop which could improve the public space. Five mentioned the need for trash cans, four brought up streetlights, bushes, tables, and to possibility of changing the path were also mentioned.

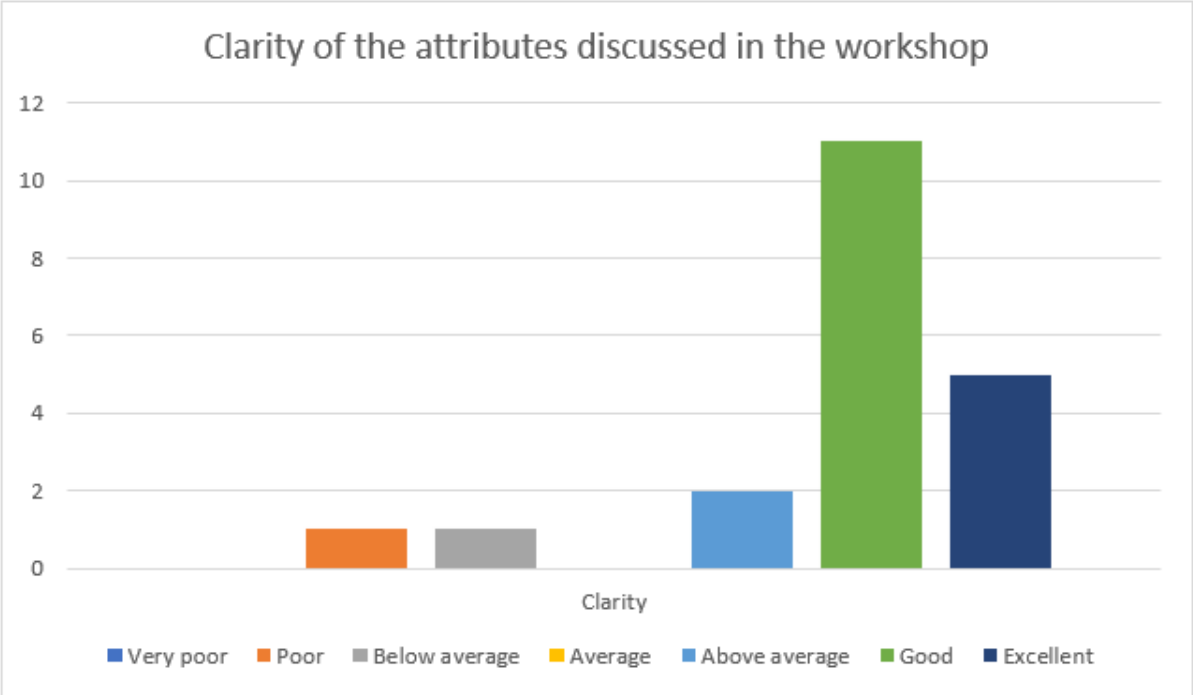


Figure 14: Clarity of the attributes discussed in the workshop.

Most participants had a positive experience with the roles of the new resident and municipality, although some improvements are suggested (Figure 15). Attendees faced challenges with the municipality as it lacked a clear goal for them. Understanding the government's preferences was difficult, especially with the absence of a defined budget.

The importance of providing context through presentation beforehand also becomes evident during this question. It is necessary to offer a general sense of municipal needs, such as saving costs, improving city connectivity, and addressing loitering. Attendees mentioned that different roles, in this case, the municipality, helped enhance immersion during the scenario.

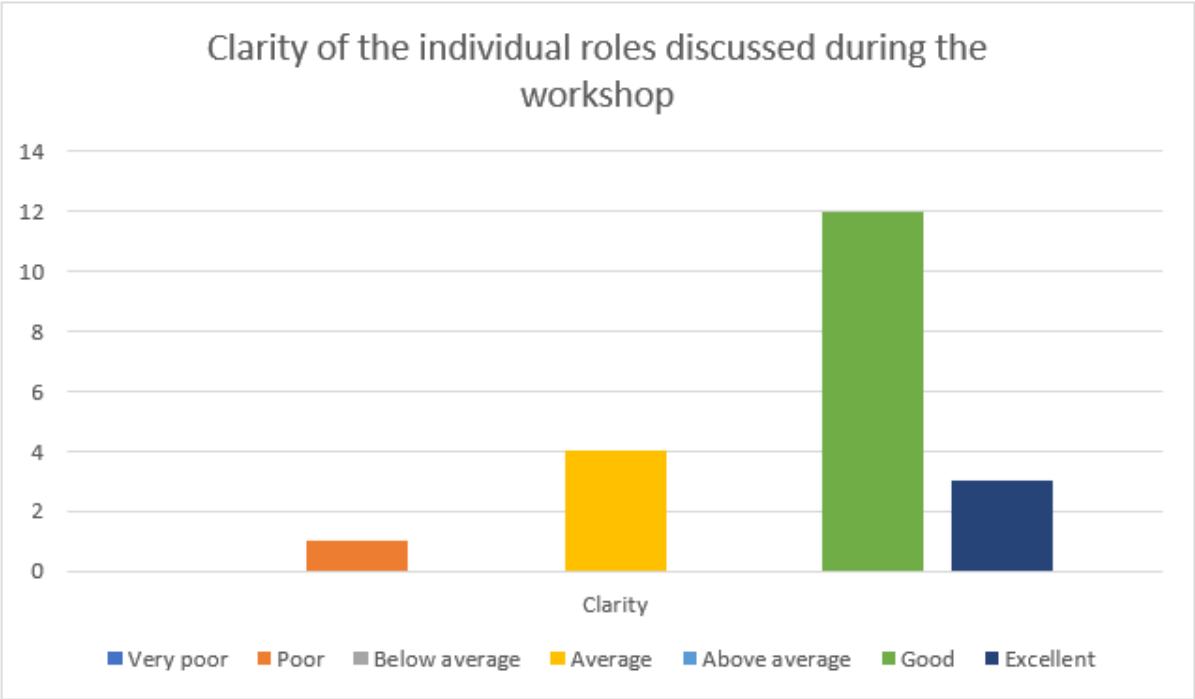


Figure 15: Clarity of the individual roles discussed during the workshop.

The workshop goal was discussed beforehand through a presentation format (Figure 16). Overall, participants provided positive feedback regarding the clarity of the workshop goals. This clarity stemmed from presenting the goal before attendees started their design, along with a sufficient explanation of what to expect during the workshop and its purpose. The overall objective, which was to design a public space in Eindhoven as a duo, was clear and easily understandable.

Some participants expressed a preference for a more detailed explanation of the VR tool and why it was chosen over other tools. Additionally, one participant was curious about the communication aspects the workshop focused on.

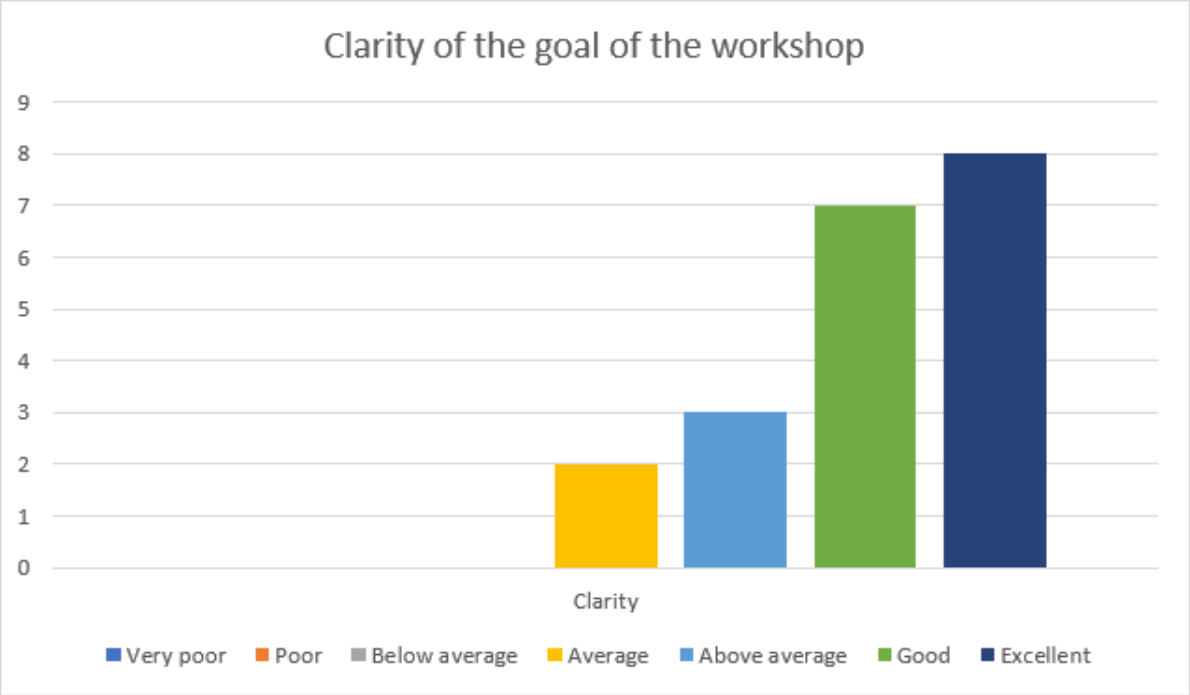


Figure 16: Clarity of the goal of the workshop.

During the trial session, participants focused on moving themselves within the model, adjusting the overall model, and manipulating attributes within the model. Overall, participants seem satisfied with the time allocated to explore Arkio before their design scenario (Figure 17). The attendee who expressed dissatisfaction with the time allocation misinterpreted the question; a later explanation mentioned prior knowledge of the VR tool. Exploration appeared to be mandatory before tackling the main design scenario, as multiple responses mentioned the preference for having explored the tool before the main assignment. Participants mentioned that the allocated time was neither too much nor too little, given that participants typically had 15 to 20 minutes for exploration.

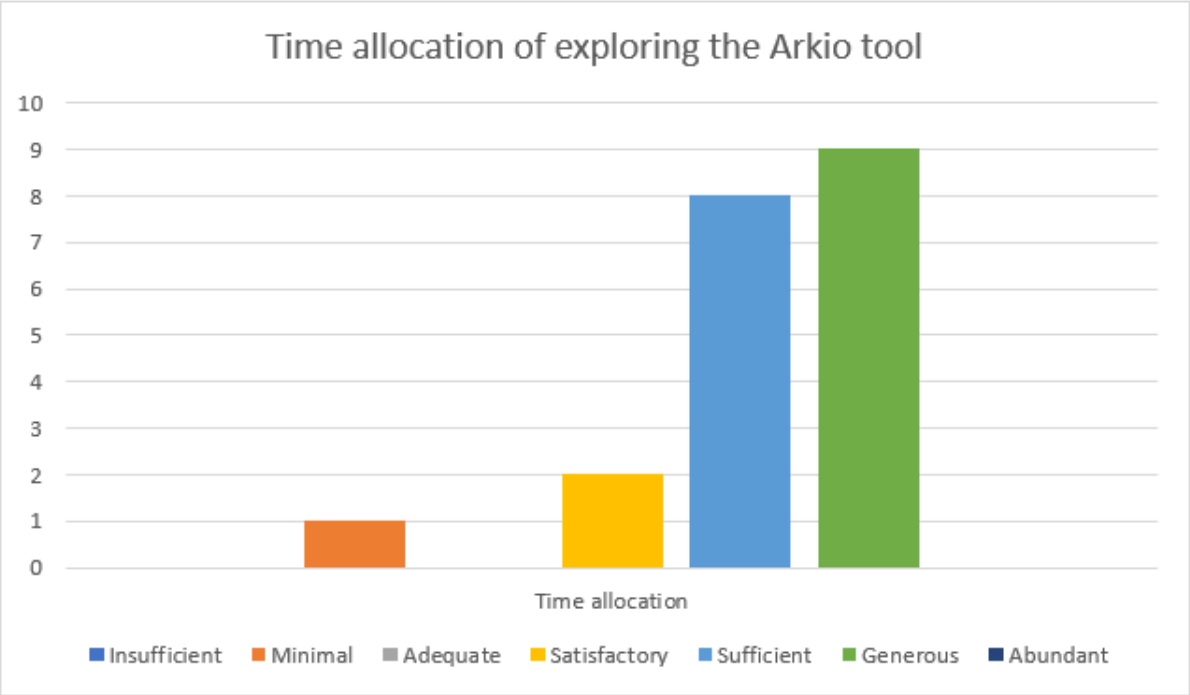


Figure 17: Time allocation to explore the Arkio tool.

