Virtual Reality Learning Environments In Architecture And Design Education: A Bibliometric Review


Arda ÇALIŞKAN[1], Suzan GİRGİNKAYA AKDAĞ[2]
Istanbul, Türkiye
Bahcesehir University; Faculty of Architecture and Design,
Department of Interior Architecture and Environmental Design
arda.caliskan@bau.edu.tr, suzan.girginkayaakdag@bau.edu.tr
https://orcid.org/0000-0002-2306-7406[1]
https://orcid.org/0000-0003-2035-0369[2]
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Abstract: *Virtual Reality (VR) technologies are increasingy being utilized in the fields of architecture and design education due to their potential to supporting creating interactive, immersive learning environments. This paper provides a bibliometric review of 68 academic studies between 2000 and 2025 that discuss the use of VR tools, platforms, and games in learning environments. The research aims to find trends, gaps in research, and thematic trends in the application of VR technologies in design education. The findings indicate a growing interest in integrating VR technologies into architectural education worldwide. Architectural design emerges as the most researched topic, highlighting VR's significant potential in supporting design-related activities, visualization, and collaborative learning. Besides design-oriented research, VR applications have also been researched in fields like construction education, architectural history, and landscape architecture. The paper categorizes the reviewed works into three broad categories of VR uses: tools and applications, platforms, and game-based learning environments. Among these, tools and applications are the most prevalent, typically developed to address specific educational needs, while game-based approaches remain less explored, despite their potential to enhance engagement through interactive, game-like settings. While the bibliometric analysis highlights the educational benefits of VR—such as enhanced visualization, interactivity, and increased student motivation—it also identifies key challenges. These include the need for more empirical evidence on long-term learning outcomes and the development of standardized and pedagogical models for effective VR integration. The paper concludes by emphasizing the importance of future research in addressing these gaps to support the evidence-based implementation of VR technologies in architectural and design education.*
Keywords: *Virtual Reality, Architectural Education, Design Education, VR Applications, Immersive Learning, Bibliometric Analysis*

Mimarlık ve Tasarım Eğitiminde Sanal Gerçeklik Öğrenme Ortamları: Bibliyometrik Analiz

Özet: *Sanal Gerçeklik teknolojileri, etkileşimli ve sürükleyici öğrenme ortamları oluşturma potansiyelleri nedeniyle mimarlık ve tasarım eğitiminde giderek daha fazla kullanılmaktadır. Bu makale, öğrenme ortamlarında VR araçlarının, platformlarının ve oyunlarının kullanımını inceleyen ve 2000-2025 yılları arasındaki 68 akademik çalışmayı kapsayan bibliyometrik bir analiz sunmaktadır. Araştırma, tasarım eğitiminde VR teknolojilerinin uygulanmasındaki eğilimleri, araştırmalardaki eksiklikleri ve tematik eğilimleri bulmayı amaçlamaktadır. Bulgular, dünya genelinde mimarlık eğitimine VR teknolojilerinin entegrasyonuna yönelik artan bir ilgi olduğunu göstermektedir. Mimari tasarım, en çok araştırılan konu olarak öne çıkmakta olup, VR'nin tasarım odaklı faaliyetleri destekleme, görselleştirme ve işbirlikçi öğrenme konularındaki büyük potansiyelini vurgulamaktadır. Tasarım odaklı araştırmaların yanı sıra, sanal gerçeklik uygulamaları yapı eğitimi, mimarlık tarihi ve peyzaj mimarlığı gibi alanlarda da incelenmiştir. Makale, incelenen çalışmaları üç geniş VR kategorisine ayırmaktadır: araçlar ve uygulamalar, platformlar ve oyun tabanlı öğrenme ortamları. Bunlar arasında, genellikle belirli eğitim ihtiyaçlarını karşılamak amacıyla geliştirilen araçlar ve uygulamalar en yaygın olanıdır. Öte yandan, etkileşimli ve oyun benzeri ortamlar aracılığıyla öğrenci katılımını artırma potansiyeline sahip olmasına rağmen, oyun tabanlı yaklaşımlar daha az araştırılmıştır. Bibliometrik analiz, VR'nin eğitimde sağladığı görselleştirme, etkileşim ve öğrenci motivasyonunu artırma gibi faydalarını vurgularken, bazı önemli zorluklara da dikkat çekmektedir. Bu zorluklar arasında, uzun vadeli öğrenme çıktılarına ilişkin daha fazla ampirik kanıt ihtiyacı ve VR'nin etkili bir şekilde entegrasyonu için standartlaştırılmış ve pedagojik açıdan uygun modellerin geliştirilmesi yer almaktadır. Makalenin sonuç bölümü, bu eksikliklerin giderilmesine yönelik gelecekteki araştırmaların önemini vurgulayarak, VR teknolojilerinin mimarlık ve tasarım eğitiminde kanıta dayalı uygulanmasını desteklemeyi amaçlamaktadır.*
Anahtar kelimeler: *Sanal Gerçeklik, Mimarlık Eğitimi, Tasarım Eğitimi, VR Uygulamaları, Sürükleyici Öğrenme, Bibliyometrik Analiz.*

1. INTRODUCTION

Architecture and design education is faced with a paradigmatic shift triggered by rapid progress in digital technology. Use of digital tools and methods has transformed architectural practice, promoting innovations such as parametric design, algorithmic processes, and simulated visualization practices [1,2]. But the pace of this technological advancement has raised questions regarding the efficiency and pedagogical appropriateness of novel tools in comparison to traditional pedagogic methods [3]. As the architectural profession adopts more advanced digital technologies, including automation, data-driven design processes, and virtual spaces [4], universities have been behind, creating a gap between curricula in teaching and professional practice [5,6]. This gap calls for a strategic transformation of architecture and design education to meet the demands of a more digital and networked professional sphere.

Traditionally, architecture and design education have revolved around studio-based education with emphasis on sketching, model making, and theoretical knowledge [7]. These traditional approaches have provided students with a solid foundation in design, spatial perception, and critical reasoning [8]. With the architectural practice moving towards computationally-driven workflows [1], challenges still persist regarding the efficiency of traditional pedagogical practices [9]. The evolution of parametric and data-driven design processes has profoundly influenced professional practice because software like Building Information Modeling (BIM) and computational design tools became common industry software [10]. But while this has transformed practice, it has historically been challenging for education programs to successfully integrate these technologies into the studio-based pedagogical model, thereby creating a gap in skills lowering students' preparedness for practice in today's era [11,12]. The adoption of Virtual Reality (VR) technologies in architecture and design education has tremendous potential for bridging this gap. VR enables immersive, interactive, and spatially accurate learning environments that go beyond the limitations of traditional 2D presentations [13]. With VR, students can virtually move through building spaces dynamically and experience scale, proportion, and spatial relationships directly rather than through symbolic visualization [14]. Current research has indicated that VR applications are suitable for experiential and situated learning, which facilitates a more intuitive understanding of architectural principles and design strategies [6,15]. Apart from enhancing spatial cognition, VR-based design environments facilitate real-time collaboration, through which students can work with fellow students and instructors regardless of geographical location [16].

With the growing interest in VR as an educational tool, there is a need for a systematic review of its application in architectural education to determine what is being done, where research is headed, and implementation challenges. This research aims to conduct a bibliometric review of academic publications from 2000-2025, with specific focus on the development and pedagogical integration of VR technologies in architecture and design education. Using the content analysis of publication trends, themes, and co-authorship networks, the paper strives to provide insight into the trend of adoption of VR in architectural education curricula. The study further aims to acknowledge the existing literatures and sketch out directions for future work that will further encourage effective and sustainable adoption of VR technologies into architecture education. Through this bibliometric overview, the paper contributes to the ongoing debate regarding digital transformation in architecture and offers a framework for aligning educational practice with the evolving needs of the profession and the new world shaped by technology.

2. METHOD

This paper follows the bibliometric review methodology in order to explore the role of virtual reality in architecture education. This method allows for an effective and structured analysis of existing literature, which helps to identify major trends, benefits, and challenges concerning Virtual Reality in the field of

architecture and design. This method is valued for its ability to synthesize and critically evaluate multiple studies in a specific field, thereby ensuring the reliability and validity of results [36].

