



Virtual Reality in Digital 3D Modeling for Art and Design Education: A Systematic Review

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Abstract: Objective: This systematic review aims to examine the research trends, technological tools, key research variables, and user experience outcomes reported in studies on virtual reality (VR)-based digital 3D modeling in higher education art and design disciplines. **Methodology:** A PRISMA-based systematic review was conducted. Relevant studies published between January 1, 2018 and March 21, 2024 were retrieved from seven databases: Google Scholar, Web of Science Core Collection, SpringerLink, Scopus, IEEE Xplore, ACM Digital Library, and Taylor & Francis. After identification, screening, eligibility assessment, and manual searching, eight empirical studies were included in the final review. **Findings:** The included studies were published between 2019 and 2023 and were mainly conducted in industrial design, with some applications in architecture and interior design. Frequently used VR tools included Gravity Sketch, Google Blocks, and FlyingShapes, supported by devices such as Oculus Quest and HTC Vive. The reviewed studies commonly examined variables related to usability, engagement, creativity, spatial perception, cognitive load, and design performance. Overall, VR-based digital 3D modeling showed positive potential in enhancing immersion, engagement, design exploration, and spatial understanding. However, findings regarding efficiency, accuracy, and cognitive load were mixed and appeared to depend on tool maturity, task complexity, and learners' prior experience. **Conclusions:** VR digital 3D modeling is a promising supplementary approach for art and design education in higher education, especially in the early stages of ideation and spatial exploration, but it should not yet be regarded as a full replacement for traditional modeling methods. **Recommendations:** Future studies should conduct longitudinal and comparative research, examine different VR tools and interaction methods, and further explore pedagogical strategies for integrating VR with conventional digital 3D modeling instruction.

Keywords: Virtual reality, Digital 3D modeling, Art and design education, Higher education, Systematic review.

استخدام الواقع الافتراضي في النمذجة الرقمية ثلاثية الأبعاد في تعليم الفن والتصميم: مراجعة منهجية

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المخلص: الهدف: تهدف هذه المراجعة المنهجية إلى فحص اتجاهات البحث، والأدوات التكنولوجية، والمتغيرات البحثية الرئيسية، ونتائج تجربة المستخدم الواردة في الدراسات المتعلقة بالنمذجة الرقمية ثلاثية الأبعاد القائمة على الواقع الافتراضي (VR) في تخصصات الفن والتصميم في التعليم العالي. **المنهجية:** أجريت مراجعة منهجية قائمة على إطار PRISMA. وتم استرجاع الدراسات ذات الصلة المنشورة بين 1 يناير 2018 و 21 مارس 2024 من سبع قواعد بيانات، وهي: Google Scholar و Web of Science Core Collection و SpringerLink و Scopus و Taylor & Francis و ACM Digital Library و IEEE Xplore و Gravity Sketch و FlyingShapes و Google Blocks و Flyingshapes، مدعومة بأجهزة مثل Oculus Quest و HTC Vive. وقد تناولت الدراسات التي شملتها المراجعة النهائية. نُشرت الدراسات المشمولة بين عامي 2019 و 2023، وأجري معظمها في مجال التصميم الصناعي، مع بعض التطبيقات في العمارة والتصميم الداخلي. وشملت أدوات الواقع الافتراضي الأكثر استخدامًا Gravity Sketch و Google Blocks و FlyingShapes، مدعومة بأجهزة مثل Oculus Quest و HTC Vive. وقد تناولت الدراسات التي شملتها المراجعة عادةً متغيرات مرتبطة بقبالية الاستخدام، والانخراط، والإبداع، والإدراك المكاني، والعبء المعرفي، والأداء التصميمي. وبوجه عام، أظهرت النمذجة الرقمية ثلاثية الأبعاد القائمة على الواقع الافتراضي إمكانات إيجابية في تعزيز الانغماس، والانخراط، واستكشاف التصميم، والفهم المكاني. ومع ذلك، كانت النتائج المتعلقة بالكفاءة، والدقة، والعبء المعرفي متباينة، ويبدو أنها تعتمد على نضج الأداة، وتعقيد المهمة، والخبرة السابقة للمتعلمين. **الاستنتاجات:** تُعد النمذجة الرقمية ثلاثية الأبعاد بالواقع الافتراضي منهجًا تكميليًا واعدًا في تعليم الفن والتصميم في التعليم العالي، ولا سيما في المراحل المبكرة من توليد الأفكار والاستكشاف المكاني، إلا أنه لا ينبغي النظر إليها حتى الآن بوصفها بديلًا كاملًا لأساليب النمذجة التقليدية. **التوصيات:** ينبغي أن تتجه الدراسات المستقبلية إلى إجراء بحوث طويلة ومقارنة، وفحص أدوات الواقع الافتراضي وأساليب التفاعل المختلفة، ومواصلة استكشاف الاستراتيجيات التربوية الخاصة بدمج الواقع الافتراضي مع تعليم النمذجة الرقمية ثلاثية الأبعاد التقليدية.

الكلمات المفتاحية: الواقع الافتراضي، النمذجة الرقمية ثلاثية الأبعاد، تعليم الفن والتصميم، التعليم العالي، مراجعة منهجية

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Introduction

Virtual reality (VR) technology has been utilized across multiple domains, including education, gaming, and healthcare (Alpala et al., 2022; Sugiyama et al., 2021; Tao et al., 2021). Suh and Prophet (2018) recognized education as a prominent domain for the implementation of immersive technologies. VR technology has been progressively incorporated into the pedagogy of art and design disciplines, including digital art design (Zheng & An, 2023), animation art (Deng et al., 2021), illustration design (Zhang, 2019), environmental art design (Wang & Hu, 2022), and product design majors (Lorusso et al., 2020), with significant impacts on all stages of creative design (Chang et al., 2022).

