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The impact of virtual reality in design education: evidence, gaps, and opportunities from a systematic review

O impacto da realidade virtual na educação em design: evidências, lacunas e oportunidades a partir de uma revisão sistemática

El impacto de la realidad virtual en la educación en diseño: evidencias, brechas y oportunidades a partir de una revisión sistemática

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Abstract

This article analyzes the impact of Virtual Reality (VR) in product design education through a Systematic Literature Review (SLR). Structured by the PICO (Population, Intervention, Comparison, Outcome) framework, the research involved systematic searches across the Scopus, Web of Science, and SciELO databases. Results indicate a maturing research field, predominated by experimental studies comparing VR with traditional methods like hand sketching and CAD modeling. Evidence consistently shows a positive impact on student engagement and design competencies, particularly in spatial perception and conceptual design quality. Key measured variables include "Usability and Satisfaction," "Engagement and Attitudes," and "Performance and Project Quality." This investigation concludes that VR is a viable and effective pedagogical intervention. However, significant knowledge gaps were identified: a strong geographical concentration of studies in Asia and Europe, with very limited research from the South American context, and a lack of investigation into long-term curricular integration beyond isolated tasks. Therefore, this study highlights the need for research contextualized to the Brazilian reality to support the creation of innovative pedagogical frameworks that effectively integrate VR tools into design curricula.

Keywords: Virtual Reality; Design Education; Product Design; Immersive Technologies; Adult Teaching and Learning.

Resumo

Este artigo analisa o impacto do uso de ferramentas de Realidade Virtual (RV) no processo de ensino-aprendizagem em design de produto, por meio de uma Revisão Sistemática de Literatura (RSL). A pesquisa foi metodologicamente estruturada com base no framework PICO (População, Intervenção, Comparação e Outcome), que orientou a busca nas bases Scopus, Web of Science e SciELO. Os resultados revelam um campo de pesquisa em maturação, com predominância de estudos de abordagem experimental que investigam a RV em comparação com métodos tradicionais, como o esboço manual e a modelagem CAD. As evidências encontradas apontam consistentemente para um impacto positivo da RV no engajamento dos estudantes e no aprimoramento de competências projetuais, especialmente no desenvolvimento da percepção espacial e na qualidade dos projetos conceituais. As variáveis mais frequentemente mensuradas para aferir tais resultados foram "Usabilidade e Satisfação", "Engajamento e Atitudes" e "Desempenho e Qualidade do Projeto". Conclui-se que a RV se apresenta como uma intervenção pedagógica viável e eficaz. Contudo, foram identificadas lacunas de conhecimento significativas: uma forte concentração geográfica de estudos na Ásia e Europa, com mínima representação sul-americana, e a carência de investigações sobre a integração curricular da tecnologia a longo prazo, para além de tarefas isoladas. Diante disso, destaca-se a necessidade de fomentar pesquisas contextualizadas à realidade brasileira para subsidiar a implementação de frameworks pedagógicos inovadores que integrem ferramentas de RV nos currículos dos cursos de design.

Palavras-chave: Realidade Virtual; Ensino de Design; Design de Produto; Tecnologias Imersivas; Ensino-Aprendizagem de Adultos.

Resumen

Este artículo analiza el impacto de la Realidad Virtual (RV) en la enseñanza del diseño de producto mediante una Revisión Sistemática de Literatura (RSL). La investigación se basó en el marco PICO (Población, Intervención, Comparación, Outcome) para guiar la búsqueda en las bases de datos Scopus, Web of Science y SciELO. Los resultados revelan un campo de investigación en maduración, dominado por estudios experimentales que comparan la RV con métodos tradicionales como el boceto a mano y el modelado CAD. La evidencia apunta consistentemente a un impacto positivo de la RV en la implicación de los estudiantes y en la mejora de competencias proyectuales, sobre todo en la percepción espacial y la calidad de los diseños conceptuales. Las variables más medidas incluyen "Usabilidad y Satisfacción", "Implicación y Actitudes" y "Desempeño y Calidad del Proyecto". Se concluye que la RV es una intervención pedagógica viable y eficaz. Sin embargo, persisten lagunas de conocimiento significativas: una fuerte concentración geográfica de estudios en Asia y Europa, con mínima investigación en el contexto sudamericano, y la falta de análisis sobre la integración curricular a largo plazo. Por ello, se destaca la necesidad de fomentar investigaciones contextualizadas a la realidad brasileña para implementar marcos pedagógicos innovadores que integren la RV en los planes de estudio de diseño.

Palabras clave: Realidad Virtual; Enseñanza Del Diseño; Diseño De Producto; Tecnologías Inmersivas; Enseñanza-Aprendizaje de Adultos.

INTRODUCTION

Virtual Reality (VR) presents high potential to transform the real world and the way society interacts with and modifies it (Rubio-Tamayo, Barrio and García, 2017; Tamayo, 2019). In this regard, it is important that design education itself be integrated into this context. To this end, it is necessary to seek evidence, identify gaps, and outline opportunities to verify the impact that the integration of VR has on the teaching-learning process of designers.