Relevant studies were found from databases like Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar. English and Turkish key words were the part of strategy in order to catch wide extent information. Examples include "virtual reality in architectural education," “VR in design education”, "game-based learning and architecture," "design and construction training by using VR games," and "immersive learning in architecture." such that Turkish-language studies may not be missed, keywords in Turkish, such as "mimarlık eğitiminde sanal gerçeklik," "oyun tabanlı öğrenme ve mimarlık," and "iç mimarlık eğitiminde VR," were also used.

Reference lists in the first set of retrieved papers were further searched to broaden this review, thus finding even more relevant material. The iteration served to facilitate thorough review for known and less-known but relevant studies on the subject. Combination database searches using sophistication, along with manual tracking references and using a set of keywords in different languages, ensured comprehensive and inclusive assessment of literature was achieved. In fact, the review has been dominated by peer-reviewed journal articles, conference proceedings, and book chapters, published from 2000 through 2025, with research on the use of virtual reality in architectural education, consequently impacting educational outcomes. Each identified paper was rated using predefined categories such as research objectives, methodology, number of participants, experimental design, technological infrastructure used, and pedagogical outcomes. A thematic analysis was done to identify recurrent themes, directions, and gaps within the literature. The comparative approach was conducted to test different methodologies using VR in architecture education contexts.

The selection of the papers relevant for this review, in relation to architectural and interior architecture education, gave a clear emphasis. Consistent with the primary purpose of the research in terms of uncovering VR-based learning environments specific to architecture and design, research from related fields such as industrial design was excluded. Also, the fact that there was a study of educational usage and not a professional or client-based project dictated that only an academic work already implemented in the university environment is included.

The citation count was also taken into consideration in order to include most referenced and significant research in the field and to further fine-tune the selection process. This strategy ascertained that the review encompassed major contributions and widely acknowledged development. The application of ResearchRabbit or related artificial intelligence algorithms for finding and ranking high-impact papers allowed a more comprehensive and efficient reviewing process. These criteria are used to emphasize the most important and relevant VR research in architectural and interior architecture education.

3. LITERATURE REVIEW

The literature review section of this study provides a comprehensive overview of existing research on Virtual Reality in architecture and design education, guided by bibliometric methods. It initially introduces bibliometric analysis as a systematic approach to map the structure and research trends in educational environments, highlighting its applicability and methodological foundations. The review thus offers a profile of VR technology and pedagogical uses within architecture and design education and historicizes the evolution over time as it focuses on how revolutionary such have proved to be in respect to studio teaching and learning practices. Subsequently, a methodology for categorizing VR learning methods is demonstrated that distinguishes three quite dissimilar types namely platforms, tools/applications and games providing very different kinds of educational purpose, with extremely disparate models for deployment.

Next, the key research themes in the reviewed literature are discussed, including immersive design studios, collaborative virtual environments, game-based learning, and simulation-based training. Finally, the review describes the existing gaps in research, pedagogical and technological challenges, and future research avenues for further studies on VR integration in architectural education.

Bibliometric Review in Academic Research

Bibliometric analysis is a technique that is in being used in academic fields for the systematic investigation of the structure, development, and trends within a particular topic. Bibliometric review is an invaluable asset in the context of education research to study patterns of publication, research cooperation, theme development, and contribution of academic work [17]. It enables researchers to identify emerging trends, assess the evolution of areas of research, and identify research gaps by quantitatively studying bibliographic data like references, co-authorship, citations, and keywords [18]. Not only does this systematic approach reveal the past history of a field of research, but also signals upcoming directions in research by uncovering untapped areas. Several approaches are commonly employed in bibliometric studies to study research productivity are:

1. Citation Analysis: Citation analysis examines the frequency with which a publication is cited, providing an indication of the impact and reach of specific studies, authors, or journals [19]. In education research, frequently cited publications are often seminal theory or methodological advances.
2. Co-Authorship Analysis:Co-authorship analysis examines collaboration patterns in research by analyzing author, institution, and country linkages. The technique is employed to identify research networks and collaboration trends in a specific area of study [20].
3. Keyword Co-Occurrence Analysis: By analyzing the occurrence of keywords together in publications, researchers are able to map the conceptual landscape of a field and identify advancing or receding topics [21].
4. Co-Citation Analysis: Co-citation analysis measures the extent to which two documents are co-cited, providing data on the intellectual structure of the field [22]. This technique is highly suitable for obtaining core literature and theoretical foundations, and for determining paradigm shifts over time.

Overview of Virtual Reality and Its Utilization in Architecture and Design Education

Virtual reality have been extensively utilized across several educational fields, such as medical training, engineering, and architecture, owing to their capacity to replicate real-world experiences and intricate problem-solving situations [6]. Researchs indicates that virtual reality enhances spatial cognition, problem-solving abilities, and collaborative learning, rendering it a valuable instrument for design-oriented fields like architecture [23]. In the realm of architectural and design education, the integration of VR has helped enhance spatial understanding, improve design comprehension, and create immersive learning experiences. Unlike traditional two-dimensional representations, VR lets students interact with design models intuitively and immersively to engage more profoundly with spatial configurations and scale [24]. Studies have shown that VR-based environments significantly help students develop a more accurate perception of spatial relationships, an important aspect of architectural design [25]. Thus, a key advantage of VR in design education is its capacity to enhance spatial cognition and improve visualization skills.

Figure 1. VR application of virtual exhibition of Bahcesehir University Faculty of Architecture and Design (Author's archive)

While the educational potential of VR and related immersive technologies is considerable, their advantages and limitations need to be balanced. As for it's advantages; VR allows for the navigation of three-dimensional architectural environments, helping students better understand spatial relationships and design principles compared to conventional 2D drawings [14]. VR enables experiential learning through real-time interaction with design components, which is consistent with constructivist pedagogical principles [13]. Collaborative VR spaces, such as The Wild and Mozilla Hubs, allow real-time interaction among students and instructors regardless of geographical location, encouraging collaboration and communication [16]. VR construction simulations, such as those used in safety training modules, allow students to practice complex or hazardous activities without risks [6]. As an example seen in Figure 1, integrating VR into the exhibition system, Bahçeşehir University verifies the potential of immersive technologies in expanding audience reach. The VR platform allows members of the public to experience virtual exhibitions in a manner as if they were present in a physical gallery, enabling a more personal and experiential understanding of the works on display.

When challenges and limitations of VR in architectural education thought; long-term exposure to VR can lead to motion sickness, confusion, and cognitive overload, particularly when moving through complex or highly dynamic spaces [26]. Acquisition and maintenance of VR hardware and software and technical expertise for their implementation are barriers for the majority of universities [6]. Teachers find it challenging to integrate traditional teaching practices into VR-based education, emphasizing the need for teacher training and curriculum materials [27]. VR environments, particularly game-based learning platforms, can be more entertainment-driven than education-centric at times, rendering learning exercises less profound and demanding [28].

Categorization of VR Learning Environments: Platforms, Applications/Tools and Games

Typology of Virtual Reality learning environments is needed to understand the different ways in which this technology is being applied in architecture and design education. VR for learning purposes vary significantly in function, intent, and technological infrastructure. To provide an organized understanding of such uses, this study categorizes VR learning environments into three broad categories: platforms, applications/tools, and games. This three-fold classification enables examination of the educational potential of VR by delineating the foundational systems that support VR experiences, the computer programs that allow design and learning activities, and the game-based environments that create interactive worlds for experience. The proposed categorization is based on existing studies of educational VR methods. Previous research has employed similar categorizations, usually based on pedagogical aims or technological features [29,30]. For instance, Zhao et al. [31] categorize VR applications based on content

delivery modes, and Radianti et al. [6] identify application domains based on learning goals. In this paper, the three categories are described in detail and their relevance to architectural and design education is explored.

VR Platforms

VR platforms are the foundational infrastructure for developing, deploying, and managing immersive experiences. VR platforms include both software development environments and hardware ecosystems, providing the technical underpinning for VR applications. Anthes et al. [32] explain that VR platforms are typically categorized into three types: desktop-based, mobile-based, and head-mounted display (HMD)-based systems.