Jaron Lanier coined the term VR in 1987 (Firth, 2013). Following the development of the concept, several technological advancements expanded the potential of early VR applications in education (Schroeder, 1993). VR systems have significantly enhanced their immersion over the past decade due to advancements in hardware and content (Hutson & Fulcher, 2023). The existing categories of VR are non-immersive, semi-immersive, and completely immersive, distinguished mainly by the degree of immersion provided by the various displays. Head-mounted displays (HMDs), which offer enhanced immersion, have been shown to facilitate skill acquisition in various domains, including cognitive, psychomotor, and affective skills. Research on their use in education and training is proliferating (Makransky & Petersen, 2021). Flow Theory posits that people immersed in highly engaging environments are more likely to achieve a flow state (Csikszentmihalyi, 1990).

Digital 3D modeling is typically a mandatory course for students in art and design disciplines, who must develop proficient digital modeling skills to ensure that their work meets

disciplinary expectations and reflects design competence (Nakazato et al., 2016). Traditional desktop 3D modeling software such as Maya and 3ds Max continues to play a significant role in professional modeling practice and education due to its mature polygon-based workflow and precise geometric control (Bao, 2024). Although these tools are powerful, they mainly rely on the mouse and keyboard for operation, and the interaction mode is relatively abstract. The digital 3D modeling process itself is also highly complex and time-consuming (Bebeshko et al., 2021; Olsen et al., 2009), which, to some extent, can easily lead beginners to feel frustrated in learning and weaken their learning motivation.

In contrast, VR modeling tools enable learners to perform 3D modeling operations in near-life-size virtual environments through immersive, multisensory, and embodied interactions, thereby transforming the traditional desktop modeling approach dominated by two-dimensional interfaces. Research indicates that immersive 3D modeling can reduce cognitive load during learning to some extent, while enhancing learner engagement and fostering the development of creative thinking and problem-solving tendencies (Chen et al., 2024). Furthermore, studies demonstrate that integrating VR modeling tools with traditional modeling methods and other design media fosters multimodal learning experiences during conceptualization and scheme development phases. This approach expands design exploration possibilities while deepening learners' understanding of and engagement with the design process (Andalib & Monsur, 2024; Lee & Peng, 2023). Therefore, based on the pedagogical needs of digital 3D modeling courses, the application of VR technology in art and design education holds potential significance for further systematic research.

Although several systematic reviews in recent years have summarized the application of VR in higher education at a macro level (Luo et al., 2021; Rojas-Sánchez et al., 2023), existing VR teaching research has predominantly focused on STEM and medical disciplines. Moreover, many studies remain at the experimental or prototyping stage, lacking systematic pedagogical pathways tailored to specific disciplinary contexts (Radianti et al., 2020). Within art and design education, existing reviews also indicate that explorations of VR technology applications remain relatively fragmented. Empirical evidence for fully immersive VR remains limited, with research overall at an early developmental stage (Wang & Mokmin, 2023). A synthesis of existing literature reveals a lack of systematic reviews specifically focused on VR-based digital 3D modeling courses in university-level art and design disciplines. Although research on VR-based digital 3D modeling is growing, it remains relatively early in development and has not yet been comprehensively synthesized. Existing reviews have primarily examined VR in education from broad perspectives or have focused on specific applications such as VR sketching and visualization. In contrast, this review concentrates specifically on VR-based digital 3D modeling in art and design contexts, providing a focused synthesis of empirical evidence across related instructional and experimental settings. By systematically integrating research trends, tool characteristics, key research variables, and student user experience, this review aims to advance a more coherent understanding of the pedagogical implications and application potential of VR digital 3D modeling.

Table (1): Publications categorized by discipline field and school (Luo et al., 2021).

Discipline	Elementary	Middle school	High school	K-12 mixed ^a	Higher education	Total
Basic science	5	4	10	2	16	37
Social science	10	5	1	0	21	37
Mathematics	3	2	0	0	1	6

Theoretical foundation

The use of VR in higher education

VR in education offers new perspectives on teaching and learning, alters the way teachers and students interact, and addresses several limitations in traditional teaching methods. For example, by creating a teaching platform for virtual simulation laboratories, students can receive skill training without risk (Dong et al., 2022). Future classrooms can enhance VR by developing virtual field trip programs that integrate 360° VR technology (Huh, 2020). VR motivates learning by providing an intuitive learning experience (Yu & Xu, 2024) that engages the learner more deeply with the content (Sattar et al., 2019).

Luo et al. (2021) performed an extensive review of the literature about the utilization of VR in K-12 and higher education from 2000 to 2019. Figure 1 illustrates the trend of VR in education, with a notable peak in publications in 2018, possibly attributed to the commercialization of the Oculus Rift and HTC VIVE. Table 1 demonstrates that VR is utilized more frequently in higher education compared to K-12 education.

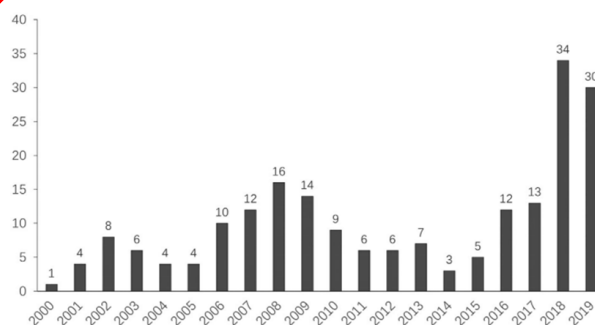


Figure (1): Literature on VR-based pedagogy in K-12 and higher education (Luo et al., 2021).

Language	2	1	1	1	8	13
Health and medicine	6	4	3	1	32	46
Engineering	0	1	0	0	14	15
Other ^b	1	0	1	0	1	3
Total	27	17	16	4	93	157

^a Studies that were conducted in K-12 settings and across different school levels.

^b Interdisciplinary fields such as STEAM education and maker education

Ding and Li (2022) examined 80 empirical studies regarding the implementation of VR in higher education from 2012 to 2021. Figure 2 illustrates that, while numerous advancements in VR research within STEM fields, its applications in the humanities and social sciences are still constrained. There is a demand for VR research to emphasize the humanities and social sciences. This trend suggests that researchers should expand the use of VR in higher education within art and design disciplines.