VR, by definition, can be understood as an environment that combines real-time computer-generated graphics, body tracking technologies, audio/video, touch, and other sensory input and output devices that can be experienced by individuals, generating interactions that cause the user to perceive it as if it were a real environment (Wang, Tsai and Wang, 2011; Jerald, 2016). Different versions of VR have been developed and implemented, each with a specific level of immersion and technical complexity, ranging from basic systems that utilize mobile devices and conventional displays to more complex and enhanced solutions involving advanced simulators and specialized devices that provide full immersion in the virtual environment (Muhanna, 2015).

The costs and complexity involved in employing VR have become increasingly accessible, allowing for suitable options to be found to meet different needs (Svidt and Sørensen, 2016), offering interactive and immersive three-dimensional environments to designers, thus expanding their capacity to explore solutions to problems. However, its implementation still faces challenges, such as the scarcity of specific content and the need for innovative approaches regarding the adoption of technological tools in the education of design professionals.

This study is an integral part of a doctoral-level investigation intended to verify whether the integration of VR into the teaching-learning process in undergraduate design programs yields significant gains regarding students' competency development and the quality of the projects developed. Specifically, it is presented here an excerpt aimed at identifying, through a Systematic Literature Review (SLR), the state of the art and knowledge gaps related to the topic. In terms of the number of studies, this excerpt identifies the highest concentration in Asian countries, followed by Europe, the Americas and the remainder divided between Middle Eastern and Oceania countries.

A well-articulated question is the foundation of quality research (Richardson et al., 1995); and to conduct a successful investigation, it is necessary that the question be formulated in a clear, focused, and answerable manner (Davies, 2011; Nishikawa-Pacher, 2022). In the field of design, given the complexity of elements to be investigated coupled with prominent subjectivity, defining a research question that is both comprehensive and concise has a direct impact on the study's quality; a poorly structured inquiry can lead to the collection of incongruent literature, unrelated data, and authors disconnected from the investigation (Davies, 2011; Goldschmidt and Matthews, 2022). In this context, this research adopted a methodological principle focused on crafting a question that would best synthesize the intended study, finding the PICO framework to be a highly relevant model.

PICO was originally conceived as a mnemonic in the field of medicine to assist in formulating clinical questions when searching for precise answers in the scientific literature (Richardson et al., 1995; Davies, 2011). Its structure was designed to decompose a clinical question into its four essential anatomical components, facilitating the search for evidence (Richardson et al., 1995):

- **P – *Patient/Problem*:** most important characteristics of the patient/problem of interest;
- **I – *Intervention*:** main intervention, treatment, or exposure considered;
- **C – *Comparison*:** main alternative to the intervention (placebo, another treatment, or the absence of intervention);
- **O – *Outcome*:** clinical outcome or effect of interest.

The main advantage of PICO is its ability to transform a broad inquiry into a well-built and focused question, not only guiding the researcher but also optimizing the search for relevant literature by providing structured and specific keywords (Davies, 2011). Although conceived in a clinical context, PICO's utility quickly transcended the field, being adapted to other fields of study with simple modifications (such as substituting "Patient" with "Population"), thus allowing for a broader and more abstract understanding and application (Davies, 2011, p.76).

The main rationale for using PICO in non-clinical fields, such as design, stems from the proposal of a "universal PICO scheme" (Nishikawa-Pacher, 2022, p. 3), an argument from which it can be inferred that the model's components correspond to four universal elements of all research: **P** – represents the research object or the unit of observation of the study; **I** – denotes the application of a method, theory, or technology to be investigated; **C** – refers to alternative theories or methods to the applied intervention or, in their absence, the null hypothesis (the assumption that the intervention produces no effect); **O** – symbolizes the objective of knowledge generation, that is, the explanation or effect one intends to achieve or measure.

This reinterpretation disconnects PICO from essentially clinical terminology, transforming it into a powerful methodological tool for structuring a research question in a logical and systematic manner. The very practice of adapting frameworks from other fields is validated in design research as a way to avoid 'reinventing the wheel,' leveraging established tools to generate new knowledge (Goldschmidt and Matthews, 2022).

This approach provides the following advantages and strengths for the structuring of this research: improvement in the clarity and focus of the study, methodological direction, optimization of the literature review, and the communicability and transparency of the investigation (Nishikawa-Pacher, 2022).

The adoption of PICO, grounded in its universality and capacity for abstraction, therefore confers upon this study a level of methodological rigor, conceptual clarity, and operational focus essential to investigate, in depth, the impact of new technologies on product design education.

Methodology

Once the universal PICO framework was adopted as the guiding methodological principle for the development of this SLR, the central research question was decomposed as follows:

- **P:** undergraduate product design students;
- **I:** use of immersive virtual reality tools;

- **C:** traditional teaching-learning methods;
- **O:** improvement in learning product design development.

Synthesizing the research question structured in PICO:

- In undergraduate Product Design students **(P)**, does the use of immersive Virtual Reality tools **(I)**, compared to traditional teaching methods **(C)**, result in an improvement in learning product design development **(O)**?

