Benefits of Virtual Reality in Co-Design for Residential Architecture

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1. Introduction

Co-design is an established practice within the field of user involvement in design projects. Sanders & Stappers (2008, p3) define co-design as "the creativity of designers and people not trained in design working together in the design development process". They describe that the design process is changing from a more product or technology focussed approach into a more needs and purposes focussed approach. Research from Cruickshank, Coupe, and Hennessy (2016, p3) further supports this statement by highlighting examples like 3D-Printing and "build-your-own" website services. Examples such as these show that the designer's role as an intermediary between the user and the production is becoming less pronounced (Cruichshank et al, 2016). In this changing world of design, co-design is becoming an increasingly more important strategy. Applying co-design in the design process will change how, what, and who designs.

This change in the way one designs brings many benefits: Firstly, by properly involving users in the design process, a higher quality outcome can be achieved (Damodaran, 1996). Users can bring up problems, questions or requirements that designers would not think of (Nielsen, 1994). Designers might have a wrong impression of the user's demands or preferences. By involving users in the design process, they can gain a better understanding of the users' requirements (Kujala, 2003). Secondly, applying co-design strategies will result in an increase in overall user satisfaction (Kaya, 2004). In fact, Campbell and Finch (2004) argue that user satisfaction is not only based on the outcome of a project, but is also impacted by the process itself. Allowing users to co-design will also result in a greater sense of ownership of the final outcome (Christiansson et al., 2008). A third benefit is a possible decrease in the amount of iterations required (Chatzoglou & Macaulay, 1996). This can save the client valuable time the planning of a project. Dealing with unforeseen iterations is one of the most common reasons for cost overruns (Mujumdar & Maheswari, 2018). A final benefit is increased sustainability and reduced costs. Better performing designs with higher user satisfaction are less likely to need adjustments, leading to a decrease in reparations, modifications and renovations. Furthermore, design features that the user doesn't want or isn't going to use can be eliminated, saving valuable resources (Kujala, 2003).

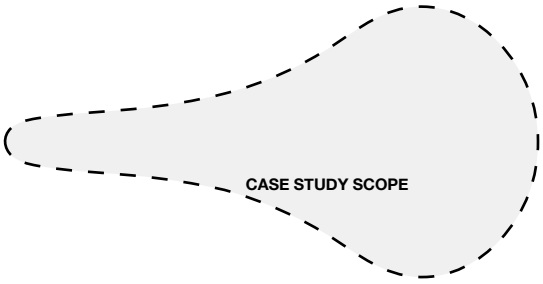
Representation	Questionary	Regionalism	Dialogue	Alternative	Co-decision	Self-decision
The architect passively considers the needs of the clients during the design process, by imagining the design from the clients perspective.	The architect bases the design on the results of statistically treated study and investigation results, generalizing needs and desires.	Similar to the questionary approach, but with an increased focus on local and historical context instead of a global one.	The architect bases design on informal conversations with clients and future users of the project, asking them to comment on proposals throughout the design process.	The architect designs several proposals within a fixed frame, from which clients and users can pick their preference.	The architect and the clients and users are equal in their role in the design process, through intensive, balanced collaboration.	The user makes most of the design decisions themselves and the architect is mainly there to check against safety and regulations.

Table 1: Different levels of participation in architecture, ranked from less (left) to more (right) user involvement. After Wulz (1986)

Involving the needs of users and clients has been a key part of the architectural design process for a while now. Since the 1960's, participation in architectural and urban planning projects has increased (Wulz, 1986). However, not all participation is equal. Wulz describes different forms of participation, as summarized in Table 1. Conventionally, participation in architecture relies on the "Representation" and "Questionary" stages, and rarely goes beyond the "Alternative" stage. Up until this stage, the architect has the decisive influence over the project (Wulz, 1986) and the user is treated as a passive subject of study instead of as an active design partner, as is to be expected from a traditional design process (Sanders & Stappers, 2008). For this reason, Sanders & Stappers (2008, p13) go as far as to claim that "The domains of architecture and planning are the last of the traditional design disciplines to become interested in exploring the new design spaces that focus on designing for a purpose". Transforming this traditional architectural design process into a co-design based process will cause the field of architecture to become more objective, inclusive and democratic, along with the other benefits of the co-design process described before.

The goal of this study is to evaluate a Virtual Reality (VR) based co-design process in the field of residential architecture. Initially, this paper describes the results of a literature study that act as a theoretical framework. In this framework, the definition and levels of co-design and user involvement will be explained. Then, common complications and shortcomings of co-design within the field of architecture will be studied. The final part of the literature study will describe how VR technology can be used to overcome some of these complications. The next part of this study will focus on a practice based case study, in which the theoretical framework will be tested and evaluated. Clients will co-design a small residential building together with the architect. During this experiment, VR will be used to test whether it can help to overcome the shortcomings of co-design in architecture. It will test whether the participants feel involved and empowered in the design process, if they have a better understanding of the architecture and architectural values by the end of the project, and how it affects the tensions between architects and end-users in co-design processes. Chapter 3 describes the approach and methodology of the experiment. Afterwards, the findings will be presented. Any noteworthy observations made during the experiment will be discussed afterwards, before concluding the research in the final chapter along with a reflection and suggestion of further research.

This study takes place as a graduation project within the MSc Architecture at Delft University of Technology. Therefore, there are certain limitations that apply to this study in terms of scope, depth and conflicts of interest. These will be discussed in the reflection chapter of this paper.



2. Background

Scope of co-design in this study

Co-design, user involvement and participation are very broad terms, that are rising in popularity. A Google Scholar search brings up 209.000 counts for "Co-design" on januari 6th 2021, compared to 11.800 on august 18th 2007 (Sanders & Stappers, 2008). There seems to be no consensus in definitions of co-design, user involvement or participation (Caixeta, Tzortzopoulos, & Fabricio, 2019). Therefore, when researching the topic of co-design, it is important to define what exactly is meant by co-design in this study.