1. Desktop-Based VR Platforms: Desktop-based VR platforms, such as Unity3D, Unreal Engine and Twinmotion, allow for the creation of virtual environments that are accessed through an interface on a computer. They are being utilised in architect and design education heavily for tasks such as 3D modeling and virtual walk-throughs.
2. Mobile-Based VR Platforms: Mobile-based systems, such as Google Cardboard and Oculus Go, offer low-cost and accessible VR experiences through the use of smartphone technology [6]. These types of systems are particularly useful in introductory-level courses and for individual, self-paced learning activities.
3. HMD-Based VR Platforms: HMD-based systems like Oculus Rift, HTC Vive, and Microsoft HoloLens provide fully immersive environments with real-time spatial interaction [26].

VR Applications/Tools

VR applications/tools are the software programs that are specifically designed to support learning activities, e.g., design modeling, collaboration, and performance analysis. Unlike platforms, which provide the infrastructure for VR development, applications/tools provide user-friendly interfaces for direct learning interaction. According to Mikropoulos and Natsis [27], VR learning tools can be categorized according to their pedagogical function, i.e., tools for exploration, simulation, collaboration, and design creation.

1. Exploration Tools: Google Earth VR and Wander are a few of the tools that enable students to explore architectural spaces and urban settings in a virtual manner. These tools are particularly helpful to instruct site analysis and environmental context.
2. Simulation Tools: Simulation software, like VR Safety Training environments, replicates actual construction settings to teach procedural knowledge and safety protocols. In architectural education, these tools assist in making students understand structural behavior and material interaction.
3. Collaborative Tools: Collaborative VR tools, such as The Wild and Mozilla Hubs, facilitate real-time interaction among the students and the tutors from distant locations [16].
4. Design Creation Tools: There are some tools like VR Sketch and SketchUp VR, which are aimed at architectural design tasks, allowing students to manipulate, work with, and analyze virtual buildings within immersive environments [33].

VR Games and Game-based Learning Environments

Game-based learning environments (GBLEs) in VR adopt the gamification concepts to implement interactive and captivating learning experiences. The application of game mechanics such as challenges, rewards, and narratives can indeed enhance motivation, engagement, and knowledge retention for architecture and design education [28].

1. Serious Games for Architectural Education: Serious educational games such as Virtual Construction Site and ArchiVR are specifically designed to educate in architectural concepts and

construction operations [34]. The games typically come with real-world construction settings in which the students can rehearse design elements and learn construction plans.

2. Simulation-Based Games: Simulation games provide interactive learning experiences in structural integrity, material performance, and energy efficiency. For instance, ConstructSim VR simulates building element structural performance in different environmental loads [35].
3. Design Games: Games like Minecraft Education Edition allow students to engage in open-ended design projects as they construct and develop their problem-solving and collaborative abilities. These spaces allow for the exploration of design ideas in a game-like yet learning-conducive setting.

Key Research Themes in VR-based Architectural Education

Uses of Virtual Reality to architecture and design education have yielded a conflicted research foundation, with authors looking at the application to enable learning of spatiality, exploration of design, and group work. The dominant themes that emanate from the literature are identified in the subsequent section, pinpointing the priority areas of concern and their impact on pedagogic practice. One of the most important research areas is spatial understanding and visualization. The nature of immersion in VR allows architecture students to walk around and explore design concepts at full size, which has been proven to increase spatial understanding and design comprehension [13]. Studies have revealed that VR software can allow students to better comprehend complex spatial relationships than 2D drawings, particularly when exploring volumetric, material, and structural aspects of architectural forms [14].

Another significant theme is the use of VR for collaborative learning and design. With professional practice increasingly based on interdisciplinary teamwork, scholars have explored how VR collaborative environments can simulate professional design processes. Programs like The Wild and Mozilla Hubs support synchronous, offsite collaboration, with students co-designing and inspecting designs simultaneously [16]. These studies hint at the capability of VR to augment collaboration, communication abilities, and joint decision-making.

Game-based learning is also a prominent topic in VR architectural education. Borrowing from the concepts of gamification, research has explored how VR games could increase motivation and engagement by using challenges, rewards, and interactive tasks [28]. Minecraft Education Edition, for example, has been used in education for design principles in a gamified but pedagogical setting with positive outcomes for creativity, problem-solving, and collaboration.

Another field that is of great interest is simulation-based training. VR applications which simulate construction works, material behaviors, and safety protocols have grown in popularity across architecture and construction education [6]. Through these applications, students are able to practice the real tasks like site visits or structural inspections, and gain clear understanding of how construction works but without the limitation of physical field visits. Collectively, these research themes point to VR's potential for augmenting architectural education in terms of interactive, collaborative, and immersive learning processes.

Gaps, Challenges, and Future Directions for VR in Architecture and Design Education

Despite the rising applications of Virtual Reality technologies in architecture and design education, several gaps and issues remain that need to be explored and innovated further. While earlier studies have determined the potential of VR in education for enhancing spatial knowledge, experimenting with design, and collaborative learning, their application in teaching practice remains uneven and fragmented [6]. This section of the chapter outlines the principal limitations in the literature, the challenges of using VR, and some potential areas for future studies.

One of the areas that are lacking in current research is longitudinal studies assessing the long-term educational impacts of VR-based learning environments [6,13]. Most of the current research is focused on

short-term effects, such as immediate performance improvement or self-reported interest, without evaluating if these experiences translate to long-term effects on knowledge retention, design thinking, or the acquisition of spatial abilities. Longitudinal study designs must be employed in future research to evaluate such long-term effects, particularly in architectural design education, where professional practice is highly dependent on spatial cognition.

A second important gap is the lack of empirical research on pedagogical methods that effectively integrate VR into architecture education. While studies like Wang et al. [15] and Milovanovic et al. [14] have examined the affordances of VR environments, few have provided concrete, evidence-based suggestions for educators who wish to incorporate these technologies into studio-based design courses. Lack of pedagogic models or framework makes it tough for academic institutions to embrace VR solutions. Upcoming research efforts must endeavor to conceptualize and empirically validate pedagogically strong models bridging VR applications to well-documented education principles like constructivism and experiential learning.

Limitations from a technical front too pose severe hindrances towards adoption of VR into architecture and design education. Hardware constraint, such as the cost of VR headsets and computational power required for rendering complex architectural models, continues to constrain adoption [32]. In addition, motion sickness, resolution of display, and interaction fidelity problems can reduce effectiveness of VR learning environments, particularly for high precision spatial manipulation tasks [26]. Advances in VR hardware, like the manufacture of less expensive, wireless, and high-definition units, are required to overcome these challenges and render VR more affordable for financially strained schools.

Pedagogical concerns extend beyond hardware and software problems. Teachers typically face a steep learning curve in using VR technology because it requires technical proficiency for design programs as well as for immersive hardware [27]. Lack of proper professional development support and instructional resources exacerbates this issue, resulting in patchy or tangential applications of VR throughout the classroom. In order to address this challenge, future research will have to focus on the development of training programs, better practice guidelines, and easy-to-use interfaces that prepare teachers to use VR in education successfully.

Ethical and psychological implications must also be probed more. Prolonged exposure to deeply immersive VR environments has been associated with symptoms of disorientation, motion sickness, and skewed perceptions of reality [26]. In educational settings, these effects could impact students' health, motivation, and performance. Moreover, the increasing use of VR creates concerns regarding data privacy, especially when applications collect behavioral data for performance assessment. Future research should address these ethical issues by creating guidelines and safeguards that preserve students' privacy while ensuring guarantees for the safe and ethical use of immersive technologies in education.

In summary, while VR has demonstrated tremendous promise in enhancing architectural and design education, gaps and challenges are significant. Addressing these requires interdisciplinary research studies, technological advancements, pedagogical innovation, and ethical concerns. Longitudinal impacts, pedagogical paradigms, platform interoperability, teacher training, game-based learning, and ethical safeguards must be the subjects of future studies to maximize the educational value of VR technologies and support the next generation of designers and architects.