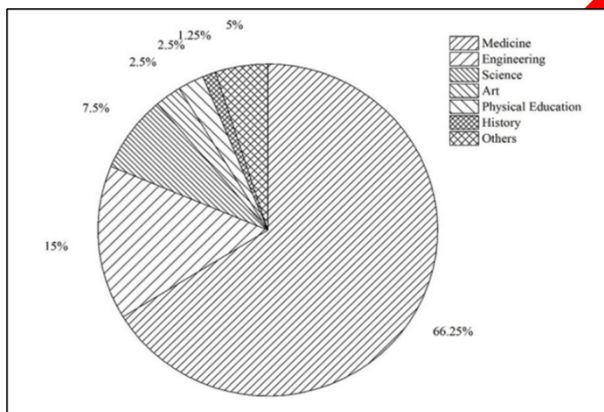


Figure (2): The professional statistics of VR applications in higher education (Ding & Li, 2022).

VR in art and design disciplines

Integrating VR into creative fields such as art and design can enhance comprehension of three-dimensional space (Nisha, 2019) and foster improved student-centered activities and interactions. Serna-Mendiburu and Guerra-Tamez (2024) developed a predictive model centered on undergraduate art and design disciplines in universities, demonstrating that usability and spatial competence in VR environments enhance student satisfaction with their learning, which in turn fosters motivation, cognitive advantages, reflective thinking, and perceptual learning.

In a virtual art studio, students can progress at their own pace and explore diverse approaches, thereby increasing the expressiveness of creative design (Chang et al., 2023; Guerra-Tamez, 2023). The VR meta-universe can improve people's attitudes toward art while increasing their knowledge and appreciation of artworks (Yang et al., 2024). Yu and Xu (2024) showed that students could develop spatial perception by creating virtual garden models and scenes in landscape architecture design.

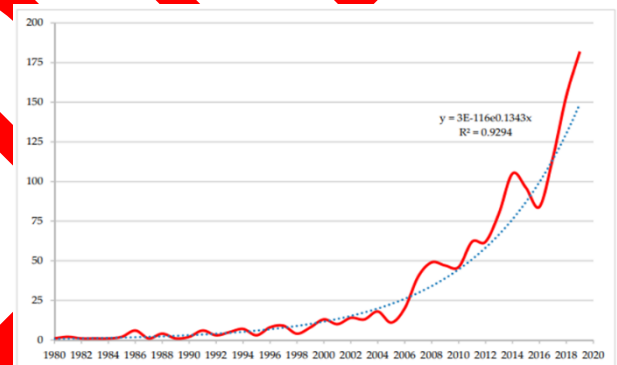


Figure (3): Evolution of scientific production (1980–2019) (González-Zamar & Abad-Segura, 2020).

González-Zamar and Abad-Segura (2020) investigated the impact of VR on art education in the context of higher education, examining 1,296 articles published between 1980 and 2019. Figure 3 shows that there were 75 articles between 1980 and 1990. Between 2000 and 2009, there were 235 articles, and from 2010 to 2019, the number increased to 986. In the past decades, the number of articles related to art education in higher education has shown an increasing trend. This observation aligns with the views of two articles by Wang and Mokmin (2023) and Wang et al. (2024), which emphasize the great potential of incorporating

immersive technologies, such as VR, into art education.

The impact of VR in digital 3D modeling

With the advancement of VR, an increasing number of design tools are being utilized in the creative field to enhance creativity by enabling designers to explore ideas more freely. For example, the immersive feel of VRAD (VR Assisted Design) can help designers accurately assess the quality of a space, thereby increasing spatial confidence (Law et al., 2020). Confidence is a significant source of creativity (Kang & Kim, 2019).

VR serves as an innovative instructional medium, enabling students to articulate their creativity inside a three-dimensional digital environment (So & Lu, 2019). So and Lu (2019) had secondary school students use “Google Tilt Brush” to create virtual digital 3D artworks and assess creativity, originality, and aesthetic quality, examining the prospects and obstacles of VR in visual arts education. Moreover, “Tilt Brush” is a VR sketching tool that emphasizes two-dimensional drawing. Dadashov-Khandan (2022) suggests addressing the problem of brush precision by introducing a digital sculpting toolkit to Tilt Brush. This study not only extends its functionality progressively to the possibilities of digital 3D design but also opens up new possibilities for creative expression.

Different VR modeling tools are distinctive in their modus operandi, interaction modes, and collaboration capabilities. Some tools focus on intuitive modeling interactions, such as Google Blocks (Toff, 2017), which allows users to quickly build digital 3D objects using basic shapes in VR environments, simplifying the learning curve of digital 3D design. Oculus Medium (Adobe, 2016), a professional-grade VR sculpting and painting tool, offers more detailed sculpting capabilities, enabling users to model as if they were sculpting in reality.

This intuitive interaction makes it easier for beginners to enter a state of mind-flow, which enhances creativity (Csikszentmihalyi, 1990).

Other tools emphasize multi-user online collaboration, such as “Gravity Sketch”, which offers a creative toolkit that enables VR users to rapidly develop digital 3D design concepts while supporting real-time cooperation. VR collaboration mitigates communication obstacles in the design process and enhances the efficiency of idea development. Furthermore, several tools emphasize innovations in modeling approaches, such as MakeVR

(Jerald et al., 2013), a system for constructing virtual digital 3D scenes by placing and modifying Lego-like shapes. These tools suggest that VR is transforming the traditional digital 3D modeling approach, offering users unlimited possibilities to express their creativity.

Many digital 3D artists have used it to create excellent works. However, it is still in the experimental stage in digital 3D modeling courses. Although Machuca et al. (2024) included 102 papers related to digital 3D sketching evaluation in their review and proposed a new framework for digital 3D sketch evaluation, they primarily focused on assessing digital 3D immersive sketching, drawing, and painting. They did not focus on digital 3D modeling, such as digital 3D sculpting systems. Therefore, a gap exists in the literature that necessitates an examination of the use of VR digital 3D modeling tools in art and design disciplines at the university. Table 2 presents the research questions (RQ) for this study.