Authors	Levels of User Involvement, Increasing Left to Right											
Damodaran (1996)		Informative			Consultative			Participative				
Kaulio (1998)		Design for			Design with				Design by			
Ho and Lee (2012)		Design for							Design with		Design by	
Olsson (2004)	Users as Subjects	Users as informants						Users as co-operation partners				
Wulz (1986)	Represen-tation	Questionary	Regionalism		Dialogue	Alternative			Co-decision		Self-decision	
Sanders & Stappers (2008)		User-centered design							Co-design			
	Architect Only	**Architect over User**						**Architect and User are Equal**			**User over Architect**	

Table 2: Comparison in definitions of level of user involvement by different authors. After Caixeta, Tzortzopoulos, & Fabricio (2019)

Kaulio (1998) proposes that user involvement "represents possible interactions between users and the design process" (Caixeta, Tzortzopoulos, & Fabricio, 2019, p11). It is a very broad term, but it can be categorized as a ladder, with each step increasing the level of user involvement and representing a specific relationship between the users or clients, and the designers. (Arnstein, 1969; Kujala, 2003; Baggott, 2005). Even though representing user involvement as a purely linear scale is debated (Caixeta, Tzortzopoulos, & Fabricio, 2019), it is generally agreed upon that the level of user involvement is related “to the range of influence that users or their representatives have over the final product” (Bergvall-Kåreborn & Ståhlbröst, 2008). Different levels of user involvement are shown in Table 2. The "Architect Only" column describes situations where the architect has full creative control over the process, and the user is only passively studied instead of actively involved. The "Architect over User" column represents levels where the users are actively involved in the design process, but the architect remains in final creative control. This changes in the "Architect and User are Equal" column. Here, no party has final creative control. This doesn't necessarily mean that every small design decision has to be debated and tasks can't be delegated between parties, but rather that everyone has equal say over the final outcome. The

final column, "User over Architect", describes situations where the user has the final creative control or ends up doing the majority of the design work, with the architect or professional designer only taking on the role of a consultant, making sure the project meets technical and legal requirements.

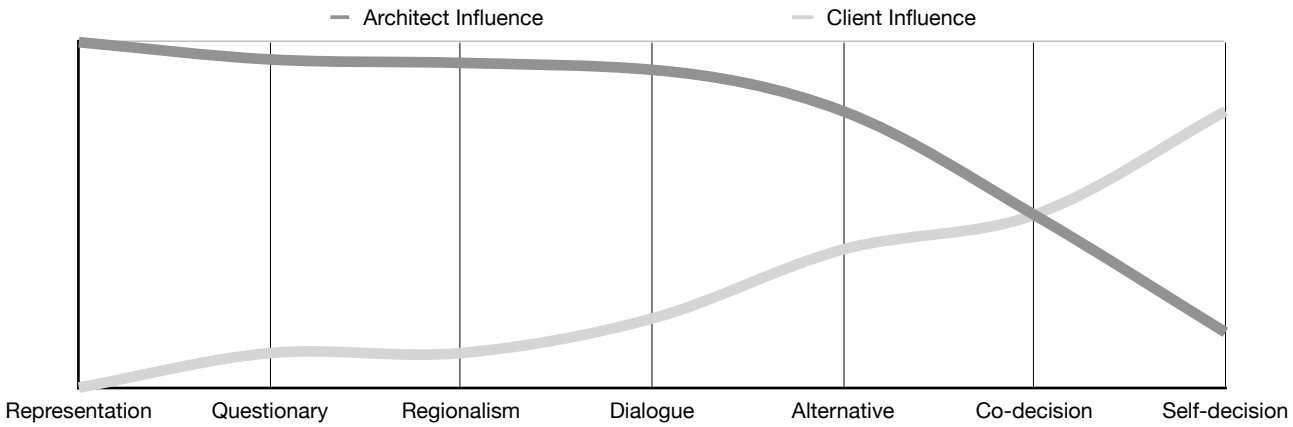


Figure 1: Level of influence of architect and client in a participatory design project. Own illustration after Wulz (1986).

This study focusses mostly on the "Architect and User are Equal" levels of co-design. Figure 1 shows the scope of user involvement applicable in this study in grey. The height of the shape is used to indicate the amount of focus on a certain level. The definition of Wulz (1986) is used because of its detail and its focus on the field of architecture. However, this study specifically focusses on co-design, as defined by Sanders & Stappers (2008), instead of co-decision, because of the focus of integrating users in the design process itself, instead of just giving them decision power. The approach and methodology chapter of this paper will go into further detail on the techniques and levels of user involvement applied in this study.

Shortcomings and complications of co-design in the field of architecture

While the advantages are apparent, integrating the co-design workflow into a design process has its issues. In practice, a design process is usually very complex, with many different and sometimes unknown users and stakeholders. While the discussions in a co-design process can be inspiring, the results are rarely directly actionable, and often need further elaboration or specification. (Zeng, 2019). Especially in fields with limited space for testing, like architecture or public policy, this can cause issues. If there is little consensus among these users and stakeholders, bad compromises can be made, reducing the final quality of the project (Kujala, 2003). Kujala also describes that finding the right users to involve in the co-design process can be hard. Co-design processes are long and intensive and therefore require a lot of time and effort. Busy end-users therefore might not always be able to participate. In fact, Cruickshank, Coupe & Hennessy (2016) describe that for a lot of co-design projects, the same kind of people tend to participate in the consultation meetings. Another issue seems to be with motivating the users. As long as the project is running smoothly, participants are happy and motivated, but when communication starts to fail or the project becomes too complicated, users get frustrated (Pemsel, Widén & Hansson, 2009). Not all co-design projects end up realized. Other projects change significantly between the consultation stage and the final delivery. This can disappoint users, making them less likely to participate in other projects.

