

TOBB UNIVERSITY OF ECONOMICS & TECHNOLOGY GRADUATE
SCHOOL OF NATURAL AND APPLIED SCIENCES

**ARKIO AS A POTENTIAL COLLABORATIVE DESIGN AND
PRODUCTION MODEL FOR FIRST YEAR IN ARCHITECTURAL
EDUCATION**

MASTER OF ARCHITECTURE

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JANUARY 2025

DECLARATION OF THE THESIS

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Senay Ürgen



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Senay Ürgen



ABSTRACT

Master of Architecture

ARKIO AS A POTENTIAL COLLABORATIVE DESIGN AND PRODUCTION MODEL FOR FIRST YEAR IN ARCHITECTURAL EDUCATION

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Institute of Natural and Applied Sciences
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Date: January 2025

Advancements in technology have significantly accelerated the adoption and transformation of digital tools in education. Among these tools, computer-aided design and virtual reality have emerged as pivotal technologies in architectural education. These innovations diminish the dependency on students' physical presence, offering transformative potential for collaborative design processes. Computer-aided design and virtual reality are increasingly incorporated into architectural education to foster environments where students can work together toward shared objectives, enabling them to engage in collaborative design practices. Arkio, a platform designed specifically for architects and architecture students, offers virtual production capabilities across domains such as building modeling, interior design, and landscape architecture. With its cloud-based collaboration and real-time interaction features, Arkio is particularly valuable for architectural education. Unlike other virtual reality platforms that emphasize individual design tasks, Arkio facilitates simultaneous multi-user collaboration on a single model. This unique structure supports collective

participation in design processes, making it an essential tool for learning design, especially for first-year architecture students. This thesis analyzes Arkio's potential and distinctive features as a collaborative design platform. By focusing on its application in first-year design courses, the study evaluates the strengths and weaknesses of Arkio in enhancing architectural education. Additionally, it examines the integration of CAD and VR technologies into collaborative design workflows, aiming to contribute to the development of Arkio and similar platforms. The research highlights the impact of these technologies on collaborative design processes and explores how they shape the educational experiences of architecture students.

In conclusion, the findings emphasize Arkio's role as a tool that supports collective engagement in architectural education. However, the discussion also addresses the platform's technical limitations and the need for improvements in user experience. The insights gained provide new perspectives on how the educational experiences of first-year architecture students can be shaped through collaboration- and production-focused processes.

Keywords: Arkio, Architectural education, Collaborative design, Virtual reality

ÖZET

Mimarlık Yüksek Lisansı

MİMARLIK EĞİTİMİNDE İLK YIL İÇİN POTANSİYEL BİR İŞ BİRLİKÇİ TASARIM VE ÜRETİM MODELİ OLARAK ARKIO

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Mimarlık Bölümü

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Tarih: Ocak 2025

Teknolojideki gelişmeler, dijital araçların eğitimde benimsenmesini ve dönüşümünü önemli ölçüde hızlandırmıştır. Bu araçlar arasında, bilgisayar destekli tasarım ve sanal gerçeklik, mimarlık eğitiminde öne çıkan teknolojiler haline gelmiştir. Bu yenilikler, öğrencilerin fiziksel varlıklarına duyulan bağımlılığı azaltarak iş birliğine dayalı tasarım süreçleri için dönüştürücü bir potansiyel sunmaktadır. Bilgisayar destekli tasarım ve sanal gerçeklik, öğrencilerin ortak hedefler doğrultusunda birlikte çalışabilecekleri ortamlar yaratmak amacıyla mimarlık eğitimine giderek daha fazla entegre edilmektedir. Mimarlık öğrencileri ve profesyonelleri için özel olarak tasarlanmış bir platform olan Arkio, bina modelleme, iç mekan tasarımı ve peyzaj mimarlığı gibi alanlarda sanal üretim olanakları sunmaktadır. Bulut tabanlı iş birliği ve gerçek zamanlı etkileşim özellikleri sayesinde, Arkio mimarlık eğitimi için potansiyeli olan bir araçtır. Bireysel tasarım görevlerine odaklanan diğer sanal gerçeklik platformlarının aksine, Arkio, tek bir model üzerinde eş zamanlı çok kullanıcıli iş birliğini kolaylaştırmaktadır. Bu yapısı ile, özellikle birinci sınıf mimarlık öğrencileri için tasarım öğreniminde kolektif katılımı destekleyerek eğitim sürecinde önemli bir araç haline gelmektedir. Bu tez, Arkio'nun iş birliğine dayalı tasarım olarak

potansiyelini ve ayırt edici özelliklerini analiz etmektedir. Birinci sınıf tasarım derslerine uygulanmasına odaklanarak, Arkio'nun mimarlık eğitimi geliştirme konusundaki güçlü ve zayıf yönleri değerlendirilmektedir. Ayrıca, bilgisayar destekli tasarım ve sanal gerçeklik teknolojilerinin iş birliğine dayalı tasarım iş akışlarına entegrasyonunu inceleyerek, Arkio ve benzeri platformların gelişimine katkıda bulunmayı amaçlamaktadır. Araştırma, bu teknolojilerin iş birliğine dayalı tasarım süreçlerine etkilerini ve bu etkilerin mimarlık öğrencilerinin eğitim deneyimini nasıl şekillendirdiğini ortaya koymaktadır.

Sonuç olarak, Arkio'nun mimarlık eğitiminde kolektif katılımı destekleyen bir araç olduğu vurgulanmaktadır. Bununla birlikte, platformun teknik sınırlamaları ve kullanıcı deneyimi konusundaki iyileştirme gereklilikleri de tartışılmaktadır. Elde edilen bulgular, özellikle birinci sınıf mimarlık öğrencilerinin eğitim deneyimlerinin iş birliği ve üretim odaklı süreçlerle nasıl şekillendirilebileceğine dair yeni bakış açıları sunmaktadır.

Anahtar Kelimeler: Arkio, Mimarlık eğitimi, İş birlikçi tasarım, Sanal gerçeklik



"All in all, it was all just bricks in the wall"

(Waters, 1979)



ACKNOWLEDGMENTS

I am deeply grateful to my supervisor, Assoc. Prof. Aktan Acar, for his invaluable guidance and support. His teachings in architecture and education, as well as his belief in mentoring each student according to their potential, have been a constant source of inspiration. I am especially thankful for his perspective on embracing diversity and for guiding me to find and nurture my own unique "color" in this field.

I am profoundly grateful for all the remarkable people I have met and the cherished memories I have accumulated throughout my master's journey. I sincerely thank Asst. Prof. Masoumeh Khanzadeh for the invaluable opportunity to teach in the Basic Design Studio, a place that shaped my dreams and career path. Guiding 58 students turned into a transformative learning experience, as their perspectives and questions deeply inspired me and shaped my vision for the future. I am profoundly grateful to them for the lessons and memories that enriched my master's journey.

I am deeply grateful to my friends Maame, Paola, Gizem, and Başak, who brought hope, joy, and unforgettable memories into my life during my time in Manchester. I also extend my heartfelt thanks to my colleagues Derya, Mehtap, and my friends Ravda, Öykü, and Gaye for their unwavering support throughout my academic journey.

A special thanks goes to Yasemin, my companion. At 17, we wondered where the future would take us, not knowing we would discover the answer together. Her presence and support have made this journey profoundly meaningful.

Finally, I would also like to express my deepest gratitude to my family, who gave me the freedom to pursue my dreams and believed in me above all else. To my dear mother, who held my hand tightly through my struggles and illuminated my path with her love; to my father, who accepted me as a free spirit, even when it was difficult, and reassured me with his presence, even from afar; to my beloved sister, who inspired me by encouraging me to face difficulties head-on and never give up; to my younger sister, who stood by me with a maturity beyond her years and gave me strength in every moment; and to Sare and Bekir, who have an extraordinary place in my life and have

showered me with unconditional love—nothing would have been possible without you. Thank you with endless gratitude and love.

And my deepest gratitude and thanks to my Rabb, who has blessed me with these beautiful paths, people, and memories and who has bestowed this knowledge upon me.

I am truly thankful for His blessings.



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ABBREVIATIONS

2D: Two Dimensional

3D: Three Dimensional

AR: Augmented Reality

CAAD: Computer-Aided Architectural Design

CAD: Computer-Aided Design

CAVE: Cave Automatic Virtual Environment

MR: Mixed Reality

MUCAD-CLF: MUCAD Collaborative Learning Framework

MUCAD: Multi-User Computer-Aided Design

VR: Virtual Reality



1. INTRODUCTION

Technological advances are influencing educational processes to address the evolving requirements of contemporary architectural practice. Architectural education seeks to equip students with a broader range of knowledge and skills in design processes by leveraging both digital tools and traditional design methods. In this context, the integration of Computer-Aided Design (CAD), Augmented Reality (AR), and Virtual Reality (VR) technologies into architectural education facilitates the exploration of design processes through digital tools. Such integration supports students in acquiring competencies relevant to professional practice.

CAD was among the first digital tools introduced into architectural education, facilitating the acceleration of design processes and enabling more precise outcomes. CAD software provides opportunities for students to enhance their technical drawing skills and assess their designs in a digital environment. The integration of CAD into architectural education laid the groundwork for incorporating technologies such as AR and VR, which offer students tools to approach multidimensional problems in their design processes. These technologies have been associated with improvements in students' three-dimensional (3D) thinking and visual perception skills and have been noted for their potential to optimize time management. Additionally, they enable students to explore spatial concepts and experiment with user-oriented designs through interactive virtual experiences.

In addition, with the potential for collaborative design, these digital tools enable the production of joint solutions without the need for a physical space or geographical association (Brown, 2009; Dorta, Lesage, Pérez, & Bastien, 2011). These collaborative processes in virtual environments allow participants to work on the same project simultaneously and exchange feedback on each other's designs in real time. This approach has the potential to optimize time management and incorporate diverse perspectives into the design process, which may contribute to more varied and detailed outcomes.

The widespread use of CAD and VR technologies in architectural education provides students with fundamental skills such as problem-solving, analytical thinking, and collaboration. These skills support the creation of collaborative environments where individuals, groups, and organizations can work collectively towards common goals and contribute to a more comprehensive understanding of the design process (Deng, Mueller, Rogers, & Olechowski, 2022; Kvan, 2000). CAD and VR, with their innovative tools, provide pedagogical benefits in both design and manufacturing processes. Moreover, continuous updates and developments in these technologies have the potential to increase their contribution to architectural education.

In the literature, many studies are addressing the transition to collaborative design through remote working models (Mayer, Chardonnet, Hafner, & Ovtcharova, 2023). However, research on sharing a culture of collaboration and solidarity through virtual environments is quite limited. VR is mostly used as a consultation tool, and studies generally focus on users exploring virtual environments, experiencing proposed design scenarios, and individual creation (Chowdhury & Hanegraaf, 2022). In contrast, research on collaborative content evaluation and approaches that encourage collaboration through virtual platforms remains insufficient.

However, it is seen that collaborative learning processes, especially in VR-based platforms, increase creative design potential and allow students to learn from different perspectives (Stevens, Hannegraaf, & Moussa, 2023). VR platforms have the potential to facilitate the transition from individual creative processes to collaborative production processes. The contributions of VR-based platforms to collaborative learning highlight the relevance of incorporating digital design technologies into pedagogical practices. These platforms provide digital ecosystems that enable users to work together on the same project, even when located in different spaces. In this context, the variety of digital tools available for architectural education and the functionalities they offer are key factors influencing platform selection and their applications.

Arkio and similar platforms represent innovative tools developed alongside technological advancements for architectural education. In addition to providing CAD and VR support, their cloud-based collaboration and real-time interaction features

enable students to work together, share ideas instantly, and collectively evaluate design decisions. These features not only accelerate the design process but also assist students in developing collaborative working skills and prepare them for teamwork scenarios they may encounter in their professional careers.

However, the potential of platforms like Arkio is not solely defined by their technological capabilities but must also be considered in light of certain limitations. For instance, the effective utilization of such platforms depends significantly on factors such as the adequacy of technical infrastructure, users' digital competencies, and accessibility. Moreover, the widespread adoption of digital technologies raises concerns about how to balance these tools with face-to-face interactions within physical studio environments.

In the first year of architectural education, students often transition from a rote-based learning approach to a more hands-on and experiential model aimed at understanding design processes. During this phase, they are encouraged to develop creative thinking and problem-solving skills while engaging with studio and workshop activities that introduce knowledge production through new methods. Additionally, students have the opportunity to reflect on design processes within historical, cultural, and social contexts.

Arkio, with its cloud-based infrastructure integrating CAD and VR, facilitates the transfer of students' traditional skills into a digital environment. These features enable students to engage with technological tools at an early stage, helping them adapt more effectively to professional life. Furthermore, Arkio's capabilities are not limited to supporting collaborative learning processes; they may also contribute to other critical aspects of architectural education.

In conclusion, Arkio and similar platforms have the potential to serve as significant tools for fostering innovative approaches in architectural education. However, their effective application requires careful consideration of both opportunities and limitations. When aligned with pedagogical and technical requirements, Arkio's potential can offer substantial contributions to architectural education and professional practices.

1.1. Research Aim

The aim of this thesis is to explore the potential of the Arkio platform as a collaborative design and production tool, with a particular focus on the first year of architectural education. The thesis aims to assess Arkio's capacity to enhance spatial perception, support collaborative learning processes and facilitate the transition from traditional to digital design methods through the integration of CAD and VR technologies, cloud-based and real-time interaction features.

By discussing the strengths and weaknesses of Arkio in the educational processes of first-year architecture students, the research aims to provide recommendations for the development of this platform and the evolution of similar tools. At the same time, by examining the impact of CAD and VR integration on collaborative design processes, it aims to reveal the contribution of these technologies to the development of creative and technological skills in architectural education. In this context, the potential of the Arkio platform for modern architectural education and practice will be evaluated.

1.2. Research Questions and Objectives

This thesis investigates how the Arkio platform can function as a collaborative design and production tool in the first year of architectural education, focusing on its potential to enhance spatial perception, support collaborative learning processes, and facilitate the transition from traditional to digital design methods through the integration of CAD and VR technologies. The research explores the platform's capacity to improve spatial awareness among first-year architecture students while examining how its real-time, cloud-based interaction features foster collaborative learning and design processes. Furthermore, it evaluates the role of Arkio's CAD and VR integration in enabling smoother transitions to digital workflows and identifies both the strengths and weaknesses of the platform within educational settings.

The thesis begins by reviewing previous research on CAD tools in architectural education, emphasizing their application and implementation in the first-year curriculum. It then transitions to the integration of virtual reality technology, analyzing its impact and implications for architectural education. As part of a broader theme on

collaborative design, the study uses Arkio as a tool to assess the potential of advanced technological design platforms in supporting architectural expression. The evaluation of Arkio's potential is based on voluntary and spontaneous feedback provided by first-year architecture students through their reflections and comments shared on OneNote.

The research is guided by fundamental questions: What distinguishes Arkio from similar platforms? How does the use of Arkio introduce innovations or limitations compared to traditional production methods in architectural education? Based on the findings, the study aims to offer recommendations for the further development of Arkio and similar tools, while evaluating their broader potential as modern instruments in architectural education and professional practice.

Ultimately, this research seeks to contribute to the understanding of collaborative design and production models in light of emerging technologies such as CAD and VR. It aspires to provide insights into how these technologies can be leveraged to enrich architectural education and facilitate innovation in the discipline.

1.3. Methodology

This thesis examines the Arkio platform from a phenomenological perspective using a reverse engineering approach. The primary reason for adopting the reverse engineering method is to gain deeper insights into the platform's functional mechanisms and technological infrastructure through a systematic analysis. This method goes beyond superficial observations or user experiences, enabling a detailed examination of the platform's design principles, tools, and collaborative potential.

The Arkio platform was deconstructed into its functional components and systematically analyzed to understand its operational framework and potential applications. During this process, key features such as real-time collaboration tools, modeling capabilities, and integration with other design software were investigated. The technical analysis was further enriched by feedback collected through Microsoft OneNote, documenting how first-year architecture students utilized Arkio in their Basic Design Studio course.

Three years of archived student feedback in OneNote provided a contextual data source for evaluating the impact of Arkio on educational processes. However, rather than directly asking students for their opinions on the platform or guiding their use, this study focused on analyzing how students employed Arkio based on the work they uploaded to OneNote. In the Basic Design Studio, all platforms were equally encouraged, and students were allowed to choose the platform they felt best suited their expression. This impartial approach not only captured feedback on Arkio's use but also provided insights into the reasons behind its non-use by some students, presenting a broader spectrum of data. This approach redirected the core focus of the research from subjective user experiences to a detailed investigation of the platform's technical structure and functional mechanisms.

While highlighting the potential of advanced technologies to contribute to architectural pedagogy, the research also offers a critical evaluation of how these technologies can be optimized in educational contexts. Ultimately, the study discusses the technical and pedagogical affordances of platforms like Arkio, emphasizing their potential to foster innovative approaches in architectural education.

1.4. Structure of the Thesis

This thesis is structured into six main chapters, offering a comprehensive exploration of its subject matter. The first chapter introduces the study with a concise overview, emphasizing its purpose, significance, and methodology. In this context, the research focuses on the role of VR and CAD tools in architectural education, aiming to address key questions regarding the integration of emerging technologies in educational settings.

The second and third chapters present an extensive literature review. These sections analyze the role of technology in architectural design, the impact of technological innovations, and the use of CAD tools. Furthermore, the use of VR technology in architectural education, its historical development, and its potential applications are examined in detail. A thorough investigation of various digital tools employed in contemporary architectural practice and education is also provided.

A significant part of the thesis is dedicated to the chapter titled "Collaboration and Design," where the concepts of collaboration and collaborative design are explored comprehensively. These discussions are supported by practical examples of their application in CAD and VR environments. This chapter offers a critical evaluation of how collaborative technologies can be effectively integrated into architectural education.

The practical component of the research focuses on the evaluation of the Arkio platform. Within this framework, the platform's general structure, user interface, menu design, and tools are thoroughly examined. The fundamental modeling and editing tools in Arkio are reviewed, alongside its collaborative features and the functionality of co-design processes within the platform. The communication tools and features enabling real-time collaboration among users are detailed. Additionally, Arkio's modeling capabilities and the transfer of these models to other platforms are discussed in the context of CAD integration.

In the final chapters, the use of Arkio in architectural education is assessed through the analysis of student feedback collected during a foundational design course conducted by Aktan Acar. The study examines how students utilized or were unable to utilize Arkio, with examples provided to illustrate these instances. Based on the data obtained, the potential of Arkio in architectural education is critically discussed. Moreover, Arkio is compared with other digital platforms to evaluate its strengths and weaknesses.

The conclusion chapter synthesizes the findings, focusing on the potential benefits and limitations of Arkio in architectural education. Comparative analyses with other platforms highlight areas for improvement and suggest ways to enhance the platform's effectiveness in educational contexts. These evaluations aim to contribute significantly to the integration of emerging technologies into architectural education.



2. ARCHITECTURAL DESIGN AND TECHNOLOGICAL INNOVATIONS

The advances in industry with the Industrial Revolution have also led to developments in the field of technology. With the advancement of technology, it becomes more integrated into daily life and shows its impact in every field. Especially with its integration into architectural education, it attracts the attention of both educators and industry professionals and leads to the transformation of the tools used. The architectural profession is undergoing a rapid transformation with technological developments reshaping the design, visualization and construction of buildings. This transformation requires the adoption of innovative educational tools that can enhance learning experiences, equip students with contemporary skills and better prepare them for the multifaceted challenges they will face in their professional careers.

Traditional architectural education, which often relies on two-dimensional drawings, physical models, and static presentations, has proven insufficient in addressing the dynamic needs of modern architectural practice (Danacı & Çakmak, 2022). These conventional methods can limit students' abilities to fully understand spatial relationships, visualize complex structures, and engage in interactive design processes. Therefore, it is necessary to integrate technologies into education that can bridge the gap between theoretical concepts and practical applications.

CAD and VR stand out among emerging technological tools that have a direct impact on education. CAD software is a tool that has long been used in the architectural profession and enables precise design development. This software enables architects to easily design complex projects, improving workflows and increasing productivity. On the other hand, the integration of VR technology into the educational process radically changes the way architectural designs are created and experienced, providing students with real-time interaction and experience, and helping them gain a deeper understanding and grasp of the design process. In order to examine these two technologies, especially within the framework of architectural education, it is necessary to examine the development process.

2.1. Evolution of Computer-Aided Design

A review of the existing literature reveals extensive research focused on the history and development of CAD. This technology emerged in the late 1950s (Tornincasa & Di Monaco, 2010) and has since undergone continuous evolution, making significant advancements over time. Numerous studies have meticulously examined the developmental stages and historical progression of CAD technology from its inception.

In this context, understanding the basic definition of CAD and the possibilities it offers plays a critical role in understanding why this technology is so important and how it has evolved. CAD refers to the use of computer software and systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is the expressive tool of designers, architects, engineers, and users, enabling them to create precise, detailed, and comprehensive representations (Brown, 2009; Sarcara, Rao, & Narayan, 2008). CAD provides tools for modeling, drafting, visualization, and simulation, facilitating the user's design process at all stages from initial sketching to production. CAD allows users to efficiently explore and iterate design ideas, improve accuracy, streamline workflows, and ultimately realize innovative products and structures.

Since the advent of CAD, it has transformed the way we design and manufacture products that will shape industries and innovations. Previously, these processes were carried out using traditional hand-drawn sketches and physical prototypes, but with the advent of CAD, they have been digitized, becoming faster, more accurate, and more flexible. The evolution of CAD, transitioning from 2D drawings to 3D modeling, and then to solid and surface modeling, has facilitated the creation of more complex and realistic models in product design. This enables a better understanding of products, early detection of design flaws, and improved optimization of products. CAD is an ever-evolving expressive tool that facilitates the product design and development processes of industries. The historical development of CAD has been shaped by advancements in computer technology and software and hardware developments that respond to the needs of industries.

When the chronological development process of CAD software is examined, it is observed that this technology has undergone a significant evolution and redefined itself in different periods. Each generation has progressed by addressing the shortcomings of the previous one and embracing new technologies. In this way, the evolution of CAD software has progressed in parallel with technology and industry needs. When reviewing the literature, it is evident that generations of CAD could be categorized into five distinct phases. Each phase builds upon its predecessor, demonstrating a progressive and developmental trajectory. It is observed that these phases mutually complement each other, contributing to the advancement of CAD technology.

The first generation of CAD development relied on the reflection of object edges within a two-dimensional plane. While this method had its constraints in effectively capturing intricate three-dimensional forms, it marked a pivotal inception for CAD technology (Tornincasa & Di Monaco, 2010)

The evolution from first-generation CAD systems to second-generation ones marked a significant advancement in the field. While the initial phase relied on reflecting object edges in a two-dimensional plane, the second generation introduced wireframe representations. These wireframes enabled objects to be depicted in three-dimensional space through edges and vertices, offering a more comprehensive visualization capability. Despite challenges related to determining object depth, wireframes represented a notable progression in CAD technology, allowing for enhanced visualization and manipulation of objects from various perspectives (Tornincasa & Di Monaco, 2010).

In the third generation of CAD technology, a notable advancement was the introduction of boundary and surface representations. BREP models became predominant, featuring volume-constraining planar and curved faces intersecting at edges and vertices to define a solid. These models offer a significantly more accurate representation of complex shapes than wireframe representations (Bi. & Wang, 2020). Additionally, they facilitate clearer visualization and analysis of objects. Surface elements amalgamate to enclose the three-dimensional space occupied by the modeled

object, ensuring an airtight boundary. This evolution in CAD technology heralded a new era of precision and efficiency in design and modeling processes.

The fourth generation of CAD systems unveiled the mathematical representations of objects within the occupied three-dimensional space, enabling precise determination of object boundaries. Objects were constructed using Boolean operations on simple solid shapes, facilitating effective modeling of complex geometries. Historically, this geometric modeling, based on techniques such as geometric modeling for sketching, detailing, visualization, and analysis, has garnered attention in the current generation of CAD systems, providing useful functionality (Tornincasa & Di Monaco, 2010). This modeling system, utilizing features and parameters, establishes connections to dimensions and variables in geometry, ensuring updates to geometry as parameter values change. This generation underscored the significance of geometric accuracy and computational efficiency in CAD systems.

The fifth generation, comprising history-based CAD systems, revolutionized the design process by capturing the designer's primary intent. These systems retain a feature history tree, allowing for seamless modification and regeneration of parts by tracking relationships and parameters. For instance, the software remembers and enforces relationships among objects created by the designer. While the designer works within the software, it generates a feature history tree tracking all relationships and parameters, storing the sequence of feature creation by users. Altering a step in this tree and replaying the history prompts ramifications to ripple throughout the model and reforge the new portion. Once a part is created, users only need to write variables to modify a preprogrammed model (Chow, Kubota, & Georgescu, 2015; Tornincasa & Di Monaco, 2010). History-based CAD systems enhance productivity and facilitate design iteration by incorporating design intent into the software (see Table 2.1).

The evolution of CAD paradigms reflects a continuous pursuit of enhanced accuracy, efficiency, and user experience. Each generation, from primitive endpoint-based projections to complex history-based systems, has contributed to the advancement of design engineering. Understanding the trajectory of CAD development is crucial for harnessing the full potential of modern design software and fostering innovation across

various industries. Below, the historical development of CAD technology is summarized through chronological and generational distinctions presented in the table.

Table 2.1: Generation of Computer Aided Design

Period/Generation	Description
Late 1950s	Emergence of CAD technology, marking the transition from hand-drawn sketches to digital design.
First Generation	2D edge projections, limited in capturing complex 3D forms but served as a foundational step.
Second Generation	Wireframe modeling, representing objects in 3D space through edges and vertices.
Third Generation	BREP models introduced boundary and surface representations, enabling precise modeling of complex shapes.
Fourth Generation	Mathematical 3D representations and parametric modeling allowed dynamic updates to geometry.
Fifth Generation	History-based systems preserved design relationships, enabling seamless modifications and updates.