Table (2): Research questions of this study.

Research question (RQ)	
RQ1	What are the research trends in using VR digital 3D modeling methods in university student art and design disciplines?

RQ2	What tools support VR digital 3D modeling methods in university student art and design disciplines?
RQ3	What are the research variables of focus in studies using VR digital 3D modeling methods in university student art and design disciplines?
RQ4	How do VR digital 3D modeling methods affect students' user experience?

Methods

This section describes a PRISMA-based systematic review aimed at fulfilling research goals (Page et al., 2021). This review involved four main steps: (1) identification, (2) screening, (3) eligibility, and (4) inclusion.

Information sources

To ensure comprehensive coverage of relevant research, we retrieved articles from seven major databases based on the research area, including Google Scholar, Web of Science Core Collection, SpringerLink, Scopus, IEEE Xplore, ACM Digital Library, and Taylor & Francis. Google Scholar can proficiently identify extensively referenced articles (Martin-Martin et al., 2017). The Web of Science Core Collection includes journals of high scholarly value and credibility. IEEE Xplore, Scopus, and the ACM Digital Library provide high-quality scholarly resources on engineering, computer science, and information technology.

Identify keywords and terms as initial search criteria: "virtual reality", "VR", "3D modeling", "three-dimensional modeling", "VR modeling", "education", "teaching", "art education", "art and design", and "design education". Use these keywords to search within article titles, abstracts, and keywords. The search date ranged from January 1, 2018, to March 21, 2024.

Search strategy

We used Boolean logic to retrieve articles from the databases and iteratively refined the search strings according to the number of

results returned. When the initial search yielded too few results, the keywords were expanded by adding synonyms or relaxing some constraints, whereas additional qualifiers were introduced when the search yielded too many results. In Google Scholar, searches were restricted to article titles to enhance the relevance of retrieved records. The detailed search strings and keywords are demonstrated in Table 3.

Table (3): The search string and the results of the databases

Database	Search string
Web of Science	("virtual reality" OR VR) AND ("digital 3D modeling" OR "three-dimensional modeling" OR "VR modeling") AND (education OR teaching OR "art education" OR "art and design" OR "design education") (Topic)
Scopus	TITLE-ABS-KEY ("virtual reality" OR VR) AND ("digital 3D modeling" OR "three-dimensional modeling" OR "VR modeling") AND (education OR teaching OR "art education" OR "art and design" OR "design education")
Springer Link	("virtual reality" OR VR) AND ("digital 3D modeling" OR "three-dimensional modeling" OR "VR modeling") AND ("art education" OR "art and design" OR "design education")
IEEE Xplore	("virtual reality" OR VR) AND ("digital 3D modeling" OR "three-dimensional modeling" OR "VR modeling") AND (education OR teaching OR "art education" OR "art and design" OR "design education")
ACM Digital Library	[[All: "virtual reality"] OR [All: VR]] AND [[All: "3D modeling"] OR [All: "three-dimensional modeling"] OR [All: "VR modeling"]] AND [[All: education] OR [All: teaching] OR [All: "art education"] OR [All: "art and design"] OR [All: "design education"]]
Taylor & Francis	[[All: "virtual reality"] OR [All: VR]] AND [[All: "3D modeling"] OR [All: "three-dimensional modeling"] OR [All: "VR modeling"]] AND [[All: "art education"] OR [All: "art and design"] OR [All: "design education"]]

Google Scholar	(intitle: "virtual reality" OR intitle: VR) AND (intitle: "digital 3D modeling" OR intitle: "three-dimensional modeling" OR intitle: "VR modeling") AND (education OR teaching OR "art education" OR "art and design" OR "design education")
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Eligibility criteria

To formulate the research questions and search strategy, this study combined the use of both the PICO (Population, Intervention, Comparison, Outcome) and SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) frameworks. The PICO framework is suitable for studies primarily involving experimental design and quantitative analysis, while the SPIDER framework is more appropriate for qualitative and mixed-methods research commonly found in educational studies. Given the diversity in research designs and methodological approaches among the included studies, the combined use of both frameworks enhances the comprehensiveness and systematic nature of the literature search (Martinez et al., 2023). Table 4 presents both the inclusion and exclusion criteria. Two researchers conducted independent eligibility screening and quality assessment based on these criteria. Figure 4 presents the PRISMA flowchart.

Table (4): Aspects of inclusion/exclusion criteria.

Inclusion criteria	Exclusion criteria
Published between January 1, 2018, and March 21, 2024	Published before January 1, 2018, or after March 21, 2024
Written in English	Non-English
Full-text articles/Conference papers/Journal articles/Peer-Reviewed Articles	Review articles/ Editorial/Retracted articles/ Dissertations/ Conference Proceedings/Journal Issue/ Book.
VR in higher education, art and design, and digital 3D modeling Relevant to the research question	Not only VR technology Not-higher education research Non-empirical research

Screening Process

The initial search based on the search string resulted in 430 records, including books, journal articles, review articles, and conference papers. We retained only peer-reviewed empirical research during the initial screening process, excluding 85 records for reasons such as duplicate entries, retractions, reviews, language barriers, books, dissertations, conference proceedings, special journal issues, and editorials. This left us with 345 studies for the next step. Subsequently, we assessed the remaining 345 records by examining the titles and abstracts to ascertain their compliance with the inclusion criteria. As a result, 317 records were excluded, and 28 records were retained for further review.