Central to common issues with co-design processes are the difficulties communication. This is the case for both the communication from the designer to the user, as well as from the user to the designer. Participants can be reluctant to talk or lack the confidence to fully participate in the discussions (Kujala, 2003). Compared to experts, users can have difficulties in formulating their opinion, especially when the discussion is more technical. When the topic of discussion is too far out of their knowledge, users can feel trapped and feel like their contributions don't matter or they have nothing significant to add (Pemsel, Widén, & Hansson, 2010). Users might also be inconsistent between what they say and their actual behavior, wishes or needs (Christiansson et al., 2008). When asking users for their opinion about design, the answer often becomes a more traditional solution. This has partially to do with the smaller frame of reference that users typically

have compared to experts (Dewulf & van Meel, 2002), and partially because users lack knowledge about how the design process itself works, or what designers need to know from them (Wilson et al., 1996). Understanding the importance and complexities of communicating with users is one of the most important aspects of co-design. "The difficulties found in practice are principally in making end-users see a greater and longer-term perspective of their situation and overcoming social and cultural barriers among participants as a means to understanding real needs. [...] The cases showed that pedagogical and behavioral skills were of critical importance for success in understanding end-users and the interdependent context of the projects" (Pemsel, Widén & Hansson, 2010, p9).

When applying the co-design process in the architectural field, some of these complexities will be less prevalent. Especially in the field of residential architecture, the user might already be involved in the project. Otherwise the future user of a project is well studied and well defined. Finding motivated users to take part in the design process is relatively easy compared to other industries. The same thing is true for involving stakeholders in the design process. Through information exchange protocols like "Building Information Model" (BIM), different stakeholders in the architectural field already actively exchange design work (Bouw Informatie Raad, n.d.; Autodesk, 2002). Design, build, finance and maintain (DBFM) contracts already focus on an integrated approach to the project, requiring close collaboration and exchange between different stakeholders (Ministerie van Algemene Zaken, 2019). However, architectural projects also bring unique challenges to co-design projects. The built environment is very traditional, and traditional successful designers and businesses are unlikely to want to give up control (Sanders & Stappers, 2008). Because of the close integration between stakeholders, if any of the them is unwilling to change their workflow to accommodate an increased level of user involvement, it is unlikely to happen. Moreover, even though the main stakeholders are well known, the built environment still has a complex business model with temporary partners and external providers (Christiansson et al., 2008). Subcontractors and consultants can be brought in or replaced at any point in the process, making the entire situation unpredictable and less controllable compared to industries with one major party responsible for design and production. This complex business model might also make it less likely for a party to feel pressure to innovate. In fact, innovating too fast can cause a company to become the odd one out, losing compatibility with the older, more traditional workflows. Only when all of the stakeholders are willing to integrate users in their workflow can co-design happen.

But even when the stakeholders are willing, integrating users in the architectural design process can be a difficult task. The architectural design process tends to be very chaotic and largely implicit, rather than a more linear and explicit process (Van Dooren, Boshuizen, Van Merriënboer, Asselbergs, & Van Dorst, 2013). Steps are taken unconsciously and tend to happen unstructured and in parallel, rather than in series. Van Dooren et al. (2013) proposes to encapsulate the design process in a framework consisting of five elements: (1) Experimenting or exploring and deciding, (2) Guiding theme or qualities, (3) Domains, (4) A frame of reference or library, and (5) Laboratory or (visual) language. Participants in a co-design session do not have to be or become expert designers. However, they need a minimum viable amount of knowledge to be properly included in key moments. In the process of making design decisions, the participants should be able to explore, question and critique the various alternative design options. This process relies heavily on efficient communication, which can be difficult to achieve. Besides the communication problems described before, the architectural field introduces some additional communication problems. First of all, the architects have developed their own language, in which they give common words a different meaning or invent words all by themselves, even confusing other industry professionals (Stott, 2015a; Stott, 2015b). This often complex sounding lingo can confuse or intimidate clients, leaving them out of the conversation. A second, perhaps even bigger reason is that spoken or written language is only a part of how architects communicate. Architects rely heavily on the use of references during the design process which is the fourth element of the framework by Van Dooren. Architectural designers use these references as examples, or to quickly and effectively communicate about ideas or solutions. Furthermore, much of the architectural dialogue relies on products like sketches, plans, sections, models, and diagrams. This process is described as the fifth, Laboratory or visual language element within the framework proposed by Van Dooren. "The process of modelling and sketching runs parallel to the process of using words" (Van Dooren et. al, 2013, p17). For effective communication, it is important that all parties can speak the same languages. The typical user or client might not be able to understand

these products at all (Norouzi, Shabak, Embi, & Khan, 2015). Wulz (1986) describes that "it seems that many architects in the communication situation overlook the fact that maps, plans, pictures, slides and even architectural models are abstractions of a reality which only exists in the brain of the architect". Only in the final stages of a design process are these kinds of products replaced with products more understandable to the user. At that time, it might already be too late for the user to properly give feedback on the design choices made. A study by Norouzi, Shabak, Embi, and Khan (2015, p3) subscribes to this claim and states the following:

> "*A disproportionate number of defects in the architectural design can be traced to the inefficiency of communication between the architect and the client. The poor communication and inadequate specifications of architectural domain knowledge from the client has been implicated as a main obstacle to increasing the quality of the design itself and the satisfaction of the client simultaneously. Thus, defining the role of architect and client in the architectural building design as a communicative activity will reduce miscommunication as well as facilitate information exchange by clarifying design aspects.*"

Based on their findings, it could be argued that the effectiveness of any co-design approach in architecture is directly related to the effectiveness of the communication between the architects and the users / clients.

A final issue is that architects tend to have a signature style, in which they are experienced and for which they are recognized. These styles might not always be compatible with user involvement or the users preferences at all. For an architectural office, their signature style is part of how they market themselves, so they might not want to deviate too far away from it. This might result in the architect adding stylistic requirements to the design brief, even though the client might not at all be interested. This conflict between an architects signature style and the clients preferences might lead to unwanted compromises in the final design as well as tensions during the design process, reducing overall user satisfaction.