2.1.1. Computer-Aided Architectural Design

When the literature is examined, it is seen that the historical development of CAD technology and its integration into architectural education has undergone a significant transformation process (Danacı & Çakmak, 2022). This integration has evolved with technological advances and changes in educational approaches. Developments in CAD technology have made significant contributions in areas where traditional architectural education is inadequate and needs to be improved. The development of CAD has met these needs by providing architectural education with more advanced tools and methods. Furthermore, with the evolution of CAD, Computer Aided Architectural Design (CAAD) has emerged and has more effectively met the needs of traditional education.

With the advancement of technology, the expression tools utilized in the field of architecture have significantly evolved and transformed. The tools employed throughout the design process, from the sketch stage to the presentation, have diversified over time. Progress in information technology has also influenced architectural education, enhancing the significance of design in the digital realm

(Akrouit & Roxin, 1999). While traditional tools such as paper and cardboard models continue to be widely utilized in conventional educational models, digital-based technical drawing programs, modeling software, and visualization tools have also been increasingly adopted. This transition may bring about differences in educational processes and professional practices, often complementing each other. Traditional and digital expression tools in architecture enhance communication in situations where words fall short. This expression is conveyed through both traditional methods and digital tools. Moreover, the use of digital tools is not only aimed at showcasing technical details but also facilitating the conceptual development and perception of design, thereby fostering the development of new forms of expression (Salman, Laing, & Conniff, 2008). The process of designing and evaluating designs using digital methods within architecture is referred to as CAAD.

CAAD is widely used both in architectural education and professional architectural practices. Its role entails providing students with rich design experiences from both technical and aesthetic perspectives. CAAD equips students with practical skills at various stages of the design process while also enabling them to develop technology-based solutions. Compared to traditional drawing tools, CAAD expedites the design process, allowing for more efficient utilization of time. Students may swiftly create, edit, and analyze projects and designs digitally using 2D drawing and 3D modeling tools. Moreover, CAAD software enables architecture students to enhance their technical skills, learn architectural drawing standards and practices, and develop digital drawing and modeling skills simultaneously. Through CAAD, students may visualize their projects more clearly and in detail. Design problems in architecture are often ambiguous and may complicate numerical formulations. The use of complex simulations may reveal undesirable features in design optimization models, thus necessitating successful solution strategies. The complexity of design tasks often requires different analysis tools, mandating the evaluation of numerous functions. These challenges have spurred advancements in digital methods and solution strategies within the field of architecture (Chouldhary & Michalek, 2005).

Due to the 3D nature of our environment, and the potential inadequacy of 2D drawings in certain expressions, areas emerge where students need to express themselves in 3D with the aid of CAAD (Danacı & Çakmak, 2022). Through 3D models created with

CAAD, students may better grasp concepts such as scale and dimension. Additionally, they may produce detailed visuals of their projects and designs by incorporating materials and textures and generating photorealistic renders using these tools. With CAAD, students may create animations to showcase the unseen aspects of a space or design in more detail. Utilizing VR, they may navigate through virtual tours they have created, allowing for exploration of every angle of the designed space and experiencing it firsthand. Moreover, CAAD software facilitates collaborative production among students. By sharing digital versions of joint projects, the need for physical proximity is eliminated. Collaborative work may be carried out simultaneously on projects, thereby facilitating cooperation among students and streamlining the process of giving and receiving feedback. These systems used in architectural education streamline monotonous computational and diagrammatic tasks, paving the way for accurate and precise results (Agoki, Ng, & Johnson, 2007).

Although there are studies available on the impact of CAAD usage on the design process of architectural students, the inclination of students toward expressing themselves may vary. Despite the encouragement of CAAD usage within the curriculum, the preference for and development in CAAD usage is ultimately the choice of the student. Most studies related to CAAD indicate positive attitudes among students toward using CAAD to express their designs (Salman, Laing, & Conniff, 2014). In addition to various courses dedicated to teaching CAAD within the curriculum, the development of students in CAAD is supported through assignments given in other courses. For instance, in addition to directly teaching technical drawing programs like AutoCAD in most universities, students are encouraged to explore computer usage, thereby creating an environment for students to discover and enhance various aspects of architectural design. Students may use computers from the initial stages of design to explore ideas and develop their concepts. The digital tools and computer programs used in architectural education not only change the presentation techniques employed for expressing designs but also allow students to focus on developing their skills in the method that best suits their expression. As each student's preferred means of expression may vary, the diversity of these tools contributes to students' ability to develop their methods.

In the professional field, the utilization of CAAD has significantly enhanced the workflow of architects and designers. Technological advancements not only improve efficiency throughout the process from architectural project design to production but also facilitate communication and collaboration. Particularly, through 3D modeling and visualization tools, architects and designers may present projects to clients and project stakeholders more effectively. 3D modeling enables more realistic visualization of the project, aiding clients, and stakeholders in better understanding the outcome. Additionally, visualization tools expedite the decision-making process by facilitating the examination and comprehension of architectural design from various perspectives. Digital expression tools are commonly preferred in the industry for their rapid production and modifiability. Consequently, in competitive market conditions, CAAD usage is an anticipated and sought-after feature in architectural offices. Architects are expected to express the desired design in the fastest and most revisable manner through CAAD. Architectural offices typically value skills such as the ability to prepare digital presentations, produce construction drawings effectively, and collaborate in the digital environment (Tasli, 2001).

Furthermore, CAAD enhances communication and collaboration among project stakeholders. By providing an opportunity for collaborative work on a shared digital platform, it enables team members to work simultaneously on the project. This accelerates idea exchange and feedback processes, leading to more efficient project management. Consequently, the utilization of CAAD technology in the professional sphere facilitates the more effective management and presentation of architectural and design projects. This, in turn, enhances customer satisfaction while increasing project efficiency.

In conclusion, the increasing use of CAAD technology in both architectural education and professional practices is recognized as an important tool to adapt to the constantly changing needs of the architecture industry and to enhance design processes. CAAD, which in some areas replaces traditional hand drawing and physical modeling methods, provides architecture students and professionals with the opportunity to offer faster, more accurate, and more innovative design solutions.

The integration of advanced digital tools into architectural practice continues to reshape traditional methods, fostering new avenues for creativity and efficiency. Among these tools, Virtual Reality (VR) emerges as a transformative technology, offering immersive and interactive experiences that redefine how architectural designs are conceptualized, presented, and experienced. To better understand its impact, it is essential to explore the evolution, definitions, and applications of VR within the architectural domain.

2.2. Virtual Reality

VR has evolved conceptually over time due to the continuous development and advancement of technology. Initially, VR was officially defined under virtual equipment and projects constituting the system (Lanier, 1992). However, research in VR has expanded and refined the definition. As a result, there are various definitions related to VR. Initially, the early definitions of VR described it as a combination of various screens and interfaces based on the mechanical assemblies of VR. However, the concept of VR has become a dynamically evolving concept with the development of technology and the expansion of its application areas.

In one of these definitions, VR, in its broad scope, refers to the use of various screens and interface devices to immersively present an environment created by interactive three-dimensional computer graphics. This technology serves the purpose of transporting the user into a virtual environment, abstracting them from the real world (Pan, Cheok, Yang, Zhu, & Shi, 2006). Furthermore, it may also be defined as an environment that includes interactive computer simulations aimed at altering or enhancing at least one of the user's senses, thereby increasing the sensation of being present or deeply involved in the simulation environment (Sherman & Craig, 2018).

When examining the definitions chronologically, VR starting from its definition in 1991, is commonly used to refer to technology that combines a visualization system, tracks hand or body movements, and provides users with a 3D experience (Krueger, 1991). Additionally, while VR technologies have been defined as 3D simulations obtained through displays such as wearable devices (Coates, 1992), another definition emphasized that this technology is an alternative world filled with digitally generated

images responsive to human movements, highlighting a sense of being in a different reality (Greenbaum, 1992). These definitions suggest that VR was initially described more in terms of systematic mechanical digital simulations.

However, when the concept of VR, is dissected into the words "virtual" and "reality" (Heim, 1993), it becomes evident that it should be defined more by the concept of reality rather than the virtual aspect. This is primarily because of the continuous focus on being in an alternative space and the concept of reality. Users experiencing VR technology interact with the virtual world simultaneously. In this interaction, they usually perceive themselves as the main characters of the virtual world and experience this world limitlessly. In this context, evaluating VR technology solely as a system is not sufficient to understand its nature. VR offers an experience where users are not merely passive observers but active participants. Therefore, this technology should be considered not only as a technical tool but also as an environment that creates a profound and personal experience.

VR technology is a significant development that enables users to interact in 3D virtual worlds and feel as if they are in a real environment. Based on this, this technology is examined under three main features: providing a three-dimensional virtual world, immersion in the environment, and having interactive capabilities (Pimental & Teixeira, 1995). Providing a 3D virtual world involves creating a digital model of a real environment and presenting users with imaginary spaces. When users immerse themselves in these environments, they feel a sense of reality and experience the virtual world separately from the real world. Immersion in the environment enables users to perceive the virtual world as if it were real. As users interact in the virtual world, they feel as if they are truly experiencing their surroundings, enhancing their sense of reality. Having interactive capabilities allows the created virtual environment to respond to the user's movements and adapt accordingly. This enables users to have a more immersive and realistic experience while interacting in the virtual world.

In addition to these definitions, a feature of VR is providing sensory feedback (Sherman & Craig, 2018). This feature allows users to interact more deeply with the virtual world because they receive sensory feedback on their actions. VR technology is presented to users through 3D models and scenes generated by computer programs.

These models and scenes are conveyed to users through display devices, while interaction tools such as position sensors, controllers, and wearable technologies are combined to provide users with a simultaneous experience.

According to Costello's classification, VR systems could be divided into three different classes: fully immersive systems, partially immersive systems, and non-immersive systems. Fully immersive systems surround the user, providing a 360° experience that fully immerses them into a virtual world. These systems are typically supported by head-mounted displays, controllers, or wearable technologies. These classifications help us understand the fundamental features of VR technology and various usage scenarios. It is observed that this technology is increasingly being utilized as it allows users to interact with a sense of reality and receive sensory feedback (Costello, 1997).

Accordingly, the concept of VR encompasses various definitions, some of which extend beyond mere systemic descriptions to include conceptualizations between humans and the virtual world. With the evolution of VR systems, awareness of these concepts also increases. While these concepts may emerge with different expressions and definitions, they are generally described with hardware such as goggles and gloves. These tools defining the VR experience enable users to exclude the real world and step into a virtual environment. In this process, conceptualizing the VR experience is a significant factor influencing users' perceptual, cognitive, and emotional responses. Additionally, with the advancement of VR technology, users' participation and interaction in virtual environments are also increasing. In this context, understanding the different aspects and definitions of VR is important for evaluating the technology's applications and impacts.

2.2.1. Evolution of Virtual Reality

VR is widely recognized as one of the most widely used technologies today. However, its origins go back a long way and the first attempts were made in the late 1960s with the development of early computer technology. Although some basic VR system designs emerged in the early 1990s, it took time for this technology to be embraced and proliferated by the masses. During this period, VR systems were mainly used by organizations for training and simulation purposes (Wohlgenannt, Simons, & Stieglitz,

2020). Despite the development of various VR platforms after this period, they generally remained costly systems that did not reach broad segments of society. However, with the impact of technological advancements, VR technology, once again revitalized, has reached a point where it is accessible to almost everyone today. It has now become a widely used technology in education, entertainment, and many other fields. Advancements in hardware and software have facilitated the release of more affordable and user-friendly VR devices. This has marked a significant turning point in the evolution of VR technology, as it is now being embraced and used by a broader audience.

The origins of VR technology begin with the steps taken by Sir Charles Wheatstone in 1838. Wheatstone laid the foundations for systems that enable stereoscopic vision, allowing users to perceive images reflected in mirrors as if they were a single image, merging in their minds (Boas, 2013).

In the 1950s, Morton Heilig developed one of the earliest recognized VR devices called the Sensorama, which was further developed using a mechanical prototype in 1962. The Sensorama provided an immersive VR experience by offering 3D visual, auditory, tactile, olfactory, and even wind stimuli, utilizing advanced technology of the time (Rampolla & Kipper, 2012).

In 1961, Philco developed the first Head-mounted Display (HMD) called Headsight. This device mounted a cathode ray tube screen onto the head and included a tracking system that allowed determining the user's head position. Headsight is considered a significant milestone in the advancement of VR technology. This development laid the foundation for future advancements in VR technology by enabling users to interactively experience their surroundings, thus accelerating research and discoveries in this field (Comeau & Byran, 1961).

One of the most significant developments occurred in 1968 by Ivan Sutherland and Bob Sproull. That year saw the development of the first HMD called "The Sword of Damocles". The Sword of Damocles was a device that consisted of glasses mounted on the user's head and presented simple 3D wireframe models. This device, capable of tracking the user's position and eyes, could update the stereoscopic view based on the

user's position. This development represented a major step forward in the advancement of VR technology and is subsequently regarded as a milestone in the world of VR (Sutherland, 1965).

In the early 1970s, Eric Howlett developed the Large Expanse Extra Perspective (LEEP) system. This system is designed to provide a wide viewing angle in VR experiences. The LEEP system has contributed to the development of VR technology by providing users with a more natural and immersive experience (Sherman & Craig, 2018).

In 1977, the Sayre Glove, utilizing fiber optic technology, was developed by Tom DeFanti, and Daniel J. Sandin. This glove was designed to detect hand movements and enable interaction in virtual environments. The Sayre Glove was a significant device used in early VR experiences. Another important device was the Wired Glove. Thomas G. Zimmerman played a crucial role in the development of the Wired Glove in the early 1980s. This glove was a device that detected hand movements, allowing users to interact in the virtual world. Zimmerman's work inspired the development of other glove-based devices in the following years, such as the Power Glove. These innovations played a vital role in the evolution of VR technology, enabling users to experience more natural and interactive experiences in virtual environments. Glove-based interfaces represent a significant step forward in enhancing the user experience in VR technology (Sturman & Zeltzer, 1994).

In the 1980s, VPL Research, pioneers in VR research, developed a series of supporting VR devices. Among these devices were several significant ones, including the EyePhone, AudioSphere, and the DataGlove and DataSuit. The DataGlove was a sensor-equipped glove capable of accurately detecting and transmitting hand movements to a computer. EyePhones, on the other hand, were goggles utilizing a pair of Liquid Crystal Display (LCD) screens along with some optical lenses. These devices were designed to enable users to interact more naturally in virtual environments (Conn, Lanier, Minsky, Fisher, & Druin, 1989).

In the early 1990s, the first HMDs targeting consumers were developed. During this period, devices like the Sega VR and Nintendo's Virtual Boy were among the first

commercial products to offer VR experiences to users at home. These devices played a significant role in the evolution and popularization of VR technology (Sturman & Zeltzer, 1994).

In 1992, at the "SIGGRAPH" computer graphics conference in Chicago, "CAVE" (Cave Automatic Virtual Environment), a fixed projection VR system, introduced a center-based VR paradigm as an alternative to head-worn VR glasses (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992). The release of the "3Dfx Voodoo" graphics card in 1995 was considered a significant advancement in the development of VR technology, as it was the first PC add-on graphics card capable of real-time 3D rendering. Similarly, in July of the same year, the Nintendo Virtual Boy was introduced, attracting attention as the first stereoscopic video game goggles accessible to the public (Jerald, 2015).

Since the early 2000s, significant progress has been made in research in the field of VR. During this period, the "Nintendo Wii" was released, an important product that enabled physical interaction in a virtual environment. In the same period, the "Wiimote", a wireless remote-control device with accelerometers and an infrared camera for location tracking, was also introduced, allowing players to transfer their movements directly to the games (Sherman & Craig, 2018).

In 2011, the first device that laid the foundation for modern VR headsets, called the "Oculus Rift," was developed by Palmer Luckey. The Oculus Rift emerged as a VR headset connected to a computer. Financed and further developed between 2013 and 2014, Facebook acquired the rights to Oculus Rift in 2014, thus increasing access to VR technology. In 2016, Facebook released the first VR system aimed at end-users with a plug-and-play approach: the "Oculus Rift CV-1." This system consisted of a headset, a tracking camera, and controllers. In the same year, HTC also announced the "HTC Vive," an advanced VR system that gained popularity worldwide. Additionally, Sony released the "PlayStation VR," which integrated with the PlayStation 4 gaming console and utilized the PlayStation camera and Move controllers. These products contributed to the proliferation of VR technology among home users (Anthes, García-Hernández, Wiedemann, & Kranzlmüller, 2016).

During this process, VR headsets or systems are continuously updated with new hardware or software, based on user feedback and the development of solutions tailored to different needs or sectors. Particularly, the popularity of VR systems for personal use has increased, spreading across various fields such as home entertainment, virtual travel, education, and healthcare. With advancing technology, factors such as the miniaturization and lightweight of equipment and technologies used in VR systems, the emergence of wireless connection devices, or the increasing attention on systems that do not require a computer, contribute to the diversification of VR systems.

Especially in recent years, not only major technology companies like Oculus, HTC, and Sony but also many startup companies have innovated in the VR field and introduced new products to the market. This continuous renewal and diversification demonstrate that VR technology is a dynamic and rapidly evolving infrastructure. This process also reflects an evolution that spans from industrial and corporate use to personal use.

2.2.2. Usages of Virtual Reality

VR technology is recognized as a rapidly developing technology that is widely used in various sectors. The impact of technology on our daily lives is increasingly pronounced, with VR being utilized and continuously developed in many different fields. Its extensive application ranging from military applications to education, healthcare, arts, and entertainment underscores the importance and impact of VR technology across various disciplines. It is crucial to examine in detail the usage areas of this technology in different disciplines and evaluate the emerging opportunities brought about by the evolution of the technology.

The earliest examples of VR technology emerged in the late 1950s as military and flight simulators (Holloway & Lastra, 1993). Even today, flight training utilizes flight simulations and VR technologies. The primary reason for this is the use of VR technologies, which make flight training less costly and safer. Additionally, vehicle simulators are the most commonly used VR applications in the military domain because they are safer than real training and, despite their expensive setup, are more

cost-effective. Flight simulations are conducted by providing users with computer monitor setups mimicking aircraft scenery or by placing the user in a real simulation cockpit (Boas, 2013). Both methods are complemented with haptic feedback and high-performance software, significantly enhancing the user experience. Ground and watercraft simulation is another important technology used in the military domain, though not as widely recognized as air simulations. These simulations include the navigation of heavily armored vehicles and tactical vehicles, as well as tactical and communication scenarios. Submarine simulation is a notable area as it does not rely on visual elements but instead employs precise methods and readings to simulate underwater movements. In military personnel training, VR technologies such as screens mounted on helmets for military simulations and joysticks mimicking real firearms are utilized. This experience resembles computer games significantly, and collaborations between military and computer game studios provide a more immersive experience ranging from weapon simulation to strategy rehearsal (Moshell, 1993).

In addition to the military, VR enables engineers and designers in the automotive industry to easily experiment with the appearance and structure of vehicles before producing expensive prototypes. Leading automotive manufacturers such as Honda, BMW, and Jaguar Land Rover have been utilizing VR technology for years to conduct design and engineering reviews, seeking alternatives to traditional clay models (de Freitas, Gomes, & Winkler, 2022). VR has significantly improved prototype production in institutes requiring most manufacturing, much like in the automotive industry. Previously, a series of prototypes would be produced and tested for each new model, resulting in high costs and time loss. However, with VR, this process has been significantly optimized. Now, engineers and designers may thoroughly examine their designs in a virtual environment, make changes, and test different scenarios. This reduces costs and saves time. Additionally, VR technology enables industries to work more effectively with a global workforce. Engineers and designers may collaborate with teams in different geographic locations, working simultaneously on the same projects. This enhances collaboration, facilitates communication, and makes the design process more efficient.

Moreover, VR plays a significant role in medicine and healthcare services. Particularly, the impact of VR technology in the healthcare sector has been

increasingly notable in recent years. Its ability to integrate real-time health information, provide visualization, and interactivity offers revolutionary advancements in medical applications (Gallegher, et al., 2005). VR applications in medicine span a wide range, from surgical training to surgery simulations. In particular, surgeons may simulate surgeries and have the opportunity to learn new techniques and improve their skills through VR technology. This enables surgical interventions to be performed more safely and effectively. Additionally, VR technology provides medical students and healthcare professionals with interactive educational tools to better understand complex medical concepts and procedures (McCloy & Stone, 2001).

VR technology also contributes to patients' treatment processes. For instance, during rehabilitation, patients may engage in exercises in virtual environments to enhance their mobility and movement capabilities. Additionally, studies suggest that VR may assist in the treatment of conditions such as phobias and anxiety when used for therapeutic purposes (Powers & Emmelkamp, 2008).

The use of VR technology in the medical field enables the continuous development of innovative applications. Particularly, advanced technologies such as head-mounted display systems, which allow for more precise surgical operations, enhance the effectiveness of VR usage in medical applications (Keller & Fuchs, 2008). In conclusion, VR technology has become a significant tool in the field of medicine and healthcare. It is expected that with further development and widespread adoption of this technology in the future, the quality and effectiveness of medical treatment methods and healthcare services will significantly improve.

The entertainment sector is a significant area where VR technologies are heavily utilized and continuously evolving (Zyda, 2005). VR offers immersive experiences that transform how audiences interact with various forms of entertainment. This technology has led to significant advancements across numerous domains such as games, films, music, and live events. Particularly in the gaming industry, software development is advancing swiftly, with VR headsets like Facebook's Oculus Quest, HTC's VIVE, and Apple's Vision Pro enhancing players' sense of presence and interaction within games.

In addition to the gaming industry, the use of VR in cinema increases interactivity in storytelling by allowing audiences to experience narratives in a 360-degree format. This technology enables viewers to choose their perspectives within scenes, creating a viewing experience that traditional films cannot offer. The potential of immersive storytelling is reshaping how narratives are consumed by fostering deeper emotional connections with the content. The future of VR in the entertainment industry appears promising due to ongoing advancements, with continuous innovations integrating VR further into mainstream entertainment applications, creating more interactive and engaging environments. Overall, VR is poised to become a fundamental component of the entertainment sector by offering experiences that blend digital and entertainment elements. The integration of VR with the entertainment industry provides a continuously evolving experience for both individuals and the industry (Bialkova & Van Gisbergen, 2017)

In addition to entertainment, VR technologies are utilized in the organization of cultural events. Virtual museum tours are a significant example in this regard. This innovative technology transcends the boundaries of traditional museum visits, offering users the opportunity to visit museums worldwide and eliminating geographical barriers. Virtual museum tours allow users to examine and explore historical and artistic artifacts through their computers or VR devices. These interactive experiences make learning more enjoyable and serve as a powerful educational tool for students (Zhou, Chen, & Wang, 2022). Therefore, the ability to explore virtual museums and engage in cultural activities with VR makes cultural heritage more accessible, enjoyable, and educational.

Education stands out as one of the disciplines where VR technology is most effectively utilized. VR enriches the learning process by simulating experiences that are not possible in the real world, thus providing an innovative learning environment. The potential of VR in education is associated with a range of positive outcomes. Firstly, it offers students the opportunity to explore and learn at their own pace, thereby personalizing the learning process and enabling students to develop a deeper understanding. Moreover, VR experiences often provide advantages such as increased task duration, entertainment value, increased motivation, deep learning, and long-term memory retention (Huang, Rauch, & Liaw, 2010).

However, there are some barriers to the widespread adoption of VR in education. Particularly, cost and accessibility are significant issues (Budziszewski, 2013; Takala, 2014). The high cost of advanced VR equipment and software may not be compatible with the limited budgets of educational institutions. Additionally, the availability of hardware and software can also be a barrier. Therefore, it is important to develop cost-effective and accessible solutions for VR technology to be more widely used. Furthermore, more research is needed for VR to be used more widely and universally in education (Lege & Bonner, 2020). These studies should be conducted to better understand the pedagogical effects of technology, learning outcomes, and student success. Additionally, solutions tailored to the needs of teachers and educational institutions should be developed to fully assess the potential of VR. In conclusion, studies indicate that VR experiences have positive effects on students, thereby serving as an example for the experiential learning model. The use of VR technology in education may shape future learning environments by enabling students to learn more effectively (Milovanovic, Moreau, Siret, & Miguet, 2017; Hussein & Nätterdal, 2015; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014).

As mentioned above, VR technology has a wide range of uses in different disciplines. In addition, it is used in various disciplines such as real estate, tourism, art, and design. Furthermore, in business events such as conferences and meetings, VR technology may be used to bring participants together virtually, providing an effective environment for remote working and collaboration across all disciplines. With the integration of this technology into our daily lives, its usage areas are gradually expanding and being adopted in many sectors. One of these sectors is architecture. The use of VR technologies in architecture and architectural education is becoming widespread and developing day by day.

2.2.3. Historical Process of Virtual Reality in Architectural Education

In architectural education, the development and integration of VR technologies into the educational process have been considered a significant turning point since the early 1990s. During this period, VR studies initiated under the architecture education at Bauhaus University led to the development of three distinct VR systems. These are the VR studies named VoxDesign, PlaneDesign, and VRAM. Developed in 1995,

VoxDesign is a software environment specifically focused on creating drawing-oriented spaces using voxels (Dirk & Regenbrecht, 1999). This system enables users to draw using voxel technology during the design process. On the other hand, PlaneDesign adopts a space-oriented approach and is developed to be used in the conceptual stages of architectural design by utilizing planes. Architects aim to define walls, ceilings, floors, and other elements flexibly using both real and digital pens. VRAM, developed in 1999, is a system designed to view, scan, edit, and model 3D models based on the Virtual Reality Modeling Language. This system serves particularly for educational and research purposes by enabling the experience and interaction of large-scale architectural models in a virtual environment. While VoxDesign is developed from sketches in the design process in a simple form, PlaneDesign is developed for conceptual stages. VRAM, on the other hand, is particularly important for experiencing and interacting with large-scale models. These three VR applications take their place in the literature as pioneering applications used by architecture students in this field (Dirk & Regenbrecht, 1999).