Most of the participants expressed satisfactory to generous time allocation for the main design scenario (Figure 18). The 30-minute time limit enabled participants to make quick and precise decisions, as additional time might have led to increased indecisiveness due to prolonged hesitation. Another crucial factor is fatigue; nine out of twenty participants mentioned experiencing some form of fatigue, ranging from tired eyes and dizziness to headaches. However, during this stage, the discomfort did not reach a level where participants took a break or had to stop the overall workshop.

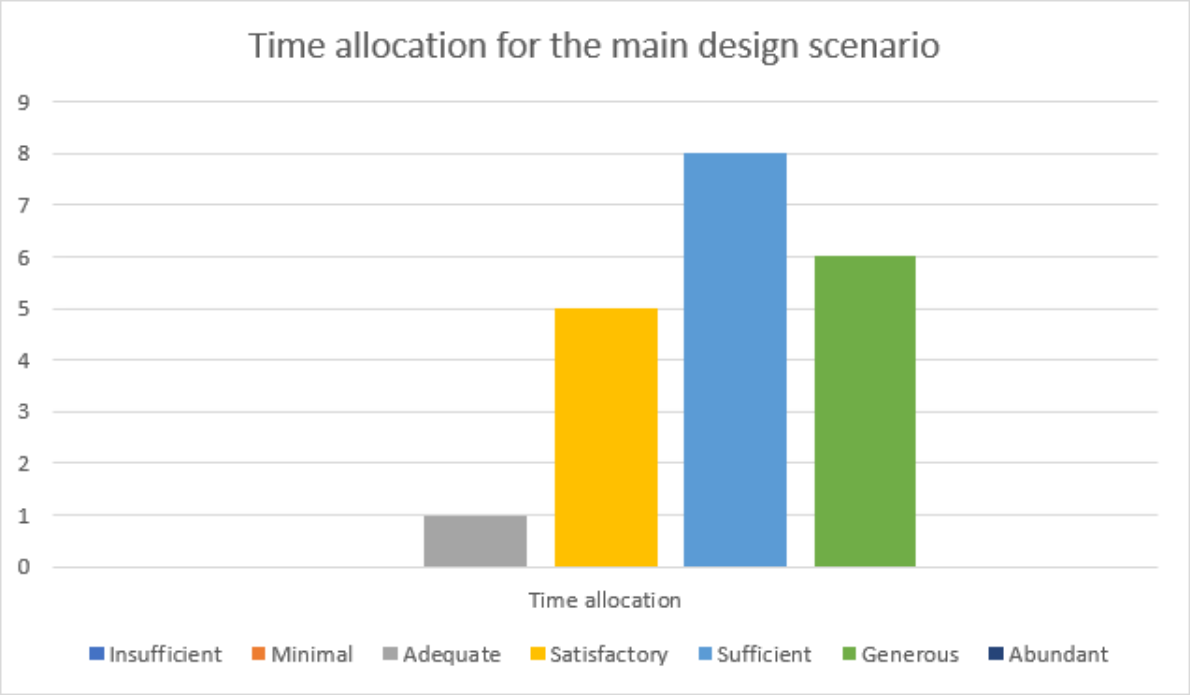


Figure 18: Time allocation for the main design scenario.

4.3.5 VR as a Tool for Co-design

This section explores the ease of use of the VR tool and its impact on participants' ability to design the public square of Eindhoven. Participants generally found the tool relatively easy to use (Figure 19). However, some participants who rated it as neutral or somewhat hard mentioned that the functions could be overwhelming and that it takes some practice to grasp the tool fully. There were also mentions of difficulties with elements accidentally being altered in size instead of moving.

Despite these challenges, the majority of participants described the tool as easy to use. They pointed out the simplicity of the design possibilities, with the constraint that participants could only move attributes that were already present within the model. Attendees appreciated the explanation of the tool using a painting metaphor, where the left hand represents the palette (interface menu for selecting different functions such as moving attributes, deleting, etc.), and the right hand acts as the brush to move elements. Even when some difficulty arose, the ability to ask questions proved helpful.

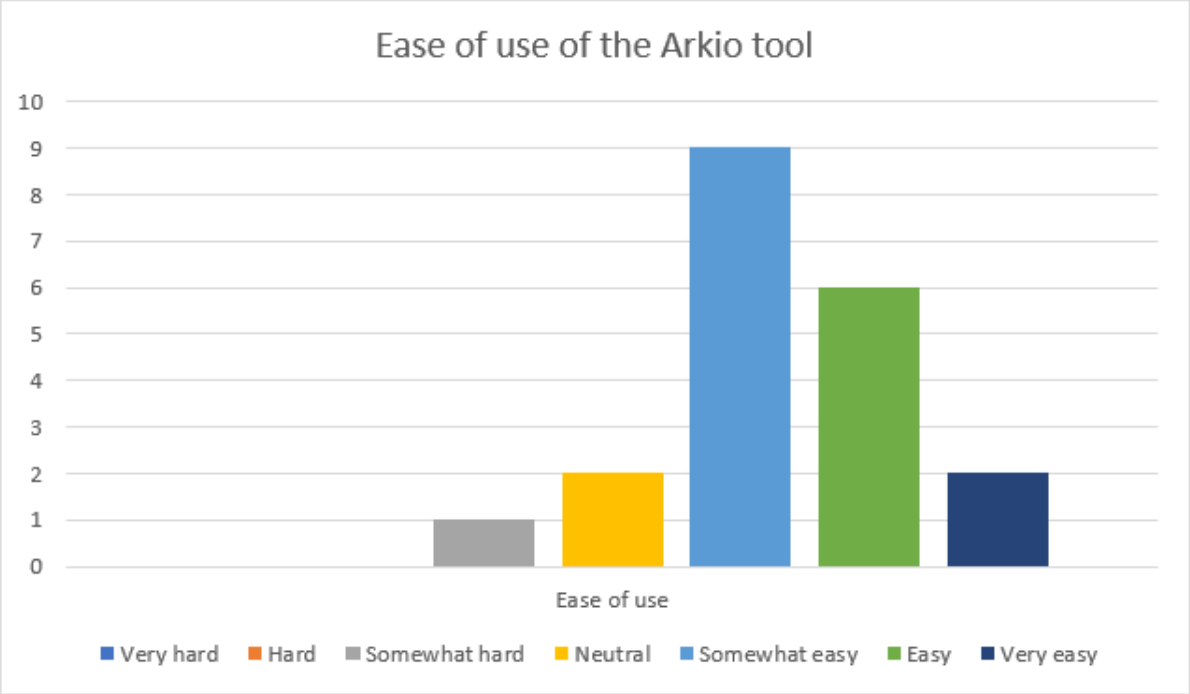


Figure 19: Ease of use of the Arkio tool.

Noteworthy is that participants either scored very high or low on for the question if VR enhanced the design compatibility (Figure 20). Eighteen attendees stated that the VR tool has enhanced their design experience. Multiple participants mentioned the various points of view allowed within an IVE and the broader model view. They also highlighted that the interactive design process assisted them in decision-making. Participants with lower ratings indicated that they liked the workshop overall but did not feel they acquired new skills in the realm of urban design.

Participants were also asked about the potential drawbacks of the VR tool in co-design. Some mention that the older generation might have a hard time getting to grips with the tool. Additionally, getting familiar with the tool is also time-consuming. Finally, potential costs to set up a 3D environment were raised.

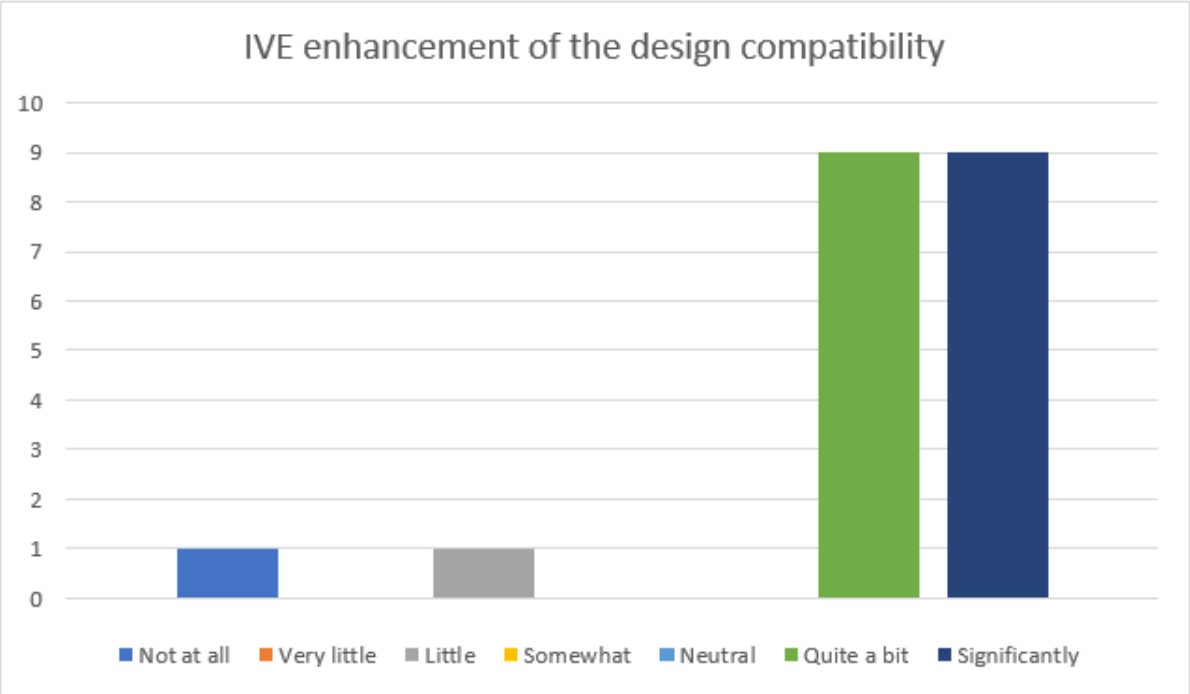


Figure 20: IVE enhancement of the design compatibility.

4.3.6 Communication and Teamwork During the Workshop

This section highlights the collaborative efforts and communication among participants during the workshops. They actively contributed design ideas and suggestions, which were integrated into the final design through collective input and discussions. Attendees addressed aspects such as the quantity and placement of trees, parking location, and the overall vision for the public square. This reflects the active engagement of participants in the workshop to witness their ideas in the final design.

Communication among group members is perceived as overwhelmingly positive (Figure 21). The interactions were characterized by fast, simple, and direct, enabling participants to understand each other's ideas. They enjoyed sharing design decisions, and even when splitting their work, nothing was considered 'permanent' until discussed collectively. This approach facilitated multiple perspectives on the design, a factor that attendees found to be positive.

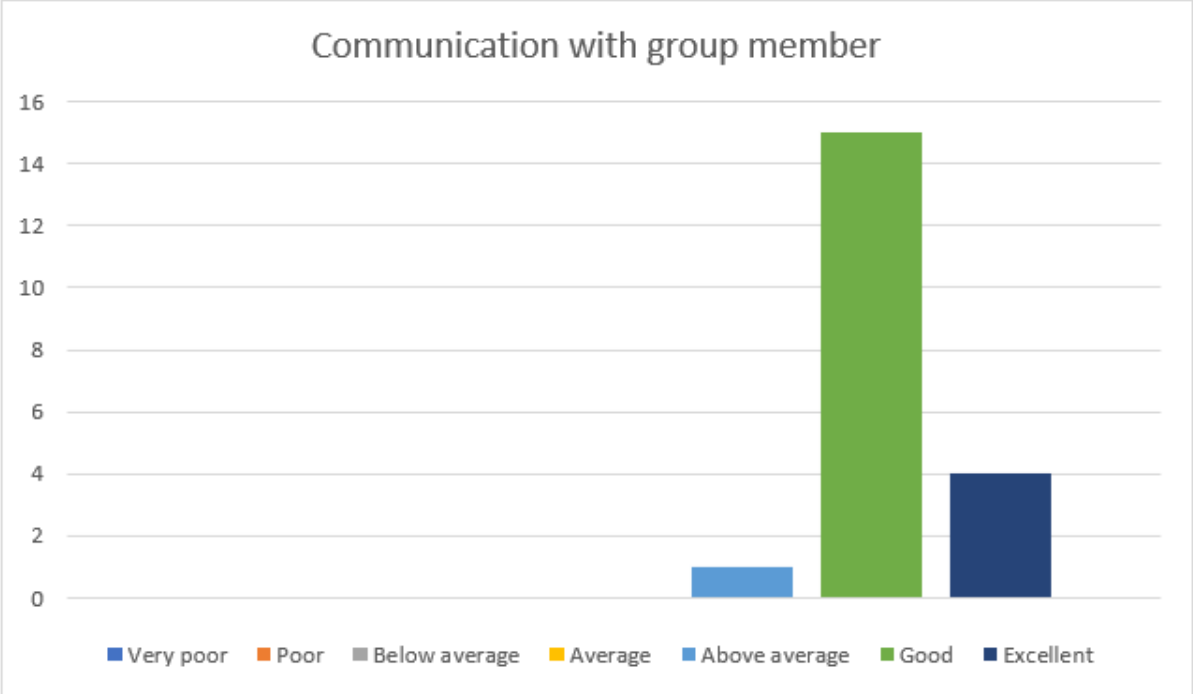


Figure 21: Communication experience among group members.