The potential of Virtual Reality in co-design

The application of Virtual Reality technology in the co-design process might help to overcome some of the complications a typical co-design process faces. First of all, VR might help to overcome the lack of experience users have regarding the design. A learning-by-doing based method of education, as conceptualized by Dewey (1916), can be used to quickly provide users with the skills necessary to participate in architectural design on-the-go. By using such methods, clients interact with a real-life simulation to learn and develop new skills. One of these methods, Inquiry based learning, can be applied to make clients explore the available material, ask deep questions and share new ideas. Virtual Reality is highly suited to support such learning approaches, by providing "a learning environment that is extremely close to reality – thus evoking a feeling of immersion and psychological sense of being in the artificial environment" (Inoue, 2012). A recent study by PwC (2020) into the effectiveness of applying state-of-the-art VR technology in professional education of soft skills shows that participants can be trained up to four times faster by using VR, were up to 275% more confident in applying the techniques that they are taught, and were 3,75 times more emotionally connected to the content, as well as more focussed, compared to classroom education. The findings of this study have been summarized in Table 3. Instead of observing and evaluating the design passively, by combining co-design and virtual reality, users are encouraged and motivated to actively engage with the design (Inoue, 2012). Another important advantage is the improved spatial understanding that VR provides (Dünser, Steinbügl, Kaufmann, & Glück, 2006). Spatial understanding is key to architectural design. The spatial representation of VR can help to overcome barriers between the architect and client in terms of design language, improving the important aspect of communication in architectural co-design processes.

	Classroom	E-learning	VR Training
Time required to complete training	2 hours	45 mintues	29 minutes
Improvement in confidence in discussing issues after the training	166%	179%	245%
Improvement in confidence in acting on issues after the training	198%	203%	275%
Emotional connection felt to learning content	4,29	5,29	20,43

	Classroom	E-learning	VR Training
Times participants were distracted during the experience	0,78	1,93	0,48
Time spend getting back on task after the distraction	1 minute	2,63 minutes	0,48 minutes

Table 3: Comparison between different methods of training professionals. After PwC (2020)

By allowing users to make design chances themselves, they are free to explore and evaluate new ideas without having to rely on the architect. This will most likely lead to an increased feeling of empowerment. This way, designers are capable of transforming the implicit knowledge of clients to explicit knowledge (Norouzi, Shabak, Embi, & Khan, 2015). Studies show that social interaction within a representative physical environment or with a prototype will accelerate the development of thoughts, ideas and cognitive activities from users (Schnabel, Wang, Seichter, & Kvan, 2007). This process of making and using prototypes is described as a significant activity for designers (Sanders & Stappers, 2014). Through the process of making and using prototypes, designers can evoke a discussion within a team, test a hypothesis, and apply and reflect on theories about the design. In a traditional architectural process, most of these prototypes are low-level prototypes such as sketches or low detail models, with a high level of abstraction. Making a higher detailed prototype will cost a significant amount of time. Only the highest level of prototypes can be understood by the users, therefore, the process of iterating over a design together with users is often expensive and very time consuming. An interactive VR environment may allow for rapid prototyping, drastically decreasing the time required to iterate in the design process, while maintaining high level prototypes. This allows the architect and the users to participate in a process of “continuous information gathering", which plays an important role in the transition from a phase-based process to an activity-based process (Hummels & Frens, 2008; Restrepo & Christiaans, 2004). This combination of fast, high level prototyping along with improved understanding, better communication and faster development of design skills that VR provides, can cause a significant impact on the success of a co-design process.

3. Experiment

Session Setup and Experiment Methodology

Based on the theory described thus far, an experiment was designed to try to address the aforementioned issues in co-design processes. Key obstacles include problems with proper communication between experts and participants, and a lack of knowledge on the participants side. A series of sessions need to be designed to overcome these issues to provide an overall smooth process. Even though using VR might be able to help, it needs to be applied strategically and at the right places. Applying VR at every step of the design process could result in a significant increase in time and required resources. Moreover, not every step in the design process is suited to VR, and adding VR at the wrong places could increase confusion or limit effective communication as well. A strategically chosen mix between VR sessions and traditional co-design sessions would probably result in the most efficient setup. The aim of the research is to simulate a co-design project, with a single expert designer and a number of non-designer participants, who will become the future inhabitants of a residential building. In order to focus specifically on the effects of VR on co-design conflicts, it has been chosen to eliminate budget from this simulation. The project will be divided into five phases. Each phase has its own goals, methods, and tools. Each subsequent phase would rely on the products from the previous phases and build from it. Earlier phases will focus more on the bigger picture and overall themes, later phases will go more into detail and small practical changes. Depending on the goals of each phase, a method of achieving said goal will be chosen, and with it corresponding tools.

The first phase introduced the participants to the project, its context and receive a general list of requirements. One of the goals was to get the participants to understand what is expected from them during the project, so they are clear on their role. A secondary goal was to obtain a general design brief. This is typically a list of practical requirements, and tends to focus more on the "what", instead of the "how". The chosen method for this phase was an open, but structured conversation with each participant individually. First, the general setup of the project and its phases was explained to the participant. Then the context of the project was explained, including, because this is a simulation, which areas they can influence, and which they can not. Then, participants were asked about their requirements and preferences for their residence. Once they had the chance to give their perspective, they were asked to give their opinion of a number of architectural themes that would fit this project, selected by the designer (shared facilities, circular design, above ground floor outdoor areas and sustainability). Based on this conversation, the designer compiled the initial design brief.

The second phase focused on making the design brief more specific and final, partially by clearing up miscommunication between the participants and the designer in the first phase, and partially by answering the "how" part of the design brief. Besides this, it created a shared frame of reference between the participants and the designer. The goal of this shared frame of reference was to create a set of examples, either good or bad, that the participants and designer can refer to during the future phases of the project. As preparation for the second phase, the designer created two design alternatives for the entire building, based on randomly mixed requirements from all of the participants design briefs. The idea is that this way, there are a large amount of references that the participants would be able to relate to, without recognizing any part of the designs specifically as their own, and hopefully therefore being more open in critiquing the projects. Because of the very visual and spatial nature of this phase and its goals, this session largely consisted of a guided VR walkthrough, in combination with an open conversation at the end. The VR walkthrough was a "multiplayer application", meaning that the participants and the designer share a virtual world, in which they could virtually see each other and their interactions with the world. This enabled hand gestures and pointing at objects, as well as drawing three dimensional annotations within the virtual world. This was also the first session the participants did collectively, meaning they will hear each others commentary and feedback, and can in turn respond. Participants were asked to use the "Think-Aloud" method of communicating, meaning they are asked to audibly describe what they are thinking about when exploring the designs. During the walkthrough, participants were asked to continuously describe what they like and don't like about a space. Afterwards, there was an open, unstructured conversation where they could give feedback on the process and anything they would like to add, or see differently.