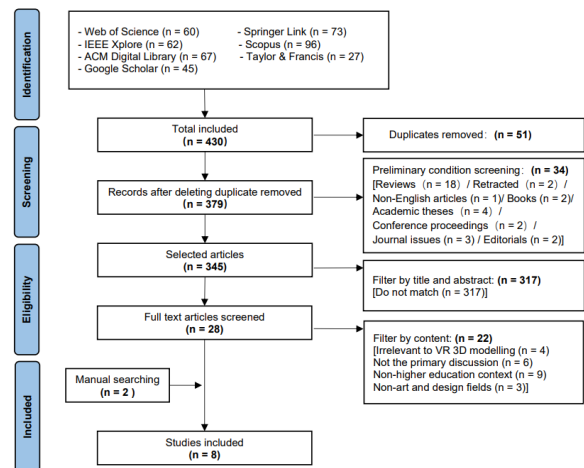


Figure (4): Flowchart illustrating the PRISMA-based selection procedure.

In the full-text review, we initially excluded four articles that were irrelevant to the topic, followed by six articles that addressed VR digital 3D modeling but did not focus on it as the primary subject. Subsequently, we excluded nine articles centered on non-higher education contexts and three articles that, while situated in higher education, were not related to the field of art and design. This process resulted in six pertinent papers. After adding two manually searched articles, the final sample consisted of eight articles focused on VR digital

3D modeling in college art and design education, as shown in Tables 5 and 6.

Table (5): The following is a list of selected literature for this review.

#	Article title	Reference
1	Factors affecting usability of digital 3D model learning in a virtual reality environment	(Huang & Lee, 2022)
2	Usability of virtual reality for basic design education: a comparative study with paper-based design	(Özgen et al., 2021)
3	An explorative study towards using VR sketching as a tool for ideation and prototyping in product design	(Joundi et al., 2020)
4	Enhancing the learning effect of virtual reality digital 3D modeling: a new model of learner's design collaboration and a comparison of its field system usability	(Huang et al., 2021)
5	How rad(-ical) is VRAD (Virtual Reality-Aided Design)?	(Law et al., 2020)
6	Examining performance of VR sketch modeling tool in personal sketches	(Lin et al., 2022)
7	Comparing VR Modeling Tool and Hand-Sketching in the Inspiration of Classic Chair Design and Modeling	(Lee & Peng, 2023)
8	User Experience Evaluation of a Virtual Reality Tool Used for digital 3D Modeling in Industrial Design Education: A Study in the Indian Context	(Banerjee et al., 2023)

Table (6): Comparative matrix of the eight core papers.

#	Published online year/ Country	Research topic	Experimental setting (Task / Benchmark / Setup / Training/Sample)	Method
1	2019; Taiwan, China	Factors affecting 3D modeling usability in VR	Task: Constructing a specified table and legs; Setup: Individual operation; Training: Practiced until familiar (~30 min experiment); Sample: 50.	Quantitative (Exploratory Experimental Study)
2	2019; Turkey	VR vs. paper-based design in basic design education	Task: Create a 3D model representing "flow of space" concepts; Benchmark: VR group vs. Paper-based group; Duration: ~2.5 hours per task; Sample: 20.	Quantitative (Quasi-experimental Comparative Study)
3	2020; Belgium	VR sketching as a tool for ideation and prototyping	Task: Drone styling using animal features; Benchmark: With context (reference images) vs. Without context; Duration: 30-minute session; Sample: 29.	Mixed (Observational Empirical Study)
4	2020; Taiwan, China	Learner design collaboration and field usability	Task: Computer mouse product design; Benchmark: VR (Flyingshapes) vs. Traditional CAD (SolidWorks); Setup: 3-person groups with role rotation; Sample: 60.	Mixed (Participatory Action Research / Within-subjects)
5	2020; Australia	Spatial perception accuracy in VR-Aided Design	Task: 1:1 scale replication of an observed room; Benchmark: VR manipulation vs. Hand drawing vs. CAD; Setup: Restricted to 1:1 first-person view; Sample: 19.	Mixed (Controlled Experimental Study)
6	2022; Taiwan, China	VR sketch modeling tool performance in personal sketches	Task: Mouse and earphone personal sketches; Benchmark: VR sketching (Gravity Sketch) vs. Pen-and-paper; Training: 4 months of prior VR software experience; Sample: 9.	Qualitative-dominant (Integrated Empirical Study)
7	2023; Taiwan, China	Inspiration from classic chair design and modeling	Task: Chair design proposals based on morphology; Benchmark: VR modeling vs. Hand sketching; Training: Video tutorials + 30 min practice; Sample: 12.	Mixed

8	2023; India	UX evaluation of VR for 3D modeling in ID education	Task: 3D water bottle modeling; Benchmark: VR-based (Oculus Quest 2) vs. Conventional 3D software; Training: 15-day intensive workshop; Sample: 34.	Quantitative
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Results

In terms of overall research distribution, the eight empirical studies ultimately included in this study were all published between 2019 and 2023, with most of the included studies published in 2020 or later. The research subjects were all students majoring in art and design at higher education institutions. In terms of disciplinary distribution, the research showed a core focus on industrial design, extending to architectural design and interior architecture. Geographically, the relevant studies were mainly distributed in Asia, Europe, and Oceania. Regarding research design, the included literature mostly employed small-sample experiments or quasi-experimental studies, with sample sizes typically ranging from 9 to 60 participants, and the research contexts were mostly based on single courses or short-term teaching tasks. Methodologically, quantitative and mixed research methods dominated, generally using standardized scales for measurement, supplemented by qualitative analysis to explore the design process and learning experience in depth. These research distribution characteristics provide a general background for subsequent analyses focusing on research trends, tool types, core variables, and user experience.

RQ1. What are the research trends in using VR digital 3D modeling methods in university student art and design disciplines?

Figure 5 illustrates the distribution of included studies over time. Based on online publication dates, the earliest relevant empirical studies were published in 2019 (n=1, 2), with a concentrated release in 2020 (n=3, 4, 5). Following 2021, related studies continued to

be published in 2022 and 2023 (n=6, 7, 8), demonstrating a consistent trend of research output since 2020. Since the literature search for this study ended in March 2024, no empirical studies meeting the screening criteria were included in the analysis in 2024.