Communication between the participants and researcher was considered positive, and by some even mandatory (Figure 22). The lowest score addresses a desire for increased communication from the researcher. The researcher played a critical role during the design process, offering assistance and guidance to participants, spanning from tool-related to design-related support. Attendees specifically mentioned the researcher's encouragement to 'think' about their design choices, providing a broader context; such as pointing out that placing a fountain on the walking path could hinder walkability in that section.

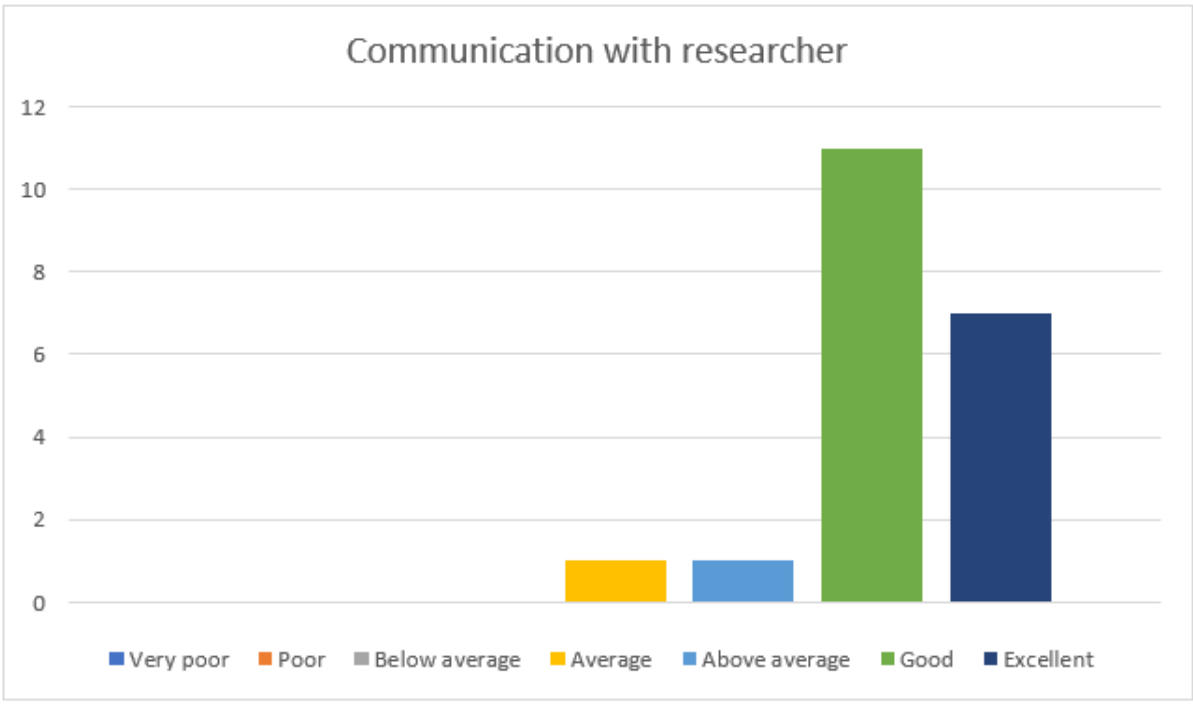


Figure 22: Communication experience with attendees and the researcher.

According to participants, a collaborative immersive experience improved the overall effectiveness of the workshop (Figure 23). The task of designing a public space became less daunting when approached collectively. Participants could assist each other, validate design choices, and engage in discussions on design decisions, leading to alterations. One participant noted that solo immersion might offer a more intense and focused experience but found it difficult to state definitively, having solely experienced collaborative immersion.

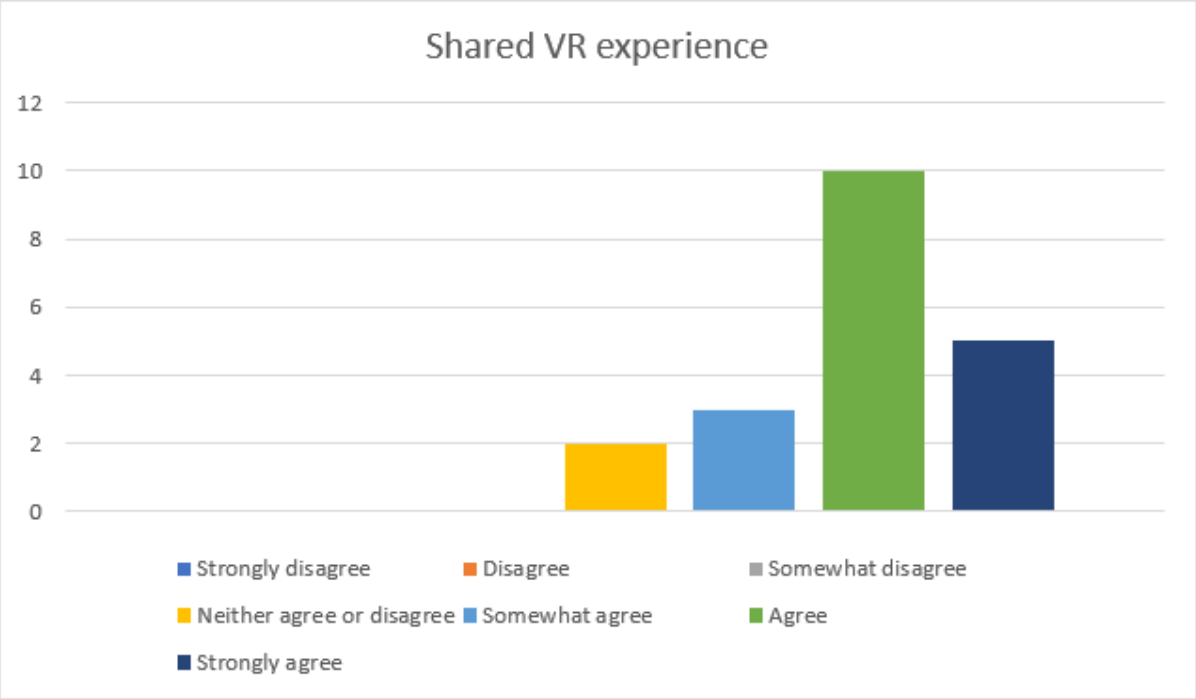


Figure 23: Shared VR experience among group members.

4.3.7 Future Use of VR with Co-design

Fifteen participants expressed their likelihood to engage in co-design with VR again if the municipality would organize another workshop (Figure 24). Notably, participants showed interest in participating only within their immediate living environment (neighbourhood). Participants were excited about using a more modern tool and having the opportunity to express design ideas as a non-expert. Conversely, less enthusiastic participants cited concerns about the potential time commitment, a general lack of interest in urban design, or feeling ill-suited for the tool.

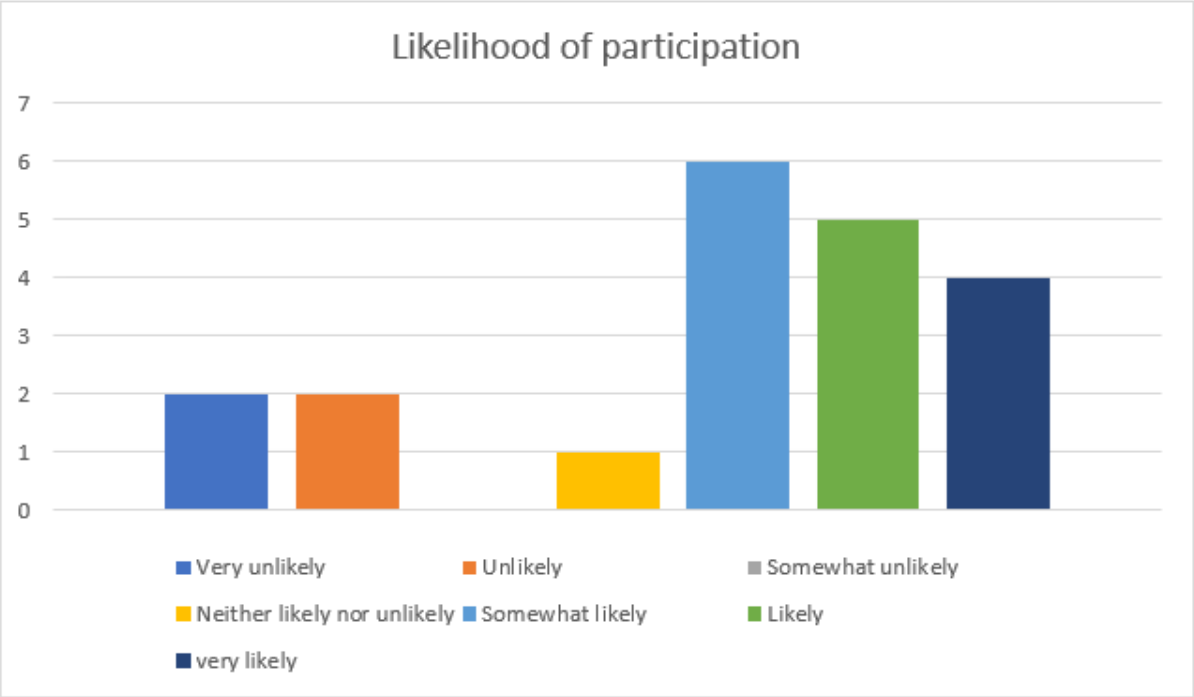


Figure 24: Likelihood for participants of future participation in co-design with VR.

As for general feedback on the workshop, attendees expressed the need for a greater diversity of attributes and providing more information ahead of the actual workshop to allow participants to familiarize themselves with the overall concept. Another point raised was the setup of the casting devices, emphasizing the need to ensure that the connection was working as intended before the actual workshop.

4.4 Analysing the Results

With the new Environmental and Planning Act, the municipality aims to give more people a voice in the overall process of urban development. However, for this cooperative methodology to be effective, the population needs to be willing to participate. Therefore, personality and socio-demographics are analyzed for their correlation with the likelihood of participation in a co-design workshop that employs the VR technology, if implemented by a municipal body. First, the Ten-Item Personality Inventory test is explained, delving into the big five personality traits, followed by Spearman's Rank correlation analysis, and finally a Binary Regression analysis.

4.4.1 Ten-Item Personality Inventory Test

Gosling et al. (2003) describe the content and purpose of the TIPI test, detailing the Big Five personality domains it measures. All participants completed the TIPI test during the workshop, which comprises ten questions rated on a 7-point Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree). It's important to note that the test does not determine if someone is a 'good' person; rather, it assesses an individual on five different personality traits. These scores are then compared to the norm based on responses from 1813 participants, indicating whether a participant falls into the categories of low, medium-low, medium-high, or high scores for these traits.

The first trait is openness to experience. Individuals with a high score are curious about the world around them, tend to enjoy creative activities, and are more inclined to explore different

alternatives to ideas in life. Lower scores in this trait indicate a person is more willing to stay within their comfort zone (Cherry, 2023).

Conscientiousness is the personality trait characterized by the degree of responsibility, organization, dependability, and goal-oriented behaviour of an individual. A high score implies more attention to detail, while a person with a low score is more inclined to just let things happen. Extraversion has a focus on external stimuli, social interactions, and outgoing behaviour. A high positive reaction to stimuli from the outside world indicates a high score in the extraversion trait, these people are more comfortable around large social gatherings. Low extraversion minimizes stimuli and focuses more inward, also known as introverts. They feel drained when around lots of people (Cherry, 2023).

The trait of a person's tendency to be cooperative, sympathetic, and compassionate towards others is known as agreeableness. A high score in this trait indicates a person is more willing to take action to make peace with others. They are also more likely to be patient with others and let go of angry feelings quickly, while highly competitive people score low in this trait (Cherry, 2023).

Emotionality, also known as neuroticism, is a personality trait reflecting emotional stability. Those low in emotionality are more often emotionally stable and resilient to stress. Ones with high emotionality are more likely to perceive heightened feelings of anxiety, paranoia, depression, and aggression. These people usually have higher highs and lower lows (Cherry, 2023).