The third phase was the first phase of the project to focus on the final design of the building, meaning when this phase of the project was finished, the products were mostly final. The goal of this phase was to divide the larger building between the participants and the shared spaces. Design themes for the shared spaces should have also be defined and agreed upon by the participants. Because of the schematic nature of this phase, this phase should most likely consist of multiple sessions. The sessions will mostly be used to evaluate and generate ideas and concepts. The time in between sessions is there for the designer to elaborate on the ideas and increase the level of detail to a point where the participants can comment on it again. Because of the lack of detail, VR might be confusing especially in earlier sessions in this phase. Recommended tools would be more traditional co-design tools like conversations and whiteboard sketches, supported by 3D visualizations.

Now that the building was divided between participants, the forth phase focused on each participants individual residence. At the end of the phase, the preliminary plans and layout of each residence were finished. Just like the third phase, it will probably consist of multiple sessions, each one more elaborated and increasing in level of detail. The main difference being that these sessions will be conducted individually between participant and designer, rather than collectively. Because of the overall increased level of detail, VR played a more significant part in these sessions, however still supported by sketches and conversation.

The fifth and final phase of the process focused on the evaluation of both the design and the simulation. The goal was to conclude the effectiveness of the proposed co-design process and deliver the finished designs to the participants. In this phase, no changes to the design were made anymore. The participants again did an individual guided walkthrough with the designer again using a "multiplayer application". Using the same "Think-Aloud" method as described in phase 2, they evaluated the design. After the walkthrough, there was an interview based on a questionnaire. Based on these questions the participants gave their perspective on the various aspects of this simulation. The experiences of the participants, combined with the experiences of the designer, resulted in the conclusion of the experiment.

Participants and Case Study

The co-design stakeholders in this experiment consisted of one architectural designer, who also acted as the co-design process lead, and three non-architect participants. The participants have been selected to have an interest in the process of designing their own house, but have not been through this process ever before. The participants are colleagues at the Delft University of Technology, and therefore know each other and could realistically enter into the more intimate process of co-design at the smaller residential scales. All participants have some, but varying degrees of expertise with VR, in order to determine whether a greater knowledge of VR will influence the results. The participants are as described below:

Participant 1: A VR developer, project coordinator and game designer, living with his partner and two pre-teen children.
Participant 2: A new media innovator and project coordinator, living with this partner, two teen children and an older child who moved out, but occasionally stays over.
Participant 3: A movie production coordinator and director, who is recently married.

The case study project used in this experiment is a residential building for the families of the three participants. The site is located in the IJburg neighborhood of Amsterdam, surrounded by a row self-built single family townhouses on either sides, single family villas on the south and the IJ lake on the north. The site is a double plot of 27 by 12 meters, of which 168m2 are buildable with a basement and five stories above ground. The site has some constraints from the municipality, with the position and materialization of the front facade being restricted. The townhouse nature of the street needs to be preserved. Behind the front facade, the design of the building is free for interpretation. Parking needs to be at the back of the site, at ground level, leaving a small space available for the garden. Besides these constraints, the team of the designer and the participants are free to design the residential building as they please.

4. Findings

Process limitations due to a pandemic

Before presenting the findings of this process, it has to be noted that this research took place during the COVID-19 pandemic of 2021. Because of this, some of the sessions and phases had to be cancelled or adjusted in nature. Some sessions in the first place were held remotely and online, rather than in person. During the second phase, the VR walkthrough could not have all participants be present at once, so one participant had the session individually at a later date. The entire third phase, with all participants and the designer dividing the larger building together, had to be cancelled and was designed by the designer exclusively, without any form of co-design. The design was however fully inspired by and based on remarks made by the participants during the second phase of the design. Due to time constraints within the graduation process, the participants were asked to take the results of this phase as-is and move on to the forth phase. The planned VR sessions in the forth phase had to be cancelled due to a lockdown as well. Because of the individual nature, the final fifth phase, containing the process results and evolution, could take place unhindered. The effects of this change in process planning will be mentioned when important in these findings and further elaborated on in the discussion chapter of this paper.

Process evaluation

When asked after evaluating the design at the end of the fifth phase, all participants remarked that they were very satisfied with the results. They used language like "exceeding expectations", "very satisfied", "very cool", and "pleasantly surprised". They explained that they felt heard and empowered during the process and could make or request adjustments whenever desired. Their requirements were integrated into the design, and they did not feel like there was anything in the final result that they did not want there. Whenever they had questions or did not understand something, they were either satisfied with the explanation given by the designer, or could request a change. However, even though positive, language like "pleasantly surprised" hints at significant, unexpected changes towards the end of the process. The fifth phase of the process should have been a confirmation of what they already knew would happen. This was not the case. When asked, participants remarked that they would've preferred to have more VR in the sessions, or additional VR sessions added. Especially missing VR in the fourth phase resulted in them not knowing exactly what to expect. For the fact that this process was a simulation, they felt the number of sessions sufficient, but in a real life scenario, they would've preferred more, especially towards the end of the process. Moreover, once participant stated the preference of having the designers findings and results of each phase communicated back to them, as a confirmation that there was a mutual understanding between the two. Adding this could further improve the communication overall and add another barrier against misunderstandings. With this final action added, the original process as planned, unhindered by a pandemic, be sufficient to overcome these issues and result in a solid co-design approach.