In addition, the ABACUS Research Unit, established within the Department of Architecture and Building Science at the University of Strathclyde, successfully created the Virtual Environments Laboratory by projecting computer-generated high-resolution images using a video projector. Furthermore, they aimed to provide users with an immersive experience in a CAVE environment by setting up a desktop-based VR system with a seating arrangement for 14 people. This laboratory is recognized as one of the first VR trials in architectural education, standing out with its wide field of view and fast interactive control. Additionally, it includes various input devices that allow users to control their movements in desktop-based VR systems (Alvarado & Maver, 1999). Another architectural VR study in a CAVE environment was conducted in collaboration with the Department of Chemistry at the Lund Institute of Technology, Lund University. Within this project, a workshop was established, and researchers from the Lund Technology Institute, along with participants from the Department of Chemistry at Lund University, architects, university facility management and administrative staff, and other relevant individuals collaborated. This workshop aimed to analyze future needs and make real suggestions on how new laboratory workspaces should be designed (Frost & Warren, 2002).

CAVE, a VR environment used in electronic visualization laboratories. In addition to its use in architectural education virtual environment research, CAVE is also employed in high-tech industries such as defense, aerospace, petroleum, and automotive sectors. In the early examples of this preferred method for creating virtual environments, a cube room with a 3-meter side length was utilized. While three walls were used for rear projection, the floor was reserved for direct projection screens. Images were generated by a Silicon Graphics ONYX Infinite Reality (MIPS R10000) computer and presented stereoscopically, consisting of one image for each eye synchronized through glasses. The computer attempted to deliver the image to the user by producing 24 image sets per second to provide real-time motion. With the advancement of technology used in CAVE, more comprehensive and detailed images have been produced by CAVE systems (Af Klercker, 1998).

CAVE has been used for modeling and visualizing design projects of students and teachers in architecture education. In addition to designing and presenting their projects in a computer environment, students also modeled and visualized the projects designed by their teachers. In addition to visualizing their designs using CAVE technology, they had the chance to experience their designs interactively. CAVE enabled both students and teachers to better understand and evaluate designs in architectural education. CAVE technology was used as an effective tool in the modeling, visualization, review, and evaluation processes of design projects in architectural education. However, since the installation of the CAVE system was quite costly in the conditions of the period, it could not be widely used in architectural education and was limited within certain universities (Af Klercker, 1998; El Araby, 2002).

Within university settings, various equipment and researcher requirements arise for conducting VR studies in architectural education. However, the introduction of more accessible VR headsets such as Oculus Rift and HTC Vive to the market in 2016 has significantly increased VR studies in architectural education (Wohlgenannt, Simons, & Stieglitz, 2020; Kharvari & Kaiser, 2022). These devices, which are suitable for personal use and more affordable than CAVE systems, have increased access for architecture students and researchers to interactive and realistic virtual environments for understanding, visualizing, and implementing design concepts. The increased

accessibility to VR has led to a rise in research and studies related to VR. This has resulted in the emergence of various research contributions to literature, expanding the use of VR in architecture and addressing topics such as principles of VR usage, its advantages, contributions to learning, and its development within architectural education.

2.2.4. Potential of Virtual Reality in Architectural Education

When examining the effects of VR technology in architectural education in literature, it becomes apparent that architectural design entails a unique practice that requires thorough examination. Architectural design is not merely about constructing a building but a creative process involving thinking. This process encompasses a journey that enables the transformation of knowledge and perception. Architectural design evolves from an idea into a physically or virtually constructed entity through various mediums, allowing for the refinement and communication of ideas. Architects develop and materialize their ideas through external representations during this communication process. These representations are realized through methods of expression such as sketches, diagrams, and various models. Architects utilize these methods of expression to organize complex information into understandable and communicable arrangements. By employing these expression methods, architects develop a language and create a dynamic network that enhances and enriches the design process by enabling the recognition of design possibilities. Therefore, how architects compile, share, and communicate within this network profoundly influences the design process and its potential.

When used as a method of expression, VR becomes a powerful tool by providing physical participation and design experience. Interactions and experiences in the virtual world create an environment where users establish a physical connection, allowing them to explore design solutions in ways previously unattainable. This allows architecture students to explore embodied interactions and integrate physical experiences into the design process. VR offers the chance to design spaces and structures, enabling designers to see and experience designs within them, thus surpassing traditional scale and time constraints. Therefore, the VR environment

contributes to creating an “immersive” and realistic environment, allowing for an in-depth exploration of design.

When VR is immersive, production processes are in interaction with the real world, creating a directly experiential space that can be navigated through physical movement. The term "immerse" signifies an experience where one is deeply engaged in something, tending to momentarily forget their surroundings. In the VR experience, the sense of immersion transports the user away from the real world, providing a fully focused experience within the virtual environment (Yuen, Yaoyuneyong, & Johnson, 2013). It is believed that this immersive experience in the virtual environment enhances learning by increasing focus (Dede, Jacobson, & Richards, 2017).

In architectural education, students learning with VR have the opportunity to examine and evaluate their designs visually in the virtual environment while physically present in the real world. While experiencing this, students can move within the virtual environment and have an experience as if they were actually there. Through experiencing this environment in architectural education, models and animations created are thoroughly examined from every aspect before being physically realized. This enhances students' mental transformation abilities and production potential. VR technology provides students with the opportunity to consider various design alternatives and see their ideas at scale. Consequently, students' spatial perceptions expand, and they gain the opportunity to experience the use of architectural materials. Virtual environments enable designers and architects to express and explore their creative visions in detail and easily, thereby enhancing their mode of expression for their products (Schnabel, Wang, Seichter, & Kvan, 2008).

When reviewing the literature, it is evident that studies are focusing on the use of VR as an important tool to facilitate collaborative design in architectural education, in addition to its impact on learning (Rauf, Shareef, & Othman, 2021). Through VR, participants can come together from different physical locations and collaborate on design in a virtual environment. Research indicates that designing in a virtual environment allows designers to collaborate and create collaborative products through avatars, despite being physically distant. These applications ensure collaboration in architectural projects while providing an environment that does not require

architecture students to physically gather. The virtual environment strengthens the collaborative design process by enabling designers to produce together and exchange ideas. Furthermore, participants coming from different geographical locations contribute to enriching the design by bringing together different perspectives and experiences.

VR promotes collaborative design in architectural education by allowing participants to fully immerse themselves in the virtual environment and focus on the creative process. In this way, the importance of physical location diminishes, enabling ideas and perspectives to be freely shared and discussed (Dorta, Lesage, Pérez, & Bastien, 2011). As a result, VR technology enables the development and more effective implementation of collaborative design in architectural education.

In addition to the reviews in the literature, there are many case studies on the use of VR in architectural education. While these studies reflect the potential of VR in architectural education, it also gives clues about how it can be developed. In one of these case studies, Rahimian and Ibrahim (2011), focus on the early process of architectural design, arguing that the abstract and complex user interfaces of CAD tools limit designers' creativity at the conceptual stage, and discuss the contributions of VR-based 3D sketching interfaces on spatial perception and collaboration. The study reveals that VR technologies could contribute to the design process not only in visual but also in cognitive and collaborative aspects and could be seen as a promising tool in architectural education and professional practices.

In another case study, Dorta et al. (2016) introduce the Hybrid Virtual Environment 3D system that supports architectural co-design with VR. This system supported architecture students to use their projects in a VR environment, enabling both their peers and instructors to spatially experience and analyze the project. The findings of the study revealed that the immersive nature of VR helps users to better understand the spatial relationships in the design. However, this also raised some questions about the cognitive load on students. Both presenting and evaluating the design in VR required more mental effort on the part of the students. These results emphasize the potential benefits of VR as well as the importance of considering the cognitive limits of users in the design process.

In another case study, the impact of VR technology on students' learning skills in architectural history courses was examined. For this purpose, an experimental approach was adopted by creating virtual environments of two different architectural examples. The study revealed that participants who were trained in a VR environment performed better in knowledge acquisition and analytical-critical thinking skills compared to traditional training conditions. It also shows that VR offers an interactive learning environment in the process of teaching architectural history, allowing students to better understand historical buildings and develop their critical thinking skills. The research provides a strong motivation for teaching architectural history in a student-centered and interactive approach (Ibrahim, Al-Rababah, & Bani Baker, 2021). Furthermore, de Fino et al. (2022) highlight the importance of digitizing historical architectural heritage for VR platforms. In this case study, a methodological workflow is proposed for the development of low-cost and user-friendly tools aimed at integrating various information contents and digital products using thematic virtual tours. The proposed methodology emphasizes that virtual tours, especially those created with 360° panoramic scenes, offer users, technicians and authorities remote access to information on protection status diagnosis and safety measures. While the study is generally positive about the potential of VR technology in education, it also emphasizes the importance of using this technology as a tool that complements, rather than replaces, traditional training methods (De Fino, Bruno, & Fatiguso, 2022; Yıldırım, 2024).

Based on the findings of these studies and case studies in the literature, the proliferation of personal VR headsets and their integration into architectural education has provided students with the opportunity to explore and understand architectural design processes more comprehensively and interactively. With this development, students can now experience architectural projects realistically in a virtual environment, allowing for deeper learning. This technology enables students to engage interactively at every stage of the design process, freely express their thoughts, and collaborate on projects. In this context, the widespread use of personal VR headsets significantly enhances students' learning experiences in architectural education and contributes to future architecture professionals being more qualified.



3. COLLABORATION AND DESIGN

Design serves as a means not only to create solutions that respond to the needs and expectations of humanity but also to make our daily lives more functional, aesthetic, and meaningful. However, the challenges faced by design today are becoming increasingly complex. Rapidly evolving technological trends, global competition, and escalating customer expectations are pushing designers toward finding new and innovative solutions. Therefore, the concept of collaboration is gaining more and more importance.

Collaboration is the process of individuals, groups, and organizations coming together to work collectively towards common goals (Deng, Mueller, Rogers, & Olechowski, 2022; Kvan, 2000). Collaboration in the design process entails people from different areas of expertise coming together to exchange ideas and combine their knowledge and skills. In contemporary design processes, the role of collaboration is becoming increasingly crucial because the capabilities of a single individual or team are often insufficient to solve complex problems and generate innovative solutions.

Collaboration plays a significant role not only in the final product of design but also at every stage of the design process. From the initial ideation phase to prototyping and user testing, collaboration occurs within a continuous cycle of interaction and feedback. This process facilitates the sharing of knowledge and experiences among stakeholders, bringing together different perspectives, and working together to achieve better results.

When aiming to produce a collaborative product in the design process, it typically involves a process that includes other individuals with expertise. While it may be possible to progress individually in some design processes, others require team collaboration. The design process often involves participants coming together to work closely in collaboration, sharing and contributing their expertise and knowledge towards solving a common problem together.

The term "collaboration" encompasses various situations where individuals work together towards a common goal and engage in incompatible efforts. The effectiveness of collaboration lies in the ability to seek assistance and engage with others who can help overcome challenges or deficiencies one may face individually, thereby collectively achieving the desired outcome. Collaboration involves the concerted effort of individuals or groups, pooling their diverse talents and knowledge to achieve a shared objective. Throughout this process, the utilization of skills such as communication, decision-making, and problem-solving is critical (Kvan, 2000). Collaboration is based on mutual understanding, trust, and respect among participants and often emphasizes the importance of cooperation to achieve successful outcomes.

3.1. Definition of Collaboration and Collaborative Design

Collaboration and collaborative design are commonly used and particularly significant concepts in the field of design today. Both express the necessity of working together among different individuals or groups to achieve common goals, yet there are significant distinctions between the concepts. Collaboration is generally defined as a process where actors from different disciplines come together to share knowledge and resources. This process typically involves communication and coordination and is characterized by the exchange of information and resources, especially among different disciplines. On the other hand, collaborative design represents a more profound approach. This approach emphasizes the active participation of stakeholders and the exchange of ideas in the design process. Collaborative design involves actors from different disciplines coming together to work collaboratively in the design process. This process involves sharing knowledge about the design process and content and entails developing a shared understanding, integrating information, and collectively striving toward designing a new product (Kleinsmann, 2006). Therefore, collaborative design represents a more participatory and in-depth process.

In this context, while collaboration is a general concept, collaborative design is a more specific application and is often considered a subset of the collaboration concept, focusing primarily on the design process. Collaborative design is an example of collaboration in the field of design and specifically refers to teamwork and knowledge sharing in design projects.

Increasing motivation in collaboration will enhance the effectiveness of the resulting product or task. Based on this, according to Sbea and Guzzo (1987), there are three main evaluation criteria to measure the productivity of collaboration in a task. These are task interdependence, which emphasizes how closely group members work together; outcome interdependence, which measures how rewards are distributed because of group work; and perceived efficacy of group member's contribution to the task, assessed as the power factor. Building on these evaluation criteria, the effectiveness of a common goal can be examined, and measures can be taken to enhance it.

Based on the definition of collaborative design, this productivity is characterized by the formation and integration of knowledge between actors from different disciplines and functions, communication between actors about the design content and process, and the formation of a common understanding of the content and process of design. This approach emphasizes the need for participants from different specializations to come together to share their knowledge and experience and to work together for the effective realization of design. In this way, the design process is enriched, and synergy is created between the participants, resulting in more innovative and effective designs.

3.2. Communication Methods Used in Collaborative Design

Communication methods used in collaborative design projects play a critical role in facilitating participant interaction and knowledge sharing. These methods serve as essential tools to ensure effective communication among teams from different geographic locations, coordinate collaboration processes, and achieve project objectives. When examining research on collaborative design, communication among actors and the efficiency of knowledge transfer are addressed from various perspectives.

Communication among actors in collaborative design projects has been explored by Chiu (2002). According to Chiu, this communication occurs in both synchronous and asynchronous forms. In synchronous communication, actors utilize tools such as verbal explanations, texts, sketches, orthographic drawings, tables, CAD drawings,

computer-generated images, and photographs. On the other hand, asynchronous communication involves verbal explanations accompanied by visual presentations.

Perry and Sanderson (1998) emphasized in their research that face-to-face interaction was the most effective communication method among actors, based on the technologies available at that time. The primary reason for this is the deep and rich communication experience that face-to-face interaction offers. Face-to-face communication allows individuals to communicate using various channels such as gestures, facial expressions, tone of voice, and body language. This enables the establishment of emotional connections, the development of empathy, and a better understanding of nuances in communication. Additionally, face-to-face communication is the most effective way to receive rapid feedback and provide immediate reactions. Especially in the design process, quick decisions may need to be made, and the direction of the design may need to be changed instantly. Face-to-face communication provides the flexibility and speed required to adapt to such rapid changes. Furthermore, face-to-face communication fosters the establishment of trust and strengthens collaboration. Mutual eye contact enhances intimacy and trust, reinforcing participants' confidence in each other. This, in turn, ensures that collaboration in the design process is more efficient and effective. Lastly, face-to-face communication facilitates a better understanding of complex ideas and concepts. During discussions, participants have the opportunity to stand beside each other, ask questions, and provide deeper explanations. This leads to a better understanding and resolution of complex problems that arise during the design process. For all these reasons, as emphasized by Perry and Sanderson, face-to-face interaction is a crucial and effective component of communication in the design process. Communication supported by technological tools cannot fully replicate the depth, speed, and trust environment provided by face-to-face interaction. Therefore, the importance of face-to-face interaction plays a critical role in completing the design process.

In communication among designers, it is observed that specific representations identified by Saad and Maher (1996) are utilized. Designers select representations for various aspects of design based on their abstraction needs. Saad and Maher categorized objects into three types of representation, as indicated in Figure 3.2.1, and illustrated the relationships between these representations with arrows between the boxes. The

arrows between the Shared Object and the three categories (Organizational, Semantics, and Graphics) indicate that each representation derives from the central concept of the Shared Object. The arrows between the categories suggest interactions and dependencies among the representations. For example, semantics representation might influence the graphical representation by providing context or functional details that need to be visually depicted. Similarly, organizational attributes might affect how the object is presented and accessed in a graphical format.

By categorizing objects into these three types of representations, Saad and Maher's model supports a comprehensive and integrated approach to collaborative design, ensuring that all necessary aspects of the object are considered and managed effectively. The computer program developed based on this model would help designers collaborate by providing tools and features aligned with these representations, facilitating better communication, understanding, and management of design objects. To support collaborative design, Saad and Maher developed a computer program aiming to establish a foundation using these three categories (see Figure 3.1).

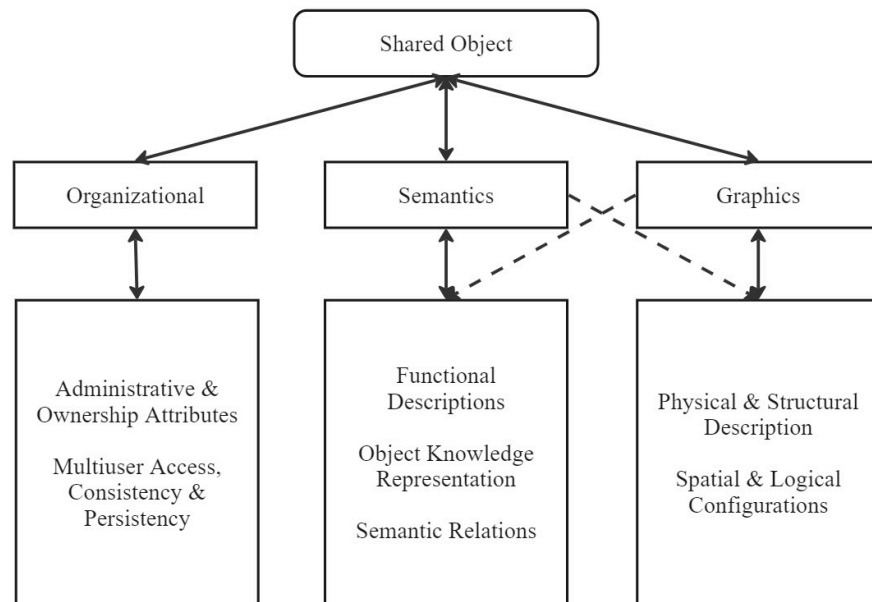


Figure 3.1: Representation of shared objects (Saad & Maher, 1996)

Peng (1994) emphasized the importance of physical models in collaborative design. Physical models assist designers in developing and conveying their ideas, as well as understanding the outcomes of ideas explored through drawings. According to Peng, there is a close relationship between making drawings and creating models. Designers often develop proposed design solutions through drawings during model construction. Additionally, designers create models to understand the outcomes of design ideas explored in drawings.

Peng states that merely existing as a drawing does not constitute a model. A drawing is a model and represents the characteristics of the model. For a drawing to function as a model, both the sender and receiver must share the same understanding. Similarly, prototypes can also serve as interdisciplinary communication tools. During the prototyping process, actors from different disciplines actively engage in discussions by associating the prototype version with the final product. If there are inconsistencies or gaps between disciplines, they will emerge during the prototyping process.

In summary, actors in the collaborative design process alternately use different communication methods, as they reinforce each other. Previous research indicates that drawings and prototypes are powerful tools in content-related communication. However, these tools are effective only when they align with the level of abstraction understood by both the sender and the receiver. Additionally, both the sender and the receiver must understand the purpose of the drawing or prototype. This can pose a challenge in collaborative design because actors create sketches and prototypes for different purposes depending on the stage of the collaborative design process and the task, they need to fulfill (Kleinsmann, 2006).

3.3. Collaboration and Computer-Aided Design

CAD technology has continuously evolved since the 1950s, being utilized in various application areas. Particularly in recent years, technological advancements in CAD software have progressed towards virtualization and collaboration. With the emergence of cloud-based Multi-User Computer-Aided Design (MUCAD) systems, replacing traditional CAD systems, these systems have been developed to address the increasing complexity of modern product design and provide users with more effective

file access and sharing capabilities. MUCAD is a platform that enables multiple users to work simultaneously on the same project and allows accessibility from different locations, thus making the design process more efficient and facilitating collaboration (Deng, Mueller, Rogers, & Olechowski, 2022).

MUCAD systems are platforms where multiple users can virtually collaborate simultaneously and manage CAD projects together. These systems enable users to work concurrently on the same projects despite being in different locations. MUCAD has the potential to enhance the efficiency of the design process by expanding the collaboration and sharing capabilities of CAD software (Kvan, 2000).

The MUCAD Collaborative Learning Framework (MUCAD-CLF) is an analytical tool used to enhance students' CAD modeling skills. This framework enables the assessment and visualization of students' performance while also helping to understand how a collaborative approach to CAD modeling contributes to the learning process. These analytical tools can assist educators and researchers in providing feedback to students, identifying challenges, and optimizing the learning process. In this way, tools like MUCAD-CLF can support students in improving their computer-aided design skills and succeeding in future engineering projects (Deng, Mueller, Rogers, & Olechowski, 2022).

Transitioning from traditional CAD systems to MUCAD systems brings about significant changes and advancements in design processes. MUCAD enhances collaboration within design teams, allowing multiple users to contribute to a CAD model simultaneously in a virtual environment. This facilitates the management of the design process more effectively and efficiently.

One of the most significant advantages provided by MUCAD is real-time synchronization. This feature allows any edits made to be instantly visible and updated by all users, enhancing communication during the design process, and enabling quick decision-making processes. Additionally, MUCAD platforms need to be supported by sophisticated collaborative software architecture, which establishes the necessary infrastructure to manage and ensure the platform's complexity. Moreover, the use of data analytics in design processes is becoming increasingly important. Data analytics

serves as a significant tool to enhance the quality and efficiency of design with CAD. However, there has been limited research on the implementation of data analytics in CAD education. This indicates the need for CAD education programs to focus more on equipping students with data analytics skills.

Researchers have proposed various strategies to enhance the learning experience of CAD processes. The first strategy involves the use of the cognitive apprenticeship method to help students better understand the thinking process of CAD design. Cognitive apprenticeship is a learning model that assists students in developing problem-solving abilities for complex problems (Deng, Mueller, Rogers, & Olechowski, 2022). The second strategy is the adoption of direct modeling methods to ensure that functional design concepts are not overlooked. This method focuses on teaching students the practical applications of the design process (Zou & Feng, 2020). Additionally, studies identifying students' different collaboration styles suggest providing appropriate instructions to students. This can help improve students' collaboration skills, making them more effective in group work (Ellis, Han, & Pardo, 2018). Similarly, using survey questions to understand the backgrounds and preferences of CAD learners is recommended. This can enhance the learning process by providing students with more personalized support (Hamade, 2009).

Developing quality modeling methods is also important for better conveying design quality requirements. This can help maintain quality standards at every stage of the design process and result in a better final product. However, there is less information available regarding teaching and learning in the field of MUCAD. This presents more research opportunities to explore the impact and necessity of new teaching methods. Therefore, conducting more in-depth studies in the field of MUCAD and developing new educational strategies is crucial.

Lawrence and Lorsch (1967), introduced the concepts of integration and differentiation in the organizational context, developing an important theory on how organizations are structured and function. This theory focuses on two fundamental concepts: "integration" and "differentiation." Integration refers to the quality of collaboration among functions within an organization. In the design field, integration reflects a designer's decision-making process considering various contexts.

Differentiation, on the other hand, signifies the division of the organization into subsystems and is crucial for the successful completion of product design projects.

This theory has been particularly effective in new product development efforts. Many authors have published articles addressing the integration of different functions in product design projects. Terms such as "external communication" or "boundary-spanning" are used to explain the phenomenon of integration. Researchers have emphasized the importance of different strategies for external communication and the frequency of communication. This highlights the critical role of external communication activities such as ambassadorial activities, task coordinator activities, and scouting activities in enhancing team performance. In this context, understanding the dynamics of internal communication within organizations is important for successfully managing and completing product design projects.

Lawrence and Lorsch's concepts of integration and differentiation are closely related to modern technologies like MUCAD in product design processes. MUCAD enhances collaboration within design teams, facilitating the integration of experts from different disciplines. As Lawrence and Lorsch suggested, this increases the quality of collaboration among functions and can contribute to the successful completion of design projects. Additionally, the MUCAD platform supports external communication and boundary-spanning concepts, easing communication among teams from different disciplines. For instance, MUCAD can enhance team performance by supporting external communication activities such as ambassadorial activities or task coordination.

In this way, MUCAD, when applied to the integration and differentiation concepts highlighted by Lawrence and Lorsch's theory, can facilitate more effective collaboration in product design processes and increase the likelihood of success.

In conclusion, Lawrence and Lorsch's theory provides a significant framework for dealing with the complexity of organizations and for collaborating successfully. This theory serves as a guide in understanding and managing the internal dynamics of organizations, while also contributing to the creation of more effective and efficient working environments through the integration of modern technologies. Therefore, the

concepts of integration and differentiation hold strategic importance for organizations and may require further research and implementation in future studies.

3.4. Collaborative Design with Virtual Reality

With the advancement of VR technology, the collaborative creation of physical products in virtual environments is rapidly becoming more widespread. This technology facilitates the transmission of information in ways that are not feasible in the physical world through the use of analog techniques. However, there is limited research on the sharing of the sense of collaboration and cooperation in working and creating together in virtual environments. While VR is often used as a consultative tool, studies typically focus on users exploring the virtual environment, experiencing proposed design scenarios, and engaging in individual production. Nevertheless, research is scarce on the evaluation of their content in a collaborative setting (Chowdhury & Hanegraaf, 2022).

The concept of "co-presence," which is a way of existing in the virtual environment, creates a sense of spatial and temporal unity among individuals present in the same digital environment. According to Nowak (2001), this concept refers to the state of being together and the mental dimension of this togetherness among multiple entities sharing the same virtual space. Co-presence enables individuals gathering in virtual projects to collaborate in production, work together on the content they produce, and provide feedback. Understanding this concept is related to various aspects of the virtual environment. For example, the physical characteristics of the virtual environment are directly related to the design of interfaces that enable users to come together and interact. Additionally, the objects and tools it contains may influence the co-presence experience, thereby determining the level of interaction and productivity of users. Co-presence serves as a factor guiding participants' interactions, affecting users' motivation and activity efficiency. Focusing on a common purpose and fostering a sense of collaboration encourages users to be present and active in the virtual environment. In this context, the concept of co-presence supports collaboration and creativity by providing designers with an interactive design environment.

Collaborative design in VR is a process where different stakeholders come together and work towards a common design goal in a virtual environment, utilizing co-presence to collaborate. In this process, designers, architects, engineers, and sometimes clients collaborate on designing an object or its components. In cases where stakeholders prefer visual communication over verbal communication in the virtual environment, the use of 3D models can accelerate communication and lead to quicker problem-solving. This is mainly because 3D objects are better perceived and can be manipulated to demonstrate real-time changes within the virtual environment. Communication facilitated by 3D models among stakeholders can enhance discussions during the design process and improve information flow, thus enhancing communication about the design within the virtual environment (Chowdhury & Hanegraaf, 2022).