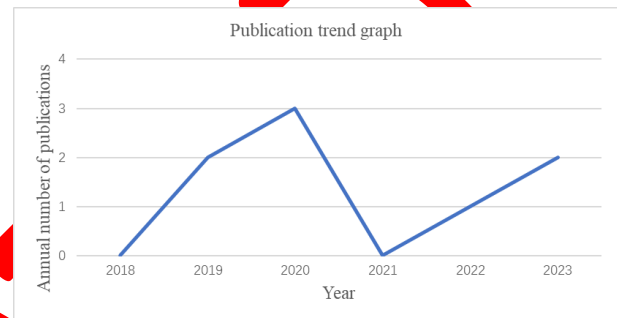


Figure (5): Publication trend graph of VR use in digital 3D modeling within higher education art and design from 2018 to 2024.

In terms of disciplinary distribution, as shown in Figure 6, the application of VR digital modeling is highly concentrated in the field of industrial design (n=4, 8, 7, 3, 1), and the research tasks cover the design and evaluation of product shapes such as mice, drones, water bottles, and classic chairs. Secondly, there is the direction of architectural design and interior design (n=2,5). This type of research focuses more on the spatial perception and proportion accuracy assessment at a 1:1 ratio. The remaining study (n=6) did not specify a secondary discipline, but all the participants had a solid background in design.

From the perspective of geographical distribution, the included studies are mainly concentrated in the Asian region, among which the studies from Taiwan, China and India together account for 50% of the total literature. In addition, relevant studies are also distributed in Europe, including Belgium and Turkey, as well as Australia in Oceania. Overall, the

existing research covers multiple countries and regions in terms of geographical sources.

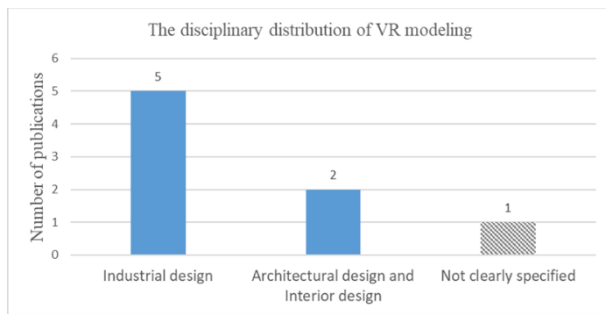


Figure (6): Applications of VR digital 3D modeling in academic disciplines

RQ2. What tools support VR digital 3D modeling methods in university student art and design disciplines?

As shown in Table 7, the tools used in the included study mainly consist of VR hardware devices, VR-based digital 3D modeling software, and traditional modeling and drawing tools. In terms of VR hardware, the devices used include Oculus Quest 2, Oculus Rift DK2, Meta Quest, HTC Vive, and HTC Vive Pro. Some studies did not clearly specify the device models and described them only as “VR head-mounted displays” or “VR goggles.” Overall, it

Table (7): Tools used in research.

#	Hand painting	Traditional software	VR software	VR equipment
1	×	×	Google Blocks	HTC VIVE Pro
2	Pencil, paper, cardboard, and glue	×	Google Blocks	Oculus Rift DK2
3	paper	×	Gravity Sketch	Unspecified HMD
4	×	SolidWorks	Flyingshapes VR	HTC Vive
5	Pencil, eraser, and paper	SketchUp	UE4 (Editor mode)	HTC Vive
6	Pencils, ball pens, and paper	×	Gravity Sketch	Oculus Quest 2
7	paper	×	Gravity Sketch	Meta Quest
8	×	Conventional software	VR Collaborative Tool	Oculus Quest

RQ3. What are the research variables of focus in studies using VR digital 3D modeling methods in university student art and design disciplines?

In this review, research variables refer to the independent and dependent variables examined in the included empirical studies. As shown in Table 8, the included studies mainly focused on

includes both head-mounted devices that need to be connected to a computer for operation and all-in-one VR devices that can operate independently.

In terms of software tools, VR-based digital 3D modeling software mainly includes Gravity Sketch, Google Blocks, and Flyingshapes, among which Gravity Sketch has been adopted in many studies. Furthermore, some individual studies use Unreal Engine 4 as the development platform for virtual environments and 3D modeling.

In addition to VR tools, some studies also combined the use of traditional digital 3D modeling software with hand-drawn tools as comparative conditions. Common traditional modeling software includes SolidWorks, SketchUp, Fusion, Autodesk 3ds Max, and Blender, while traditional drawing tools mainly include paper, pencils, and other solid modeling materials. Some studies simultaneously use devices such as computers and laptops as auxiliary tools.

the setting of independent variables (IV) around different modeling environments, tool types, and learning situations. Most studies take different learning environments or modeling methods as independent variables to compare traditional desktop digital 3D modeling with VR-based modeling practices (n=3, n=4, n=8). Some studies further introduce multi-condition

comparative design, such as comparing VR-assisted design tools, traditional digital modeling software with pen-and-paper hand-drawing methods (n=5), or making comparisons among different VR modeling

scenarios, tools, or experience levels (n=2, n=6, n=7). In addition, some individual studies have examined the tool features, functional configurations, or environmental settings of VR systems as independent variables (n=1).

Table (8): Research variables of the 8 Core References.