Virtual Reality as a visual language

In their research, Van Dooren et al. (2013) describe the importance of the visual language of sketching and modeling, next to verbal communication, within the design process. Even though VR is less effective as a design language compared to sketching and modeling (it takes significantly more time to develop ideas), it is much easier to learn and understand for non-designers. Translating the visual language of sketching and modeling into the visual language of VR at key stages in the process, has shown to limit miscommunication and answer questions or solve issues well before they become problematic. Participants described VR as "crucial", "amazing" and "essential" for them to understand the design and properly take part in discussions. They also remarked the difference between looking at three-dimensional images on a computer screen, and seeing them in VR afterwards. Even though they were looking at the same design, the experience was anything but the same. Within VR, they could clearly understand and "get a feel" for the spaces, describing the environment as "coming alive", something they could not do in front of a desktop computer. One participant, who had experience reading architectural plans and technical drawings, still went as far as to say that "Virtual Reality should become a legally obligated tool in communicating any architectural project to clients and stakeholders". With VR not being present in the forth phase of the project, participants felt like they were missing an

important part of the communication. This probably resulted in them being "pleasantly surprised" at the final phase. The lack of VR did not result in design conflicts at this stage, but it did limit their understanding of the result they were getting. This again supports the importance of VR as a communication tool in co-design processes. However, these VR experiences were still relatively static. Participants were able to freely observe the design in VR, and even have guided walkthroughs, but they were not able to make changes to the design within the virtual environment itself. In this process, VR was mostly used as a language or tool of presentation and evaluation, not of ideation or iteration. This more dynamic experience was supposed to be tested in the cancelled VR sessions in the forth phase of the process. When asked about missing this feature of VR in the final evaluation of the process, participants differed in opinion. While all agreed that making small changes (replacing materials, rearranging furniture, resizing windows, moving doors) or having the ability to sketch in VR would be beneficial to the communication, the participants with less experience in VR remarked that making significant changes to the design (moving walls, changing the plans) while in VR would probably confuse them more than help them. In those cases, they would prefer taking a small break, while the designer makes the changes, and then invites them back in to evaluate the results. Overall, VR performs very well as an easy to understand visual language, that can be used next to, or instead of the more traditional visual language of sketching and modeling when communicating with non-designer participants in a co-design process.

Shared frame of references

As discussed in the theory, expert designers make excessive use of a frame of references in their design process. This is an area of knowledge that non-designers typically don't have. The second phase of the process was introduced to test whether a shared frame of project specific references between the designer and the participants could help improve communication and understanding between the parties. Two building alternatives containing a total of six residences were designed, based on a randomly mixed set of participant requirements, and evaluated during this phase. Because of the randomization of requirements, participants felt they could comment and give feedback on every part of the design. This resulted in the predicted improved set of participant requirements for the designer to work with. Because these references had been designed to be project specific, they helped overcome misunderstandings from the first phase. The spoken requirements obtained in this first phase were additionally supported by a set of more loose, interpretive requirements that would have been harder to communicate. When asked in the final interview about the effects of this second phase to the overall process, participants explained that it had definitely helped, especially themselves. They confirmed that this was the moment when misunderstandings where spotted, but because these were reference projects, and not the final design, they would not have any negative effects or needs to be resolved, and therefore supported learning. They also better understood the themes introduced by the designer better, and started to see the benefits of adding them to the project. Furthermore, this shared frame of references had additional, unpredicted benefits in the overall process. Just as in communication between expert designers, the references were constantly used and referred to when proposing new ideas. Referring to the shared references improved even discussions based on sketching and modeling. In the detailed forth phase of the process, spaces could be described as "similar to what we saw in this reference from phase two", improving not only communication, but also limiting the time needed between designer and participant. Even though the forth phase ended up relying heavily on the visual language of sketching and modeling, rather than better to understand VR, the participants ended up with designs that fitted their expectations very well, with hardly any conflicts or misunderstandings at all. Moreover, the second phase acted as an important reference of VR based communication as well. Even though VR technology had advanced significantly in the previous years, it still has limitations, that could affect the interpretation of designs presented in VR compared to real life. Having visited multiple designs in VR, participants would get an idea of what to expect from VR in terms of level of detail, graphic quality, and field-of-view based scale interpretation. This allowed participants to compare ideas from one VR environment to another VR environment, rather than having to compare a VR environment to reality. It has to be said though that when making such comparisons, it is the responsibility the designer to ensure that the qualities of the space in VR will reflect the qualities in real life. Therefore it is recommended that the designer has sufficient experience with both creating VR environments, as well as understanding how VR environments translate to the real world.

Tensions, questions, disagreements and priorities

One of the aspects that architectural co-design processes typically face, are tensions between the architectural designers and the non-designer participants. As explained before, architects tend to have have their own signature styles and generally bring their own themes to the projects they are working on. These themes do not necessary align with the priorities of the participants in a co-design process. In this process, the designer introduced themes like co-habitation areas and shared functions, a circular building method and a standardized structural system. None of the participants requested or hinted at these themes during the first phase interview. One of the participants was even skeptical of the social themes, especially before seeing them visualized in phase two. At the end of the process however, all participants remarked they were happy with these designer-introduced themes. When asked during the fifth phase evaluation about whether they had experienced any conflicts between themselves and the designer during the process, the participants would respond with a clear "no". This statement could be interpreted in two ways. Either the process has been entirely conflict free, with everyone being in full agreement with each other, which seems unlikely, or the conflicts where resolved quickly and smoothly enough that they would not be interpreted as such. When asked, the participants confirmed this second interpretation. Besides having potentially conflicting themes or ideas explained to them during the process, participants remarked that seeing the effects of these themes visualized significantly helped them understand why the designer introduced them. They mentioned that "the clear and understandable explanation of why things happen or are they way they are" was important, and that conversations "felt open and respectful of their input". Because of this improved understanding, whenever ideas proposed by the designer would conflict with the wishes and requirements of the participants, the conflict would be spotted quickly and resolved well before its implementation was final. However, there is also the possibility that this improved understanding and communication would lead to the participants moving more towards the architectural domain in their role. This was clearly not the case. Participants suggestions and feedback mostly stayed within the more functional domains of the design process. Whenever the participants suggested architectural ideas, the ideas were mostly disjointed and lacked a central guiding theme, which in their implementation would result in a more discordant overall design. That is not to say that these contributions were not meaningful, but they required examination and interpretation by the designer to get to the important, underlying values. Participants remarked that this separation between the functional domains and the architectural domains was to their preference. They expected the architectural designer to take on these tasks of integrating the various ideas into a single, coherent design, and then present it to them for feedback and evaluation. "The advantage of having an expert designer who looks at what we are not looking at, comes with new ideas based on this, thinks out of the box and acts as a connecting entity between different parties" is what a participant was quoted saying during the final interview, when asked to describe the role of the architectural designer during the process. This evaluation of the process supports the notion that good communication is important in overcoming many of the issues that traditional co-design processes face, and that a process designed to overcome traditional issues with miscommunication will result in less perceived conflicts at the end.