Chowdhury and Hangreaaf conducted a study examining collaborative design as co-presence within a VR platform called Arkio. Participants came together to redesign the landscape of a virtual campus area. During this process, participants were expected to communicate from their own avatars' perspectives and make design decisions together to take action. The data obtained were reported for a detailed analysis of design discussions in the virtual environment. The study involved three different participants. One participant entered the virtual environment using an HMD device, while the other two participants viewed 3D objects from their laptops. The participants using the HMD interacted with the other two participants while providing an immersive experience for editing from a primary perspective. All three participants worked on creating their landscape designs by adding and arranging various objects within the virtual environment. Communication during this process facilitated collaborative design as a team rather than individual efforts, reflecting the best practices of design collaboration in the virtual environment. Participants experienced a "sense of being" by interacting in the same environment and creating a shared design. This study demonstrates the effectiveness of using innovative and creative communication tools in showcasing a collaborative design process in the virtual environment. The research emphasizes the importance of collaborative design processes in virtual environments. Participants gained a new perspective on their interactions in the virtual environment, different from traditional design methods. This

method not only brings out participants' creative potential but also demonstrates the power of teamwork. The interaction in communication enabled participants to come together to achieve common goals and collaboratively generate innovative solutions. Therefore, this collaborative design work in the virtual environment provides an effective communication and collaboration model that can be used in similar projects in the future. This approach, especially when used in remote working environments and complex design projects, can enhance productivity, and foster creative solutions.



4. ARKIO PLATFORM: A COLLABORATIVE DESIGN AND PRODUCTION ENVIRONMENT

The Arkio platform was officially launched on June 1, 2021, after the beta period. It is a platform that can be obtained free of charge by students and professionals and is suitable for use on VR headsets, desktop computers, tablets, and mobile devices (Gunnarsson, A new collaborative tool for architecture, 2021). Launched with four usage plans, Arkio offers continuous access to all modeling tools with the free plan and the opportunity to organize meetings up to 20 minutes with up to 4 users. In this free plan, it is possible to import and export three-dimensional models. The Pro plan has the ability to import and export from Revit, Rhino, and SketchUp. It can be downloaded for free from Oculus, Steam, iOS App Store, and Google Play, and Revit, Rhino, Sketchup, and Unity Arkio plugins can be installed from www.arkio.is (Arkio, n.d.).

Arkio serves as a cutting-edge VR and AR platform, transforming traditional design and review processes in the architecture, engineering, and construction sectors. It provides users the opportunity to design, evaluate projects, and collaborate in a 3D environment. By fostering innovation, Arkio enhances planning processes, minimizes risks, and increases engagement with potential clients. Beyond professional applications, it also facilitates a more interactive and collaborative learning environment, empowering educators and students to explore the potential of virtual design technology (Stevens, Hannegraaf, & Moussa, 2023).

One of the main functions of Arkio is to provide an alternative to traditional 2D design methods in architectural education and professional design processes in terms of different visual modeling and collaborative work of participants. With the platform, users can create digital models of buildings, spaces, landscapes, and other structures, view them from different perspectives, and make changes simultaneously. Furthermore, Arkio's integration with CAD software contributes to professional processes by facilitating the transfer of designs made in VR to traditional digital tools.

The immersive experience offered by the platform allows users to evaluate their designs from a more realistic perspective. The main reason is that it creates an alternative virtual world to the 3D world that users are used to. It is also accessible from desktop and mobile devices, making it easier for users to participate in the design process regardless of geographical constraints, thus saving time and physical proximity requirements. The cross-platform collaboration and “passthrough” feature offered by Arkio supports the transition from VR to Mixed Reality (MR), providing more flexibility and collaboration in design processes. Real-time Boolean operations and the ability to produce with various objects give users a wide range of freedom in their design process.

With these features, Arkio has significant potential in architectural education. Through the platform, students may develop their design skills, enrich their creative processes, and deepen their conceptual understanding. In addition, the collaboration opportunities provided by Arkio enable professionals and students from different disciplines to work more efficiently on collaborative projects.

These features of Arkio support collaborative design. Collaborative design is widely used in today’s design sector and enables different individuals and groups to design and work together. In this working method in which communication is important, actors from different or the same discipline need to share information and resources. The potential of co-production with different disciplines due to the natural structure of architecture and the intensity of the act of co-production in architectural education cause tools and systems that support collaboration to be widely preferred. As Hilmar Gunnarsson, founder and CEO of Arkio, points out, unlike traditional VR platforms, Arkio allows designers and architects to design directly in a VR environment instead of just using it for exploration (Gunnarsson, 2021).

With its innovative features and emphasis on collaboration, Arkio demonstrates significant potential to enhance architectural design and education. By providing a versatile platform for creating, reviewing, and collaborating in virtual environments, it offers an alternative to traditional methods. However, the platform's long-term impact will depend on its adoption across professional and educational contexts, as well as its ability to integrate seamlessly into existing workflows and technologies.

4.1. Features and Functionality of Arkio

The Arkio platform offers a new tool that supports collaborative and spatial design among the new generation of digital tools included in the traditional architectural design process. Developed specifically for architects and designers, this platform aims to provide its users with an effective working environment as individuals and teams in spatial planning and design processes. The functionalities offered by Arkio include features that will directly contribute to the design process.

One of the prominent features of Arkio is that it enables real-time and immersive modeling with solid modeling. Using VR equipment, users can create volumes with extrusion and obtain complex forms in 3D models with Boolean operations. It also offers the ability to combine multiple objects into a single model. With the platform's intuitive editing feature, basic editing operations such as copying, moving, pasting, tilting and carving can be easily performed (Kwak, 2023). Thanks to its user-friendly interface, Arkio offers quick learning and instant action, making the workflow of users efficient.

In addition to Arkio's ability to produce directly in a VR environment using VR equipment, cross-device compatibility and collaboration features enable production and project sharing over different devices. Compatible with tablets, mobile devices and computers, the platform enables users to come together on the same project regardless of location and work in a real-time collaboration environment. Thanks to its compatibility with popular 3D modeling software such as Revit, Rhino and SketchUp, file import and export from this software can be done seamlessly, making it possible to process projects produced on different platforms in the Arkio environment.

The Passthrough feature enables users to switch from VR to AR, allowing them to examine their designs at scale in a real environment. This feature provides a significant advantage in detail reviews and error detection, especially in large-scale projects, so that users can experience the real-world posture of the design during the production process. With features like these, Arkio stands out as an effective tool that supports

the collaborative design process in VR to meet the need for rapid prototyping and modeling.

4.2. User Interface and Tools

The menus and tools of Arkio platform provide the user with a variety of options to enable them to design efficiently in VR. Different ways of accessing the menus and tools are offered. The main menu (see Figure 4.1) in provides access to all of Arkio's tools and can be activated in three different ways.

In the first method, when the left wrist is turned towards the user, the menu can be seen as a paint palette on the user's wrist. The user can attach the menu to any fixed point around it by grabbing the center of the menu with the help of the trigger. The menu can be closed by turning the user's wrist down again. In the second method, the user can open the sliding menu by quickly pressing the menu button on the top of the controller. This menu appears in front of the user in a fixed position and can be closed by pressing the same button again. This operation can be done with both hands. The menu can be expanded into the left and right drawers to accommodate additional objects and can be removed, moved, or reinserted into the main menu by pressing and holding the trigger. In the third method, the user can switch to quick selection mode by pressing and holding the menu button of the remote control and hovering over it with the mouse. In this mode, the user can quickly switch between Arkio's tools. To deactivate any selected tool, the user must squeeze the trigger and release it.

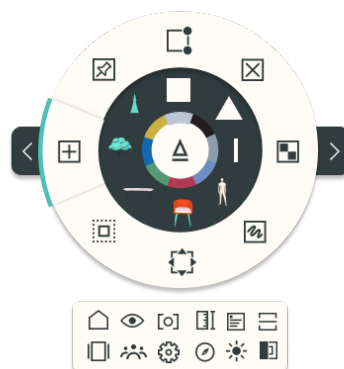


Figure 4.1: Arkio platform's main menu interface (Hanegraaf, Main Menu, 2024)

To move the selected menu to the scene, a trigger on any controller can be used to grab the center point of the menu and place it in a fixed position. This method is also valid for asset and material drawers (Hanegraaf, Main Menu, 2024).

The first inner ring of the main menu shown in Figure 1 is referred to as the favorites menu. This ring functions as a palette that allows the user to drag and drop their favorite objects and colors from their respective drawers. The outer ring contains all the primary editing tools, while the inner ring provides shortcut access to favorite paint materials for newly created shapes. The images in the outer ring (see Figure 4.2) include basic creation and editing tools such as edit, delete, paint, sketch, move, group, create, pin. These are the first tools that the user needs to learn in order to be able to create and edit.

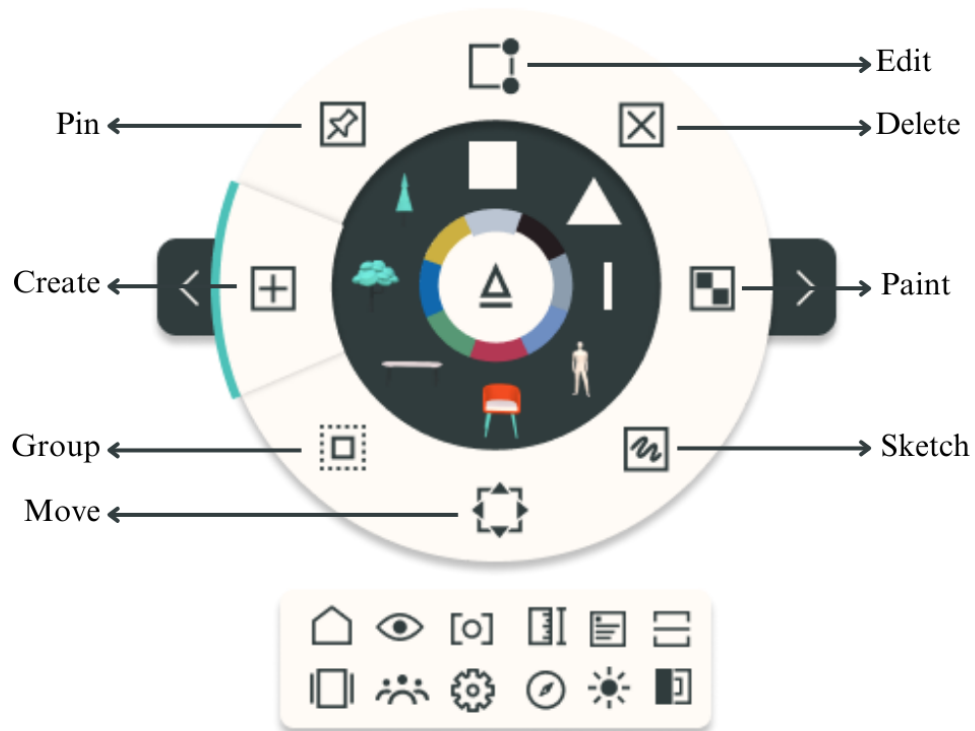


Figure 4.2: Arkio platform's main menu interface's detailed (editing by author)

The drawers (see Figure 4.3) to the left and right of the outer ring are the tools for transferring geometry and materials to the scene. These drawers can be opened by clicking on the right and left tabs when the building or painting and drawing tools are selected. These drawers have a modular structure and can be placed in different

locations by hovering over the drawer, dragging it and holding down the trigger. These drawers contain categorized accessories and materials, and shortcuts can be created by dragging them to the favorites area in the inner ring.

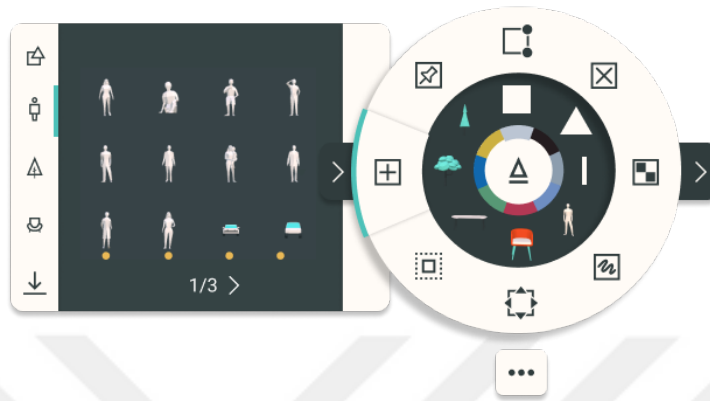


Figure 4.3: Left side of the main menu, material drawer (Hanegraaf, Secondary Menus, 2024)

The bottom drawer, indicated by the three dots (...), contains additional tools and utilities. There are 12 tools in this drawer (see Figure 4.4). These tools are home panel to return to the main screen, review panel to review and examine the design, camera to photograph and save the design from various angles, measure to take measurements and determine the dimensions, note to add text to the design as needed, split to divide and separate the design, scenes to switch to different scenes, meeting for collaboration, settings to change the application properties and license, map to position the design, solar study to adjust the daylight and section to create sections of the design.



Figure 4.4: Bottom drawer, additional tools and utilities (Hanegraaf, Secondary Menus, 2024) (editing by author)

Users first provide access to training videos, samples, scenes, passthrough, and meetings in Arkio's home panel interface (see Figure 4.5). Users can access innovations, popular features, and sample projects in Arkio from here. They can also access scenes to start a meeting and access support. These are the basic menus and tools available in Arkio, and unlike most CAD programs, they are easy to access. These features help new users to master the interface of the platform and to learn more quickly, as opposed to complex, detailed production models. Detailed tutorials are available on Arkio channel on YouTube and in Arkio for explanatory demonstrations of menus and tools, and detailed tutorials are available in the support section of the official website.

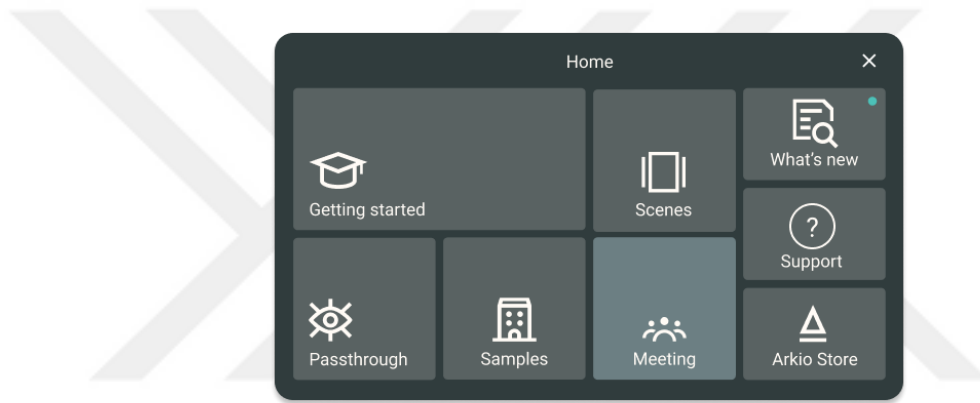


Figure 4.5: Arkio platform's home panel interface (Hanegraaf, Secondary Menus, 2024)

4.2.1. Basic Model Creation and Editing

In order to be able to navigate and produce within Arkio platform, it is necessary to master the basics of navigation. When logging in to Arkio platform, the user first encounters a green floor where they can produce models in a virtual environment (see Figure 4.6). By holding down the trigger on the right or left controller and aiming at the floor and releasing the trigger, the user can teleport themselves to the floor. And the productions made as a result of this teleportation are in a 1:1 scale. By pressing the hold buttons on both controllers at the same time and moving the user's hands closer and further away from each other, the user can scale themselves closer or further away according to the model. Also, when the user teleports themselves toward the sky, they return to the god scale of 1:1000 (Hanegraaf, VR Controllers and Hand-tracking, 2021).

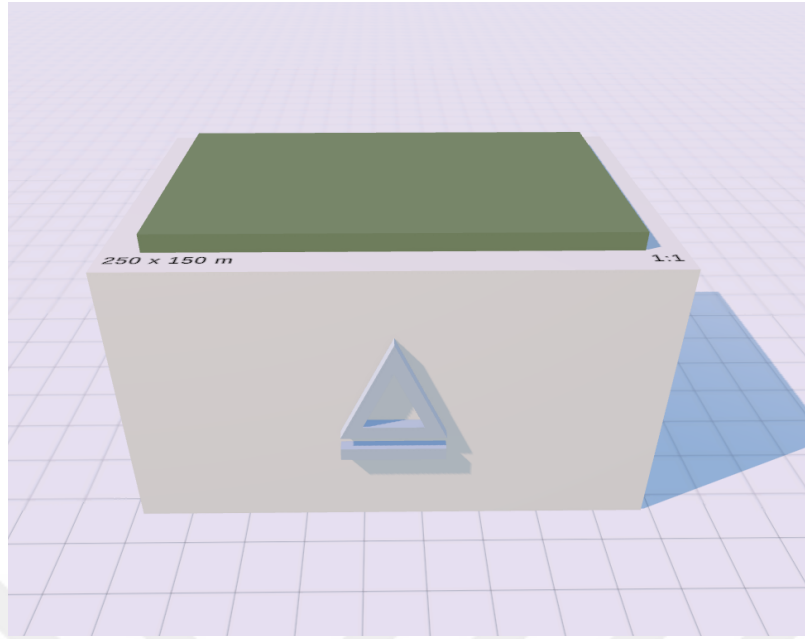


Figure 4.6: Arkio platform's floor (screenshot taken by author)

In order to be able to produce within Arkio platform using VR, the user must first master the controller or the hand tracking system if the VR headset is compatible. Arkio includes experimental support for hand tracking. There are various differences in the hand tracking system according to the model of the VR headset used by Arkio. The user who experiences HTC Vive controllers uses the main index finger trigger for all main actions. The grips on the side of the controller are used for panning and zooming the virtual environment and hand tracking is not available for now. The Vive touchpad is used for most of Arkio's teleportation and secondary modeling actions. Windows Mixed Reality controllers offer similar features to Oculus touch controllers, with a touchpad and joystick for quick menu and secondary modeling actions. The Oculus Quest, Rift, Rift-S versions of Meta include hand tracking that supports hand model interactions. For hand tracking to work, controllers can be placed on the ground and the user can switch between controllers and hands by looking at their hands. The model can be interacted with by pinch gestures. When working with the hand-tracking method, there are two methods to open the menu. The user opens the menu by opening his/her right or left palm in front of him/her and pinching his/her middle finger and thumb together. In order to rotate the model, the user must place his/her hand in front of him/her and make a fist movement to grasp the entire model. To scale and rotate the model, the user must make a fist with their hand at the same time, then zoom their

hand in and out to scale or rotate the model like holding a wheel. To activate teleportation, the user has to make a pointing gesture with the index finger and thumb and then turn the palm up and down again. To teleport it, he/she needs to apply a pinching gesture (Hanegraaf, VR Controllers and Hand-tracking, 2021).

While this hand tracking within the platform offers a different experience compared to controllers, this experimental feature needs to be improved. Although there are problems such as not detecting and not getting fast returns in some cases, it is still open to improvement. The hand tracking feature helps users to interact more easily with the VR environment by using their physical hands instead of traditional controllers. This allows users in the design process to provide a natural and intuitive approach while maintaining the natural structure of production.

There are several available ways to navigate the virtual environment on Arkio platform. The main way to navigate around and produce in the virtual environment is to navigate the user's body and head in the preferred direction and interact with the model by looking at it more closely. In this way, users can navigate and produce at any scale, human scale, or god scale. With the other way, teleportation, users can assign themselves to the preferred region with the help of triggers and examine their production from various perspectives. In order to navigate by scrolling, users need to hold down the controller's triggers. The users can use both hands and grasp the virtual environment and move it around, allowing the users to see from other perspectives. To navigate scaling, the users must hold down both trigger and zoom in and adjust the scale of the model that appears above the white line to preferred scale (see Figure 4.7).



Figure 4.7: Scale in Arkio (screenshot taken by author)

When producing in Arkio, the user must initially create a shape. Modeling starts with the use and transformation of the selected basic shape. In order to start the creation process, the users can first determine the position where the shape will be created with the help of the trigger and hold it down until the desired shape is created. To create solid shapes, the user must move the trigger upwards, while to create empty shapes, the user must push the solid shape downwards.

Arkio offers flexibility to bring the created shapes to the desired form and can be resized with the measure tool according to the need. With the help of the quick selection menu, the user can switch to the edit tool and the shape can be stretched remotely. Editing mode and wrist strap adjustment allow the user to switch between vertical editing and freehand drawing. With the help of the move tool, the user can pick up and move shapes horizontally and vertically by touch. To rotate the shapes, the user must swipe the screen with the other hand while moving the object. This also applies to Arkio accessories and custom 3D models.

“Modeling in Arkio is inspired by working with physical objects and using the user’s hands” (Hanegraaf, Volumetric Modeling, 2021). In Arkio, geometric shapes can be created, and these shapes can be organized, stacked and transformed with the help of other shapes in the scene. Models are first created by gluing volumetric masses on the

ground, then sliding on surfaces and sticking to the faces and edges or corners of other shapes. A shape can be stacked or glued on top of another shape. This enables the creation of objects that stand on gravity, as in the real world, and hierarchy within shapes.

Because Arkio supports real-time Boolean operations, any primitive shape in Arkio can be transformed into a solid or a void. Boolean operations that provide union, difference, and intersection allow geometric shapes to be transformed into more complex and detailed models. Since Arkio supports these operations, it allows two or more masses to merge into a single mass and subtract one mass from another. In addition, it creates the intersection region of two masses, preserving the area and erasing the other parts. In this way, Arkio allows for the rapid creation of complex models, precise modeling and flexibility in editing.

In addition, the interior masses in Arkio facilitate the use of ready-made objects during modeling. These objects, such as doors and windows, can be arranged in desired dimensions and organized according to the space. Offering smart volumetric object support, Arkio offers a more intuitive environment compared to traditional CAD tools. It can add as much detail as the user wants by duplicating or sorting the object groups hosted in Arkio, which can offer fast modeling, with all attached geometries(see Figure 4.8).

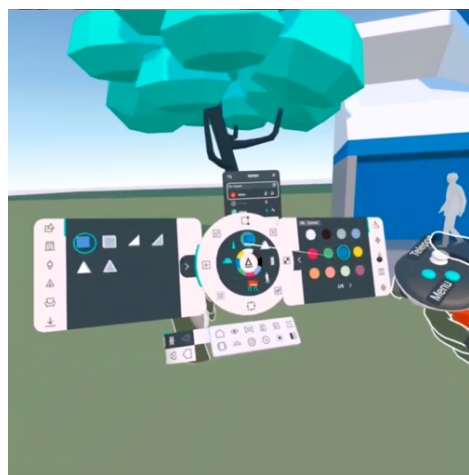


Figure 4.8: Production in Arkio (screenshot taken by author)

4.2.2. Passthrough Features

Arkio Meta Quest VR devices support passthrough, enabling the user to experience physical reality in a virtual environment. This experience is realized in Quest 1 and Quest 2 devices with the physical environment appearing in black and white. In Quest Pro and Quest 3 devices, on the other hand, the real and virtual environment blends more seamlessly and reflects the virtual-real integration to the users more fluently with color transition. The user can fix their models in the virtual environment to their position in the physical environment and design, shift and scale their model by incorporating their virtual productions into the physical environment. When the user teleports themselves to the god scale, the default model will be defined as their location. This allows the user to work on interior designs and scaled architectural projects and prevents the workspace and the real environment from clashing.

However, when the users scale themselves beyond the 1:2 scale or teleports themselves to the workspace, the position with the environment will be locked and immersive to prevent misalignment and understanding of the design. At this scale, if the user wants to map their physical environment with Arkio geometry, they can switch to complex reality and switch to VR mode by working in real dimensions again. The user can also switch from MR to VR by clicking the passthrough icon on the secondary bracelet (see Figure 4.9). According to the virtual scene, the location marker indicates where the user is in the real environment.

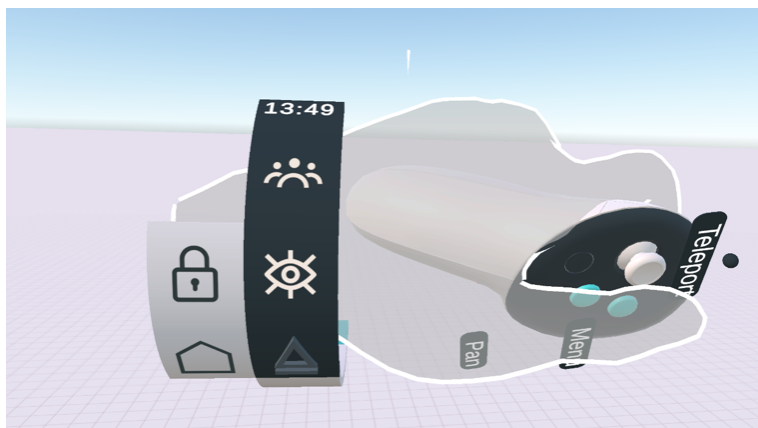


Figure 4.9: Passthrough in the secondary bracelet (screenshot taken by author)

While working with VR in Arkio, it is possible to move out of the boundary, which was first set for the VR headset, and transition to the physical environment. When the user goes beyond the boundary line, they can interact with the real environment. This interaction of virtual and real environments allows the user to move without restrictions and limits.

4.2.3. LiDAR Feature

Potential uses for Arkio include its integration with LiDAR (Light Detection and Ranging) scanning. LiDAR scans support architectural and urban design projects by creating a detailed 3D model of the environment or specific objects using light waves. These scans can be used to measure particularly complex structures or terrain, providing a high level of data. Using Scaniverse and Polycam applications with the help of an iOS device as a LiDAR scanner, the user can convert the 3D environment and objects into GLB format that can be uploaded to Arkio. In this way, they can transfer data sets taken from the real world to the virtual environment. Users can examine the topography or building information obtained from LiDAR scans directly in Arkio, make edits, and continue their design processes on a much more realistic and data-driven basis. Such integration is especially useful in digital twin projects or renovation projects of existing buildings.