4.4.2 Spearman's Rank Correlation Analysis

The goal was to investigate correlations between age, living environment, or any of the five big personality traits and either likelihood of participation or confidence in the final design. Appendix C shows the results of Spearman's Rho analysis. None of the independent variables have a significant correlation with the dependent variables. Therefore, the null hypothesis cannot be rejected, suggesting no significant correlation between variables exist.

4.4.3 Binary Logistic Regression

There are 2 participation likelihood variables created for this analysis. For ParLik (Table 18) levels of very unlikely (1) to somewhat likely (5) are considered to not participate in this method again while the levels of likely (6) and very likely (7) are considered for participants willing to participate in this method again. This is to create a rather even distribution. ParLik2 (Table 19) levels 1-4 are considered as participants not willing to engage in the method again while levels 5-7 are participants willing to engage in the method again.

Table 18: Crosstabulation of participation likelihood and ParLik.

		ParLik		Total
		0	1	
how likely are you to participate in urban development projects that employ this specific tool and methodology?	Likely	0	5	5
	Neither likely nor unlikely	1	0	1
	Somewhat likely	6	0	6
	Unlikely	2	0	2
	Very likely	0	4	4
	Very unlikely	2	0	2
Total		11	9	20

Table 19: Crosstabulation of participation likelihood and ParLik2.

		ParLik2		Total
		0	1	
how likely are you to participate in urban development projects that employ this specific tool and methodology?	Likely	0	5	5
	Neither likely nor unlikely	1	0	1
	Somewhat likely	0	6	6
	Unlikely	2	0	2
	Very likely	0	4	4
	Very unlikely	2	0	2
Total		5	15	20

All predictor variables described in section 3.3.8 were included in the BLR for both ParLik and ParLik2. Age and the Big Five personality traits are measured on a scale level. Since the Big Five personality traits are on a 7-point Likert scale, these variables are allowed to be measured on a scale level. First is the more evenly distributed variable of ParLik. After performing the analysis, only the variable of agreeableness shows a significant correlation with the likelihood of participating. The Nagelkerke value of 0.166 indicates a reasonable model (Table 20); however, the classification table (Table 21) correctly predicts 13 out of 20 (65%) cases, suggesting the model has acceptable predictive power. The variable is significant at a 15% level (Table 22), which is acceptable given the small sample size. The negative parameter estimate suggests that individuals with lower agreeableness are more likely to participate.

Table 20: Model summary ParLik.

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	24.879[a]	.124	.166

Table 21: Classification table ParLik.

	Observed		Predicted		
			ParLik		Percentage Correct
			0	1	
Step 1	ParLik	0	3	6	33.3
		1	1	10	90.9
	Overall Percentage				65.0

Table 22 Variables in the equation of ParLik.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Agreeableness	-.861	.597	2.081	1	.149	.423
	Constant	3.352	2.509	1.785	1	.182	28.572

The results for ParLik2 are similar to those of ParLik. Agreeableness remains the only significant variable after eliminating insignificant ones. The Nagelkerke R-square, however, has improved to 0.325, indicating a good model fit (Table 23). The model exhibits adequate predictive strength with 16 out of 20 correct predictions (Table 24). The significance of agreeableness persists at the 15% level (Table 25). It has a stronger negative parameter estimate than ParLik, suggesting a higher likelihood for participants with a lower agreeableness score to be willing to participate.

Table 23: Model summary ParLik2.

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	17.546[a]	.219	.325

Table 24: Classification table ParLik2.

	Observed		Predicted		
			ParLik2		Percentage Correct
			0	1	
Step 1	ParLik2	0	1	4	20.0
		1	0	15	100.0
	Overall Percentage				80.0

Table 25: Variables of the equation of ParLik2.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Agreeableness	-1.698	1.067	2.532	1	.112	.183
	Constant	8.574	4.847	3.129	1	.077	5291.371

Alternatively, agreeableness and openness were recoded as nominal variables. Agreeableness was categorized as either agreeable (levels 5-7) or not (levels 1-4). Similarly, openness was classified as open (levels 6-7) or not (levels 1-5.5). This recoding was implemented to establish an even distribution in the predictor variables. Table 26 and Table 27 illustrate the recoded variables.

Table 26: Crosstabulation of Agreeableness and Agree.

		Agree		Total
		0	1	
Agreeableness	2.0	1	0	1
	2.5	1	0	1
	3.0	2	0	2
	4.0	6	0	6
	4.5	0	6	6
	5.0	0	3	3
	6.5	0	1	1
Total		10	10	20

Table 27: Crosstabulation of Openness to experience and Open.

		Open		Total
		0	1	
Openness to experience	2.5	1	0	1
	4.5	3	0	3
	5.0	1	0	1
	5.5	4	0	4
	6.0	0	4	4
	6.5	0	6	6
	7.0	0	1	1
Total		9	11	20

After recoding the variables, no significant correlation could be found between the predictor variables and ParLik in any combination. The Nagelkerke value was also below 0.09, indicating a weak model. However, for ParLik2, the analysis indicates that age is a significant predictor variable. When openness is added, the Nagelkerke value improves to 0.307 (Table 28), and the model achieves 18 correct predictions (90%, Table 29). Considering the low number of participants, these values suggest a decent model. Nonetheless, openness does not reach significance at a 15% level. In contrast, age does, with a positive coefficient indicating that older participants are more likely to participate (Table 30).

Table 28: Model summary ParLik2 and ordinal variables.

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	17.842[a]	.208	.307

Table 29: Classification table ParLik2 and ordinal variables.

	Observed		Predicted		
			ParLik2		Percentage Correct
			0	1	
Step 1	ParLik2	0	4	1	80.0
		1	1	14	93.3
	Overall Percentage				90.0

Table 30: Variables in the equation of ParLik2 and ordinal variables.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Age	.527	.352	2.244	1	.134	1.694
	Open	-1.704	1.373	1.539	1	.215	.182
	Constant	-10.613	8.247	1.656	1	.198	.000

According to the BLR agreeableness and age have a significant correlation with likelihood of participation.

4.5 Conclusion of the Results

Survey responses revealed that attendees expressed eagerness to participate in urban design as non-experts once again, but only if it were to occur in their immediate environment. On an urban scale, this includes their neighbourhood, while on a smaller scale, this involves their own house. Confidence in the final design was above average; however, there was scepticism about whether it met the standards of the built environment.

The protocol analysis revealed that participants actively engaged in the design process, even without prior experience in the subject. This was evident in the dominance of conversation topics related to the scenario, followed by the examination of design choices and tool-related communication. Overall, communication between attendees and researchers was experienced positively, with a low number of interruptions by members or instruments. In the thesis by Chowdhury (2021), design communication emerged as the most dominant form of communication as well. Nevertheless, a distinction lies in the fact that social communication was a more prominent topic in Chowdhury's study (2021). Collaborative immersion could be a major factor contributing to less social communication. Participants concentrate more on design than social communication by engaging in discussions about overall design ideas since they work together.

The collaborative immersive experience significantly enhanced participants' engagement. The interactive approach allowed for discussions on design decisions, contributing to an overall increase in confidence. The incorporation of various points of view within the model facilitated an interactive design process, ensuring that decisions were not considered final until collectively discussed.

The importance of context to the model is also highlighted by the protocol analysis and the survey. Participants expressed a good understanding of the attributes, attributed to pre-discussions. Conversations about attributes, shading, and the general location of the square within the city were common. The model however could be improved by incorporating lamppost.

The Spearman's rank correlation indicated no significant relationships, while the BLR analysis identified significant relationships involving only two predictor variables: age and agreeableness. Openness might be a potential predictor as well. Nevertheless, the negative coefficients associated with agreeableness and openness appear counterintuitive. A low openness score suggests a preference for staying within one's comfort zone. Conversely, individuals with a high openness score tend to be curious about the world, enjoy creative activities, and explore various alternatives for ideas and life. In the case of agreeableness, individuals with a low score often exhibit traits such as competitiveness, assertiveness, determination, and a critical approach, displaying less concern for the feelings of others. Both low scores in openness and agreeableness may not align with the method discussed in this thesis. However, it is important to note that a counterintuitive outcome does not necessarily imply false results. These findings are not definitive and should be viewed as indicative of potential connections between various personality traits and socio-demographics with participants' willingness to engage in urban design with VR. Further research is necessary to come to a concrete conclusion on this topic.

The small sample size introduces low statistical power, posing challenges in identifying statistically significant findings. Other potential factors contributing to these results include limited variability in the independent variable, signifying similar levels among participants in the sample. Small sample sizes are also more susceptible to random variability, impacting overall results.

It is noteworthy that in nine out of ten workshops, both participants responded similarly when asked about their likelihood to participate again. This trend was observed using the yes and no scale employed in this analysis, with only one workshop showing a different pattern. Due to the small number of teams, no definitive conclusions on this topic can be drawn at this stage.

5. Conclusions and Recommendations

This final chapter aims to reflect on the findings from the thesis, trying to answer the research questions imposed during the start of this research. Furthermore, the weaknesses, obstacles, and limitations of the research are discussed, followed by recommendations for future research in this field.

5.1 Conclusion

This study found that a relatively young audience expressed excitement about participating in urban design as non-experts again, should this be implemented in their immediate environment.

The approach enables non-experts to collaboratively generate designs while actively expressing their wishes and needs for the designated area. Results from the protocol analysis indicated that design communication and examination were the most common topics discussed during the workshop, with a low number of interruptions suggesting an overall smooth design process in which participants actively engaged. The adaptability of the tool, allowing for multiple points of view in conjunction with an interactive design process, enhanced their ability to conceptualize the overall square. This flexibility empowered attendees to modify their design choices based on the examination of their creations. These preferences should be considered in a more general sense given the constraints of a 30-minute design workshop that limits the ability to delve into details.

Simultaneous immersion with the ability to both communicate via vision and verbally enhanced their confidence in the design. Individuals could assist one another in this collaborative approach, making the overall task less intimidating. Multiple viewpoints not only eased the process but also ensured that each participant had someone to validate and approve their ideas. The smooth flow of conversation during this collaborative immersion highlighted working together enhances creativity and problem-solving.

The expert plays a crucial role in this process. This is supported by literature that mentions that in the methodology of co-design, the designer or researcher changes roles from designing to facilitating, allowing non-experts to express their creativity. Therefore, the number of experts should be proportionate to the participants immersed in the VE, given their role in facilitating the expression of participants' needs. Throughout the process of designing the public square, participants expressed a strong appreciation for the researcher's collaborative approach in contemplating their design choices. The researcher's ability to provide additional context and discuss potential consequences was well-received, stimulating participants to engage in more thoughtful consideration of their design decisions. Assisting attendees with the tool was also essential to maintain the overall flow of design within the limited 30-minute window, as indicated by the tool-related conversations in the protocol analysis during the workshop. Therefore, the expert should possess both knowledge of the tool and design capabilities.

The duration of designing within the IVE should not exceed 30 minutes due to fatigue. Almost half of the attendees experienced some form of fatigue within this 30-minute window, highlighting that this timeframe represents the maximum limit for effective use. However, this time constraint compelled participants to make swift decisions. This could be considered a strength, as both literature and survey results suggest that the time commitment is one of the main deterrents for potential participants.

This method should be applied during the early design phase, at the finalization of the initiative phase, and throughout the feasibility phase to aid in shaping the structural vision for the area.

Within this document, the municipality is mandated to explain how citizens were engaged during the creation of the area structure vision. The area structure vision outlines the intended structure and development of the area, encompassing goals, requirements, and design elements. This aligns with the overall capability of the method employed in this research, where citizens can voice their general wishes and needs for urban development projects.

Participants need to acquire knowledge and expertise related to the design area, goals, attributes, other participants, and the VR tool. Therefore, when implementing this approach in a real-life application, it is recommended to conduct several workshops, each addressing specific stages. A significant portion of design communications revolved around the context of the area, such as the city center's location, popular walking paths, and the square's overall shadow patterns throughout the day. Participants emphasized in the survey the crucial role of this context in enabling them to make thoughtful design decisions.

5.2 Discussion

A limitation of this research format is that it is an exploratory qualitative study, implying that the overall quality relies on the competencies of the researchers (Anderson, 2010), and the possibility of mistakes and errors should be kept in mind.

The model used in this research demonstrated limitations, as noted by participants. While the model allowed for changes in the time of day, some participants lacked the expertise to perform this task. Additionally, several participants expressed a desire to examine lamp post attributes for dynamic night lighting, indicating the absence of important features in this research, a concern supported by existing literature. Another limitation was the participants' difficulty envisioning the overall use of the square. A dynamic model featuring people walking around to showcase the popularity of walking paths should be a crucial addition if implemented by the municipality.