4. FINDINGS

In summary, this review are based on 68 academic studies on the role of virtual reality concepts in architecture and design education. These academic researches has been selected from years between 2000-

2025. Selected studies are presented in Table 1 and are arranged chronologically according to their publication years.

Table 1. Selected studies

#	Title	Authors	Year
1	An immersive virtual reality learning system for building systems in architectural design education	Natephra, W., Shahinmoghadam, M., & Motamedi, A.	2025
2	A 3D quick sketch algorithm in virtual reality for concept design in architectural studio	Erdem, E., & Çiftçioğlu, Ö.	2024
3	A Comparative Study on the VR Experience of Students in a Digital Documentary Game	Şahin, P., Çalışkan, A., Hacıtahiroğulları, Z. V., Ceylan, S., Çatak, G., & Masalcı, S. Z.	2024
4	Co-Created Virtual Reality (VR) Modules in Landscape Architecture Education: A Mixed Methods Study Investigating the Pedagogical Effectiveness of VR	Andalib, S. Y., & Monsur, M.	2024
5	Design of Interactive Walkthrough System of Huizhou Style Architecture Based on 3D and VR Technology	Wang, Huasheng & Qiu, Duorong & Li, Weimin & Li, Weiwei & Wu, Zeying.	2024
6	Enhancing Online Learning in Architectural Education: A Virtual Reality Enabled Experiment with Arkio	Yıldırım, E.	2024
7	Mimarlık Öğrencilerinin Sanal Gerçeklik Ortamında Safranbolu Tabakhanesinde Rölöve Alma Deneyimi	Küçükkara, M. Y., Özacar, K., & Ortakcı, Y.	2024
8	On the application of virtual reality technology in the teaching of "landscape architecture design"	Yu, A., & Xu, Z.	2024
9	Project Beyond: An Escape Room Game in Virtual Reality to Teach Building Energy Simulations	Arbesser-Rastburg, G., Safikhani, S., Gustin, M., Hopfe, C., Schweiger, G., & Pirker, J.	2024
10	Research on the Application of Three-Dimensional Virtual Reality Technology in Landscape Architecture Design	Chen, Y.	2024
11	A Proposed Framework for integrating IVR Technology in Architectural Design courses; Application on architectural schools in Egypt	Abdelhameed, W. A.	2023
12	BIM-enabled virtual reality (VR)-based pedagogical framework in architectural design studios	Rasouli, A. H., Banihashemi, S., Sanders, P., & Rahimian, F. P.	2023
13	Design with Sound: The Relevance of Sound in VR as an Immersive Design Tool for Landscape Architecture	Luoma, L., Fricker, P., & Schlecht, S. J.	2023
14	Immersive Virtual Reality, Tool for Accessible Design: Perceived Usability in an Interior Design Studio Setting	Santos, R. M., & Duarte, J. P.	2023
15	Integrating Virtual Reality and interactive game for learning structures in architecture: the case of ancient Chinese dougong cognition	Pei, W., Lo, T.T.S., & Guo, X.	2023
16	Mimarlıkta Yapı Dersleri Müfredatı Dijital Dönüşüm Modeli	Seyman Güray, T., & Kısmet, B.	2023
17	Virtual Reality Technology in Architectural Theory Learning: An Experiment on the Module of History of Architecture	Shanti, Z., & Al-Tarazi, D.	2023
18	VRArchEducation: Redesigning building survey process in architectural education using collaborative virtual reality	Özacar, K., Ortakcı, Y., & Küçükkara, M. Y.	2023
19	A workflow for multi-user VR application within the physical classrooms of architecture and urbanism courses	Gomes, Emerson Bruno & Rebelo, Francisco & Vilas Boas, Naylor & Noriega, Paulo & Vilar, Elisângela.	2022
20	BIM LOD + Virtual Reality -- Using Game Engine for Visualization in Architectural & Construction Education	Anifowose, H., Yan, W., & Dixit, M.	2022
21	Building a virtual Roman city: teaching history through video game design	Forsyth, H.	2022
22	Dreamscape Bricks VR: An Experimental Virtual Reality Tool for Architectural Design	Doma, O. O., & Şener, S. M.	2022
23	Introducing Immersive Virtual Reality in the Initial Phases of the Design Process—Case Study: Freshmen Designing Ephemeral Architecture	González, M. A., & Blanco, A.	2022
24	The Application of Virtual Reality Technology in Interior Design Education: A Case Study Exploring Learner Acceptance	C. Li and G. Xie	2022

25	The potential of immersive virtual reality for representations in design education	Horvat, N., Martinec, T., Lukačević, F. et al.	2022
26	Applying immersive virtual reality for remote teaching architectural history	Chan, C.-S.	2021
27	Embedding VRAD (Virtual Reality Aided Design) in Architectural Pedagogy	Alizadehsalehi, S., & Yitmen, I.	2021
28	FAMU Digital Documentation, a VR narrative for architectural education	Lescop, L., Chin, A., Park, S. B., Ehtemami, A., & Bernardin, S.	2021
29	Integrating virtual reality technology into architecture education: the case of architectural history courses	Ibrahim, A., Al-Rababah, A. I., & Bani Baker, Q.	2021
30	Mixed Assessment of Virtual Serious Games Applied in Architectural and Urban Design Education	Fonseca, D., Cavalcanti, J., Peña, E., Valls, V., Sanchez-Sepúlveda, M., Moreira, F., Navarro, I., & Redondo, E.	2021
31	SimYA: A virtual reality–based construction studio simulator	Şahbaz, E.	2021
32	Strategies for the Utilization of Virtual Reality Technologies in the First Year of Architectural Education	Ceylan, S	2021
33	The Drawing and Perception of Architectural Spaces through Immersive Virtual Reality	Gómez-Tone, H. C., Bustamante Escapa, J., Bustamante Escapa, P., & Martin-Gutierrez, J.	2021
34	The effectiveness of interactive virtual reality for furniture, fixture and equipment design communication: an empirical study	Prabhakaran, Abhinesh & Mahamadu, Abdul-Majeed & Mahdjoubi, Lamine & Manu, Patrick & Che Ibrahim, Che Khairil Izam & Aigbavboa, Clinton	2021
35	Developing an Integrated VR Infrastructure in Architectural Design Education	Aydin, S., & Aktaş, B.	2020
36	Immersive Virtual Reality for Assisting in Inclusive Architectural Design	Lach, E., Benek, I., Zalewski, K., Skurowski, P., Kocur, A., Kotula, A., Macura, M., Pamuła, Z., Stankiewicz, M., & Wyrobek, T.	2020
37	Implementing Virtual Reality Headsets in Design Education	Chan, C. P.	2020
38	The Influence of Virtual Reality on Design Process Creativity in Basic Design Education	Obeid, S., & Demirkan, H.	2020
39	User Study on Virtual Reality for Design Reviews in Architecture	Zaker, R., & Coloma, E.	2020
40	Using Virtual Reality to Improve Visual Recognition Skills of First Year Architecture Students: A Comparative Study	Ceylan, S., Şahin, P., Seçmen, S., & Süher, H. K.	2020
41	Vr-Based Interactıve Learnıng In Archıtectural Educatıon: A Case On Safranbolu Hıstorıcal Bathhouse	Şahbaz, E.	2020
42	A New Game-Based Immersıve Vırtual Learnıng Tool For Perceıvıng Behavıour Of Structures: Structurepuzzlevr	Güney, E.	2019
43	CubeVR: Digital Affordances for Architecture Undergraduate Education using Virtual Reality	Goulding, J., Rahimian, F. P., & Wang, X.	2019
44	Design and Development of a Virtual Reality Educational Game for Architectural and Construction Reviews	Castronovo, Fadi & Nikolic, Dragana & Mastrolembo Ventura, Silvia & Akhavian, Reza & Gaedicke, Cristian & Yilmaz, Semih.	2019
45	Integration of Virtual Reality (VR) in Architectural Design Education: Exploring Student Experience	Williams, J., Orooji, F., & Aly, S.	2019
46	The application of virtual reality technology in architectural pedagogy for building constructions	Al-Rawabdeh, W., & Al-Azhari, W.	2019
47	Thinking in Virtual Spaces: Impacts of Virtual Reality on the Undergraduate Interior Design Process	Pober, E. & Cook, M.	2019
48	Usability of virtual reality for basic design education: a comparative study with paper-based design	Özgen, D. S., Afacan, Y., & Sürer, E.	2019
49	Usability studies on building early stage architectural models in virtual reality	de Klerk, R., Mendes Duarte, A., Pires Medeiros, D., Pinto Duarte, J., Jorge, J., & Simões Lopes, D.	2019
50	User-centered interior finishing material selection: An immersive virtual reality-based interactive approach	Zhang, Y., Liu, H., Zhao, M., & Al-Hussein, M.	2019
51	An Educational Application Based on Virtual Reality Technology for Learning Architectural Details: Challenges and Benefits	Maghool, S. A. H., Moeini, S. H. I., & Arefazar,	2018
52	Implementing and Evaluating an Immersive Virtual Learning Environment for Learning How to Design in Human-Scale	Sönmez, O.	2018