Arkio's user-friendly interface, LiDAR scan data can be visualized, edited, and shared on the platform for various purposes. This allows users to easily process data collected in the field in Arkio's VR environment. For example, uploading LiDAR data collected from the field to Arkio during an architectural design process allows designers to analyze the existing conditions of the site much more precisely. This is especially important in design projects that require sensitivity to the urban fabric, where environmental factors need to be directly related to the design.

Arkio's integration with other programs also provides an advantage in this process. LiDAR data can be exported from Arkio to different software such as Unity, SketchUp or Rhino. In this way, users can easily move the design process to other platforms and manage their projects in a broad perspective by providing a flexible data flow while working on LiDAR-based models (Hanegraaf, LiDAR scans, 2024).

4.2.4. Cloud and Local Import/Export

Arkio platform offers its users the opportunity to transfer their projects through the system by logging into their own cloud system. In Arkio, which enables the import and export of images and 3D models from various tools, also offers the possibility to import/export locally, making it possible for users to work on different platforms. With these features, users can store their productions in Cloud and access them from different devices. When necessary, they can convert them to local file formats and integrate them into different CAD software. In order to access Arkio's Cloud system, users need to log in via cloud.arkio.is. A plus, pro or enterprise license is required for the user to import/export more than 100k triangles 3d models. For uploading files smaller than 100k triangles to Cloud, no user account, email or license is required. The user can upload files directly by creating a group.

Arkio's Cloud, it can be uploaded and downloaded directly to Arkio or from Arkio to any device where the platform can be used. In order to share with other users or their own devices, the user needs to create a new group and give a new name to the group via Cloud. After the group is created, the user can log in to the same group from any device with a 15-minute invitation code. Arkio's Cloud service is used for easy access and sharing local files by the user. Files uploaded to Cloud can be used for 7 days and are removed when they expire. Models uploaded to Arkio are stored locally and are end-to-end encrypted. It is shared with other users through a live Arkio meeting. Imports shared and uploaded with connected devices can be used offline. The user can work on the file without an internet connection and collaborative meetings. Imports shared with Cloud group are downloaded until the user leaves the group. This ensures that the work can be continued by the user.

Images and 3d models (OBJ and GLB) can be uploaded to Arkio's Cloud and can be exported using plugins for Arkio from other CAD platforms that can be integrated. When the user uploads their files to Cloud and collects them from their devices in the same Cloud group, the files will be downloaded to Arkio and the assets will appear in the import drawer. By uploading from there, the user can make changes to the model. The imported model and images can be placed on the floor of Arkio and the stage as a non-moving reference. The files fixed on Arkio floor can be positioned concerning the

starting point and can be used to build a model on top of the plan view. The imported building models and environments can be manually positioned and fixed in the user scene.

When the user selects Cloud panel in the creation tool, they can log in to the group with the usual invitation code and access any file uploaded through Cloud. In addition, by connecting Arkio-compatible plugins to the same Cloud group, files can be shared directly with all connected devices without starting an extra meeting. When the user uploads a new version of their model to Cloud with the same name, Arkio automatically downloads the file and sends a yellow notification to indicate that a new version is available. To update to the new version, the user needs to update their model by clicking on this yellow notification. Arkio ensures that the previous version is also stored and if the user wants the previous version, he/she can select the specified date and return with the update option. However, this only to models that are fixed to starting point.

In order to export files from Arkio, the user needs to select the export format from the scene viewer. Cloud export button must be turned on for the file to be exported from Arkio. In Arkio, the user can export the photos taken in the last 48 hours, the current scene and 3d models. Exported files are available in the downloads section in Cloud.

4.2.5. Integration of CAD Plugin with Arkio

Arkio offers the ability to work simultaneously with a lot of CAD software, and the software plugins are available to include projects in Arkio and make changes to them. Arkio plugin for Unity, which is one of the software that Arkio is compatible with for CAD and VR integration and collaboration, can be obtained by the user from the Unity Asset Store. With the plugin installed, the user can upload Unity scenes to Arkio on the computer or mobile devices. In this way, a new Arkio menu will be added to the tools section created for exporting to the Cloud. The user can add all GameObjects and Prefabs that appear in the Unity scene as a compatible object to the Arkio scene. The user will be able to connect the plugin to their device by going to Create in Arkio and entering their 6-digit connection code from the Cloud and Unity section. Existing uploads can be downloaded from this section and after processing, the file can be

uploaded to the starting point and uploaded by import where the user can place it in the scene they have created. Unity scenes can be imported into Arkio as GLB file format and for performance reasons it is recommended that the scene should not contain more than 1000 GameObjects and should not exceed 500K triangles (Hanegraaf, Unity & Arkio, 2024). After these steps, the user can move and edit Unity scenes, ready-made structures and GameObjects from Arkio. The user who can make changes to the scene and model for the required design can continue to edit the model using Arkio tools. The user can take advantage of Arkio's collaborative nature while producing on the Unity stage and start a meeting for other users to make changes. And when the required work is created, the files can be imported back into Unity.

Arkio allows importing Revit models, another CAD software, to the platform. When these models are transferred to Arkio, all markup and geometry can be edited in Arkio and restored as specific to Revit. These are two ways to transfer from Revit to Arkio. In one of these transfers, local export, all the required objects are visible in the 3D view and can be visible and used in Arkio by clicking the Local Export button. The exported model is uploaded locally to Arkio and can be shared with other devices. Locally exported models are stored in the Documents\Arkio\Import folder and can be placed in the scene from the Create\Import drawer in Arkio. In the cloud transfer method, Revit models uploaded to the Cloud allow the user to access Quest and other devices without needing a PC. However, for this, Revit plugin and devices must be connected to the same Cloud group. Arkio's Revit plugin, all BIM Data related to objects can also be transferred. This data can be seen in the BIM Data tab of the Review Panel in Arkio. Changes made can be updated by exporting the same object again in Arkio.

The Rhino plugin allows Rhino 6 and 7 models to be transferred to Arkio in NURBS and Mesh formats. Together with materials and textures, these models can be assigned to Arkio. The models created in Arkio can be loaded back to Rhino by the model coordinates. After the installation of the Arkio plugin, the user can locally export the existing 3D view to Arkio by clicking the "Export to Arkio" button. During the transfer process, the user needs to enter a value between 0.0-1.0 as the detail level in the Rhino console. A better performance is offered by starting with a smaller scene and turning off the layers that the user doesn't want and hiding the geometries they do not use. As

in Revit, in Rhino Cloud-based transfer, the Rhino plugin and devices must first join the same cloud group. By opening the ArkioRhinoPlugin toolbar in Rhino, the user can select the relevant file and import the model to Rhino in Mesh format. Also, to convert Arkio geometry into editable Rhino geometry, integration with Autodesk Revit can be used to convert the Arkio geometry into Revit families and then export to DWG format.

Arkio also includes a SketchUp plugin. This plugin, which allows the models in 2019-2023 versions to be imported into Arkio, allows the user to access the imported models on the same computer from the Create/Import menu. These models can be shared by the user with other devices and can also be used during meetings. To provide cloud-based transfer from SketchUp to Arkio, the ZIP file of the model is uploaded from Documents/Arkio/Import/SketchUp folder to the Arkio Cloud group. These models are automatically downloaded by the devices connected to the same Cloud group and become ready for the user to use in the scene. In order not to include unnecessary geometries in the model, the user should turn off the layers and optimize the surface orientation before transfer. Since SketchUp models contain two-sided surfaces, it is important to orient the white outer surfaces correctly. Arkio's Sketchup plugins are currently only available on Windows, and to use the SketchUp model on Mac, it must be exported in OBJ or GLB format and uploaded to Arkio Cloud.

In addition to import/export features from different CAD software, 3D scanning applications such as Arkio, Scaniverse, Polycam support the import of LIDAR scans on the user's iOS devices. When the user completes the scan, he/she can examine the results and export the models he/she has created in OBJ and GLB format. In order to do this, the user must first open a menu after saving the file and, if Arkio is installed, export to Arkio. After completing the export, the user needs to load the models from the import drawer and place them on the scene by switching to the Arkio application. The user who places the models on the scene can use the default settings or lock the object to the origin. As with other sharing methods, for sharing LIDAR scans, the user needs to start a meeting and make it accessible to other users. In addition, the user can share the model with multiple devices by uploading it to the Arkio Cloud portal. By using these scans in VR environment, users can create new shapes on them. In

addition, plugins can be used to transfer these scans to other CAD applications supported by Arkio.

4.3. Collaboration in Arkio

Arkio platform offers a collaborative design feature that allows users to design together with many users and edit the usual design. In the free plan of Arkio, collaborative design can be carried out with a maximum of 4 users and for a limited time of up to 20 minutes, while in the Pro plan, meetings with a maximum of 24 users can be arranged. With the Pro plan, it becomes possible to co-produce by assigning the role of editor to users. Thanks to the use of multiple devices together and the increase in user diversity, it creates a shared virtual production environment. It enables multiple users to contribute and build together by getting real-time ideas from each other. The ability to present various perspectives at the same time and to shape production within the framework of these ideas makes an important contribution to the design process.

In order to make collaborative production in Arkio, it is necessary to log in to the meeting from the meeting's panel on the bottom tab of the main menu. In the meeting panel, a meeting can be started with a username, room name, and an optional password so that other users can be included in that scene. The first user to enter the meeting is directly assigned as the host. In case there is another room with the same credentials, the user will join the existing room. During the meeting, clicking the microphone icon next to the user's name will allow the user to mute or unmute themselves. In addition, the user can switch between microphones on their device from the settings menu. If the user wants to bring the users in the meeting to a specific location, users can do so by clicking on the other tab next to the user's name. The host who started the meeting should select the pencil icon next to the user's name on the meeting panel so that other users can make edits. In this way, other users can also make changes to the design and create new productions. The meeting within the platform ends when the last user logs out. However, the main users who attended the meeting can access and edit the models shared during the meeting. These features are the same in the VR headsets as in other devices such as PC, tablet, and mobile.

The figures below provide examples of the collaboration realized on the Arkio platform through different devices within the same project. In this example of collaboration, each user uses different devices (tablet (see Figure 4.10), personal computer (see Figure 4.11) and VR headset (see Figure 4.12)) to simultaneously produce in a virtual environment. While a participant using a tablet contributes to the design process through a mobile interface, another participant works on a computer, and the third participant enters the space with a VR headset and guides the design with a three-dimensional experience. This diversity of devices, combined with the multi-user support offered by Arkio, demonstrates how a collaborative design process can be carried out on the same project by utilizing different perspectives and forms of interaction.

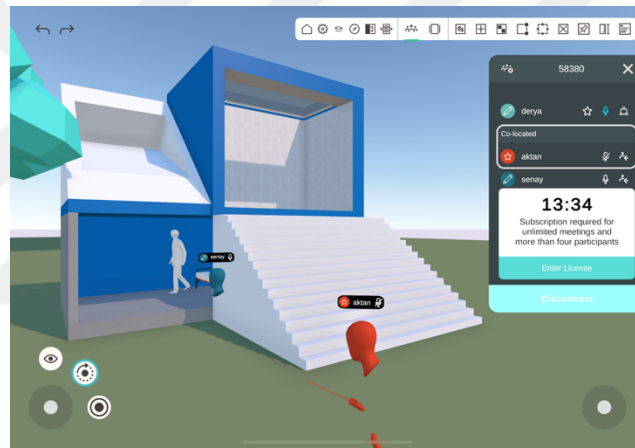


Figure 4.10: A tablet view of collaboration in Arkio (screenshot taken by author)

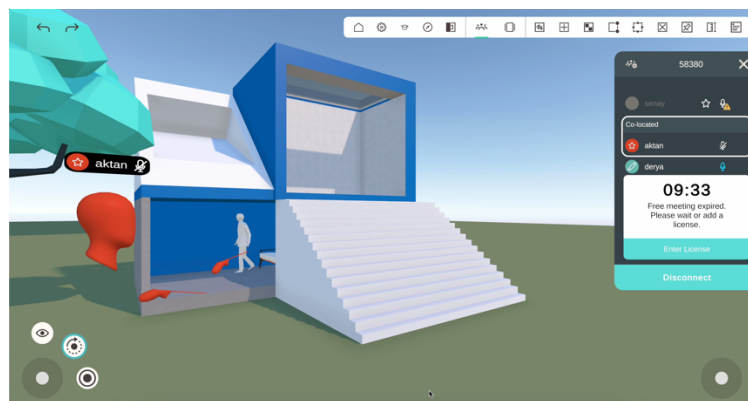


Figure 4.11: A personal computer view of collaboration in Arkio (screenshot taken by author)



Figure 4.12: A virtual reality headset view of collaboration in Arkio (screenshot taken by author)

Since the launch of the beta version, Arkio has released many updates to fix any shortcomings in the system and has taken important steps to improve the platform continuously. These updates are shared in the support section of Arkio's official website so that users are regularly informed about new features and developments.

For example, the ability to export to the Revit plugin was integrated into the platform in v0.6.4, while Less memory usage when exporting large Revit projects was improved in v0.8.0. The import of LiDAR scan data for third-party scanning applications was introduced in v1.2.0, while the ability to upload Revit and Rhino plugins directly to the Arkio cloud was made possible in v1.5.0 (Arkio, 2024).

In the latest release of Arkio, v1.9.1 (checked on November 2, 2024), several important improvements have been made to enhance the user experience and functionality. In this release, support for the Logitech MX INK stylus pen has been improved to provide users with a more precise and fluid drawing experience. In addition, an issue with importing Unity-sourced files has been fixed, resulting in a smoother file integration process. Improvements were made to increase the performance of the platform, especially in meetings with more than eight users. In addition, a button has been added in the Apple App Store that allows users to restore purchases. Finally, several minor bug fixes have been made with the release, aiming to improve overall system stability (Hanegraaf, Release notes v1.9.1, 2024).

Arkio responds to the expectations and needs of users by basing the development process on user feedback. When the release notes are analyzed, it is seen that it aims to solve the problems experienced in production and sharing processes in VR and other devices as well as performance improvements. In addition, users' feedback through the Community directly contributes to the platform's development by sharing the problems they encounter and the aspects that need improvement. This interactive development process demonstrates that Arkio takes a user-centered approach and is committed to being a continuously innovative platform.





5. ARKIO IN ARCHITECTURAL EDUCATION

Architectural education is a multifaceted process that aims to enable students to gain competence in different disciplines and to develop critical thinking and creative design skills. In this education, students acquire both technical knowledge and a critical perspective, as well as the ability to analyze historical, cultural and social contexts. Architecture students, especially in the first year, enter a challenging period in which they move from a rote-based traditional education system to a practical and experience-based learning model; during this period, they face various challenges due to their different experiences and backgrounds, expectations and motivation levels. (Acar, 2008). While developing their creative thinking and problem-solving skills in this new learning environment, first year students are introduced to a different form of knowledge production through the experiential processes offered by environments such as the architecture studio. In this context, the processes of producing, discussing, experiencing, and transferring knowledge are intertwined in architectural education, especially in the studio and workshop environment.

In the first year of architectural education, it is aimed for students to represent design knowledge with external visual-spatial tools on the one hand, and to build an internal and intellectual knowledge base on the other. This process of representing space allows students to develop both their conceptual thinking skills and their abstraction and analysis abilities (Acar, Acar, & Ünver, A Research On the Relationship Between Problem-Solving Appraisal, Attention, and Visuospatial Skills of First-Year Architecture Students, 2021). This period of architectural design education is considered a problematic process for students in many respects, as they are expected to quickly acquire skills and competence in a new field of knowledge. In this process, utilizing fields such as history, culture, theory, expression, and technology enables students to create an intellectually equipped infrastructure, not only technically but also intellectually. In this context, architecture students not only design spaces but also develop a critical and multi-layered perspective that questions these spaces' social and cultural meanings.

In the first year, students receive basic design education to understand the complex nature of design. The design process is treated as an undefined problem; students are expected to develop and critically evaluate creative solutions within this uncertainty. The basic design studio in architectural education is a unique learning environment where students experience the processes of discovering, producing, experimenting and criticizing knowledge. This environment has a structure that ensures that architectural education does not only provide theoretical knowledge, but also enables the student to assimilate this knowledge by actively applying it. Here, students encounter design problems, develop their solution proposals and have the opportunity to evaluate these proposals from various perspectives. Thus, architectural thinking, problem-solving, and creative design processes develop together through concrete projects.

One of the most important functions of the basic design studio is to strengthen students' critical thinking skills and give them the ability to defend their projects. During studio work, the student puts forward his/her ideas, interacts with peers and instructors, revises his/her design proposals and improves them in the light of the feedback he/she receives. The criticism and jury evaluations made during this process allow the student to see the deficiencies in their projects or the aspects that need to be improved. This evaluation environment enables the student to look at his/her own design practice with a critical eye and to gain the skills to defend and develop his/her design. This process exposes the student to a dynamic epistemic culture that is constantly changing due to the nature of design. Here students not only acquire new knowledge, but also reproduce it through their own creative experiences. Producing the knowledge of design through design, these students develop in a learning culture that feeds on different aspects such as imagination, criticism, collaboration and self-expression.

The basic design studio immerses students in open-ended problems, often with no single right answer. Such problems reveal the student's capacity for creative thinking and the ability to generate original solutions. These problems, which are ambiguous and have multifaceted solutions, do not limit the student to a single solution, but lead them to approach from different perspectives. In this process, students have a creative experience that both stimulates imagination and strengthens critical thinking. Discussions in the studio provide a platform for the free expression of different ideas and approaches, and enable students to look at their projects from new perspectives.

In the studio environment, students also gain the ability to express their designs through effective communication techniques. In this process, the student presents his/her project using visual-spatial means of expression, receives criticism and encounters different mindsets. This not only enables the student to develop their own designs, but also to learn different design languages, methods of representation and means of communication. Offering the opportunity to put theoretical knowledge into practice, the studio involves the student in a multidimensional process of knowledge production.

According to Dewey's pragmatist understanding of education, knowledge gains meaning only through experience. In this context, the importance of practical experiences in architectural education comes to the fore. The designs made by the student in the studio allow him/her to apply abstract concepts in a concrete reality. In line with Dewey's understanding of “learning by doing”, the student produces knowledge through his/her own experiences and this knowledge develops him/her both in approaching design problems and in social adaptation (Dewey, 2008)

In addition, Schön's notion of “reflective practice” points to the importance of creating a “community of practice” in which students interact with their peers and share information and feedback. Within this community, students come together for common purposes, learn from each other's experiences and develop themselves in a continuous interaction. Such a community strengthens the student's sense of belonging and deepens the learning process (Schön, 2017)

As a result, in the basic design studio, students generally go through a process of deepening their design knowledge through “learning by doing” and “peer learning”. In line with Dewey's understanding of “learning by doing”, students could experience abstract concepts through concrete projects by combining theory and practice in the studio. In this process, they confront design problems, generate knowledge through their own experiences, and develop their creativity. Learning by doing not only helps students to internalize knowledge but also to strengthen their critical thinking, analysis, and evaluation skills. Peer learning also plays a critical role in this process. By sharing information and receiving feedback, students can feed on different perspectives and re-evaluate their design with a critical eye. Schön's concept of “community of practice”

emphasizes the impact of working with peers in the studio on the learning process; within this community, students have the opportunity to learn from each other while developing a sense of belonging, and their creative processes are supported. As a result, learning by doing and peer learning stand out as key elements in architectural education that support understanding the multi-layered nature of design and developing a critical and creative approach. These elements allow students to develop not only design knowledge but also an intellectual and social perspective.

In summary, the use of Arkio in the basic design studio has the potential to add an innovative dimension to architectural education by supporting the principles of experiential and peer-based learning. This digital tool can contribute to the development of students' spatial awareness, critical thinking and collaboration skills in a digital environment. Arkio's 3D modeling and virtual interaction features can enable students to visualize abstract design ideas in real time, experience various spatial solutions, and conduct a more comprehensive analysis of designs. Furthermore, collaborative work in a digital environment can enable students to communicate more easily with each other, exchange ideas and approach their projects from different perspectives.

These possibilities show that the application of Arkio in the studio environment can contribute to architectural students' deeper understanding of the design process and more effective development of critical thinking skills in this process. This digital learning environment provided by Arkio can encourage students to draw on different perspectives, allowing them to rethink their designs more critically and creatively. Thus, the use of Arkio in the basic design studio has the potential to support students not only in the acquisition of traditional design knowledge but also in developing an intellectual and social perspective using modern digital tools.

5.1. Experience of First-Year Students with Arkio

TOBB University of Economics and Technology (TOBB ETU) Faculty of Architecture aims to provide students with a contemporary architectural education by emphasizing the integration of technology into the design process (Acar, Koç, Bancı, & Abbas). In this context, TOBB ETU encourages the use of advanced technologies such as VR in education and offers VR experience to its students with Oculus Quest 2 headsets. The VR devices within the faculty are actively used especially in the first-year basic design studios and are also included in other architecture courses when needed. Thanks to this technology, students could construct and experience spaces in virtual environments and test their design ideas.

Architectural education has been intertwined with technological developments throughout history, as the development of technology has significantly influenced and shaped design parameters. Today, this relationship has become even more complex and integrated, and the tools offered by technology have become an essential component of architectural education. The first-year basic design studio at TOBB ETU is conducted with an approach that emphasizes ways of thinking and producing with technology as an integral part of the architectural design process (Acar, Koç, Bancı, & Abbas). Accordingly, an educational model encourages students to question the interaction between technology and space, design, and digital tools.

Architectural education at TOBB ETU aims to provide students with a space for free thinking and creative exploration. Within this framework, students are encouraged to discover their own methods, styles and tools in the basic design studios and are supported to produce original solutions. During the education process, students are given the freedom to determine the tools, media, and methods they will use and are given the opportunity to submit their own assignment proposals. Thus, students experience that architecture is not only a discipline that must be practiced within the framework of certain rules, but also that their personal perspectives and preferred technologies can find a place in the design process. In addition, collaboration plays an important role in the education model. The assignments and projects carried out in the basic design studios encourage students to work together to generate, share, and collaborate ideas. In this way, by utilizing the opportunities offered by technologies

such as VR headsets, students have the opportunity to get to know each other's points of view and experience different techniques through joint projects (Acar, Koç, Bancı, & Abbas).

In this context, within the scope of basic design education, students have the opportunity to make various productions and experiments on different platforms using VR headsets. Among the students who experience different platforms with VR headsets, the use of Arkio is especially encouraged. The main reason for this encouragement is that Arkio not only enables direct production in VR, but also works in harmony with other devices such as tablets and computers. In this way, students can re-examine the designs they have developed on different devices by transferring them to the VR environment and enrich their production processes with multi-platform support.

In the Basic Design Studio, students utilize Microsoft OneNote as a collaborative platform to share their design processes, feedback, and reflections. Each student is provided with a dedicated OneNote folder where they document their progress, including the challenges they face during the design process and the resources that support them in overcoming these challenges. This documentation enables both students and instructors to track and analyze their development over time.

Within this platform, students are encouraged to express themselves freely, incorporating visuals and comments about tools like Arkio and similar applications. These contributions are organized under dedicated sections, such as the Designer Chest and Shelter folders, creating a comprehensive archive that captures the evolution of their design process. By integrating these reflections, OneNote fosters a space where students not only engage with the content taught in class but also create a resource for themselves and instructors to revisit and evaluate. This structured approach not only supports individual growth but also facilitates a richer dialogue around design methodologies.

As part of the studio experience, students are encouraged to explore various platforms equally, allowing them to identify the tools that best align with their personal design methods. This approach empowers students to make choices based on their own

experiences, leading to valuable insights about their preferences. For instance, while the pull-push system operates similarly in both Arkio and SketchUp, some students prefer Arkio, whereas others opt for SketchUp. Understanding these choices provides significant insights into the reasons behind their platform preferences.

The integration of Microsoft OneNote enhances this exploration by serving as a platform for detailed documentation of the design process. Students record their reflections, including why they select or avoid certain tools, and how they utilize platforms like Arkio in VR for design and collaboration. This documentation highlights the benefits and applications of Arkio in architectural education, showcasing its potential as a collaborative and interactive design tool. Such insights contribute to a deeper understanding of its role in shaping architectural pedagogy. Below are examples of student reflections showcasing their experiences with Arkio.

One student stated the following about using Arkio in the Labirent or project: *“I was in Arkio - virtual reality design in both groups. I was more curious because it was a field I had not experienced before. Thanks to this curiosity, I realized there were features other than the cube while examining the program before I had a clear design. I think one of them and the most important one of the projects is the staircase. When we shared this feature with the VR group, we realized that if the design is done carefully, the result will be interesting, and we started working.”* This student comment shows that the Arkio platform offered a new experience for the student and that the student developed a strong curiosity towards designing in a VR environment. The student's encounter with a space he had not experienced before encouraged the process of exploring the features of the platform. In particular, recognizing the “staircase” feature from Arkio's various ready-made objects enabled him to make an original contribution to the project (see Figure 5.1).

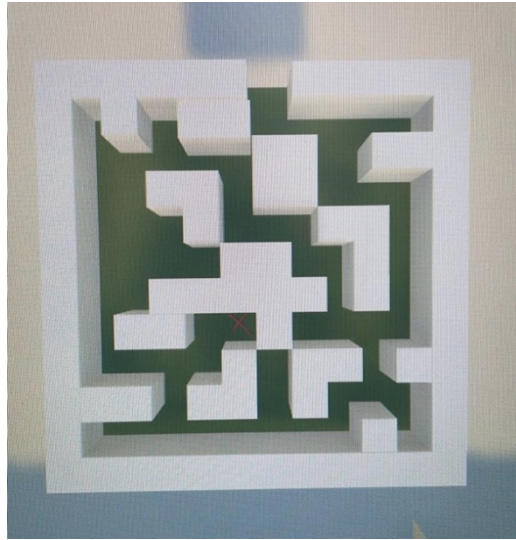


Figure 5.1: The student's "Labirent" study in Arkio

Another student shared his experience of using Arkio in the Manifold Garden project as follows: *"First I tried a 1/1 scale model from the Arkio platform, and I was doing very well, and the practice was suitable for the modeling I was going to do. But then I realized that this application did not have features such as making objects as a single solid or selecting and copying them. So after I made MG1, I would rotate the same thing 90 degrees and create other MGs, which would be a huge waste of time. So I thought of Tinkercad. I compared this platform with Arkio, and it was much easier to take measurements and do copy-paste operations, so I continued with this application and experimented."*

In this OneNote sharing, the student states that Arkio offers limited features in terms of certain modeling functionalities. The student made a successful start with 1:1 scale modeling on the Arkio platform and found the platform adequate for modeling in the first phase. However, student later realized that Arkio lacked basic features such as converting objects into a single solid object or selecting and copying objects. This led the student to think that repetitive modeling processes could be a serious waste of time. In response, the student switched to the Tinkercad platform and compared it with Arkio and observed that Tinkercad offered easier operations such as measuring, copying and pasting. As a result, the student preferred Tinkercad and continued his experiments on this platform. This suggests that Arkio may be limited in terms of some basic modeling

tools and users may look for the features they need in other platforms (see Figure 5.2, 5.3).