Non-verbal communication in Multiplayer Virtual Reality

One of the unexpected findings in this process were the benefits brought by having a multiplayer VR application. By having multiple people share the same virtual environment while being able to see and interact with each other, multiplayer VR environments not only allow for both verbal and non-verbal communication to take place, but it facilitates a more natural flow of the conversation. This is a significant improvement over non-multiplayer VR processes, where typically one person is in the virtual environment while others look at the same picture on a screen. The person in VR would be isolated and only able to hear, but not see, what the others are discussing or referring too. Hand gestures made by either one of the parties would typically be missed by the other party. In a multiplayer environment, people can see where the other person is and what that person is looking at, simply by following their line of sight. Moreover, it becomes easy to point at things or make hand gestures to indicate scale or movements. When asked about multiplayer VR, the participants responded with terms such as "crucial" and "essential", as well as pointing out the benefits to communication and the amount of additional information it provides. These benefits of a multiplayer VR environment should make it an essential part of any VR projects that rely on communication and participation.

5. Discussion

Graduation and Scope of Research

The fact that this study took place during a graduation project within the MSc Architecture at Delft University of Technology, had an impact on the overall process. Primarily, the scope of the research was influenced. Because of the limited timeframe and lockdown measures in place, the amount of participants was kept low. This limited amount of participants, as well as the fact that all three were men working in the same field, makes the outcome of the study less impactful, since it can be more easily biased. Having a more diverse group of participants with different backgrounds could give further insights. Additionally, the graduation context also had impacts on the design process itself. Normally a co-design process would take place between the designer, participants and third party stakeholders. In this process, teachers were added who supervised the designer. Even though these teachers could be viewed as third party stakeholders, because they will grade the final product, this results in a skewed balance of power. Alternatively, the teachers could be seen as neutral observers of the process, and ideally this would be the case. However, in practice, teachers end up bringing a lot of their own ideas, values and experience to the table, therefore either consciously or accidentally affecting the process. This meant that the designer had to balance the wishes and demands of the participants on the one hand, with the values and feedback of the teachers on the other hand. Furthermore, graduation as an architecture student means meeting a number of set requirements. These requirements of what an architect should be able to do, and what skills they should have, are based on a more traditional approach to architecture. From inside the field of architecture, architecture is evaluated differently than how non-designer participants evaluated it. This created a tension between what participants value in the process and the result, versus what architects value. This resulted in themes being introduced into the process, even though no participant specifically mentioned or requested it. And even though the participants ended up being satisfied with these themes being present, they would not have been introduced if not for the graduation context.

Simulation and Budget

In order to emphasize the process, rather than the result, it was chosen to simulate a design process, rather than use a real life case study. In parts, this decision came out of the graduation context, with real life projects being discouraged in the graduation track so students can focus on the experiment rather than rules and regulations. Moreover, it was a time-saving measure. Private residential co-design and co-housing projects are rare in The Netherlands. Finding multiple participants that would fit this studies description would prove difficult and time-consuming. Additionally, the title of architect is legally protected within The Netherlands. With the designer being a student, rather than a registered architect, the entire process would have to be overseen by an additional architect, further complicating the research. This decision to use a simulation, rather than a real life case study, had an undoubtable effect on the process. Since participants would not have to live with the result, they could be more accepting to compromise. Participants remarked that for a simulation, they were satisfied with the process, but in a real life alternative, they would have preferred more co-design sessions and evaluations. Furthermore, it was chosen to eliminate budget from this simulation. Even though adding budget would make this a more realistic study, it was feared that the significant effects budget imposes on any design project would distract from the testing of methods of co-design. Eliminating budget from the conversation prioritized topics like architectural values and participant wishes. The focus was on "what do you want", rather than "what can you afford". It can be argued that the methods used to successfully communicate priorities between designer and participant on these topics would be effective when communicating about budget as well. However, when evaluating the final result, participants are more likely to be positive since the absence of budget can more easily result in an improvement over their current living standards.

Pandemic

The fact that this study was conducted during the 2020-2022 COVID-19 pandemic resulted in some changes to the proposed setup. As described before in the findings chapter, multiple phases were adjusted and the entire third phase of the process was cancelled due to the pandemic. Cancelling the third phase has had a major impact on the scope of co-design in the process, making it a more of a dialogue instead of co-decision, by the definitions of Wulz (1986).

Even though the design was still based on participant input and ideas, they did not get a chance to actively participate in the design steps of this phase. Furthermore, the pandemic meant limiting each participant to one representative, instead of inviting their entire family to participate in the design process. This however should not have impacted the findings, since the participant who represented the family is also the one who evaluated the design. Allowing the families to participate however, could have been an easy way to increase the number of participants in the study.

Participant bias towards Virtual Reality

All of the participants selected for this study had prior experience with VR. Although the level of experience differed between participants, the range was between "familiar" and "expert". With multiple participants working in the field of VR, they are more likely to speak positively about its effects in general. However, this experience also allowed them to evaluate its use more critically and extensively. This allowed the study to define not if VR should be used in co-design, but rather how VR should be used in co-design. However, in overall remarks from the participants about VR, there is definite bias towards the technology.