Participants were recruited through direct contact via mail, word-of-mouth, and messages. All participants had a prior acquaintance with the researcher, and a majority were familiar with each other. The groups were organized by the researcher, ensuring that participants did not have a say in choosing their team members. However, the pre-existing connections could potentially positively impact their overall workshop experience.

Not all workshops were executed flawlessly, particularly the first one, which struggled with time management and tool utilization. Due to time constraints, attributes couldn't be thoroughly discussed before participants entered their design scenario. These limitations were reflected in feedback from two participants who perceived the clarity of attributes as low. Another issue occurred when the license on one of the Oculus devices was terminated, requiring participants to add it manually, leading to expressed frustration with the tool. Both of these participants indicated a low likelihood of participating in this method again, potentially influenced by the challenges encountered during this workshop.

Another recurring issue was the inability to cast both devices to a screen, preventing the researcher from observing what the participant saw. Through the Oculus application, only one device could be cast at a time. To overcome this limitation, the setup required a device with the application and a TV with Google Chrome to which the other device could cast. While this limitation did not deter participants from future participation, it restricted the researcher's ability to assist participants in these cases. It is crucial that if this method were to be implemented, the expert should have the ability to see what the participants see to guide them to the best of their ability.

The analysis is indicative of a correlation between age, agreeableness, and openness, and their willingness to participate in this method. However more participants with a wider range of personal characteristics needed to come to conclusions on this subject.

5.3 Recommendations

The future of this method should be considered alongside additional costs and time for municipalities during the initiative and feasibility phases of the project. However, these workshops offer inhabitants the opportunity to express their wishes and needs, reducing the likelihood of opposing the zoning plan, to which they have a legal right. This could ultimately decrease time commitment and costs associated with potential legal challenges later in the process. As BIM and Smart Cities technology become standard within the Built Environment, both costs and time commitment are expected to decrease. The method also allows for the importation of models from other programs. If these models already exist for other purposes, they could be imported.

Consideration of the overall workshop setup and professionalism should be taken into account for future endeavours. Mistakes during the workshop, such as licensing issues, time management, and casting problems, could hinder the overall experience, preventing attendees from expressing their wishes and desires as intended. This aspect aligns with familiarizing participants with the overall context of the area, allowing them to explore factors like sun and shadow throughout the day, explaining hot points of the area through dynamic models, etc.

Another noteworthy aspect is that participants often approached the design either through attribute-related or area-related methods. While many began with parking and then focused on the fountain, some felt somewhat lost after addressing these aspects. Examining overall approaches to handling designs within the given timeframe could lead to an overall improvement in the method.

Refinement of the overall method involves dividing it into multiple workshops, starting with an explanation of the overall scenario, attributes, and goals, followed by a design in the virtual environment workshop. The first workshop could be conducted in larger groups, enabling multiple perspectives and spreading information to a broader audience. However, recommendations for designing within the virtual environment suggest pairs, as simultaneous immersion was well-received by participants, facilitating multiple perspectives and discussions of design ideas. Further research should explore the optimal number of participants immersed simultaneously, as no more than two were in this research. It is essential to note that the expert needs the capability to guide all participants immersed in the virtual environment for the method to realize its maximum potential.

Future research should investigate how this method can be enhanced or adapted to remain relevant throughout the entire design process, across different scale levels. This thesis explored the method of large-scale urban development from an early design phase, suggesting its potential after some modifications. For instance, in the case of a social housing complex, where individuals are usually allowed to register later in the design process, could this method still enable them to express their opinions? This might involve using a VR model of the building, allowing participants to choose finishing materials, colours, etc. As an example, consider the perspective of private investor stakeholders. In the Netherlands, it is common to pre-sell housing before the realization phase begins. Engaging these end users early in the process the method employed in this thesis may increase their willingness to purchase an apartment, potentially reducing overall

development time. So, there is ample room for exploration across scale levels, design phases, and stakeholders.

References

Akach, J. A., Osanjo, L., & Maina, S. (2021). Co-Design: Tools, Methods and Techniques for Designing with Users. *Africa Habitat Review Journal*, 15(1), 2145–2156. http://erepository.uonbi.ac.ke/bitstream/handle/11295/155613/Akach%20J.A._%20Co-Design.%20Tools,%20Methods%20and%20Techniques%20for%20Designing%20with%20Users.pdf

Anderson C. (2010). Presenting and evaluating qualitative research. *American journal of pharmaceutical education*, *74*(8), 141. https://doi.org/10.5688/aj7408141

Antonini, M. (2021). An Overview of Co-Design: Advantages, Challenges and Perspectives of Users' Involvement in the Design Process. *IEEE/OSA Journal of Display Technology*, 2(1), 45–60. https://doi.org/10.22059/jdt.2020.272513.1018

Arkio (n.d.a). Collaborative Spatial design. Retrieved, from https://www.arkio.is/

Arkio. (n.d.b). Experience seamless workflow integration with Arkio. Retrieved from https://www.arkio.is/workflow/

Arkio (2020) Navigation. Retrieved, from https://support.arkio.is/hc/en-us/articles/360002026498-Navigation

Arkio (2023). Start & join a meeting. Retrieved, from https://support.arkio.is/hc/en-us/articles/360002027678-Start-join-a-meeting

Atkinson, A. (2022, August 17). How Much Space Do You Need For VR? (Essential Info). vrlowdown.com. https://vrlowdown.com/how-much-space-do-you-need-for-vr/

Birenboim, A., Ben-Nun Bloom, P., Levit, H., & Omer, I. (2021). The Study of Walking, Walkability and Wellbeing in Immersive Virtual Environments. *International Journal of Environmental Research and Public Health*, 18(2), 364. https://doi.org/10.3390/ijerph18020364

Bowman, D. A., & Hodges, L. F. (1995). User interface constraints for immersive virtual environment applications. Atlanta: Graphics, Visualization and Usability.

Chang, E., Kim, H. T., Yoo, B. (2020). Virtual reality sickness: A review of causes and Measurements. *International Journal of Human–Computer Interaction*, 36(17), 1658–1682. https://doi.org/10.1080/10447318.2020.1778351

Cherry, K. C. (2023, March 11). What are the big 5 personality traits? Verywell Mind. https://www.verywellmind.com/the-big-five-personality-dimensions-2795422

Chowdhury, S. (2021). Virtual Environments as Medium for Laypeople's Communication and Collaboration in Urban Design (thesis). North Carolina Agricultural and Technical State University, USA. Retrieved, from https://www.researchgate.net/publication/348735127_Virtual_Environments_as_Medium_for_Laypeople%27s_Communication_and_Collaboration_in_Urban_Design.

Chowdhury, S., & Hanegraaf, J. (2022). Co-presence in remote VR co-design: Using Remote Virtual Collaborative Tool Arkio in campus design. Proceedings of the 27th CAADRIA Conference, Sydney, 9-15 April 2022, pp. 465-474. https://doi.org/10.52842/conf.caadria.2022.2.465

Cook, M. R. (2011). The emergence and practice of co-design as a method for social sustainability under New Labour. University of East London, UK. https://doi.org/10.15123/pub.3014

Creswell, J.W. & Creswell, J.D. (2018). *Research design: Qualitative, quantitative and mixed methods approaches (5th ed)*. Thousand Oaks: SAGE

Dahlstrom-Hakki, I., Edwards, T., Larsen, J., Alstad, Z., Belton, G., Lougen, D., & Sant'Ana, D. (2021). Inclusive VR through Inclusive Co-Design with Neurodiverse Learners. 2021 7th International Conference of the Immersive Learning Research Network (iLRN), USA. https://doi.org/10.23919/ilrn52045.2021.9459322

Dane G. & Evers S. (2023). Co-designing Healthy Public Spaces via Immersive Virtual Environments. Unpublished Manuscript. Eindhoven University of Technology.

Den Boer, J. M. (2022). Citizens' preferences for participation in urban planning: towards an inclusive and representative process (thesis). Eindhoven University of Technology, Eindhoven.

EWUU. (2022). Zaaifonds maart 2022. Retrieved at 30-11-2023 from: https://ewuu.nl/nl/samenwerking/zaaigeld/zaaifonds-maart2022/

Eindhoven municipality. (2022a). Herinrichting Binnenstad. Retrieved, from https://www.openeindhoven.nl/binnenstad/herinrichting-binnenstad

Eindhoven municipality. (2022b). Participatie bij Bouwplannen en initiatieven. Gemeente Eindhoven. Retrieved, from https://www.eindhoven.nl/bouwen/bouwprojecten/intake-nieuwe-bouwinitiatieven/participatie-bij-bouwplannen-en-initiatieven

LuField, A. (2013). Discovering statistics using IBM SPSS statistics. Sage.

Franzen, A., Hobma, H., Jonge, H.D., & Wigmans, G. (2011). *Management of Urban Development Processes in the Netherlands : Governance, Design, Feasibility*. Technepress.

Gosling, S. D., Rentfrow, P. J., & Swann, W. B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in Personality*, 37(6), 504–528. https://doi.org/10.1016/s0092-6566(03)00046-1

Geekiyanage, D., Fernando, T., Keraminiyage, K. (2020). Assessing the state of the art in community engagement for participatory decision-making in disaster risk-sensitive urban development. *International Journal of Disaster Risk Reduction*, 51, 101847. https://doi.org/10.1016/j.ijdrr.2020.101847

Geekiyanage, D., Fernando, T., Keraminiyage, K. (2021). Mapping participatory methods in the urban development process: A systematic review and case-based evidence analysis. *Sustainability*, 13(16), 8992. https://doi.org/10.3390/su13168992

Grylls, T., & Van Reeuwijk, M. (2022). How trees affect urban air quality: It depends on the source. *Atmospheric Environment*, 290, 119275. https://doi.org/10.1016/j.atmosenv.2022.119275

Von Heland, F., Westerberg, P., & Nyberg, M. (2015). Using Minecraft as a citizen participation tool in urban design and decision making. Future of Places, Stockholm.

Herring, S. C. (2007). Questioning the Generational divide : Technological exoticism and adult constructions of online youth identity. Indiana University, Bloomington. Retrieved, from https://www.semanticscholar.org/paper/Questioning-the-Generational-Divide-%3A-Technological-Herring/eb4331c2f310dfff3ba5ac86b82c5ec90902c492

Ibrahim, H. (2017). Car parking problem in urban areas, Causes and Solutions. 1st International Conference on Towards a Better Quality of Life, 2017. https://doi.org/10.2139/ssrn.3163473

KnoopXL. (2022). KnoopXL Retrieved, from https://www.knoopxl.nl/

Koutsabasis, P., Vosinakis, S., Malisova, K., & Paparounas, N. (2012). On the value of virtual worlds for collaborative design. *Design Studies*, 33(4), 357-390.

Laerd Statistics. (n.d.a). Spearman's Rank Order Correlation using SPSS Statistics - A How-To Statistical Guide by Laerd Statistics. Retrieved, from https://statistics.laerd.com/spss-tutorials/spearmans-rank-order-correlation-using-spss-statistics.php

Laerd Statistics. (n.d.b). Spearman's Rank-Order Correlation - A guide to how to calculate it and interpret the output. Laerd Statistics. Retrieved, from https://statistics.laerd.com/statistical-guides/spearmans-rank-order-correlation-statistical-guide-2.php

Lee, Y., Kozar, K. A., Larsen, K. R. T. (2003). The Technology Acceptance Model: Past, present, and future. *Communications of the Association for Information Systems*, 12, pp-pp. https://doi.org/10.17705/1cais.01250

Lee, A., & Maheswaran, R. (2010). The health benefits of urban green spaces: a review of the evidence. *Journal of Public Health*, 33(2), 212–222. https://doi.org/10.1093/pubmed/fdq068

L'Ortye, F., & Van Brunschot, A. (2019). Participatie in de Omgevingswet. Retrieved, from https://aandeslagmetdeomgevingswet.nl/ondersteuning/webinar-training/webcolleges-webinars/webcollege-participatie/webcollege-participatie-deel-2/

Lu, Y., Sun, G., Sarkar, C., Gou, Z., & Xiao, Y. (2018). Commuting mode choice in a high-density city: Do land-use density and diversity matter in Hong Kong? *International Journal of Environmental Research and Public Health*, 15(5), 920. https://doi.org/10.3390/ijerph15050920

McKercher, K. A. (2020). Beyond Sticky Notes: Co-design for Real: Mindsets, methods and movements. Thorpe-Bowker Identifier Services Australia.