#	IV	DV
1	10 VR Interaction Elements (Presence, Interactivity, Stability, etc.),	Extracted Usability Factors (PCA), System Usability Scale (SUS),
2	Design Medium (VR-based vs. Paper-based),	Technology Acceptance (TAM: PU, PEU, IU, PE), Design Effectiveness,
3	VR Design Context (With contextual objects vs. Without context),	Ideation Performance, Learning Curve, User Feedback (Dizziness, Precision),
4	Learning Field (VR Modeling Practice Field vs. Traditional Field),	Field System Usability (SUS), Design Outcomes (Creativity, Aesthetics, Accuracy),
5	Drawing Mode (Hand Drawing, 3D Modeling, VRAD 1:1),	Spatial Acuity (Dimension accuracy, Proportion), Task Time, Confidence Level,
6	Sketching Medium (VR Sketching vs. Conventional Pen-and-paper),	Efficiency (Quantity, Time), Thinking Strategy (Lateral vs. Vertical), Visual Ambiguity,
7	Design Tools (Hand-sketching vs. VR); Experience Level (Expert vs. Novice),	Behavioral Patterns (Action frequencies), Styling Inspiration, User Acceptance,
8	Modeling Setup (Conventional 3D Software vs. VR-based Software),	Cognitive Workload (NASA-TLX), Engagement & Enjoyment, Task Time, Acceptance Rating,

In terms of the dependent variable (DV), the included studies mainly focus on dimensions such as learning experience, cognitive performance, and design outcomes. Common measurement indicators include system usability and user experience, cognitive load, engagement and enjoyment, learning or task performance, spatial perception and proportional accuracy, as well as creativity, design quality, and learning attitudes. Some studies also focus on variables such as learners' behavioral patterns, cognitive processes, and tool acceptance. Overall, existing research has systematically evaluated the potential impact of VR digital 3D modeling on the learning process of art and design through multi-dimensional variable combinations.

A cross-study synthesis of the above findings reveals two emerging patterns. First, in the early stages of design ideation, virtual reality environments appear to offer distinct advantages in supporting spatial imagination,

immersive engagement, and immediate three-dimensional expression. Several studies indicate that VR-based modeling tools may enhance creative performance, confidence levels, and proportional perception, particularly in tasks involving volumetric form exploration and spatial structuring. The immersive and direct manipulation of three-dimensional forms in VR may lessen the reliance on mental reconstruction from two-dimensional representations. However, this facilitating effect appears to be more pronounced in spatial refinement and form elaboration, whereas evidence for its superiority in promoting large-scale divergent idea generation remains inconclusive.

Second, inconsistencies are observed across studies regarding efficiency, accuracy, and cognitive load. Such discrepancies may be associated with differences in the maturity of VR tools, interaction precision, system stability, and participants' familiarity with the

technology. More established VR modeling systems tend to demonstrate better user experience and task efficiency, whereas less mature or technically constrained systems may impose higher operational demands and cognitive load. Therefore, variations in performance outcomes across studies may partly reflect differences in technological development stages rather than purely pedagogical effects.

RQ4. How do VR digital 3D modeling tools affect students' user experience?

In terms of system usability and technology acceptance, several empirical studies have recorded quantitative feedback through standardized scales. The results of Huang et al. (2021) showed that the SUS score of the VR modeling practice field (VRMPF) was significantly higher than that of the traditional field. Huang and Lee (2022) found that among the usability dimensions, stability and visual perspective were regarded by users as the most important indicators, while the importance score of sound effects was the lowest. Furthermore, Özgen et al. (2021) confirmed that there were significant differences between the VR group and the pen-and-paper group in the dimensions of intention to use and perceived enjoyment. Law et al. (2020) recorded that participants showed a higher level of confidence in the VR modeling results than in traditional tools.

In terms of task performance and output characteristics, empirical data reflect the dual performance of VR tools in terms of efficiency and quality. It should be noted that variations in software versions, hardware configurations, and interaction modalities across studies may have contributed to fluctuations in efficiency and quality outcomes. In terms of modeling efficiency, the average completion time of the VR group recorded by Banerjee et al. (2023) was significantly shorter than that of the

traditional software group. However, in the spatial restoration task, Law et al. (2020) observed that the participants at the virtual reality-aided design site had the longest task completion time. In terms of output quality, Huang et al. (2021) pointed out that the VR group performed well in the creativity score, but was lower than the traditional group in the accuracy dimension. The experiment of Lin et al. (2022) found that the quantity of sketches produced by students in VR was significantly less than that of pen-and-paper sketches, and due to the low ambiguity of the VR environment, participants were more inclined to exhibit a vertical thinking tendency rather than lateral thinking. This finding suggests that VR-based modeling in early-stage ideation may tend to support spatial refinement and elaboration of a selected concept, whereas its role in facilitating extensive divergent idea generation remains mixed across studies. Joundi et al. (2020) found that when designers lack a clear mental image, it is more difficult to start modeling in a VR environment.

In terms of cognitive load and physiological feedback, empirical studies have recorded the multi-dimensional responses of students in immersive environments. Banerjee et al. (2023) showed that the average weighted cognitive load triggered by VR modeling is higher than that of traditional software. In terms of spatial perception, Law et al. (2020) found that participants had the most accurate perception of proportion in the VR environment, but there was a widespread underestimation phenomenon of physical distance. Furthermore, some empirical records have mentioned negative physiological feedback, including the dizziness phenomenon during the first use, the steep learning curve of the handgrip controller, as well as physical blindness and collision concerns caused by the inability to observe the real environment.

Discussion

Based on the results, this section explores the underlying mechanisms, context-dependent factors behind the research findings, and their implications for educational practice at a higher level.

The underlying mechanisms of VR digital 3D modeling in design learning

Overall, the potential value of VR digital 3D modeling in art and design education primarily stems from its immersive spatial interactive characteristics. Compared to traditional two-dimensional interfaces, VR environments can directly place learners in a three-dimensional virtual design space, thereby reducing the burden of transitioning from a planar interface to spatial mental representation (Chen et al., 2024; Ka et al., 2025). This characteristic is particularly important in design tasks that heavily rely on spatial cognitive abilities, providing a reasonable explanation for its application in industrial design, architectural design, and interior design courses.

From a cognitive perspective, the gestures, body movements, and perspective switching in VR modeling transform the design process into an embodied cognitive process, facilitating the externalization of abstract concepts and the exploration of complex forms and spatial relationships (Çoruh, 2025). In contrast, traditional digital modeling tools emphasize parameter control and precise operation, with their advantages typically manifesting in the later stages of the design process (Camba et al., 2016; Gill et al., 2024; Stals et al., 2021).