Further Research Recommendation

Because of the before mentioned limitations to the process, it is recommended that this study is primarily used as an example of how to set up a co-design process, rather than act as proof of such practice. Further study into the field of VR in co-design is needed, but the process proposed in the experiment chapter of this paper can be used as a basis for such study. It is recommended that this study would be repeated outside the scope of graduation, or any other education related context. Furthermore, an increase in the amount of participants, together with using a real life case study, can make the study more significant. This can be achieved easily by allowing family members to participate in the process, rather than using a single representative. This would also introduce less VR-experienced participants into the study, further increasing the scope. However, the combination of existing theory and the beneficial findings of this study still provide a strong argument towards using VR in co-design processes.

6. Conclusion

The goal of this study was to determine whether adding VR to a co-design process in the field of architecture can help end-user involvement in the design process. It tested whether the participants felt involved and empowered in the design process, if they had a better understanding of the architecture and architectural values by the end of the project, and how it affected the tensions between architects and end-users in co-design processes.

In terms of involvement and empowerment, adding VR causes significant improvements in terms of communication and the participants understanding of the project. The improved communication eliminated misunderstandings between the designer and the participants, and saw all of the participants needs and wishes fully implemented into the final design. In the final interview, the participants confirmed that they felt well heard, understood and involved during the process, and praised both the final result, as well as the process overall. They specifically remarked VR, and the different ways it has been implemented throughout the process, being of crucial importance in achieving this.As for the understanding of architecture and architectural values, the results are a bit more mixed. By seeing them in VR, the participants were able to better understand the ideas and themes brought in by the designer. They were better able to understand and accept technical limitations, and how those affected their wishes. However, they did not actively propose new, or evaluate existing design themes. Participants remained in their role as end-user, focusing on requirements and day-to-day use, but ignoring broader context. They were still actively involved in the process, making key decisions affecting the outcome, but not transitioning into the architectural domain of the design process.

Finally, the way this process has been designed resulted in no perceived tensions between the participants and the designer. Even though priorities of the participants and designer differed, through visualization in VR, participants were able to understand why the designer proposed certain ideas and themes. Through the improved communication, disagreements were quickly and smoothly resolved, well before they could become problematic. This meant that all participants were fully satisfied with the end result.

7. Literature

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Appendix 1: Reflection

Looking back at the graduation process, I am happy with the findings and the results. I have to admit that this process started well before the graduation studio started, with me thinking about how to approach the topics of co-design and VR in the context of graduation, as well as in practice. That is also why some colleagues and I started a company to develop tools to support such a process, parallel to the graduation, but split up on purpose. The company developed the tools, the graduation process tested them. This however meant that delays on the development side could transfer into the graduation process, so the two of them grew further apart. The goal of this study is to discover and test how to approach co-design. Through experience, VR was already added into this equation, as a tool to help improve communication. Research in the early stages of this project backed up this decision.

From what I understand about the graduation process at the Architecture track, its mostly research first, then design, and then some reflection at the end. For this process however, I wanted to include the evaluation of the process as the key part of the research phase, and fully integrate the design part as a case study for the research theory. This proved very difficult within the traditional graduation process in the Architecture track. There simply isn't enough time in the traditional planning between the P3, P4 and P5 to take some weeks to step back from the design and evaluate from a distance, especially with external parties, in my case the participants, involved as well. Products are expected to be handed in at points where they simply would, and should not have been finished yet. Even though Explore Lab is a very free studio in terms of planning and control over the process, even though I took another half a year for my graduation process, and even though my mentors were very understanding and supportive throughout this process, I would not be comfortable recommending a similar process to any other students until the faculty loosens its strict control over the graduation topics and timelines.

As for the research itself, the limited scope and simulation of the design process mean that findings should be taken with a grain of salt. Even though the main conclusions should hold, a larger set of participants might be able to give more insight into the particularities of the findings. I was unable to test for example, how people with no VR experience would respond to such a process, or how elderly people would view the technology. However, from personal experience as a VR Developer, I would predict these would only result in minor adjustments. The simulation of the design process however is likely to have resulted in my participants being less critical about the result than in a real world scenario. It is easy to be happy with a result if you do not have to pay for it, or live in it, or look back at it after the process has ended. Yet, this should not have impacted the effectiveness of the communication and tools used in the process much. And testing their effectiveness was the main goal of this study. Furthermore, the approach and findings from this study could be used to build a more extensive study into this topic.

The key of this process was the planned five phases. A process designed on the basis of the preceding research, as well as personal experience. What proved essential in the projects success however, was the idea to first create a shared understanding of requirements, wishes, and ideas in the first two phases. This created a communication baseline that I have been able to use in all further stages of the design. I have very consciously steered away from any sessions using post-its or mind-maps, or other more traditional co-design techniques in these phases, and rather focused on just listening to the participants, then interpreting, and then displaying, in VR, my interpretation for evaluation by those participants. This worked very well. Of course there were misunderstandings, many in fact, but because this evaluation in the second phase was not related to the final product, but rather to a communication baseline and shared frame of reference, simply pointing out the positive and negative features of the design was enough for me and my participants to get on the same page, before starting with the actual process. The use of VR meant the participants were able to evaluate the design in a way that they understood and worked for them, rather than using tools and products that work for me as a designer. Furthermore, due to the pandemic this process ended up with limited face time between me and the participants. Sessions that were planned were few and far between, and VR was only used twice. Even following participant recommendations and introducing one or two extra VR sessions in the forth phase, towards the end of the process, the approach I introduced in this graduation project should not be more time consuming than a traditional collaboration between architect and users. For someone with the experience, translating the design proposals into the multiple VR

applications should only take a few days. The feedback from those sessions however could potentially end up saving time overall by eliminating changes. Moreover, empowering end users in the design process could make our industry more democratic. Especially in larger scale projects, municipalities often face pushback from inhabitants regarding a lack of participation and communication. Using the tools and findings from this project, some of these issues might be able to be resolved. I am looking forward to applying the findings in this study in the years to come, and to consult other industry professionals on how to implement them in their unique projects.