Ministerie van Algemene Zaken. (2023). Burgerparticipatie. Burgerschap | Rijksoverheid.nl. Retrieved, from https://www.rijksoverheid.nl/onderwerpen/burgerschap/burgerparticipatie

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2022). Invoering van de Omgevingswet naar 1 juli 2023. Rijksoverheid.nl. Retrieved, from https://www.rijksoverheid.nl/actueel/nieuws/2022/10/14/invoering-van-de-omgevingswet-naar-1-juli-2023

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2023). Groen licht Eerste Kamer: Invoering Omgevingswet op 1 januari 2024. Nieuwsbericht | Rijksoverheid.nl. Retrieved, from https://www.rijksoverheid.nl/actueel/nieuws/2023/03/14/groen-licht-eerste-kamer-invoering-omgevingswet-op-1-januari-2024

Efe, R. (2016). Seating furniture in open spaces and their contribution to the social life. *Environmental Sustainability and Landscape Management*, 169-187.

MyVision. (2022). Is virtual reality (VR) bad for your eyes? MyVision.org. Retrieved, from https://myvision.org/guides/is-vr-bad-for-your-eyes/

Netherlands Enterprise Agency, RVO. (2021, July 5). Zoning plan. business.gov.nl. Retrieved, from https://business.gov.nl/regulation/zoning-plan/

NOS. (2017). Waarom we allemaal in De grote stad willen wonen. NOS. Retrieved, from https://nos.nl/op3/artikel/2178292-waarom-we-allemaal-in-de-grote-stad-willen-wonen

Onishi, A., Cao, X., Ito, T., Shi, F., & Imura, H. (2010). Evaluating the potential for urban heat-island mitigation by greening parking lots. *Urban Forestry & Urban Greening*, 9(4), 323–332. https://doi.org/10.1016/j.ufug.2010.06.002

Oram, T., Baguley, A. J., & Swain, J. (2018). Effects of outdoor seating spaces on sociability in public retail environments. *The Journal of Public Space*, Vol. 3 n. 3 | 2018 | FULL ISSUE, 75–102. https://doi.org/10.32891/jps.v3i3.668

Gomes, S. (2017). Factors of good public space use. In XIII Iberian Geography Colloquium. Responses of Iberian Geography to the current crisis. Universidade de Santiago de Compostela, October 2012, Santiago de Compostela, Spain. 608-618. https://shs.hal.science/halshs-01422747

Pelczynski, J., & Tomkowicz, B. (2019). Densification of cities as a method of sustainable development. IOP Conference Series: *Earth and Environmental Science*, 362(1), 012106. https://doi.org/10.1088/1755-1315/362/1/012106

Rahman, M. A., Stratópoulos, L. M. F., Moser-Reischl, A., Zölch, T., Häberle, K., Rötzer, T., Pretzsch, H., & Pauleit, S. (2020). Traits of trees for cooling urban heat islands: A meta-analysis. *Building and Environment*, 170, 106606. https://doi.org/10.1016/j.buildenv.2019.106606

Rašković, S., & Decker, R. (2015). The influence of trees on the perception of urban squares. *Urban Forestry & Urban Greening*, 14(2), 237–245. https://doi.org/10.1016/j.ufug.2015.02.003

Rishbeth, C., & Rogaly, B. (2017). Sitting outside: Conviviality, self-care and the design of benches in urban public space. *Transactions of the Institute of British Geographers*, 43(2), 284–298. https://doi.org/10.1111/tran.12212

Sanders, E., Brandt, E., & Binder, T. (2010). A framework for organizing the tools and techniques of participatory design. Proceedings of the 11th Biennial Participatory Design Conference, 191. https://doi.org/10.1145/1900441.1900476

Sanders, E. A., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign*, 4(1), 5–18. https://doi.org/10.1080/15710880701875068

Sanoff, H. (2011). Multiple views of participatory design. *Focus*, 8(1). https://doi.org/10.15368/focus.2011v8n1.1

Sanoff, H. (2022). Participatory design. *Journal of Design Planning and Aesthetics Research*. https://doi.org/10.55755/deparch.2022.8

Schnabel, M. A. (2009). Framing mixed realities. In: Wang, X., Schnabel, M.A. (eds) Mixed Reality In Architecture, Design And Construction, pp. 3–11, Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9088-2_1

Song, X. P., Tan, P., Edwards, P. J., & Richards, D. R. (2018). The economic benefits and costs of trees in urban forest stewardship: A systematic review. *Urban Forestry & Urban Greening*, 29, 162–170. https://doi.org/10.1016/j.ufug.2017.11.017

Sorrows, M. E., & Hirtle, S. C. (1999). The nature of landmarks for real and electronic spaces. *In Lecture Notes in Computer Science*. 37–50. https://doi.org/10.1007/3-540-48384-5_3

Southey, B. (2020). Academic Loitering: Observations from Sitting in Three Toronto Parks (thesis). Queen's University, Toronto, Canada. https://qspace.library.queensu.ca/handle/1974/27753

Stelzle, B., Noennig, J. R. (2017). A database for participation methods in urban development. *Procedia Computer Science*, 112, 2416–2425. https://doi.org/10.1016/j.procs.2017.08.173

Tham, J., Duin, A. H., Gee, L. K., Ernst, N., Abdelqader, B., & McGrath, M. (2018). Understanding virtual reality: presence, embodiment, and professional practice. *IEEE Transactions on Professional Communication*, 61(2), 178–195. https://doi.org/10.1109/tpc.2018.2804238

Van Loon, J., & Hochstenbach, C. (2019). Beleggers: oplossing voor de woningnood? *Agora Magazine*, 35(2), 21-24. https://doi.org/10.21825/agora.v35i2.16105

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, 46(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

APPENDIX A Survey

* indicates a mandatory question
Under each question shows … for open questions or the different choices for participants.

Section 1: Personal background information

1: Participation number *
…

2: Age *
…

3: Gender *
Male, Female, Non-binary, Prefer not to say

4: In what urban environment do you live based on the following scale: *
Rural area (<3,000 residents), Small town (3,000-10,000 residents), City (10,000-100,000), Large city (100,000+

5: Do or did you follow a built environmental related study? *
Yes, No

6: Could you please give answers to the following statements? *
I see myself as:

Extroverted, enthusiastic;	Strongly disagree, Disagree, Somewhat disagree, Neither agree or disagree, Somewhat agree, Agree, Strongly agree
Critical, quarrelsome	
Dependable, self-disciplined	
Anxious, easily upset	
Open to new Experiences, complex	
Reserved, quiet	
Sympathetic, warm	
Disorganized, Careless	
Disorganized, careless	
Calm, Emotionally stable	
Conventional, uncreative	

Section 2: Prior experience with co-design or VR

7: were you familiar with the concept of co-design in the context of urban design before participating in the workshop? If yes, how? *
…

8: Have you ever been immersed in a Virtual Environment before participating in the workshop? If yes, for what purpose? *
…

9: Have you ever participated as a non-expert in urban design projects? if yes, in what context? *
…

Section 3: End result

10: How confident are you in your final design if it were to be implemented in real life? *
No confidence, Very low confidence, Low confidence, Neutral, Confident, High confidence, Very high confidence

11: What specific challenges or factors contribute to your low confidence in your final design if implemented in real life?
…

12: Any remarks on your confidence of your final design?
…

13: What specific challenges or factors contribute to your high confidence in your final design if implemented in real life?
…

Section 4: Learning experience during the workshop

14: Please rate the clarity of the attributes discussed and their corresponding effects during the workshop. *
Very poor, Poor, Below average, Average, Above average, Good, Excellent

15: Could you please provide details explaining the reasons behind your lower rating of the attributes discussed in the workshop?
…

16: Do you have any further remarks on the attributes discussed in the workshop?
…

17: Could you please provide details explaining the reasons behind your higher rating of the attributes discussed in the workshop?
…

18: Were there any attributes missing during the workshop? *
…

19: Please rate the clarity of your individual role discussed during the workshop. *
Very poor, Poor, Below average, Average, Above average, Good, Excellent

20: Could you please elaborate on the reasons behind your lower rating regarding the clarity of the role assigned to you during the workshop?
…

21: Do you have any remarks on the clarity of the role assigned to you during the workshop?
…

22: Could you please elaborate on the reasons behind your higher rating regarding the clarity of the role assigned to you during the workshop?
…

23: On the following scale, how clear was the overall goal of the workshop to you? *
Very poor, Poor, Below average, Average, Above average, Good, Excellent

24: Could you please elaborate on the reasons behind your lower rating regarding the goal of the workshop?
…

25: Do you have any further remarks regarding the goal of the workshop?
…

26: Could you please elaborate on the reasons behind your higher rating regarding the goal of the workshop?
…

27: Was the time allocated to explore Arkio sufficient before engaging in the main scenario? *
Insufficient, Minimal, Adequate, Satisfactory, Sufficient, Generous, Abundant

28: Could you please provide more details or insights explaining your lower rating regarding the time allocated for exploring Arkio?
…

29: Do you have any comments or feedback regarding the time given for exploring Arkio?
…

30: Could you please provide more details or insights explaining your higher rating regarding the time allocated for exploring Arkio?
…

31: How much time did you feel you had to customize the environment to suit your preferences within the main scenario? *
Insufficient, Minimal, Adequate, Satisfactory, Sufficient, Generous, Abundant

32: Could you please provide more details or insights explaining your higher rating regarding the time allocated for customizing the main scenario?
…

33: Do you have any comments or feedback regarding the time given for customizing the main scenario?
…

34: Could you please provide more details or insights explaining your higher rating regarding the time allocated for customizing the main scenario?
…

Section 5: Usability of the VR tool within co-design

35: Could you rate the ease of use of the Arkio tool? *
Very hard, Hard, Somewhat hard, Neutral, Somewhat easy, Easy, Very Easy

36: Could you please provide an explanation regarding the specific challenges or difficulties you encountered while using the tool?
…

37: Do you have any additional remarks regarding the overall ease of use of the tool?
…

38: Could you please explain what aspects of the tool's usability contributed to your perception of it being easy to use?
…

39: Did you experience nausea (sickness), claustrophobia, fatigue (tiredness), or any other negative effects while being immersed in VR? *
…

40: How much did the immersive experience enhance your ability to engage in the design process? *
Not at all, Very little, Little, Somewhat, Neutral, Quite a bit, Significantly

41: You rated the immersive experience as having little to no impact on your ability to engage in the design process, please elaborate on the specific aspects that you believe hindered its effectiveness.
…

42: Do you have any remarks on the effectiveness of the immersive experience on your ability to engage in the design process?
…

43: You rated the immersive experience as enhancing your ability to engage in the design process, could you elaborate on the specific elements or features that you found most influential in its effectiveness?
…

44: What potential drawbacks or limitations do you see in the use of VR for participatory design in urban development? *
…

45: Did you suggest any design ideas yourself, and if so, were they implemented the way you envisioned it? If not, why not? *
…

46: How would you rate your experience of communication with your group member? *
Very poor, Poor, Below average, Average, Above average, Good, Excellent
…

47: Could you please provide specific details or examples explaining why you rated the communication with your group member low?
…

48: Do you have any comments on the communication between you and your group member?
…

49: Could you please provide specific details or examples explaining why you rated the communication with your group member high?
…

50: How would you rate your experience of communication between you and the researcher? *
Very poor, Poor, Below average, Average, Above average, Good, Excellent

51: Could you please provide specific details or examples explaining why you rated the communication between you and the researcher low?
…

52: Do you have any remarks on the communication between you and the researcher?
…

53: Could you please provide specific details or examples explaining why you rated the communication between you and the researcher high?
…

54: The immersive experience is more effective when shared with another person at the same time. *
Strongly disagree, Disagree, Somewhat disagree, Neither agree or disagree, Somewhat agree, Agree, Strongly agree

55: Could you please provide context or specific reasons why you disagree with the notion that the immersive experience is more effective when shared with another person simultaneously?
…

56: Do you have any remarks on the shared immersive experience with another person?
…

57: Could you please provide context or specific reasons why you agree with the notion that the immersive experience is more effective when shared with another person simultaneously?
…

Section 7: Future use of VR with co-design

58: How likely are you to participate in urban development projects that employ this specific tool and methodology? *
Very unlikely, Unlikely, Somewhat unlikely, Neither likely nor unlikely, Somewhat likely, Likely, Very likely

59: Could you give context to why you would be reluctant to participate in future urban development projects that employ this specific tool and methodology?
…