53	Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems	Paes, D., Arantes, E., & Irizarry, J.	2017
54	Integrating Procedural Modelling Process and Immersive VR Environment for Architectural Design Education	Lin, C.-H., & Wang, Y.-C.	2017
55	Investigating the Effect of Employing Immersive Virtual Environment on Enhancing Spatial Perception within Design Process	Abu Alatta, R. T., & Freewan, A. A.	2017
56	Sanal gerçekliğin iç mimarlık eğitimine etkisi	Şekerci, C.	2017
57	Development of High-Definition Virtual Reality for Historical Architectural and Urban Digital Reconstruction: A Case Study of Azuchi Castle and Old Castle Town in 1581	Fukuda, T., Ban, H., Yagi, K., & Nishiie, J.	2015
58	Rediscovering Virtual Reality in the Education of Architectural Design: The immersive simulation of spatial experiences	Angulo, A.	2015
59	Heritage conservation and architectural education: "An educational methodology for design studios"	Elkadi, H.	2014
60	Virtual Reality Use in Architectural Design Studios: A Case of Studying Structure and Construction	Abdelhameed, W. A.	2013
61	An affordable immersive environment in beginning design studio education.	Gundrum, J.	2012
62	Development of Virtual Reality Tool for Creative Learning in Architectural Education	Kamath, R. S., Dongale, T. D., & Kamat, R. K.	2012
63	Digital preservation of historical buildings using virtual reality technologies	Hrozek, F., Sobota, B., & Szabó, C.	2012
64	Evaluating Relative Impact of Virtual Reality System Variables on Architectural Design Comprehension and Presence	Kalisperis, L. N., Muramoto, K., Balakrishnan, B., & Zikic, N.	2006
65	Boosting up Architectural Design Education with Virtual Reality	Dvorak, J., Hamata, V., Skacilik, J., & Benes, B.	2005
66	Integrated architectural surveying and planning: Methods and tools for recording and adjusting building survey data	Boeykens, S., Neuckermans, H., & Neuckermans, H.	2005
67	Virtual Reality in the Design Studio: the Eindhoven Perspective	Verbeke, J., & Vanhoutte, T.	2002
68	The representation of virtual reality in education	Antonietti, A., Rasi, C., Imperio, E., & Sacco, M.	2000

The studies listed in Table 1 illustrate the gradual integration of virtual reality technologies into educational contexts within architectural studies. Research developed over time is distributed with a view to providing an accurate picture of what happened regarding developments in the use of this technology. The trend of temporal publications allows the scientific world to increase interest in this area of VR learning and take part in discussion of the role that this new paradigm assumes. The following table shows the chronological distribution of the reviewed studies, underlining the increased focus on immersive methodologies over time.

Chart 1. Yearly distribution of selected studies

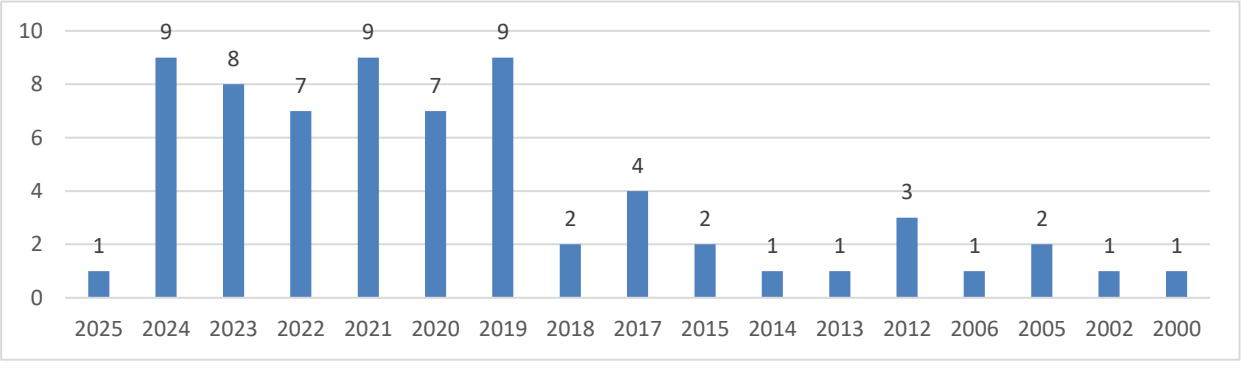

Chart 1 illustrates the distribution of publication years across 68 academic studies focused on VR applications in architectural and design education. The graph provides evidence of increased research

activity, particularly between 2019 and 2025, with publication rates peaking at nine studies per year in 2019, 2021, and 2024. Such a trend might refer to an increased interest in integrating VR technology into the field in the period in question, probably due to advances in VR technology and the quite reasonable price theretofore. Another point is that hinting at the very infant stages of application, as far as applying VR in the domain in the years like 2002 and 2005. Observing the graph, one can perceive a sharp upward trend after 2019, highlighting the growing recognition and development of VR's potential in enhancing learning within the field of architecture. The consistent flow of numbers starting from 2019 demonstrates continuous scholarly interest in and maturity through pedagogical use. This growth further underlines the relevance of VR in contemporary educational practices, and the data suggests continuing momentum that researchers may continue to draw on, availing themselves of emerging technologies and methodologies.

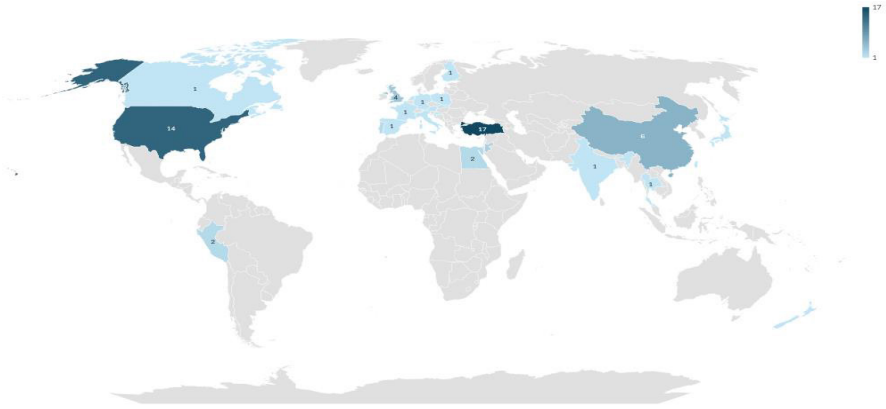

Figure 2. Country distribution of selected studies

Figure 2 illustrates the distribution of research into the use of virtual reality-based learning environments in architecture education across different nations. Of the 68 studies analyzed, the largest concentrations of research came from Turkey with 17 studies and the United States with 14 studies. Other significant contributors were China with 6 studies, while a number of countries made more minor contributions, including Egypt, Germany, and Italy. The prominence of Turkey in the current review is arguably because this review included specific Turkish research keywords that made many studies from the country more traceable. Although the prevalence of the studies in certain nations underlines unequal development and interest across areas, the representation of the nations in Asia, Europe, and North America denotes the global importance of VR-based learning in architecture education.