At the emotional and motivational level, VR learning scenarios typically bring higher levels of enjoyment, engagement, and willingness to use. In basic design education, VR often reduces subjective workload and enhances engagement and enjoyment. This partly explains why some studies focus more on the application potential of VR in the design conception and creative generation stages,

rather than viewing it as a complete replacement for traditional modeling tools (Banerjee et al., 2023; Özgen et al., 2021).

Possible reasons for differences in research conclusions

While some studies have reported the positive effects of VR digital 3D modeling on learning and modeling performance, existing research conclusions are not entirely consistent. This difference is more likely due to variations in research contexts and experimental design conditions, rather than the inherent instability of VR technology itself. Existing research indicates that multiple factors can influence the learning outcomes and task performance of VR modeling, including differences in the functional maturity and interactive sophistication of VR modeling tools, the type and complexity of modeling tasks, and learners' prior experience and skill levels (Banerjee et al., 2023; Matovu et al., 2024; Vlah et al., 2021). These factors tend to have a more significant impact on learning experience and performance in short-term educational interventions or when learners are first exposed to VR modeling technology.

The role of hardware and task design

The development of hardware devices provides important support for the application of VR in educational scenarios. Integrated head-mounted display devices have lowered the usage threshold in terms of deployment cost, portability, and operational simplification (Jensen & Konradsen, 2018), making VR more easily integrated into classroom teaching. However, the hardware itself still has limitations in terms of field of view, physical security, and comfort of use (Fransson et al., 2020), and these factors need to be taken into consideration in instructional design.

Tugtekin and Odaba (2023) manipulated task characteristics and multi-task scenarios in a VR learning environment and found that

different task difficulties and operational requirements significantly affected academic performance and maintained scores, and had an interaction effect with cognitive load. This suggests that in VR, if the task is too difficult, it will increase the load and weaken learning outcomes. The difficulty of the tasks needs to be carefully matched. Therefore, in teaching practice, it is necessary to reasonably design the difficulty of tasks based on the course objectives, so that they can not only give full play to the technical characteristics of VR but also not impose excessive burdens on learners.

Implications for educational practice

Based on the analysis of this review, VR digital 3D modeling is more suitable to be regarded as a supplementary tool in design education rather than a complete replacement for traditional modeling methods (Andalib & Monsur, 2024; Banerjee et al., 2023). In teaching practice, VR modeling can be introduced into the early stage of the course to support concept generation and spatial thinking, and complement pen-and-paper sketches as well as traditional digital modeling tools. Furthermore, providing step-by-step operational training and clear task guidance may help reduce the cognitive load associated with initial use, thereby enhancing the overall learning experience (Chen et al., 2024).

Taken together, the findings of this review also suggest a preliminary conceptual structure for VR-based digital 3D modeling learning. This structure highlights three interrelated dimensions: technological factors such as hardware characteristics and software maturity, task-related factors including the type and complexity of modeling activities, and learner-related factors such as prior experience, spatial ability, and cognitive load. The interaction among these dimensions appears to influence learning outcomes and design performance. This perspective may provide a useful basis for

interpreting inconsistent findings and guiding future research.

Recommendations

Teaching digital 3D modeling based on VR technology can be a powerful complement to traditional teaching methods. Educators should consider how to integrate VR technology into existing curriculum structures, for example, by creating VR simulation experiments or designing workshops to enhance student motivation to learn. Meanwhile, students should be provided with scientific and healthy instructional training on using VR technology, and their performance should be continuously observed and evaluated to optimize teaching strategies and tools.

Limitations

This study has several limitations. The number of eligible empirical studies remains limited, and only eight studies were finally included. Most participants in the included studies were undergraduate students, which limits the generalizability of the findings to other educational levels and contexts. In addition, differences in experimental design, measurement tools, and evaluation criteria across studies restrict direct comparison of results. The review focuses on higher education and does not cover K–12 or industry contexts. Furthermore, the reviewed studies were published between 2018 and 2024 and were predominantly short-term studies that lack long-term follow-up data to evaluate the enduring effects of VR digital 3D modeling on the development of students' creativity.

Conclusions

This systematic study aims to examine the trends, tools, factors, and user experiences associated with the application of VR in digital 3D modeling within art and design education at the higher education level. The review results show a general growth trend in the published related studies. The main technology used to

immerse participants in virtual environments is HMDs, of which VR all-in-one devices are gaining popularity due to their portability and ease of use. The immersion in VR digital 3D modeling is more engaging than traditional modeling software, which enhances students' interest and motivation. In addition, collaborating with others on design decisions and co-modeling effectively changed the learning experience of traditional digital 3D modeling and increased the creativity and motivation of participants. However, improvements are still needed in the accuracy and functionality of VR modeling tools, as well as in reducing fatigue and attentional decline associated with prolonged immersive work. Nonetheless, there is still great potential for research on this topic, as only some scholars have attempted to integrate VR modeling applications into modeling learning in the classroom.

Future research may concentrate on a comprehensive examination of user experiences with VR tools in digital 3D modeling, the creation of VR digital 3D modeling curricula, and the enhancement of pedagogical strategies or course frameworks, particularly the effective integration of conventional modeling techniques with contemporary technologies, to augment learner engagement and yield superior design outcomes. Future studies could conduct case-based investigations to examine the learning effects of applying VR technology in actual digital 3D modeling courses, including students' creative efficiency, work quality, and creativity. In addition, longitudinal studies may be considered a goal for future research to assess behavioral and attitudinal changes of students over time and to comprehend the enduring effects on student learning outcomes.

Disclosure Statement

The following declarations apply to this article:

- **Thesis statement:** This article is not derived from a master's or doctoral thesis.
- **Ethical approval and consent to participate:** This study received ethical approval from the Institutional Review Board (IRB) of Universiti Sains Malaysia.
- **Availability of data and materials:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Author contribution:** N.L.J. designed the review, conducted the search and screening, and drafted the manuscript. P.G.P. contributed to the design and revision. N.A.M.M. supervised, reviewed, and approved the final manuscript. All authors approved the final manuscript.
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- **Open Access**

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