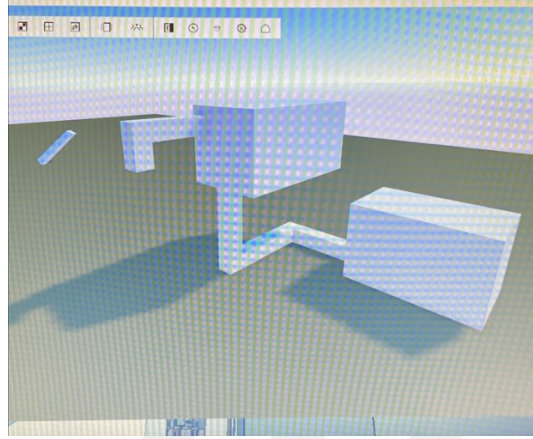


Figure 5.2: The student's “Manifold Garden” study in Arkio

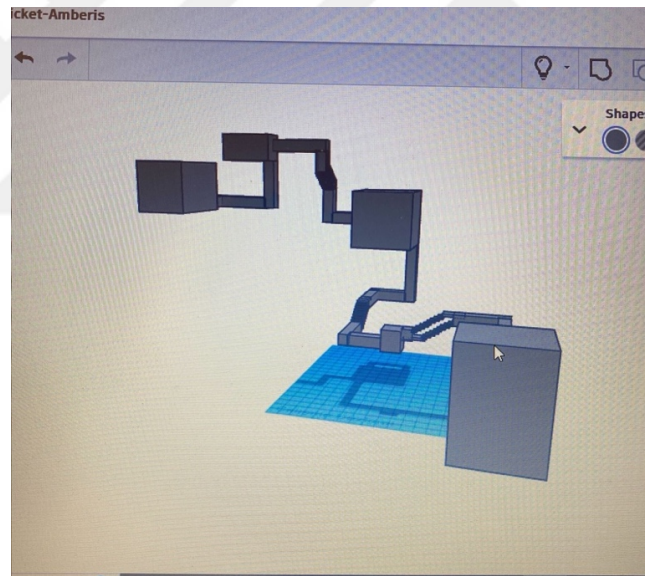


Figure 5.3: The student's “Manifold Garden” study in another platform

Another student shares his experiences regarding the Piriñ Han project as follows:
“When I stood in the courtyard of the Piriñ Han and looked at the walls surrounding the courtyard, I noticed that there was a height difference between the walls. I made modeling using Arkio to show the height difference of the walls that form the boundaries of the courtyard. Since I could not find the dimensions of the Piriñ Han, I made my modeling without measurements. In order not to forget that there is a height difference and to grasp the difference, I aimed to show the difference by drawing a

sketch during the time I was in Piriñ Han. While modeling in Arkio, I started with my sketch and observations.” This feedback shows that Arkio allows the user to transfer spatial elements observed in the real world to the virtual environment. The fact that the student was able to express the height differences he noticed in the physical environment with a virtual model reveals that Arkio allows users to integrate spatial features and proportions into the virtual environment (see Figure 5.4).

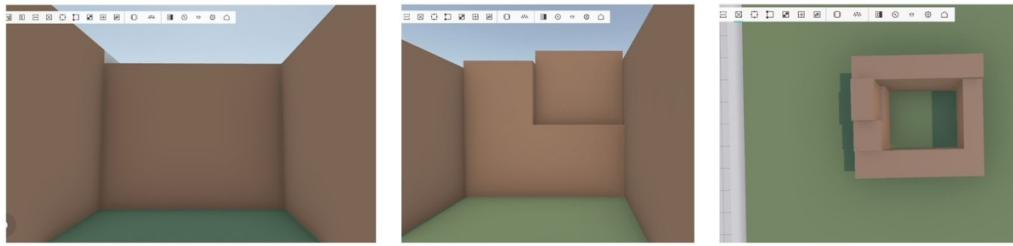


Figure 5.4: The student's “Piriñ Han” study in Arkio

Another student states the following about the design process: “...*When we started from the beginning, I worked on how I could make improvements by manipulating the model. I started to shape my model like dough by using Blender and SketchUp simultaneously. I was satisfied with the outlines of the mass, but not with the surfaces. I tried to soften the surfaces. After some work on it, I was happy with my design and I transferred my model to Arkio and used VR headsets to experience it better, but I was still not completely happy with my surfaces. The asymmetrical curves created by different elevations felt worse inside the space than outside. I couldn't use different geometries inside and outside the space because the surfaces with different geometries created non-functional gaps. So, I went back to the beginning and started to rethink. I reviewed what was asked of me and started to draw sketches in line with these items.*”

This student feedback highlights the creative use of modeling tools in the design process and the evaluation of the detailing of the design. Working on the model with programs such as Blender and SketchUp, the student was generally satisfied with the main mass design but was not fully satisfied with the surface features. In order to increase the spatial experience of the model, the student transferred it to the Arkio platform and continued to examine it with VR headsets and observed that the

asymmetrical curves on the surfaces negatively affected the internal and external perception of the space.

This experience led the student to re-evaluate the functionality of the design and to analyze the effect of surface features on the spatial experience. Recognizing the potential of different surface geometries to create non-functional voids, he reconsidered the design and began to explore alternative solutions through sketches, focusing on the initial requirements. This reveals that Arkio enriched the student's design experience and contributed to the development of a critical perspective on the model (see Figure 5.5).

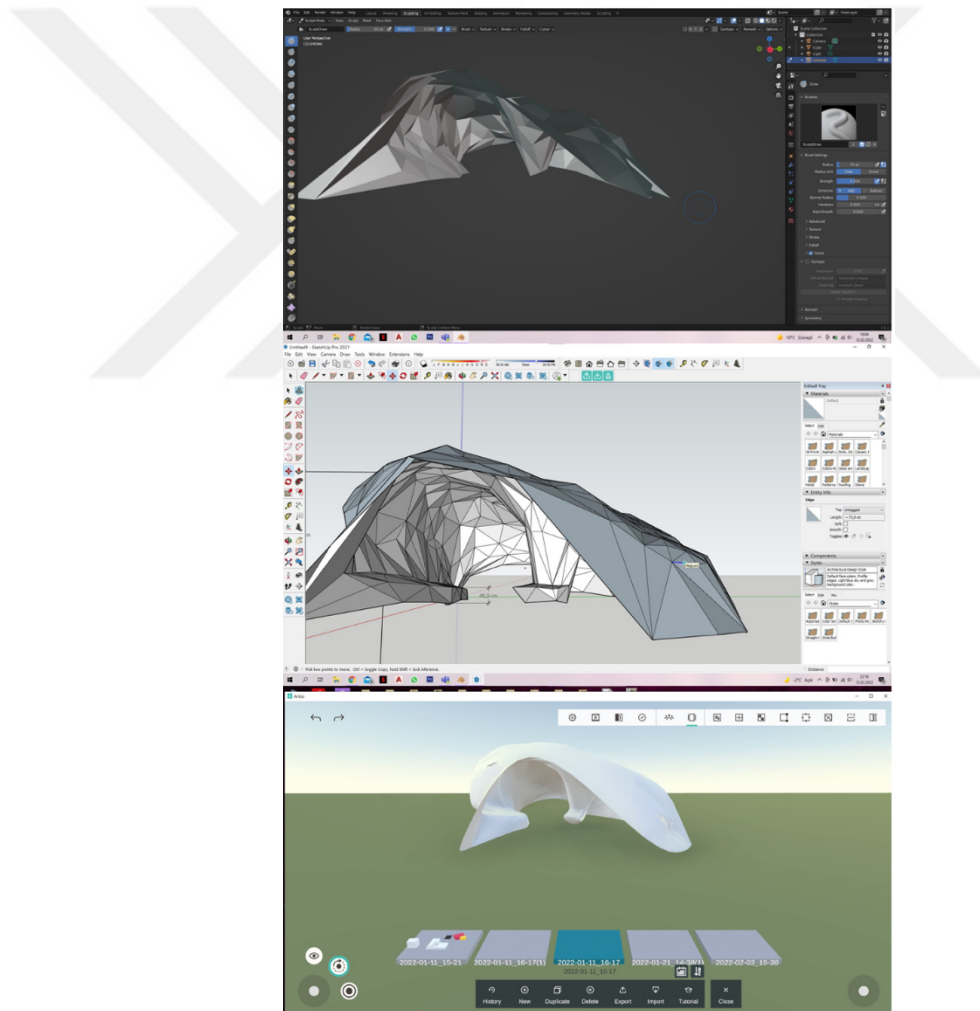


Figure 5.5: Blender, SketchUp and Arkio productions during the student's design process

Another student mentioned their experience with using Arkio on a previous project, saying, “...While I didn’t have any issues with other programs, the PC version of Arkio

was limited in object translation, and I couldn't achieve the first-person view I wanted. By Friday, I plan to prepare first-person-view videos in both Arkio and SketchUp, along with lighting experiment videos on the realism of the object using different software.” The student wrote this feedback while continuing their study: “...All created volumes and objects are ready to import into Arkio, but I haven't yet resolved my issue with Arkio. Resolving this issue will be my priority.”

From the student's feedback, it can be concluded that some of Arkio's limitations may affect the user experience, especially in object translation and obtaining a first-person view. The student's first comment states that Arkio is limited in object manipulation and cannot provide a first-person view as desired. Such limitations suggest that some of Arkio's functions may not fully meet the user's expectations, whereas other programs may work better. In the second feedback of the student, it is emphasized that there was a problem with the volumes and objects transferred to Arkio and that solving this problem was the priority part of his work. This suggests that Arkio may need some technical improvements in data transfer and integration processes (see Figure 5.6).

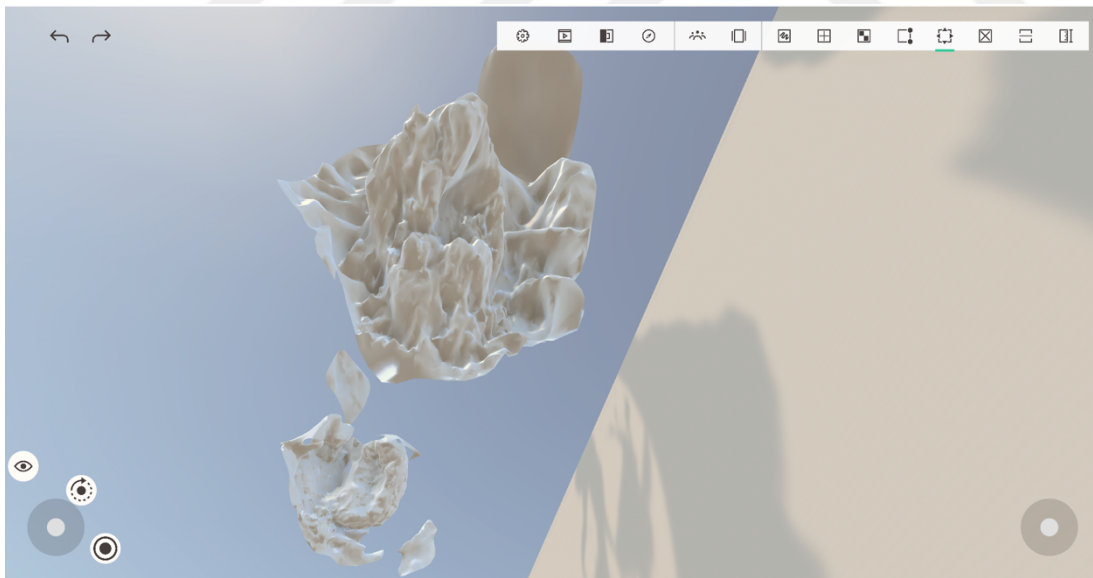


Figure 5.6: The student's study in Arkio

Another student shared the visuals of their work without specifying the software used for the initial modeling, stating that the model was later imported into Arkio, where further refinements were made using the desktop version of the platform (see Figure 5.7).

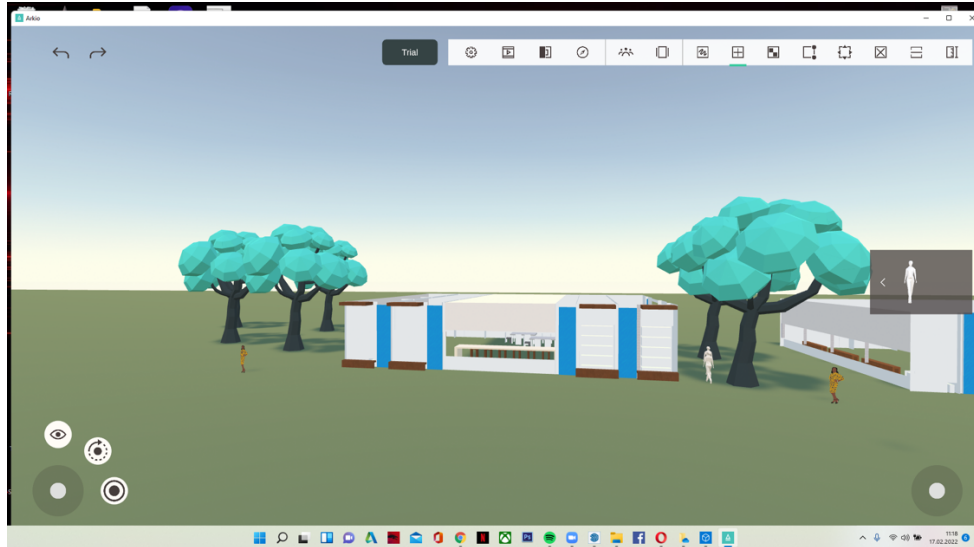


Figure 5.7: A study of the student's experience in the desktop version of Arkio

Upon reviewing this feedback, it is evident that students employed Arkio in various projects and through diverse approaches. While some students chose to initially model their designs in CAD software and subsequently import them into Arkio to experience their work through VR, others preferred to leverage Arkio's PC version to continue their modeling process directly within the platform. This variation in approach appears to stem from factors such as the limited availability of VR headsets within the institution, as well as a preference among some students for computer-based production.

One student's feedback on OneNote highlights their experience with Arkio: *"Additionally, I modeled a mass in Arkio. I wondered if we could use the presence of shadows when placing it in the mine. I need to model in Arkio for Mirny, but I faced some challenges."* The student's reflection indicates difficulties encountered while modeling the mass in Arkio. Upon reviewing subsequent work, it is observed that the student continued their production in SketchUp after facing challenges with Arkio. However, the student did not specify the reasons for their difficulties, leaving the underlying cause unaddressed (see Figure 5.8).

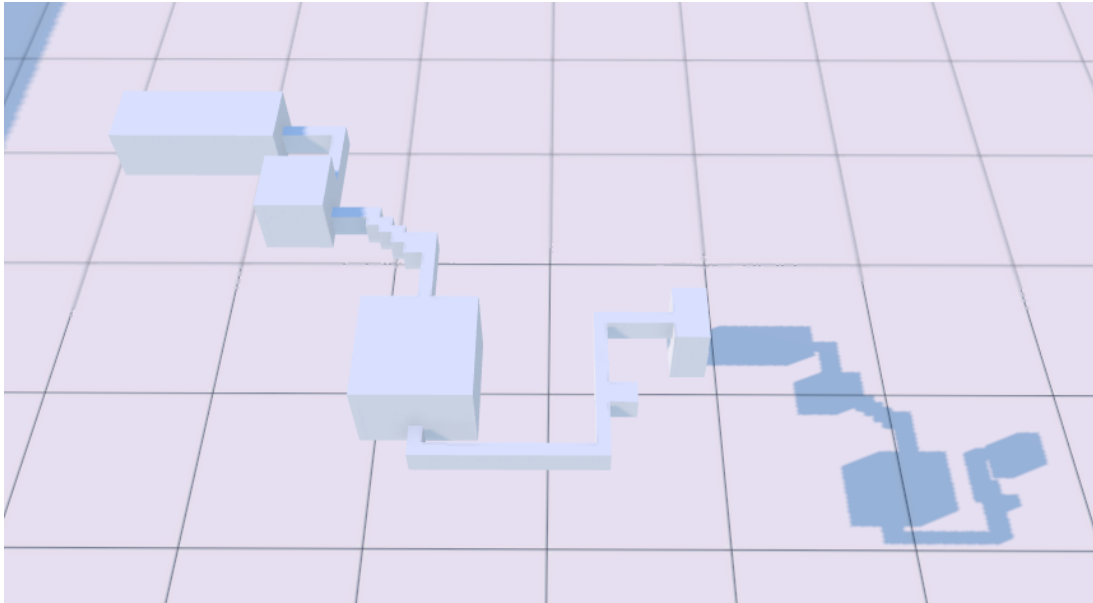


Figure 5.8: The student's Mirny Project in Arkio

Additionally, another student noted, "At this point, I wanted to use my VR headset, but despite my attempts, I could not transfer my model to Arkio. Therefore, I started exploring alternatives and discovered that when you upload your model to Autodesk Drive, it has a mode that allows you to navigate within the model."

This reflection highlights the student's proactive approach to overcoming technical challenges by seeking alternative solutions. The inability to transfer the model to Arkio led them to explore Autodesk Drive, where they discovered a new functionality that supports immersive exploration within the model. This example underscores the importance of providing robust support and clear documentation for VR tools like Arkio to ensure seamless integration into design workflows. While the student's initiative in finding an alternative is commendable, such challenges may discourage users from fully engaging with the intended platform. To enhance user experience and retention, platforms like Arkio could benefit from improving the transfer process and offering detailed tutorials or troubleshooting resources.

Another student provided a series of feedback statements: *"We could try using Arkio to explain the cinema performance,"* followed by, *"If Arkio doesn't work, we can demonstrate it using a model."* The student further noted, *"I couldn't produce the masses correctly, nor did I know how to create the cinema space within them."*

Additionally, they remarked, *"When I tried Arkio, it felt challenging to me."* These reflections highlight the student's initial interest in utilizing Arkio for a creative design purpose, such as representing a cinema performance. However, their feedback indicates technical and conceptual challenges, including difficulties in mass production and spatial creation within Arkio. The final remark, describing the platform as "challenging," suggests that these obstacles may have discouraged further engagement with the tool (see Figure 5.9).

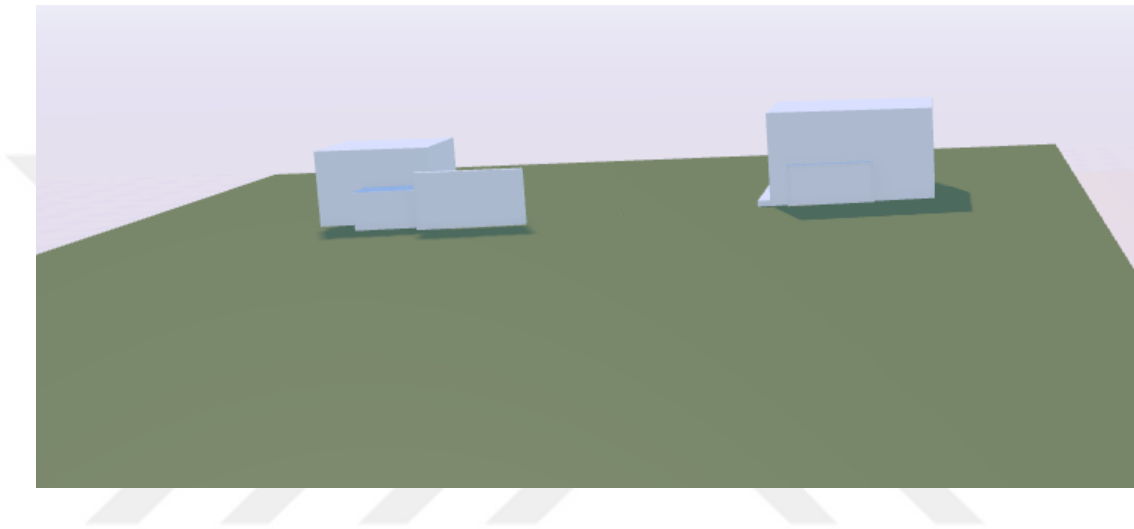


Figure 5.9: The student's study in Arkio

Another student provided the following feedback: *"The structure is actually cube-shaped. It looks quite simple and plain, but it has strange and, in my opinion, very interesting details. That's why it is so captivating. It was also enjoyable to view it from the inside. Maybe I'll model it in Arkio later."* While the student expressed enthusiasm for the structure's intriguing details and even considered modeling it in Arkio, an examination of their design process reveals that they did not continue working with Arkio. This discrepancy between the student's initial intent and subsequent actions highlights a potential gap in motivation, technical capability, or accessibility that may have influenced their decision.

This observation suggests that while students may find certain design tools inspiring, their continued engagement often depends on the ease of use, alignment with their design goals, and the availability of support resources. The feedback also implies that Arkio's potential as a design tool was recognized but not fully realized in this case.

Another student shared the following reflection regarding their design process: *"I converted all my plaster casts into 3D models using Recap, but I couldn't transfer any of them to SketchUp, which prevented me from making modifications. Instead, I uploaded my model to Arkio, where I examined it and attempted to make changes."*

This feedback illustrates the student's attempt to integrate physical models into the digital environment using 3D scanning technology via Recap. While the student was unable to transfer the models to SketchUp, they successfully utilized Arkio to examine and modify their designs. This process demonstrates how Arkio can be employed as an alternative platform when challenges arise with other software. The student's workflow reflects the potential for adapting tools to address specific needs in the design process (see Figure 5.10).

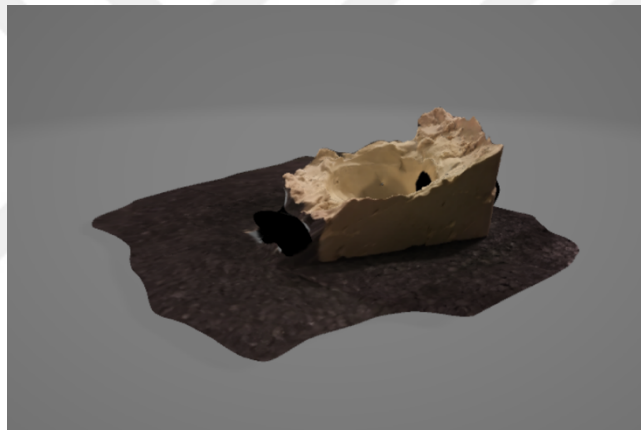


Figure 5.10: The student's Recap model

Additionally, while some students expressed enthusiasm about creating directly within Arkio, others reported that the platform did not fully meet their expectations in terms of functionality. The student reflections recorded in OneNote serve as a valuable resource for assessing Arkio's usability and effectiveness from the user's perspective. These diverse experiences provide insightful data on Arkio's capability to address different design processes and requirements within an educational setting.

5.2. Applications of Use Cases of Arkio in Architecture

Arkio has a wide range of uses in architectural education and professional practice, demonstrating its adaptability and impact in various disciplines. The case studies on

Arkio's official page showcase in detail how the platform is used in different architectural studios and educational institutions. They demonstrate how Arkio has transformed the design process and enabled teams and students to develop their projects more interactively.

One notable example of how Arkio is being integrated into education took place at the University of Nottingham. Second-year Product Design and Manufacturing students had the opportunity to learn and practice advanced VR software such as Arkio using a VR classroom. Located in the University's Engineering Science and Learning Center, this VR classroom facilitated remote viewing and communication, providing an interactive environment between lecturers and students. Initiated by Simon Harrison, this VR studio was initially set up with seven headsets and has grown into one of the largest VR labs in the world. This transformation has renewed the learning process by giving students access to cutting-edge software such as Arkio (University of Nottingham, 2024).

In addition, Manchester Metropolitan University's Center for Learning Enhancement and Educational Development uses Arkio as an innovative tool to support the integration of digital technologies in education. They use Arkio, a collaborative tool that uses mixed reality for concept design at the architectural or game art level. It also aims to modernize educational processes by enabling educators to adapt to new technologies (Ali & Reid, 2024).

Another case in point is Dr. Kevin J. Jones' project as an “Extended Reality Fellow” at Indiana University Columbus. Dr. Jones integrates XR technologies into the IU Columbus MBA program, enabling students to develop innovative solutions to improve the performance of organizations. In this process, XR tools such as Arkio enable students to create virtual and augmented reality experiences, and students explore their designs in VR using Meta Quest 2 titles. These experiences enhance students' professional skills by developing critical thinking, creative problem solving and VR competencies (Indiana University Indianapolis, n.d.).

Architect and designer Gael Ranc uses technology, especially augmented reality AR and VR, to enhance the perception of space and make design processes more

interactive. Through a method he calls “hyper-contextualization”, Ranc combines the physical and virtual worlds to design spaces with a deeper context. This method aims to expand the perception of space by providing a stronger context for the design process. At the same time, it contributes to architectural education, exploring how future generations will use technology in their design processes. Gael Ranc has used Arkio as an effective tool to strengthen context in architectural design. Initially used to design spaces in VR, Arkio was supplemented with techniques such as photogrammetry to enable Ranc to create contextualized designs. Later, Ranc linked his designs to a deeper context with augmented reality technologies and aimed to influence the perception of space with virtual elements through the concept of hyper-contextualization. This approach strengthens the relationship between context and space in the design process, allowing the design to be deeper and more meaningful (Morgan, 2024).