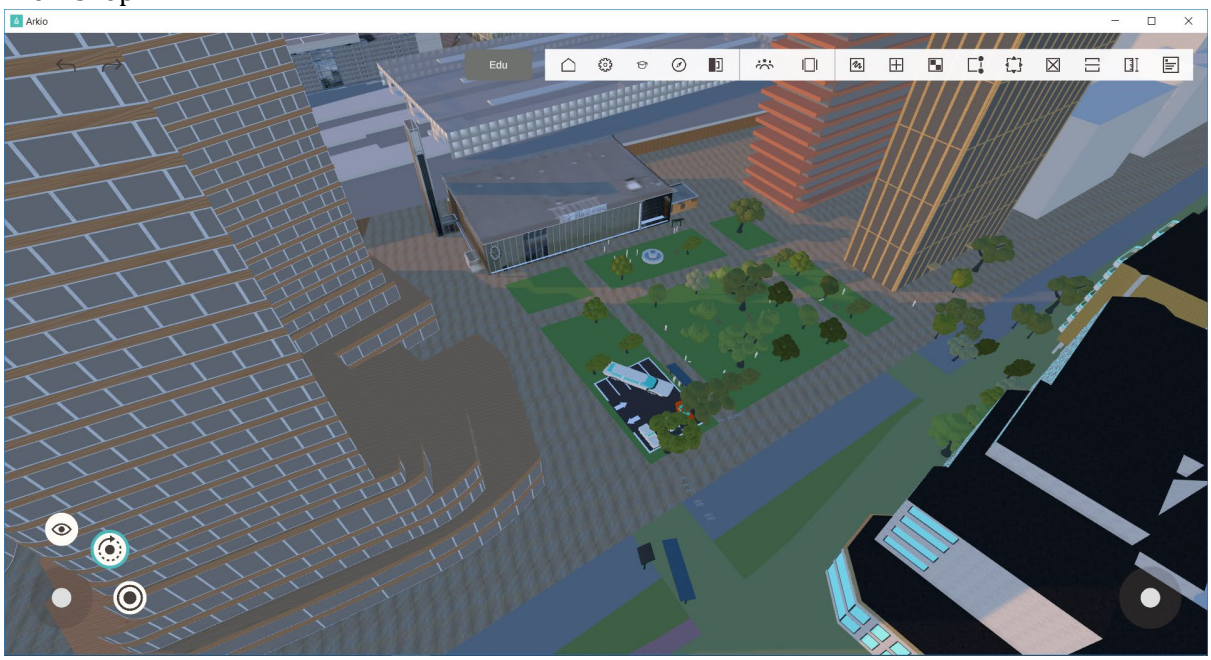
60: Do you have any remarks on your likelihood to participate in future urban development projects that employ this specific tool and methodology?
…

61: Could you give context to why you would be excited to participate in future urban development projects that employ this specific tool and methodology?
…

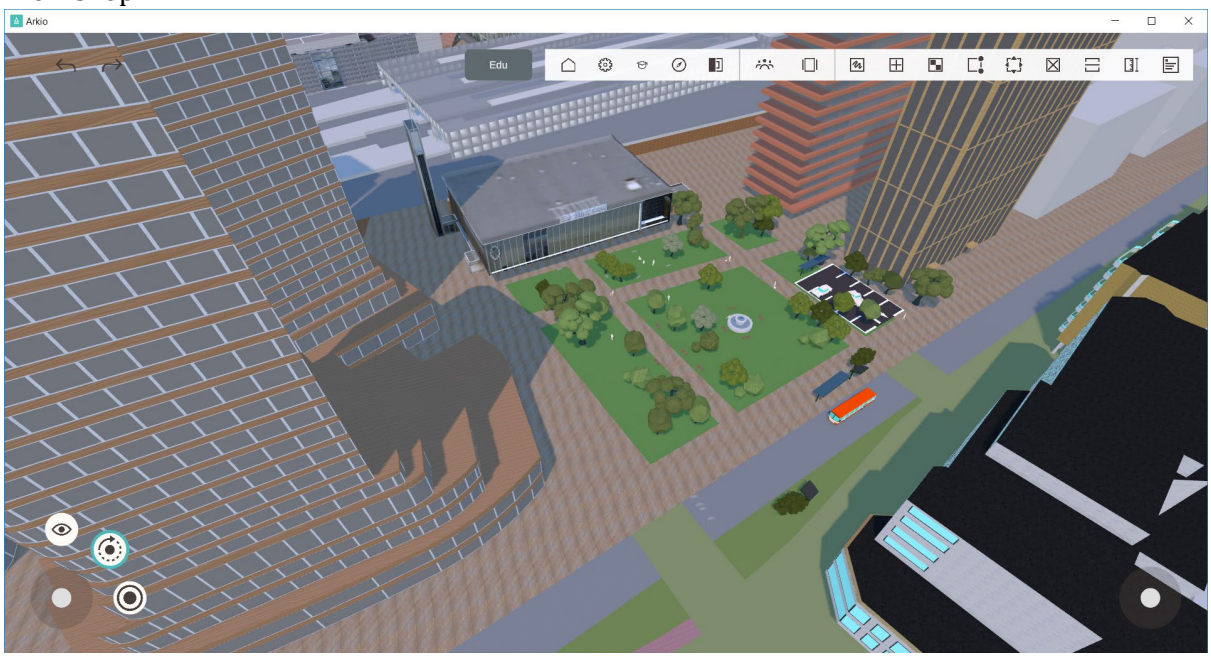
62: Do you have any recommendations to improve the experiment and process? *