Chart 2. Distribution of selected studies based on publication type

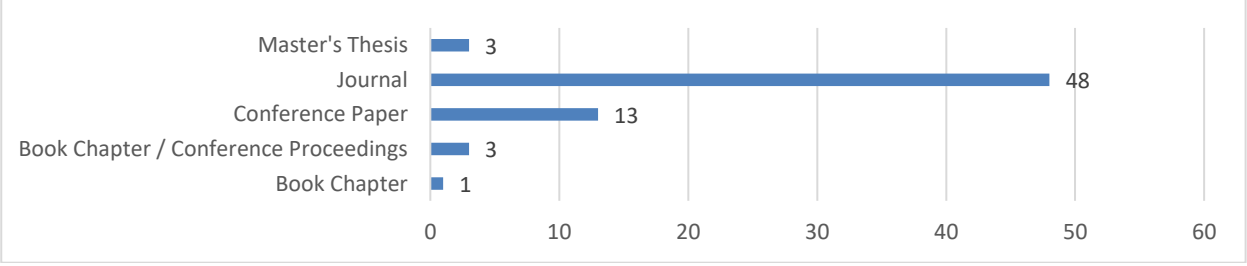

Chart 2 indicates the publication types of the 68 works under examination. Of these, the dominant group comprises 48 studies in the class of journal articles, amounting to about 71% of the total. This may mean that the most preferred channel for sharing research on VR-based learning environments in architectural

education is the peer-reviewed journals. Thirteen papers, or 19%, of the works are conference papers, showing that conferences also form an important avenue for presenting new research in this area. The representation is low for other formats, such as book chapters, at three studies, 4%, and master's theses, at one study, 1%. Three works, four percent, are also represented in the category "Book Chapter/Conference Proceedings.

Chart 3. Focus areas of selected studies

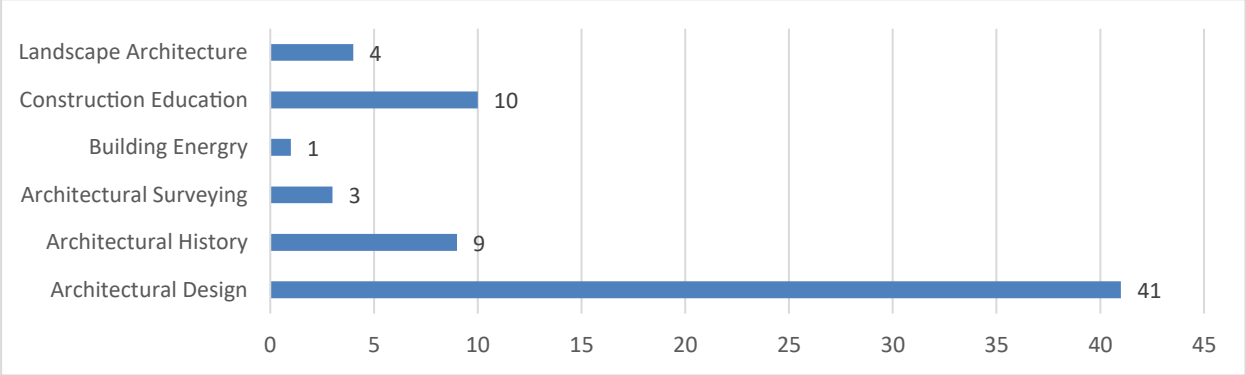

Chart 3 shows the distribution according to the subject focus of 68 studies in a greater context of architectural education using virtual reality-based learning environments. About 60%, or 41 studies, were about architectural design, which remains at the leading edge in research into VR applications in architecture. This represents great interest in learning how the use of virtual reality technology could improve visualization, creativity and other issues related to design. With 10 research (15%), construction education is the second-largest focal area, demonstrating the value of virtual reality in teaching and training students in construction-related procedures and practices. Nine works (13%) relate to architectural history and demonstrate how virtual reality serves as a tool for learning about, reconstructing, or teaching architectural history. The other fields, which account for a smaller part of the research, include Landscape Architecture with 4 studies or 6%, Architectural Surveying with 3 studies or 4%, and Building Energy 1 study or 1%. These results show that the use of virtual reality has newly found applications in subfields such as surveying or energy efficiency but have been restricted up to now.

Chart 4. Types of VR integration in selected studies

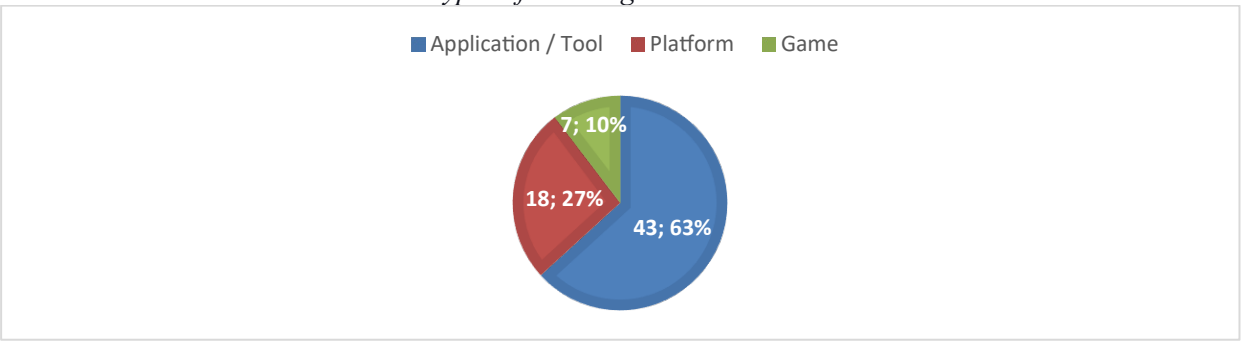

Chart 4 reflects the distribution of the studies based on their focus within VR-based learning environments in architectural education. Application/Tool, Platform, and Game are the categories under review. Application/Tool has the highest share, with 43 studies at 63%. This area indicates that most of the research involves creating customized solutions for education by either creating or making use of some sort of stand-alone program or tool designed for VR environments. The prevalence underlines the considerable relevance of exploiting virtual reality to create interactive applications for architectural education. On the other hand,

Platform 18 (27%) studies use VR as a platform or interface to investigate pre-existing models or to carry out analyses in VR. This category represents a use of VR mainly for viewing or interaction rather than creating new tools or games. The smallest portion comprises game-based learning, with seven research (10%); gamification of architectural instruction and places them into virtual reality games. Though this category is underrepresented, it can be seen that the use of gamification as a teaching method is gaining momentum in virtual environments.

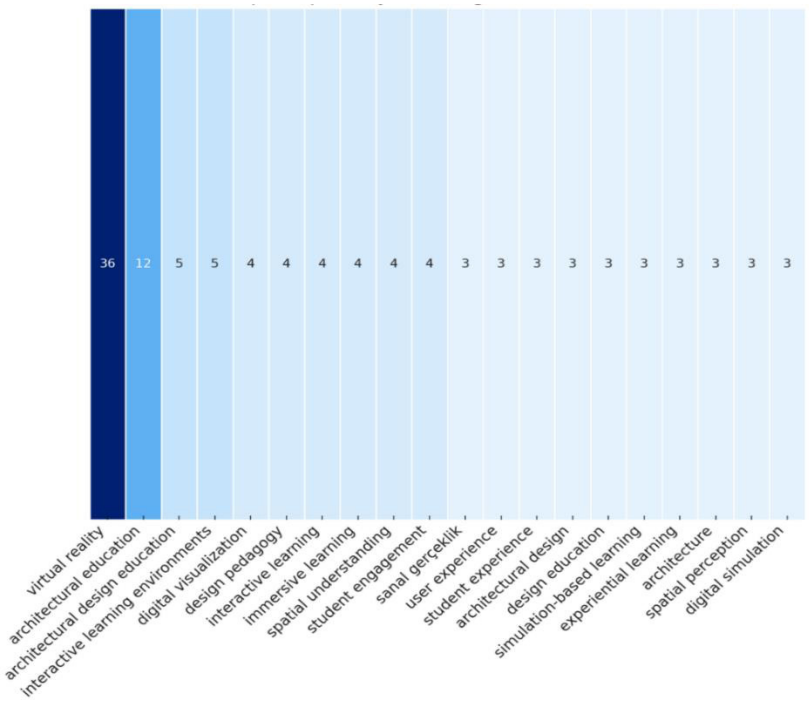

Figure 3. Keyword frequence (of the most 20) of selected studies

Figure 3. represents the frequency distribution of most used 20 keywords from 68 academic studies related to virtual reality and architectural education. In this context, the most dominant terms are virtual reality (VR), architectural education and architectural design education. The analysis focuses on keywords that appear four or more times, which can provide information on dominant research topics, educational needs, and potential gaps. The frequency of the keywords virtual reality, architectural education and architectural design education is to be expected, given the topic of the research. The studies at hand were purposefully selected as being relevant to the use of VR in architectural and design pedagogy. The frequency of the keywords is thus simply a reflection of the core thematic extent of the literature at hand rather than an indicator of an emergent or nascent trend. "Virtual reality" is the primary field of technology that is in research, and "architectural education" is the pedagogical setting wherein these technologies are implemented.