Similarly, Arkio played a key role in the Volterra-Detroit Foundation's International Digital Preservation Workshop in Volterra, Italy. The workshop aimed to digitally reconstruct historical and cultural heritage, examine it in a spatial context and experience it at full scale. In this context, Arkio enabled the digital reconstruction of historical monuments such as Porta all'Arco and Teatro Romano, aligning them with physical spaces. This process helped to analyze spatial relationships and deepen the perception of historical buildings (see Figure 5.11). Arkio was used as an interactive collaboration and educational tool for the participants, as well as supporting historic preservationists and AEC professionals by providing them with the necessary data for decision-making. This application demonstrates the potential of technology in cultural heritage conservation and education (Campbell, 2024).

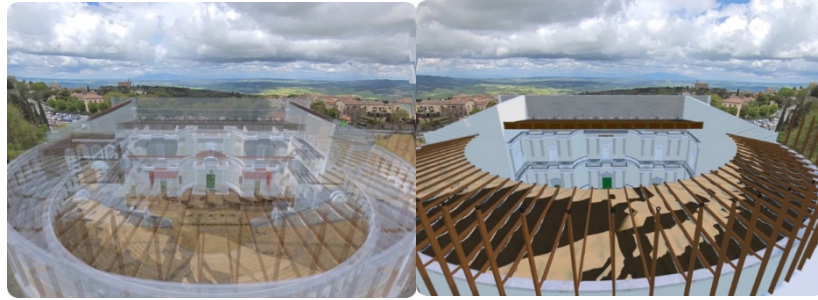


Figure 5.11: Digital Preservation in Volterra. Accessed December 23, 2024. Retrieved from <https://www.arkio.is/blog/volterra/>

The benefits of Arkio in professional practice have also been observed in the projects carried out by RISE Architecture. RISE Architecture uses the Arkio platform to improve design processes and offer innovative solutions to its clients. By integrating Revit models into Arkio and conducting detailed examinations in VR environment, the team is able to visualize the designs in real scale and detect possible errors at early stages. Arkio is especially useful for renting pre-construction spaces and enabling investors to experience projects at scale. By enabling models to be reviewed from different perspectives in meetings, Arkio has strengthened collaboration, accelerated RISE's decision-making processes, reduced communication problems and increased design development efficiency. RISE manager Jeff Akerman states that Arkio revolutionized workflows. This example highlights Arkio's effectiveness in professional architectural practice and its role in design processes (Hanegraaf, Case Study- RISE Architecture , 2024).

Norconsult prefers Arkio for engineering and architecture projects, especially for VR and AR projects where multi-user collaboration is needed. Arkio's ability to integrate with Revit projects and its own geometry engine provides a wide range of efficient tools from the early stages of the design process to the construction phase. This feature facilitates design creation and editing, especially in VR environments, enabling effective collaboration between users. By providing easy access to participants, Arkio makes it possible to incorporate customer and user feedback into the design process, allowing designs to be customized and avoiding surprises. Marius Jablonskis emphasizes Arkio's quick learnability and ease of scaling in the field, saying that the platform adds great value to Norconsult's projects (Hanegraaf, Norconsult case study, 2023).

In the same way, SPINN Arkitekter uses Arkio to quickly convert their designs into 3D models and bring their teams together from different locations around the same model in VR. During the pandemic, when the use of physical models was limited, they took advantage of the VR collaboration opportunities offered by Arkio. By exporting their 3D models in Archicad as .obj files, they send these models to Meta Quest 2 devices and use Arkio as a VR meeting and collaboration tool. Arkio's fast 3D model conversion allows teams from different offices to gather around the same model and discuss designs interactively (see Figure 5.12). They can also enter the model in VR and examine details such as volume, geometry and scale in a more realistic way. Thanks to these features, Arkio increases efficiency in projects and allows clients to better understand the final version of their projects (Gunnarsson, SPINN Arkitekter case study, 2023).

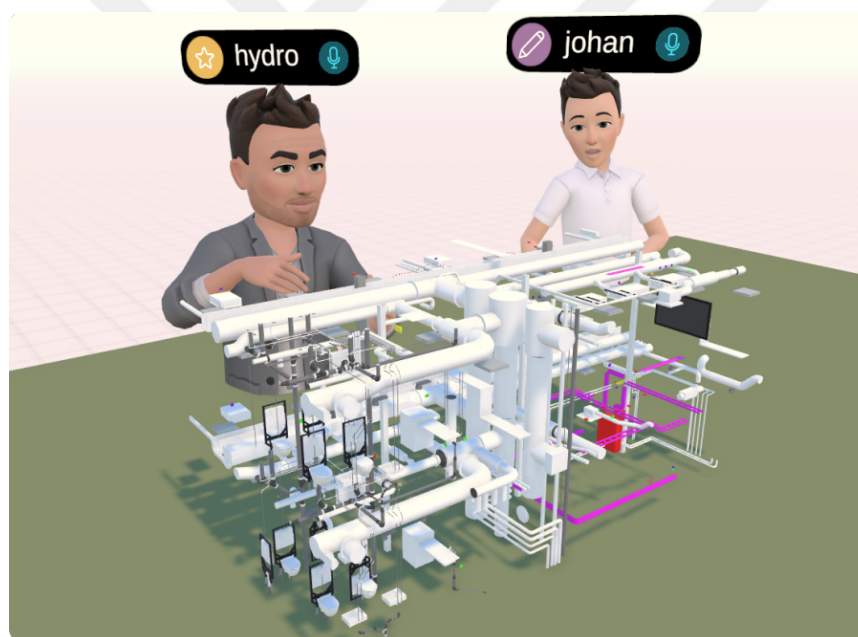


Figure 5.12: Norconsult case study. Accessed December 23, 2024. Retrieved from <https://www.arkio.is/blog/case-study-norconsult/>

Arkio's use cases have been expanded by Davey Smith Architects to streamline workflows and make them more efficient. Initially used only for visualization purposes, VR technology has been extended to a wider range of applications once it was realized that Arkio offers a powerful tool that meets modeling and production requirements. It is especially used to quickly test different massing schemes by

importing site geometry from Archicad. Arkio's modeling functionalities enable more detailed sketches to be created and the highlights of specific projects to be highlighted in planning reports. Furthermore, Arkio's meeting features make internal collaboration and presentations more efficient, and its integration into the project development process is particularly useful during the feasibility and research phases. A massing model can be quickly created from sketches or hard-line 2D drawings from Archicad, and this process can be realized much faster thanks to Arkio. The speed and efficiency provided by Arkio helps to communicate more effectively with the client or planning authorities (Gunnarsson, Davey+Smith Architects case study, 2023).

As a result, Arkio stands out as an important tool that transforms design processes, both in education and as a platform used in various ways by architecture professionals. In education, Arkio's integration of VR and AR technologies enables students to engage more deeply and interactively in the design process. As with the University of Nottingham and Manchester Metropolitan University, Arkio provides students with innovative experiences in space design, encouraging collaboration and creative thinking. On the professional side, firms such as Norconsult, SPINN Arkitekter and Davey Smith Architects are using Arkio at every stage of design, especially in multi-user collaboration and real-time modeling, to increase efficiency and provide more effective solutions to clients. These examples show how Arkio's flexibility and ease of use play an important role both in education and in the professional practice of architecture. Thus, Arkio is being used as an important digital transformation tool not only in architectural education, but also in professional practice in the industry.

5.3. Comparison of Virtual Reality Platforms

This chapter discusses the features of VR platforms that can be used as design tools. Different platforms are analyzed in terms of the features they offer and evaluated in comparison with Arkio. During the evaluation process, data on the platforms were collected from sources such as official websites and Meta Store. This analysis aims to provide a comprehensive understanding of the platforms' contributions to design processes and architectural education.

The integration of VR into architectural education has become possible as technological advances have accelerated and VR headsets have become more affordable for users. These advances have led to the development of various VR platforms that aim to both facilitate design processes and encourage creative thinking. These platforms have gained an important place in architectural education and design practices by offering different focal points and functions according to the needs of users.

For instance, Arkio stands out with a user-friendly interface specific to architectural design and features such as CAD integration. This platform specifically supports collaborative design processes, increasing usability in both educational and professional contexts. Shapespark (see Figure 5.13) enables architects, designers and professionals to easily present their designs and create realistic visualizations for real estate marketing projects. It provides users with access through the connection and offers the opportunity to show in a virtual 3D environment. Additionally, it supports importing models from platforms such as SketchUp, 3ds Max, Revit, and many others. Within the VR environment, users can walk through spaces, and experience gravity. However, editing and modification tools within VR are limited.



Figure 5.12: The Shapespark platform in the desktop environment. Accessed December 22, 2024. Retrieved from <https://help.shapespark.com/hc/en-us/articles/360009032738--3-Bake-a-draft-version-of-the-lightmap>

OpenBrush (see Figure 5.14) and Tilt Brush provide a space for creative expression, especially for artists and designers, with free drawing and painting tools that expand the boundaries of digital art. These platforms support visual storytelling while allowing users to reflect their style in a virtual environment.



Figure 5.13 : Production within Tilt Brush. Accessed December 22, 2024. Retrieved from <https://www.roadtovr.com/tilt-brush-webxr-google/>

Fuzor offers real-time simulation and visualization for architectural and engineering projects, making technical analysis of designs and client presentations more effective. These platforms showcase the potential of VR technology in various fields, offering a wide range of tools for different creative disciplines and professional needs.

In addition, VR platforms such as Enscape (see Figure 5.15), Unreal Engine (see Figure 5.16) and Unity Reflect are widely used and effective tools, especially in the fields of architecture, interior design and spatial visualization. Key features of these platforms include advanced rendering engines and extensive customization options that allow users to realistically visualize complex design projects. In particular, these platforms target professionals with technical visualization skills and are widely preferred both in educational processes and professional applications. These platforms stand out with their high-performance hardware requirements. Advanced graphics processing technologies and the ability to provide high-resolution output cause these

tools to require powerful systems in terms of hardware. This shows that these platforms are designed for professional applications that require more technical expertise and their users generally have advanced technical knowledge.



Figure 5.15: Enscape in virtual environment. Accessed December 22, 2024. Retrieved from <https://enscape3d.com/features/architectural-virtual-reality/>

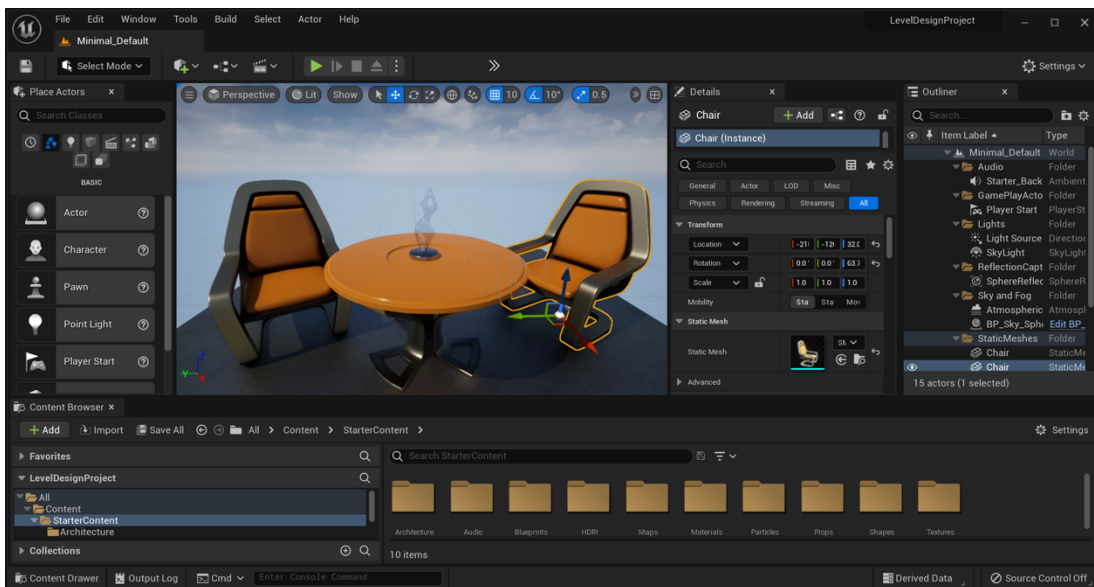


Figure 5.16: Unreal Engine's interface. Accessed December 22, 2024. Retrieved from <https://dev.epicgames.com/community/learning/tutorials/PnXj/unreal-engine-in-development-overview-of-the-unreal-editor-interface>

In this context, the possibilities offered by VR platforms are not only limited to technical visualization and individual use but also transform collaborative working processes. In particular, collaboration platforms that allow multiple users to work on projects simultaneously increase efficiency in design and development processes and facilitate the collaboration of different disciplines. These platforms have become an important tool that supports both the creative and technical aspects of designs with their features that strengthen the interaction between teams.

When VR platforms with collaboration features are analyzed, it is seen that there are many options for the needs of different target audiences. These platforms are categorized (see Table 5.1) based on features such as CAD integration, AR support and content creation directly in VR.

Table 5.1: Features of Collaborative Virtual Reality Platforms

Platform Name	Collaborative Design	Direct VR Creation	AR Support	CAD Integration	Target Audience
Arkio	+	+	+	+	Architects, Designers, Students
ARKit	+	-	+	-	Developers
CenarioVR	+	+	-	-	Training And Education
Enscape	+	-	-	+	Architects, Designers
Fuzor	+	-	-	+	AEC
Gravity Sketch	+	+	+	+	Designers, Artists
Masterpiece Studio Pro	+	+	-	-	Artists, Designers
Openbrush	+	+	-	-	Artists, Hobbyists
RealityMAX	+	-	+	-	AEC, Designers
Resolve	+	-	-	+	AEC
Retail VR	+	-	-	-	Retail, Marketing
SentioVR	+	+	-	+	Architects, Designers
Shapspark	+	-	-	+	Architects, Real Estate

Sketchfab	+	-	+	-	Creators, Developers
Tilt Brush	+	+	-	-	Artists, Hobbyists
Unity Reflect	+	+	-	+	VR Developers
Unreal Engine	+	+	+	+	Developers, Designers

When design-oriented collaborative VR platforms are analyzed, Arkio, Enscape, Fuzor, RealityMAX, Resolve, SentionVR and Shapspark stand out among the platforms with a target audience in the field of architecture. However, the other platforms mentioned here also have the potential to be used in architecture projects. This shows how the multifaceted requirements in the discipline of architecture can be met with VR technologies.

When these collaborative platforms are evaluated as tools that enable direct production in VR, Arkio, CenarioVR, Gravity Sketch, Masterpiece Studio Pro, OpenBrush, Sketchfab, Tilt Brush, Unity Reflect and Unreal Engine stand out. Being able to produce directly in VR provides a great advantage for users to realize their design processes in a virtual environment independent of the physical world. In this way, users can produce their creations completely in VR without the need for an external connection or third-party software and have a more flexible experience in this process.

In terms of AR support, Arkio, ARKit, Gravity Sketch, RealityMAX, Sketchfab and Unreal Engine stand out. AR support is important in that it allows designs to be evaluated simultaneously with physical spaces. This feature is widely used by architects and designers, especially to visualize how designs will interact with scale, location and environmental effects in the real world. In this context, AR support both enhances the user experience and enables more effective design decisions to be made.

In the context of CAD integration, another important element for architecture projects, platforms such as Arkio, Enscape, Fuzor, Gravity Sketch, Resolve, SentionVR, Shapspark, Unity Reflect and Unreal Engine stand out. CAD integration enables users to transfer the productions they have created in different environments to VR platforms and edit them in this environment. This feature both increases efficiency in the design process and strengthens collaboration between different disciplines.

When evaluated within the framework of these features, Arkio, Gravity Sketch and Unreal Engine stand out among the platforms with the highest potential for use in architecture. These platforms have an important place in the discipline of architecture with their contributions to both technical and creative processes. However, among these three platforms, Arkio stands out with some distinctly differentiating features.

One of the prominent features of Arkio is its ease of use. Thanks to its user-friendly interface and simple workflows, it offers the opportunity to learn and practice basic design elements quickly and effectively, especially for beginning architecture students. This allows the platform to be used as a powerful tool in educational processes. Arkio allows users to create and easily edit architectural forms without the need for complex technical skills, helping students to adapt to the creative process faster.

Gravity Sketch and Unreal Engine, with their powerful toolkits and advanced features, offer a wide range of possibilities for professional users, while the learning curve for beginners can be steeper. While Gravity Sketch provides exceptional flexibility for free-form modeling and creative design, it appeals more to industrial design and art-oriented users. Unreal Engine is a powerful tool for large-scale projects in architecture with its photorealistic visualization and interactive simulation capabilities, but it requires technical know-how and a strong hardware infrastructure.

Another important point that differentiates Arkio from these platforms is that it transforms the design process into an intuitive and accessible experience by offering direct production and editing in VR. For beginners, the ease with which basic geometries and spatial arrangements can be made makes Arkio an ideal option for both students and professionals who want to start designing quickly.

In conclusion, Arkio stands out more than other platforms with its ease of use, accessibility and support for architectural education. These features allow the platform to be preferred not only by professional users but also by beginners and students.



6. CONCLUSION

6.1. Discussion

In this part of the thesis, the potential benefits and limitations of the Arkio platform for first-year architecture students are discussed in detail. In the first chapters of the thesis, the historical development and usage characteristics of CAD and VR technologies are mentioned and the innovations and benefits that these technologies have brought to the field of architecture are discussed. In line with this information, the concept of collaborative design is analyzed in depth and its interaction with CAD and VR technologies is examined. The features of the Arkio platform, which is one of the examples of CAD and VR integration and supports collaborative design, are detailed; the data and student comments on how it is used by first-year students of TOBB ETU architecture department are also analyzed in this context. Based on the available information, the potential and limitations of Arkio and its contributions to first year architecture education are comprehensively evaluated.

The Arkio platform can offer various opportunities for architecture students to experience the design process digitally and to develop their 3D thinking and production skills. Since the platform offers a VR and AR-supported modeling environment, students have the opportunity to see their designs in real scale, examine them in detail in 3D, and develop their work in an immersive environment. However, in addition to these potentials, there are some challenges and limitations arising from the nature of the technology offered by Arkio and user habits.

One of the most important changes in integrating CAD technologies into architectural education is the acceleration of the student's design process and the more efficient use of their time. Traditionally created on paper with the help of a ruler, scaled drawings are now transferred to the digital environment through CAD software, enabling students to produce work more quickly and accurately (Danacı & Çakmak, 2022). VR-supported platforms such as Arkio take this digital transformation one step further.

Arkio allows students to transfer the 3D models they create in the CAD environment to the platform through a plugin, thus accelerating the modeling process. Since the models transferred to Arkio can be viewed in a 1:1 scale in the VR environment, students can examine their models in real size with the immersive experience offered by VR and thus evaluate their designs from different perspectives, identifying aspects that might have been overlooked during the production process. This has the potential to help students overcome the difficulties they experience in transferring the 3D perception of the physical world to 2D drawings, especially when they start their architectural education. Platforms such as Arkio offer students the opportunity to produce in a virtual environment and work with the digital twins of these productions, making a significant development in architectural education.

Students can transfer the 3D models they have created in CAD to Arkio or continue their digital design processes in the VR environment by modeling directly in the Arkio environment. This situation adds a new aspect to the design process by enabling students to produce directly in the VR environment rather than using 2D drawing methods. The fact that Arkio offers 3D production in screen-based environments other than VR contributes more to students compared to traditional 2D production, and the ability to work directly in VR makes the design process more user-friendly and interactive.

While Arkio's experience of modeling in VR offers users the opportunity to experience the production process in an immersive environment, it can also present some estimated challenges and limitations. Modeling with a VR controller may be more challenging for users who are used to working with a mouse in computer-aided modeling software (Kukreja, Cox, Gopsill, & Snider, 2024). For instance, while tasks in CAD programs like SketchUp can often be performed efficiently and precisely using a mouse, achieving comparable speed and precision in a VR environment may require a period of adaptation and practice. This difficulty may be due to users' habits of working with a mouse and keyboard, but it may also be due to technical limitations such as the slower execution of some Boolean operations in VR. Users may need to adapt to the VR controller in order to model at the speed they are used to in the CAD environment. However, it is also possible that users who get used to the VR environment can achieve a faster and more efficient production process over time.

In Arkio, students can explore and analyze plans remotely using teleportation, even navigating inside them for a closer examination. Despite this capability, student feedback reveals that many tend to shift their production efforts toward SketchUp. Both Arkio and SketchUp support the transformation of planes into masses using the pull-push method without requiring detailed input of dimensions for precise modeling. However, it raises questions as to why students, when encouraged to engage equally with both platforms, appear to prefer SketchUp. Understanding the factors influencing this preference could provide insights into optimizing the use of VR tools like Arkio in architectural education.

However, it is seen that this potential offered by Arkio in theoretical terms may encounter some technical limitations in practice. In terms of efficient use of time, which is one of the most critical factors in the architectural design process, the transfer from CAD to Arkio may not be realized with the desired speed and accuracy, especially due to reasons such as cross-platform file compatibility and complex model grouping. While transferring from CAD to Arkio with a cloud-based system, students may sometimes encounter incompatibilities in model groupings or problems arising from the comprehensive structure of the systems. Such limitations can directly affect the user experience and make it difficult for the student to quickly access the desired production.

Furthermore, when the user experience of Arkio on different devices is analyzed, there are significant differences between the PC and tablet versions. While modeling can be done more quickly with mouse support in the PC version, modeling using only fingers on the touch screen in the tablet version can be more challenging for the user. Especially detailed and precise modeling operations may require more effort on the tablet version due to the limitations of the touch screen.

The hand tracking system, another feature offered by Arkio in VR, aims to provide practical use in some VR headsets. While theoretically, controlling hand gestures can facilitate the modeling process, in practice, various perception problems can be experienced. These problems can be caused not only by Arkio's system limitations, but also by the technical shortcomings of VR headsets in detecting hand gestures. Failure

to detect hand gestures correctly can cause interruptions in the users' production process and complicate the modeling process.

In addition, while Arkio's AR-to-VR transition feature theoretically offers efficient use, it may also present some potential problems. For example, there may be scaling or perspective issues during AR and VR transitions, making it difficult for users to match their models to the scale of the real world. In addition, projects that utilize AR and VR transitions frequently may encounter technical issues such as system crashes or slow processing speeds. These are areas that need to be addressed during the platform's development process and are an important focus for improving the user experience.

As Arkio is a new startup, users may encounter systemic problems from time to time. However, the platform attaches importance to user feedback and takes quick actions to resolve problems. Arkio's support and community departments aim to improve the user experience by providing quick feedback to the issues raised. When I communicated the problems, I experienced during my own use to the Arkio team, I was able to get a response within a day at the latest and the resolution processes were initiated quickly. Furthermore, Arkio's regular version updates and release notes show that the platform is constantly being developed and improvements are being made in line with user feedback.

Arkio's collaborative design potential is evaluated based on the characteristics mentioned in the thesis under the heading Communication Methods Used in Collaborative Design. In this context, Chiu argues that a successful collaborative design process requires synchronous and asynchronous communication (Chiu, 2002). Arkio supports synchronous communication by enabling users to work on the same project simultaneously through cloud-based data sharing. In this way, students can share many different materials from the very beginning of the design process in Arkio to the final transfer and can quickly interact with each other to convey their ideas. However, the inability of users to convey gestures, body language or facial expressions in Arkio's VR-based environment means that the depth of face-to-face communication that Chiu mentions cannot be fully achieved in a digital environment. Although design conversations in VR offer a certain level of visual enrichment, they do not fully reflect

the rich communication elements of face-to-face communication such as gestures, facial expressions, and tone of voice. In terms of asynchronous communication, Arkio allows users to save, update and share the models they have previously created, which supports asynchronous work. However, asynchronous communication may be limited in terms of accompanying visual presentations with verbal descriptions; for example, users are not able to add audio notes about the models recorded in VR. This shortcoming may reduce the depth of explanation that can be provided in asynchronous communication.

Peng's (1994) emphasis on the importance of physical models in collaborative design leads Arkio to question whether digital models alone are sufficient in a collaborative design environment. Physical models provide a more tangible expression of ideas among participants in the design process and contribute to the 3D thinking process. Although Arkio enables working with virtual models in a digital environment, the intangibility of digital models does not fully meet the tactile, dimensional, and spatial feel of physical modeling. This can bring difficulties in working with abstract digital models, especially for first-year architecture students. Replacing physical models completely with digital models in the design process may make it difficult for students who are less experienced in the learning process to perceive design solutions. According to Peng, there is a close relationship between the drawing and modeling processes, and designers often develop design solutions with drawings during model making. Arkio theoretically supports this process by enabling CAD-based drawings to be ported to the VR environment; however, in practice, it may struggle to fully respond to users' drawing and modeling habits. For example, students who are used to modeling more quickly in a CAD environment may find it difficult to adapt to controllers in a VR environment and production processes may slow down. This can lead to situations where the collaborative opportunities offered by the digital environment do not fully meet student needs.

Arkio offers a digitalized, VR-supported collaborative model for architectural education, allowing students to work remotely and share their projects virtually, thus creating a learning and design environment where spatial constraints are eliminated. However, it is difficult to replace the wealth of communication and design tools such as gestures, body language, and physical models offered by the physical environment

with purely digital methods. Arkio has some shortcomings, especially for first time users, such as getting used to the controllers, detailed modeling in the VR environment, and the inability to fully meet the synchronous-asynchronous communication needs of the users. Therefore, Arkio's ability to offer the best potential of collaborative design in architectural education can be further improved with continuous updates to improve the user experience and solutions to hardware compatibility issues.

Arkio offers four different plans to its users to support collaboration. However, when we consider class or group work in the context of architectural education, the features offered by the free plan, which is available to all users, are limited. The free plan offers only 20 minutes of collaboration time for a maximum of four users. While this may seem sufficient for students to complete specific tasks, it may be insufficient for more extensive and detailed collaboration. To meet broader collaboration needs, users may need to consider a paid option such as the Plus plan (\$8 per month) or the Pro plan (\$45 per month). The Plus plan offers unlimited meeting time, while the Pro plan allows up to 24 participants to meet at the same time. However, Arkio's free plan is a valuable starting point, allowing all users to experience the platform. Furthermore, the availability of affordable upgrade options for students provides an accessible solution for high-performance collaboration.