APPENDIX B Final designs of the workshop

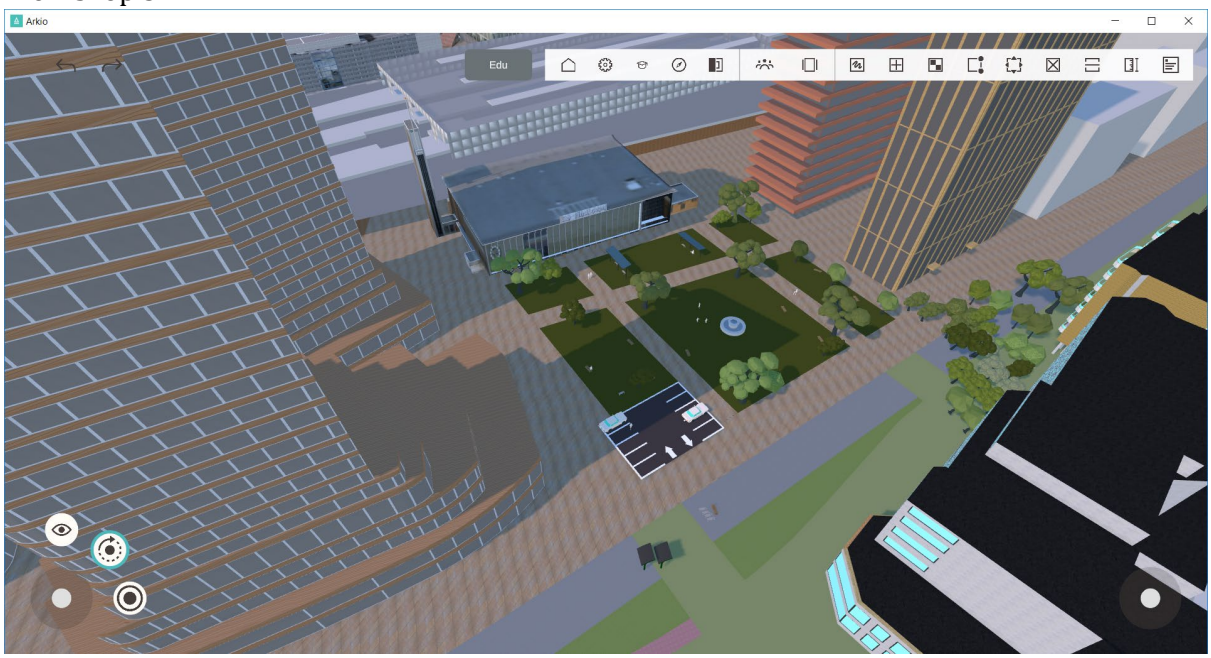
Workshop 1



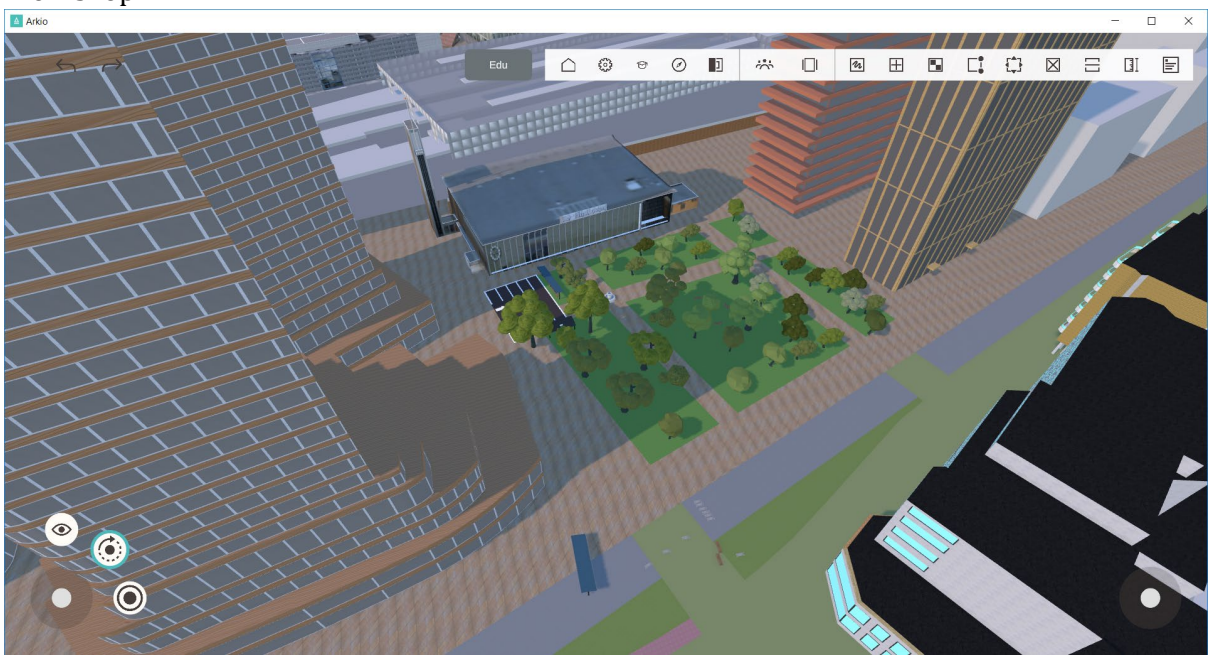
Workshop 2



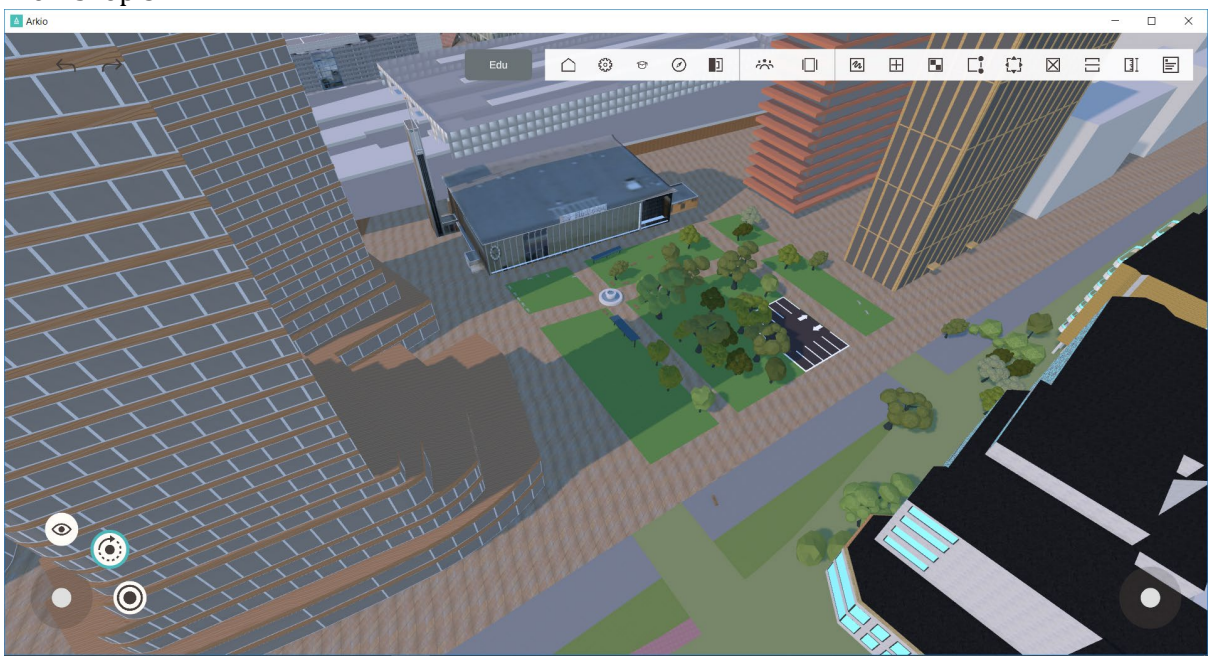
Workshop 3



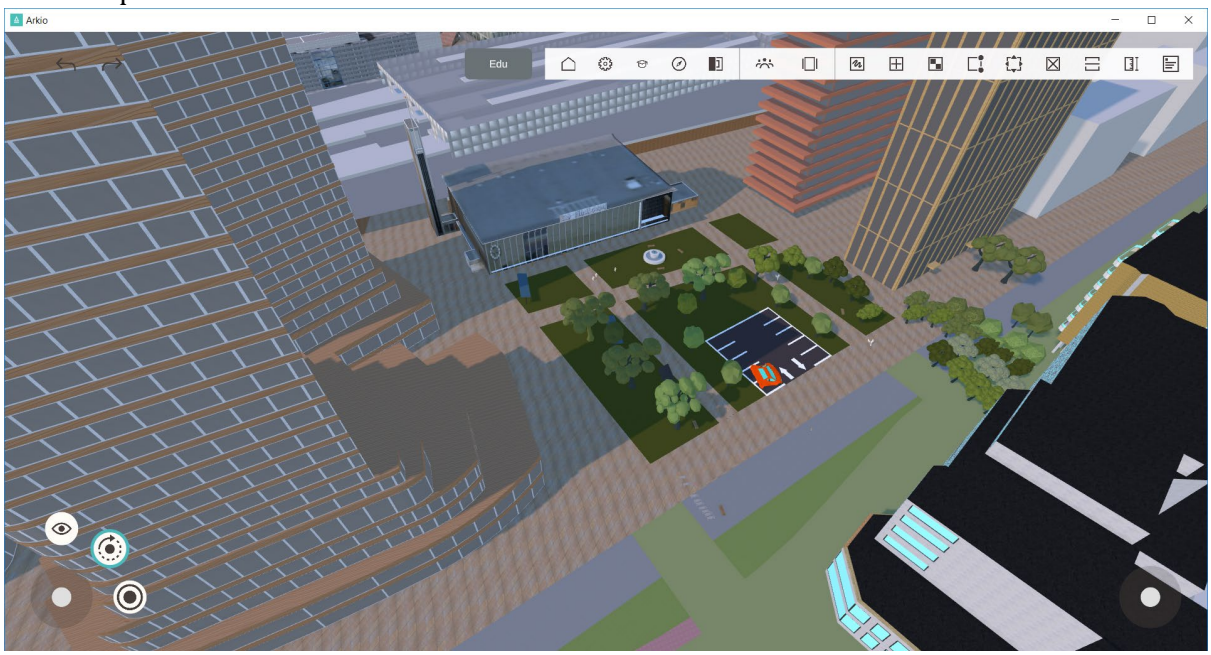
Workshop 4



Workshop 5

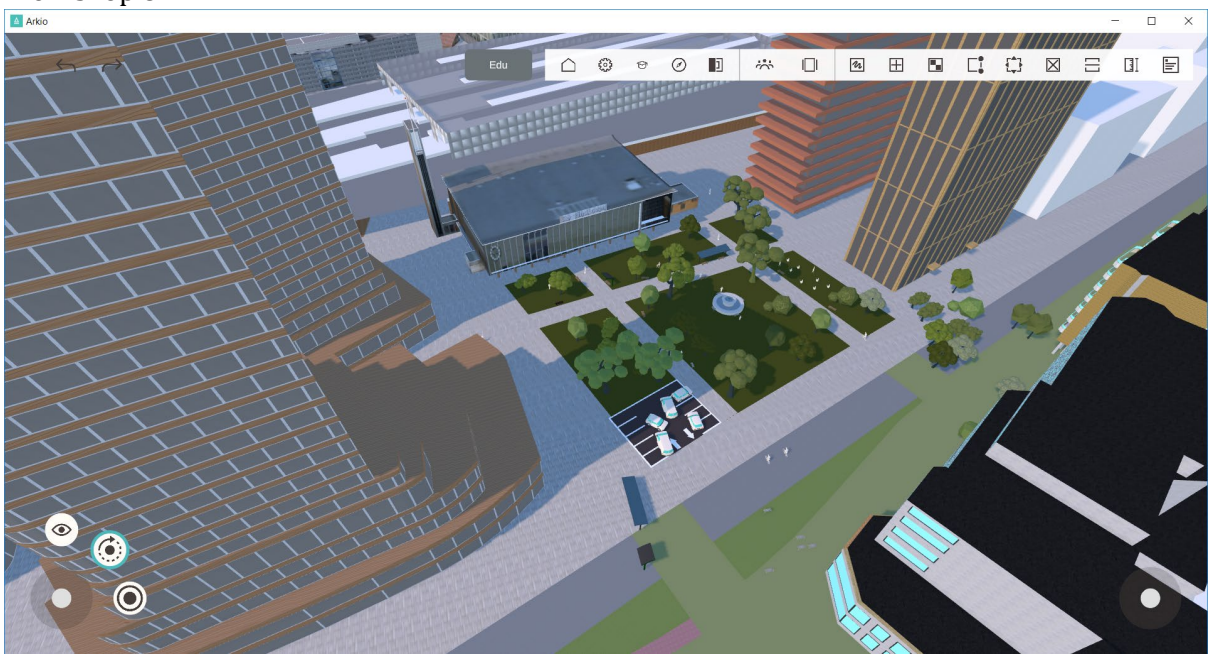


Workshop 6

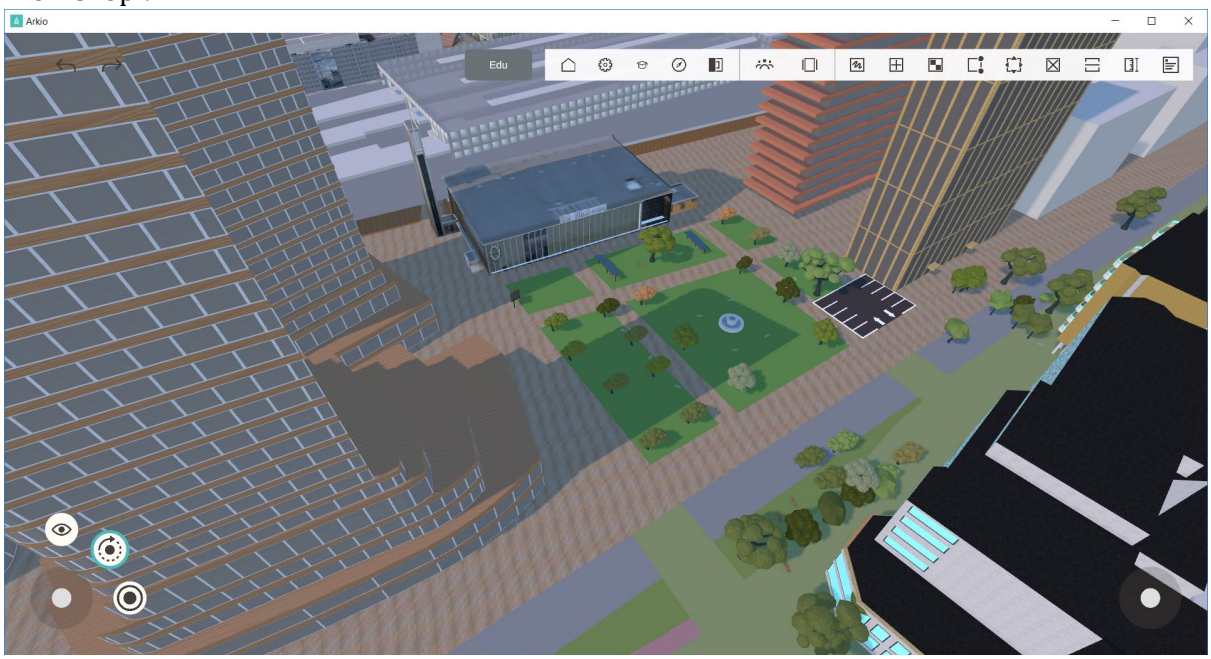


Workshop 7

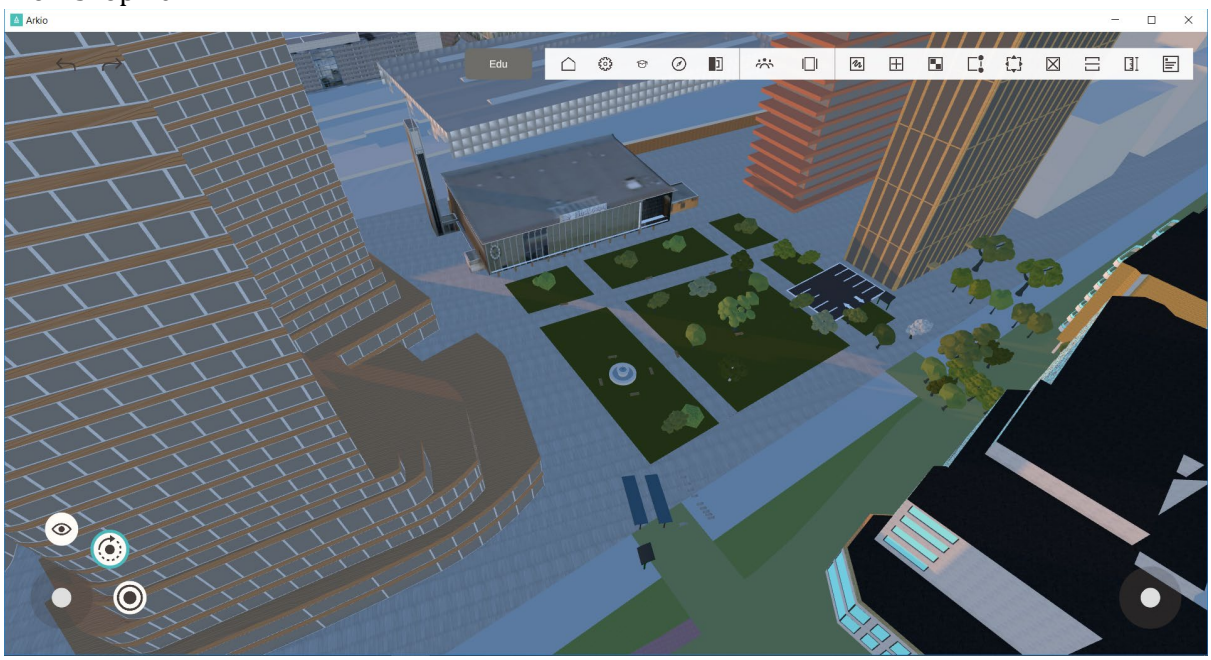
Workshop 8



Workshop 9



Workshop 10



APPENDIX C Results of the Spearman's Rank

Results of the Spearman's Rank analysis.

		Participation likelihood	Extraversion	Openness to experience	Agreeableness	Conscientiousness	Emotionality	Age
Participation likelihood	Correlation Coefficient	1.000	.253	.118	-.265	.069	-.083	.219
	Sig. (2-tailed)	.	.282	.621	.258	.771	.728	.353
	N	20	20	20	20	20	20	20
Extraversion	Correlation Coefficient	.253	1.000	.621**	-.127	-.249	-.149	.169
	Sig. (2-tailed)	.282	.	.004	.594	.290	.531	.477
	N	20	20	20	20	20	20	20
Openness to experience	Correlation Coefficient	.118	.621**	1.000	.284	-.311	-.382	-.035
	Sig. (2-tailed)	.621	.004	.	.225	.182	.097	.885
	N	20	20	20	20	20	20	20
Agreeableness	Correlation Coefficient	-.265	-.127	.284	1.000	-.278	.143	-.423
	Sig. (2-tailed)	.258	.594	.225	.	.235	.549	.063
	N	20	20	20	20	20	20	20
Conscientiousness	Correlation Coefficient	.069	-.249	-.311	-.278	1.000	.135	.064
	Sig. (2-tailed)	.771	.290	.182	.235	.	.570	.790
	N	20	20	20	20	20	20	20
Emotionality	Correlation Coefficient	-.083	-.149	-.382	.143	.135	1.000	-.042
	Sig. (2-tailed)	.728	.531	.097	.549	.570	.	.861
	N	20	20	20	20	20	20	20
Age	Correlation Coefficient	.219	.169	-.035	-.423	.064	-.042	1.000
	Sig. (2-tailed)	.353	.477	.885	.063	.790	.861	.
	N	20	20	20	20	20	20	20