The repeated occurrence of interactive learning environments reflects the pedagogical shift towards more interactive, participatory learning experiences. VR enables interactive learning by immersing students in spatially dynamic, context-rich environments that promote active exploration and critical thinking [13]. The frequency of this keyword indicates a need to leverage VR in shifting from passive to active learning strategies. The focus on digital visualization reflects utilization of VR as a tool for supporting the re-enforcement of the visual communication of design concepts. The visualization capability of VR allows

students to grasp abstract design principles since it provides life-like, zoomable, and editable virtual environments [34]. Design Pedagogy indicates scholarly interest in the ways VR technology influences teaching methods and designs methods of instruction. The move toward tools in technology necessitates pedagogic creativity to adequately deploy VR in studio courses [27]. Frequency of this word indicates ongoing movement toward integrating good school design practice with technology-driven educational techniques. Like "interactive learning environments," interactive learning keyword maintains the teaching community's enthusiasm for creating participatory, active learning experiences. VR uses in design education often revolve around interaction as a means to enhance problem-solving and spatial reasoning skills [6]. The immersive learning theory, which closely aligns with VR's affordances, alludes to the use of VR in creating rich context-based learning. Immersion in virtual space promotes deeper thinking, as learners can experience and interact with forms of architecture within simulated worlds [26]. The usage frequency of this keyword suggests sustained interest in researching the cognitive benefits of immersion on architectural design processes. Spatial understanding is the foundation of architectural education, and the ability of VR to describe spatial relationships dynamically explains the predominance of this term [14]. Student Engagement remains a deciding factor in learning attainment, and VR's game-based, interactive nature has been shown to motivate learners [28]. The occurrence of this keyword in its accessible frequencies aligns with research demonstrating that interactive VR applications can enhance attentiveness and engagement, particularly when combined with game-based learning practices.

5. DISCUSSION

The results of this review have highlighted the huge development and diversity in the application of Virtual Reality technologies within architecture and design education. The selected studies, ranging from 2000 to 2025, indicate an accelerating interest in integrating VR tools, platforms, and games to improve learning outcomes. This might be explained by the rising interest in VR, especially after 2018, which has gone along with the enhancement of hardware and software for VR technologies and their availability within educational settings. First, improvements in VR technology at around this time probably made it more affordable and available for use in research and teaching. The advent of robust, relatively inexpensive hardware such as Meta Oculus headsets and software platforms would naturally have encouraged these researchers to investigate what virtual reality has to offer from state-of-the-art educational settings. Second, the general global trend of digital transformation, especially during and after the COVID-19 pandemic in 2020, may have accelerated the adoption of VR in education. As the pandemic created a growing demand for remote and immersive learning solutions, virtual reality emerged as a practical method to enhance engagement and participation in architectural education. Last but not least, growing awareness of the pedagogical benefits of VR-like better visualization, interactivity, and the possibility of simulating real conditions-may have contributed to the rise in study interest. The fact that researchers are increasingly becoming aware of the potential of VR to solve conventional problems in teaching and learning does indeed mark a shift in the status of this technology within architectural education. This increasing trend in VR-related research is likely to further intensify as the technology becomes increasingly integrated into teaching methodologies.

Geographical distribution of the selected studies underlines the global relevance of VR in architecture and design education, with countries such as Turkey, the United States, and China standing out. The analysis of the publication types allows seeing the dominance of journal articles, at about 71%, while the second biggest category corresponds to the conference publications. This can reflect partiality toward such publications and high importance given to peer-review research in this domain. On the other hand, conferences represent equal and important ground to present novelties or preliminary results, as shown in the case of conference papers representation. While represented to a lesser extent, master's theses and book chapters also offer insights and exploratory approaches that complement the wider literature.

The thematic distribution of the studies reveals a strong predominance of the architectural design theme, constituting the majority of the research. This dominance may suggest that VR is mainly used to support design processes, enhance spatial cognition, and develop capabilities for visualization. Other topics, such as construction education, architectural history, and landscape architecture, further reveal the flexibility of VR in responding to a wide range of educational aims. In contrast, building energy and surveying have seldom been discussed, and therefore offer some avenues for further research into new applications of VR. The very diversity of the types of VR-based approaches themselves-applications/tools, platforms, and games-emphasizes further the multifunctionality of VR in architectural education. The most prevalent category here is applications and tools, representing a focus on the creation of tailored solutions for particular educational needs. Platforms are mostly used for visualization and interaction and underline the utility of VR as a supportive interface for already existing models. Game-based learning, though underrepresented, has the potential to engage learners in interactive and gamified experiences that correspond to the current trends in serious gaming and immersive learning. The prevalence of the Application/Tool category would indicate that the researchers first focus on the development of custom VR applications, which meet certain learning objectives. The low percentage of game studies would suggest that game-based learning is still in its infancy as a discipline within architectural education and requires further research to reach its full potential. This release, focused on the development of specialized tools while considering both the use of platforms and gamification, represents the different ways in which VR can be applied to architectural education. Despite the considerable contribution of these reviewed studies, there are still important empirical gaps related to long-term influences of VR on learning outcomes and development of standardized curricula. These shortcomings should be addressed in future research: proceedings that incorporate a strong methodology, coupled with longitudinal designs, are urgently needed to determine the continued effectiveness of VR technologies. Moreover, interdisciplinary collaboration can help further increase both access and usability regarding VR equipment-a guarantee for full integration across educational settings.

6. CONCLUSION

This bibliometric review has revealed that VR technologies have been increasingly integrated into architecture and design education, demonstrating their transformative potential. It has highlighted a global interest in VR, from Europe to USA. Most of the literature has been found to be based on journal articles, reflecting the rigorous peer-review process that high-quality research typically undergoes. Thematic analysis has also highlighted architectural design as the primary focus, supported by virtual reality tools, platforms, and game-based learning environments. Additionally, it has indicated that VR can enhance spatial cognition, design understanding, and collaborative learning in studies of valuable insight into its evolving role within educational settings. Significant gaps remain in understanding the long-term impacts of VR in architectural education and the development of standardized curricula. Future research should focus on empirical studies and interdisciplinary approaches to enhance the accessibility and effectiveness of VR-based learning. This, in turn, provides a foundation for further research, guiding educators and researchers in leveraging VR technologies for innovative and immersive learning environments.

Beyond VR-based learning spaces, advancements in technologies such as Artificial Intelligence, Virtual Reality, Augmented Reality, Mixed Reality, and Extended Reality are reshaping architectural concepts, development, and execution while introducing new possibilities for creativity and efficiency. This transformation necessitates a reevaluation of pedagogy to equip future architects and designers with the necessary digital competencies while preserving spatial awareness, core design principles, creativity, and critical thinking skills. Thus, a balanced approach, supported by a restructured curriculum that integrates traditional architectural methodologies with emerging technologies, will be essential in preparing designers for an evolving professional landscape. Collaborative programs between academic institutions and

professional disciplines can play a key role in standardizing tools and methods while ensuring that educational content remains relevant to industry practices. Furthermore, longitudinal studies on the cognitive and pedagogical impact of these technologies will be crucial in refining instructional strategies and maximizing their educational value, ensuring that students are well-equipped to navigate and innovate within a technologically advanced architectural field.