Arkio has a more user-friendly and simpler interface compared to Unreal Engine, another platform with similar features. The use of these simple and ready-made objects speeds up the process and offers a more practical modeling experience, especially for beginner architecture students. For projects that do not require complex parametric designs, students can quickly use the predefined objects offered by Arkio. This is especially advantageous for meeting simple and basic modeling needs at the first-year architecture level.

However, given Arkio's limitations in parametric design, platforms with more advanced features, such as Unreal Engine, offer more flexibility for professional developers and designers. Unreal Engine is especially suitable for advanced users working on complex projects by providing parametric designs and detailed control possibilities. However, the features offered by Arkio remain at a sufficient level due to the fact that first-year students in architecture education focus on simpler modeling

needs. In particular, the transfer of objects using LiDAR technology and Arkio's basic modeling tools provide a suitable environment to meet the needs of first year students in the educational process. In this context, Arkio's simple interface and fast production capacity constitute an effective alternative for basic modeling processes in architectural education.

When the Arkio platform is analyzed especially within the framework of the first year of architectural education, it is seen that it has the potential to offer an effective learning environment for students in the context of Dewey's (2008) “learning by doing” approach and Schön's (2017) “community of practice” and “reflective practice” concepts. It is important for first-year students to have the opportunity to learn basic design principles by practicing them during the architectural education process in order to put theoretical knowledge into practice. In this context, the experiential learning opportunities offered to students by Arkio as a virtual platform can encourage students' active participation in the design process. The interactive environment offered by Arkio is also in line with Schön's “community of practice” approach. The collaborative nature of the platform allows students to design together in a virtual environment and encourages peer learning in the process. While working together in the Arkio environment, students can observe each other's ideas, analyze problems together, and come up with solutions. In this way, shared learning and knowledge sharing, which are the requirements of the concept of “community of practice”, are supported in the digital environment through Arkio. Furthermore, the tools and environments provided by Arkio are in line with Schön's “reflective practice” approach in that students can receive feedback on the design process and improve themselves by reflecting on mistakes. Students can receive immediate feedback while producing in the VR environment and can make corrections by observing their mistakes. This enables students to gain a deeper understanding of their design process and develop their critical thinking skills.

6.2. Architectural Practice and Arkio: An Evaluation

This thesis examines the preferences, feedback, and criticisms of first-year architecture students regarding the use of various digital platforms within the framework of the TOBB Basic Design Studio. The voluntary nature of the students' comments, which

are considered to be more impartial and spontaneous, is noteworthy. This section explores students' usage habits and preferences for the Arkio platform discusses these insights in the context of traditional architectural practices.

First-year architecture students are introduced to both traditional and digital methods throughout their basic design education. Traditional methods include physical model-making, orthographic projections, and isometric plans, emphasizing two-dimensional and physical production techniques. Digital methods, on the other hand, offer three-dimensional design opportunities through software like SketchUp and Arkio. However, a noticeable divergence in students' preferences for these platforms has been observed.

Despite Arkio's simple interface and user-friendly system, students more frequently prefer SketchUp. SketchUp offers a workflow familiar to many users, where an object is first drawn and then extruded to create height. Conversely, Arkio begins the design process directly in three dimensions, allowing elements (e.g., cubes) to be placed immediately. This distinction highlights Arkio's deviation from conventional drawing and design methods. Nonetheless, this innovative approach has not been widely adopted by students.

Several factors may underlie this situation. Firstly, first-year students' lack of experience with digital design tools significantly influences their habits and makes it challenging for them to adopt new platforms. SketchUp is a well-established tool in architectural practice, widely known and commonly taught, which motivates students to leverage their existing knowledge and experience.

While Arkio offers a more innovative approach by enabling direct three-dimensional modeling, habits around this platform may not yet be fully developed. Additionally, students mentioning that they could have utilized Arkio but ultimately chose not to indicates a critical point for reflection on the dynamics between traditional and digital methods in architectural education.

The preferences of first-year students are directly linked to educational approaches during the formative stages when production and design habits in architectural practice

are established. Students experiencing the differences between traditional methods and digital platforms often gravitate toward familiar and trusted techniques. Arkio's innovations could be better conveyed to students through more guided and hands-on exercises.

Finally, the reasons behind these preferences necessitate deeper discussion about how production habits in architectural practice shaped and how digital transformation are influences these habits. Analyzing the experiences of first-year students can contribute to developing recommendations for innovations in architectural education and effectively integrating traditional and digital practices.

In architectural education, students engage in a variety of activities to develop theoretical and practical skills, such as drawing and visualization, model-making, collaborative design studios, learning about materials and construction, and presentation techniques. While Arkio has the potential to significantly enhance some of these areas, it falls short in meeting certain student needs in others.

Arkio excels in enabling intuitive three-dimensional modeling, allowing students to bypass traditional two-dimensional drafting processes and engage directly with spatial design. This feature can streamline the design process, particularly in collaborative settings where multiple users can interact in real-time within the same virtual environment. Additionally, Arkio's ability to work at a 1:1 scale offers students a unique opportunity to experience their designs in a spatially immersive way, which is challenging to achieve with traditional methods.

However, Arkio also has limitations. While it supports innovative modeling practices, it may not fully address the need for detailed technical drawings or intricate material and structural analyses, which remain critical aspects of architectural practice. Furthermore, students accustomed to traditional tools like SketchUp or physical model-making may find Arkio's workflow unfamiliar or less conducive to their current design habits. This hesitancy suggests that Arkio might benefit from additional features or training modules to better align with students' expectations and the broader requirements of architectural education.

Overall, while Arkio offers transformative possibilities for collaborative and three-dimensional design, its integration into architectural education should be approached with consideration of its strengths and gaps. Addressing these gaps through targeted improvements or supplementary tools could enhance its adoption and effectiveness among architecture students.

6.3. Future Works

Arkio and other platforms used in architectural education have significant development potential with the advancement of technology. First of all, the development of cloud-based workflows and multi-platform integrations has the potential to facilitate access from different devices and make design processes more efficient. Continuous updates and improvements give strong signals that this potential will be realized. In addition, based on user comments, this integration, which is one of the most time-consuming processes, is expected to become more efficient over time.

Advances in VR and AR technologies can enrich the design experience with more realistic models, haptic feedback devices and environmental simulations. VR technologies offer great potential for transformation in the fields of architecture and design by integrating with innovative systems such as 5G networks, remote rendering technologies, geographic information systems GIS, 3D scanning, MR and digital twins, which are rapidly developing today (Rafsanjani & Nabizadeh, 2023). These integrations will lead to more dynamic, efficient and context-driven workflows that enable the physical and digital worlds to work together. In the future, the combined use of these technologies may not only accelerate design processes, but also add a deep analytical dimension to them, enabling more sustainable and intelligent design approaches to be adopted.

One of the most striking features of VR technology is its capacity to enable both synchronous and asynchronous collaboration. In this context, adding asynchronous working support to platforms such as Arkio can provide a more flexible collaboration environment between users. In particular, the ability for users to leave voice notes is a factor that strengthens communication; in this way, revisions or suggestions needed during the design process can be shared more effectively. Such innovations can

contribute to users reaching the targeted production output more quickly and effectively.

Technological advances in the VR environment offer elements that can make communication and collaboration more effective. For example, haptic feedback not only enables the feeling of spatial and material textures during the production process, but also allows users' facial expressions and gestures to be more clearly communicated during collaboration. These features have the potential to enable deeper interaction, especially in team communication and decision-making.

Implementing these innovations brings with it a number of challenges. Usability, accessibility and the development of user-friendly interfaces are critical for wider adoption of VR technologies. In addition, issues such as data security, ethical responsibilities and addressing technological inequalities need to be addressed. Overcoming these issues will enable VR to become an integral part of design and education processes, rather than just a technical tool.

The future of VR in architecture and design disciplines will continue to be shaped by technological developments, pedagogical innovations and changing social needs. In this process, VR is on its way to creating an ecosystem that encourages creativity, collaboration and innovation by redefining both design processes and educational approaches.



REFERENCES

- Acar, A. (2008). A Developmental Perspective for Architectural Design Education. *Edinburgh Architecture Research*(31), 22-25.
- Acar, A., Acar, Ş. S., & Ünver, E. (2021). A Research On the Relationship Between Problem-Solving Appraisal, Attention, and Visuospatial Skills of First-Year Architecture Students. *Megaron*, 16(2), 212-222.
- Acar, A., Koç, M., Bancı, S., & Abbas, G. M. (n.d.). Borderline: An Interdisciplinary Spatial Installation. *2nd AE International Symposium* (pp. 76-84). IKU Department of Architecture.
- Af Klercker, J. (1998). A CAVE-interface in CAAD-education. *ECAADE-98 Conference*,. France: University of Paris-Val-de-Marne.
- Agoki, G., Ng, B.-C., & Johnson, R. (2007). Development of communication skills and teamwork amongst undergraduate engineering students. *37th Annual Frontiers In Education Conference-Global Engineering: Knowledge Without Borders*.
- Akrout, N., & Roxin, L. (1999). Broadband multimedia for distance education via satellite. *Advanced Research in Computers and Communications in Education*, 223-228.
- Ali, T., & Reid, D. (2024). *Virtual Reality for an immersive educational experience*. Retrieved from Learning and Teaching Conference 2024: <https://www.mmu.ac.uk/sites/default/files/2024-06/Learning%20and%20Teaching%20Conference%20Programme%20and%20Book%20of%20Abstracts%202024.pdf>
- Alvarado, R., & Maver, T. (1999). Virtual reality in architectural education: defining possibilities. *Acadia Quarterly* 18.4 , 7-9.
- Anthes, C., García-Hernández, R., Wiedemann, M., & Kranzlmüller, D. (2016). State of the art of virtual reality technology. (pp. 1-19). 2016 IEEE aerospace conference.
- Arkio. (2024). *Release Notes*. Retrieved from Support Arkio: <https://support.arkio.is/hc/en-us/sections/360000545938-Release-Notes>
- Arkio. (n.d.). Retrieved from Pricing Arkio: <https://www.arkio.is/pricing/>
- Bi., Z., & Wang, X. (2020). *Computer aided design and manufacturing*. John Wiley & Sons.
- Bialkova, S., & Van Gisbergen, M. S. (2017). When sound modulates vision: VR applications for art and entertainment. *2017 IEEE 3rd workshop on everyday virtual reality (WEVR)*, 1-6.
- Boas, Y. (2013). Overview of virtual reality technologies. *Interactive Multimedia Conference*, 1-6.
- Brown, P. (2009). CAD: Do computers aid the design process after all? *The Stanford Journal of Science, Technology, and Society* 2(1), 52-66.
- Budziszewski, P. (2013). A Low Cost Virtual Reality System. *Physical Therapy*, 88(10), 32-39.
- Campbell, D. (2024, August 6). *Digital Preservation in Volterra*. Retrieved from Arkio Blog: <https://arkio.is/blog/volterra/>

- Chiu, M.-L. (2002). An organizational view of design communication in design collaboration. *Design studies* 23.2, 187-210.
- Chouldhary, R., & Michalek, J. (2005). Design Optimization in Computer-Aided Architectural Design. *The Association for Computer-Aided Architectural Design Research in Asia*, 149-158.
- Chow, P., Kubota, T., & Georgescu, S. (2015). Automatic detection of geometric features in cad models by characteristics. *Computer-Aided Design and Applications* 12., 784-793.
- Chowdhury, S., & Hanegraaf, J. (2022). CO-PRESENCE IN REMOTE VR CO-DESIGN. *Proceedings of the 27th International Conference of the Association for Computer-Aided*, (pp. 465-474). Hong Kong.
- Coates, G. (1992). *Program from Invisible Site—a virtual sho*. San Francisco, CA: George Coates Performance Works.
- Coltey, E., Tao, Y., Wang, T., Vassing, S., Chen, S., & Shyu, M. L. (2021). Generalized structure for adaptable immersive learning environments. *2021 IEEE 22nd International Conference on Information Reuse and Integration for Data Science (IRI)*, 294-301.
- Comeau, C., & Byran, J. (1961). *Headsight Television System Provides Remote*. Electronics.
- Conn, C., Lanier, J., Minsky, M., Fisher, S., & Druin, A. (1989). Virtual environments and interactivity: Windows to the future. *ACM SIGGRAPH 89 Panel Proceedings*, (pp. 7-18).
- Costello, P. (1997). *Health and safety issues associated with virtual reality: a review of current literature*. Loughborough.
- Cruz-Neira, C., Sandin, D., DeFanti, T., Kenyon, R., & Hart, J. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, 35(6), (pp. 64-73).
- Danacı, H., & Çakmak, A. (2022). Computer-aided Design and Virtual Reality in Architecture. *Journal of Scientific Reports-A*, 98-112.
- De Fino, M., Bruno, S., & Fatiguso, F. (2022). Dissemination, assessment and management of historic buildings by thematic virtual tours and 3D models. *Virtual Archaeology Review*, 13(26), 88-102.
- de Freitas, F. V., Gomes, M., & Winkler, I. (2022). "Benefits and challenges of virtual-reality-based industrial usability testing and design reviews: A patents landscape and literature review. *Applied Sciences* 12.3.
- Dede, C. J., Jacobson, J., & Richards, J. (2017). *Introduction: Virtual, Augmented, and Mixed Realities in Education*. Singapore: Springer.
- Deng, Y., Mueller, M., Rogers, C., & Olechowski, A. (2022). The multi-user computer-aided design collaborative learning framework . *Advanced Engineering Informatics*, 51.
- Dewey, J. (2008). *The Collected Works of John Dewey*. (J. A. Boydston, Dü.) PergamonMedia.
- Dirk, D., & Regenbrecht, H. (1999). Using Immersive Virtual Reality Systems . *AVOCAAD Second International Conference*, 307-318.
- Dorta, T., Kinayoglu, G., & Hoffmann, M. (2016). Hyve-3D and the 3D Cunsor: Architectural co-design with freedom in virtual reality. *Inter J Architectural Comput* 14(2), 87-102.

- Dorta, T., Lesage, A., Pérez, E., & Bastien, C. J. (2011). Signs of collaborative ideation and the hybrid ideation space. *Design creativity 2010* (pp. 199-206). Springer London.
- El Araby, M. (2002). Possibilities and constraints of using virtual reality in urban design. *Proceedings of the 7Th International CORP Symposium*, (pp. 457-463). Vienna, Austria.
- Ellis, R., Han, F., & Pardo, A. (2018). When does collaboration lead to deeper learning? Renewed definitions of collaboration for engineering students. *IEEE Transactions on Learning Technologies* 12.1, 123-132.
- Frost, P., & Warren, P. (2002). Virtual reality used in a collaborative architectural design process. *An International Conference on Computer Visualization and Graphics*, 568-573.
- Gallegher, A. G., Ritter, E. M., Champion, H., Higgins, G., Fried, M. P., Moses, G., . . . Satava, R. M. (2005). Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. *Annals of surgery* 241.2, 364-372.
- Greenbaum, P. (1992). *The lawnmower man*. Film and video 9(3), 58-62.
- Gunnarsson, H. (2021, June 1). *A new collaborative tool for architecture*. Retrieved from Arkio: <https://www.arkio.is/blog/arkio-a-new-collaborative-tool-for-architecture/>
- Gunnarsson, H. (2023, January 11). *Davey+Smith Architects case study*. Retrieved from Arkio Blog: <https://www.arkio.is/blog/user-story-daveysmith/>
- Gunnarsson, H. (2023, July 5). *SPINN Arkitekter case study*. Retrieved from Arkio Blog: <https://www.arkio.is/blog/case-study-spinn/>
- Hamade, R. F. (2009). Profiling the Desirable CAD Trainee: Technical Background, Personality Attributes, and Learning Preferences . *J. Mech. Des. Trans. ASME* 131.
- Hanegraaf, J. (2021). *Volumetric Modeling*. Retrieved from Arkio: <https://support.arkio.is/hc/en-us/articles/360002018697-Volumetric-modeling>
- Hanegraaf, J. (2021). *VR Controllers and Hand-tracking*. Retrieved from Arkio: <https://support.arkio.is/hc/en-us/articles/360002027298-VR-Controllers-and-handtracking>
- Hanegraaf, J. (2023, October 22). *Norconsult case study*. Retrieved from Arkio Blog: <https://www.arkio.is/blog/case-study-norconsult/>
- Hanegraaf, J. (2024, February 20). *Case Study- RISE Architecture* . Retrieved from Arkio Blog: <https://www.arkio.is/blog/case-study-rise/>
- Hanegraaf, J. (2024). *LiDAR scans*. Retrieved from Arkio Support: <https://support.arkio.is/hc/en-us/articles/6085227678993-LiDAR-scans>
- Hanegraaf, J. (2024). *Main Menu*. Retrieved from Arkio Support: <https://support.arkio.is/hc/en-us/articles/360002017137-Main-menu>
- Hanegraaf, J. (2024). *Release notes v1.9.1*. Retrieved from Arkio Support: <https://support.arkio.is/hc/en-us/articles/16534632957596-Release-notes-v1-9-1>
- Hanegraaf, J. (2024). *Secondary Menus*. Retrieved from Arkio Support: <https://support.arkio.is/hc/en-us/articles/360002017157-Secondary-menus>
- Hanegraaf, J. (2024). *Unity & Arkio*. Retrieved from Arkio Help Center: <https://support.arkio.is/hc/en-us/articles/4848060548113-Unity-Arkio>
- Heim, M. (1993). *The metaphysics of virtual reality*. USA: Oxford University Press.

- Holloway, R., & Lastra, A. (1993). Virtual environments: A survey of the technology. *Eurographics*.
- Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3), 1171-1182.
- Hussein, M., & Nätterdal, C. (2015). The benefits of virtual reality in education-A comparison Study. *University of Gothenburg, Göteborg, Sweden*.
- Ibrahim, A., Al-Rababah, A., & Bani Baker, Q. (2021). Integrating virtual reality technology into architecture education: the case of architectural history courses. *Open House International*, 46(4), 498-509.
- Indiana University Indianapolis. (n.d.). *Genişletilmiş Gerçeklik Girişimi (XRI) aracılığıyla Eğitimde İnovasyon*. Retrieved November 2024, from Indiana University Indianapolis: <https://ctl.indianapolis.iu.edu/workshops-events2/extended-reality-initiative>
- Jerald, J. (2015). *he VR Book: Human-Centered Design for Virtual Reality*. Association for Computing Machinery.
- Keller, K., & Fuchs, H. (2008). Head mounted displays for medical use. *Journal of display technology* 4.4, 468-472.
- Kharvari, F., & Kaiser, L. E. (2022). Impact of extended reality on architectural education and the design process. *Automation in Construction* 141.
- Kleinsmann, M. S. (2006). *Understanding collaborative design*.
- Krueger, M. (1991). *Artificial reality*. Gary, Indiana: Addison-Wesley Professional.
- Kukreja, A., Cox, M., Gopsill, J., & Snider, C. (2024). A comparative study of VR CAD modelling tools for design. *Proceedings of the Design Society*, 4., 643-652.
- Kvan, T. (2000). Collaborative design: what is it? *Automation in construction*, 9(4), 409-415.
- Kwak, E. (2023). Impact of the digital design process in an architectural engineering technology program: Integration of advanced digital tools (work in progress). *2023 ASEE Annual Conference & Exposition*. American Society for Engineering Education.
- Lanier, J. (1992). Virtual reality: The promise of the future. *nteractive Learning International* 8(4), 275-79.
- Lawrence, P., & Lorsch, J. (1967). Differentiation and integration in complex organizations. *Administrative science quarterly*, 1-47.
- Lege, R., & Bonner, E. (2020). Virtual reality in education: The promise, progress, and challenge. *Jalt Call Journal* 16.3, 167-180.
- Mayer, A., Chardonnet, J. R., Hafner, P., & Ovtcharova, J. (2023). In New Digital Work: Digital Sovereignty at the Workplace. In *Collaborative Work Enabled* (pp. 87-117). Berlin, Germany: Springer International Publishing.
- McCloy, R., & Stone, R. (2001). Virtual reality in surgery. *Bmj*, 323(7318), 912-915.
- Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & education*, 70, 29-40.
- Milovanovic, J., Moreau, G., Siret, D., & Miguet, F. (2017). Virtual and augmented reality in architectural design and education. *17th international conference. CAAD futures 2017*.

- Morgan, D. (2024, July 22). *Made in Arkio - Verified in Field with Gael Ranc*. Retrieved from Arkio Blog: <https://www.arkio.is/blog/gael-ranc/>
- Moshell, M. (1993). Three views of virtual reality: virtual environments in the US military. *Computer* 26.2, 81-82.
- Nowak, K. (2001). Defining and differentiating copresence, social presence and presence as transportation. *Presence 2001 Conference*, (pp. 686-710). Philadelphia.
- Pan, Z., Cheok, A., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & graphics*, 30(1), 20-28.
- Peng, C. (1994). Exploring communication in collaborative design: co-operative architectural modelling. *Design studies*, 15(1), 19-44.
- Perry, M., & Sanderson, D. (1998). Coordinating joint design work: the role of communication and artefacts. *Design studies*, 19(3), 273-288.
- Pimental, K., & Teixeira, K. (1995). *Virtual reality: Through the new looking glass*. New York: McGraw-Hill Press,.
- Powers, M., & Emmelkamp, P. (2008). Virtual reality exposure therapy for anxiety disorders: A meta-analysis. *Journal of anxiety disorders* 22.3, 561-569.
- Rafsanjani, H. N., & Nabizadeh, A. H. (2023). Towards digital architecture, engineering, and construction (AEC) industry through virtual design and construction (VDC) and digital twin. *Energy and Built Environment*, 4(2), 169-178.
- Rahimian, F. P., & Ibrahim, R. (2011). Impacts of VR 3D sketching on novice designer's spatial cognition in collaborative architectural design. *Design Studies* 32(3), 255-291.
- Rampolla, J., & Kipper, G. (2012). *Augmented reality: An emerging technologies guide to AR*. Elsevier.
- Rauf, H. L., Shareef, S. S., & Othman, N. N. (2021). Innovation in Architecture Education: Collaborative Learning Method Through Virtual Reality. *Journal of Higher Education Theory and Practice*, 33-40.
- Saad, M., & Maher, M. L. (1996). Shared understanding in computer-supported collaborative design. *Computer-Aided Design*, 28(3), 183-192.
- Salman, H., Laing, R., & Conniff, A. (2008). The changing role of CAAD in the architectural design studio. *The Built and Human Environment Review* 1, 25-39.
- Salman, H., Laing, R., & Conniff, A. (2014). The impact of computer aided architectural design programs on conceptual design in an educational context. *Design Studies*, 35(4), 412-439.
- Sarcar, M. M., Rao, K., & Narayan, K. (2008). *Computer aided design and manufacturing*. PHI Learning Pvt. Ltd.
- Sbea, G., & Guzzo, R. (1987). Group effectiveness: What really matters? *Sloan Management Review* (1986-1998) 28(3), 25-31.
- Schnabel, M. A., Wang, X., Seichter, H., & Kvan, T. (2008). Touching the untouchables: Virtual-, augmented-and reality. *International conference on the association for computer aided architectural design research in Asia*, (pp. 1-8).
- Schön, D. A. (2017). *The reflective practitioner: How professionals think in action*. Routledge.

- Sherman, W., & Craig, A. (2018). *Understanding virtual reality: Interface, application, and design*. Morgan Kaufmann.
- Sherman, W., & Craig, A. (2018). *Understanding virtual reality: Interface, application, and design*. Morgan Kaufmann.
- Stevens, A., Hannegraaf, J., & Moussa, A. (2023). An empirical study of using Arkio and Pacelab WEAVR for immersive. *EdMedia+ Innovate Learning*, (pp. 1046-1050). Vienna, Austria.
- Sturman, D., & Zeltzer, D. (1994). A survey of glove-based input. *IEEE Computer graphics and Applications* 14.1, (pp. 30-39).
- Sutherland, I. (1965). The ultimate display. *Proceedings of the IFIP Congress. Vol. 2.*, (pp. 506-508).
- Takala, T. (2014). RUIS: A toolkit for developing virtual reality applications with spatial interaction. *Proceedings of the 2nd ACM symposium on Spatial user interaction*, 94-103.
- Tasli, S. (2001). Bridging the Gap Between Theory and Practice in Architectural Education: The Case of CAAD Teaching. In N. Çağlar (Ed.) *Proceedings of the 19th EAAE International Conference*, (pp. 203-209). Ankara, Turkey.
- Tornincasa, S., & Di Monaco, F. (2010). The future and the evolution of CAD. *Proceedings of the 14th international research/expert conference: trends in the development of machinery and associated technology* , (pp. 11-18).
- University of Nottingham. (2024, February 12). *World-leading virtual reality teaching facility opens at the University of Nottingham*. Retrieved from University of Nottingham: <https://www.nottingham.ac.uk/news/world-leading-virtual-reality-teaching-facility-opens-at-the-university-of-nottingham>
- Waters, R. (1979). Another Brick in the Wall. *The Wall*. Columbia Records.
- Wohlgenannt, I., Simons, A., & Stieglitz, S. (2020). Virtual Reality. *Business & Information Systems Engineering*, 455-461.
- Yıldırım, E. (2024). Enhancing Online Learning in Architectural Education: A Virtual Reality Enabled Experiment with Arkio. *Black Sea Journal of Engineering and Science*, 7(6), 11-12.
- Yuen, S. C.-Y., Yaoyuneyong, G., & Johnson, E. (2013). Augmented Reality and Education: Applications and Potentials. *Reshaping Learning: Frontiers of Learning Technology in a Global Context* (pp. 385-414). Berlin, Heidelberg: Springer.
- Zhou, Y., Chen, J., & Wang, M. (2022). A meta-analytic review on incorporating virtual and augmented reality in museum learning. *Educational Research Review*, 36, 100454.
- Zou, Q., & Feng, H.-Y. (2020). A decision-support method for information inconsistency resolution in direct modeling of CAD models. *Advanced Engineering Informatics* 44 .
- Zyda, M. (2005). From visual simulation to virtual reality to games. *Computer*, 38(9), 25-32.