REFERENCES

[1] Oxman, R. (2017). Thinking about computational design. Design Studies, 52, 1–12. https://doi.org/10.1016/j.destud.2017.04.001

[2] Celani, G., & Vaz, C. E. V. (2012). CAD scripting and visual programming languages for implementing computational design concepts: A comparison from a pedagogical point of view. International Journal of Architectural Computing, 10(1), 121–137. https://doi.org/10.1260/1478-0771.10.1.121

[3] Ibrahim, S., et al. (2021). Digital tools and architectural education: Bridging the gap between academia and industry. Design Studies, 75, 101023. https://doi.org/10.1016/j.destud.2021.101023

[4] Merschbrock, C., & Munkvold, B. E. (2015). Effective digital collaboration in the construction industry – A case study of BIM deployment in a hospital construction project. Computers in Industry, 73, 1–7. https://doi.org/10.1016/j.compind.2015.07.003

[5] Dossick, C. S., & Neff, G. (2011). Messy talk and clean technology: Communication, collaboration and BIM. Engineering Project Organization Journal, 1(2), 83–93. https://doi.org/10.1080/21573727.2011.569929

[6] Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*,. https://doi.org/10.1016/j.compedu.2019.103778

[7] Schön, D. A. (1983). The Reflective Practitioner: How Professionals Think in Action. Basic Books.

[8] Salama, A. M. (2015). Spatial design education: New directions for pedagogy in architecture and beyond. International Journal of Architectural Research, 9(1), 1–4.

[9] Rogers, J., et al. (2019). Challenges of integrating digital design into architecture curricula. International Journal of Technology and Design Education, 29(2), 235–256. https://doi.org/10.1007/s10798-018-9443-5

[10] GhaffarianHoseini, A., et al. (2017). Building Information Modeling (BIM) uptake: The global view. Renewable and Sustainable Energy Reviews, 73, 982–999. https://doi.org/10.1016/j.rser.2017.02.066

[11] Sacks, R., et al. (2013). The role of Building Information Modeling (BIM) in design education: A review of pedagogical approaches. Automation in Construction, 34, 98–109. https://doi.org/10.1016/j.autcon.2013.01.011

[12] Mollaert, M., et al. (2022). Digital transformation in architecture: A comparative study of industry needs and educational practices. Architectural Science Review, 65(3), 265–279. https://doi.org/10.1080/00038628.2022.2036423

[13] Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? British Journal of Educational Technology, 41(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

[14] Milovanovic, J., Morel, L., Babic, A., & Baucal, A. (2017). Spatial skills and virtual reality in architectural education. Computers & Education, 113, 144–159. https://doi.org/10.1016/j.compedu.2017.05.013

[15] Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. International Journal of Environmental Research and Public Health, 15(6), 1204. https://doi.org/10.3390/ijerph15061204

[16] Abdellatif, A. M., & Abdelwahab, H. T. (2022). Collaborative learning in VR design studios: An evaluation of Mozilla Hubs in architectural education. Computers & Education, 185, 104567. https://doi.org/10.1016/j.compedu.2022.104567
[17] Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. Organizational Research Methods, 18(3), 429–472. https://doi.org/10.1177/1094428114562629
[18] Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070
[19] Garfield, E. (1972). Citation analysis as a tool in journal evaluation. Science, 178(4060), 471–479. https://doi.org/10.1126/science.178.4060.471
[20] Katz, J. S., & Martin, B. R. (1997). What is research collaboration? Research Policy, 26(1), 1–18. https://doi.org/10.1016/S0048-7333(96)00917-1
[21] van Eck, N. J., & Waltman, L. (2010). Software survey:VOSviewer, a computer program for bibliometric mapping.Scientometrics,84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3
[22] Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. Journal of the American Society for Information Science, 24(4), 265–269. https://doi.org/10.1002/asi.4630240406
[23] Conesa, J., Mula, F. J., Bartlett, K. A., Naya, F., & Contero, M. (2023). The Influence of Immersive and Collaborative Virtual Environments in Improving Spatial Skills. *Applied Sciences*, *13*(14), 8426. https://doi.org/10.3390/app13148426
[24] Al-Suwaidi, M. F., Agkathidis, A., Haidar, A., & Lombardi, D. (2023). Application of immersive technologies in the early design stage in architecture education: A systematic review. *Architecture and Planning Journal (APJ), 28*(3), Article 27. https://doi.org/10.54729/2789-8547.1222
[25] Wang, X., & Tsai, M. H. (2022). Exploring immersive learning technology as learning tools in design studio pedagogy. *Open House International, 47*(1), 1-15. https://doi.org/10.1108/OHI-01-2022-0020
[26] Slater, M. (2017). Impacts and implications of virtual environments on human perception. Annual Review of Psychology, 68, 373–399. https://doi.org/10.1146/annurev-psych-010416-044610
[27] Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). Computers & Education, 56(3), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020
[28] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "gamification". Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, 9–15. https://doi.org/10.1145/2181037.2181040
[29] Hodge, C., Smith, T., & Jones, R. (2021). Beyond genre: Classifying virtual reality experiences. Virtual Reality, 25(3), 345–362. https://doi.org/10.1007/s10055-021-00482-5
[30] Motejlek, J., & Alpay, E. (2021). A taxonomy of virtual and augmented reality applications in education. Computers & Education, 168, 104214. https://doi.org/10.1016/j.compedu.2021.104214
[31] Zhao, Y., Li, H., & Chen, X. (2022). Categorizing educational VR applications: A systematic review. Education and Information Technologies, 27(3), 4121–4145. https://doi.org/10.1007/s10639-022-10892-x
[32] Anthes, C., García-Hernández, R. J., Wiedemann, M., & Kranzlmüller, D. (2016). State of the art of virtual reality technology. IEEE Aerospace and Electronic Systems Magazine, 31(3), 18–27. https://doi.org/10.1109/MAES.2016.160122
[33] Zhang, Y., Yang, L., & Liu, C. (2021). VR-based architectural design tools: Opportunities and challenges. Journal of Architectural Education, 75(4), 527–542. https://doi.org/10.1080/10464883.2021.1944562
[34] Whyte, J. (2002). Virtual reality in built environment education. ITcon, 7, 43–53.
[35] Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). Virtual Reality for design and construction education environments. Automation in Construction, 113, 103146. https://doi.org/10.1016/j.autcon.2020.103146

[36] Yıldız, A. (2022). Bir araştırma metodolojisi olarak sistematik literatür taramasına genel bakış. *Anadolu Üniversitesi Sosyal Bilimler Dergisi*, 22(Özel Sayı 2), 367-386. https://doi.org/10.18037/ausbd.1227366

Arda ÇALIŞKAN, Teaching Assistant
Arda Çalışkan graduated from Bahçeşehir University, Department of Interior Architecture and Environmental Design in 2017. He started his master's education in Bahçeşehir University Interior Design program and graduated in 2020 with the thesis titled "Place-Making Practices of Z Generation: Case of Dormitory Rooms". During this time, he worked as an interior architect at Uğur Schools and Bahçeşehir College. Since 2019, he has been a Teaching Assistant at Bahçeşehir University's Faculty of Architecture and Design. He continues his PhD in Architecture and Design at the same university with the topic of virtual reality and game-based learning in design education.

Suzan GİRGİNKAYA AKDAĞ, Assoc. Prof. Dr
Assoc. Prof. Suzan Girginkaya AKDAĞ, is a full-time lecturer in the Department of Interior Architecture and Environmental Design at Bahçeşehir University. She earned her undergraduate degree in Architecture from METU (2003), followed by a master's degree in Architectural Design Informatics (2007) and a doctorate in Architectural Design (2011), both from ITU. With a strong background in architectural and interior design, she has been actively engaged in various design projects throughout her career. She began her academic journey as a research assistant at Yeditepe University (2007-2011) and has been a faculty member at BAU since then. Her primary research interests lie in the integration of urban, architectural, and interior design, with a special focus on digital technologies. She has authored numerous articles and book chapters on topics such as digital design, user experience, and sustainable design. Additionally, she serves as a referee and academic advisor for projects within the AEC industry.