Subsequently, keywords were defined for each PICO component, and based on these, search strings were formulated and applied to the SCOPUS, Web of Science (WoS), and SciELO databases[1]. The obtained list of publications (SCOPUS – 527; WoS – 114; SciELO – 1) was validated to exclude duplicate references, resulting in a total of 536

Next, eligibility criteria were established for screening: involves undergraduate students; the context is the teaching of Product Design, Industrial Design, or directly related Design areas; explicitly utilizes immersive VR as a teaching or learning tool; reports or evaluates any outcome related to learning or the design process.

Through title and abstract screening, 466 references were excluded, and 70 were selected for full-text reading. However, 26 publications could not be accessed, resulting in a final number of 44 analyzed texts. Data charting was then performed according to the following protocol: Identification; Final verification of inclusion criteria; Research characterization; Data extraction (PICO); Reviewer notes.

At the end of this stage, 4 references misaligned with the research topic were identified and excluded from the final analysis.

The obtained data were then organized and displayed in charts and tables, applying a quantitative analysis to highlight and describe the most employed methods, tools, and research principles. These elements were then related to the research question, employing the PICO protocol as a guide for the discussion and subsequent conclusion of the study.

Data Presentation and Analysis

Chart 1 demonstrates that the four most employed research types were Case Study (25%), Quasi-Experiment (20%), Literature Review (20%), and Experiment (12.5%). It is noteworthy that some studies employed more than one research type; for instance, Díaz González et al. (2025) reported using a Case Study combined with a Quasi-experiment.

1 Searches were limited to publications from the last 15 years.

Research type	N	%	References
Case Study	10	25.0%	(Dorta, Kinayoglu e Boudhraâ, 2016; Camba, Soler e Contero, 2017; González, 2018; Damgrave, Lutters e Putnik, 2019; Koohgilani *et al.*, 2019; Evans e Soderlund, 2020; Zhang e Ranscombe, 2021; Hamurcu, Timur e Rizvanoglu, 2023; Liao, 2024; Díaz González *et al.*, 2025)
Quasi-Experiment	8	20.0%	(Rahimian e Ibrahim, 2011; Jimeno-Morenilla *et al.*, 2016; Shih *et al.*, 2019; Halabi, 2020; Henrich *et al.*, 2021; Jalil *et al.*, 2022; Rossoni *et al.*, 2024; Díaz González *et al.*, 2025)
Literature Review	8	20.0%	(Berni e Borgianni, 2020; Hamurcu, Timur e Rızvanoğlu, 2020; Liu *et al.*, 2021; Hamad e Jia, 2022; Jindal, Mittal e Bansal, 2023; Jiawei, Mokmin e Shaorong, 2024; Lee e Chen, 2024; Nazlidou *et al.*, 2024)
Experiment	5	12.5%	(Huang e Chen, 2019; Huang, Lin e Cai, 2021; Huang e Lee, 2022; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023)
Qualitative Study	3	7.5%	(Hamurcu, 2018; Hamurcu, Timur e Rizvanoglu, 2023; Zhang *et al.*, 2023)
System Development	2	5.0%	(Pan *et al.*, 2021; Zhang, 2023a)
Mixed Methods	2	5.0%	(Mohamed e Sicklinger, 2022; Taylor, 2023)

Chart 1: Research types employed in the studies

Source: The authors

Literature Reviews feature cases such as Berni and Borgianni (2020), who present an overview of VR usage in design research, particularly in the process's early stages; Hamurcu, Timur, and Rızvanoğlu (2020) discuss the current status and potential of VR use in design education; Hamad and Jia (2022) focus on providing an overview of VR applications and limitations in education; Liu et al. (2021) investigate potential applications of immersive technology, ranging from concept generation to final product assembly; Lee and Chen (2024) review the application of VR in design education, proposing a prototyping tool with a low learning curve; Jindal, Mittal, and Bansal (2023) investigate the use and outcomes of VR applications in engineering education; Jiawei, Mokmin, and Shaorong (2024) explore the development trend of VR in education related to product design courses; and Nazlidou et al. (2024) aim to provide an overview of interactive technologies used in education, examining their integration into the learning process.

In studies with experimental approaches (57.5%), Koohgilani et al. (2019), Zhang and Ranscombe (2021), and Hamurcu, Timur and Rizvanoglu (2023) focused on exploring the visualization feature within the VR environment, sometimes employing comparisons with traditional mechanisms; conversely, Dorta, Kinayoglu and Boudhraâ (2016), Camba, Soler and Contero (2017), González (2018), Damgrave, Lutters and Putnik (2019), Evans and Soderlund (2020), and Díaz González et al. (2025) explored the creation process in VR – Camba, Soler and Contero (2017) and Evans and Soderlund (2020) explored collaborative environments, while Dorta, Kinayoglu and Boudhraâ (2016), González (2018), Damgrave, Lutters and Putnik (2019), and Díaz González et al. (2025) focus on more complex design processes involving other types of creation techniques beyond VR, such as traditional sketching and 3D modeling.

Regarding studies with Quasi-experiments, Rahimian and Ibrahim (2011), Shih et al. (2019), Halabi (2020), Henrich et al. (2021), Jalil et al. (2022), Rossoni et al. (2024), and Díaz González et al. (2025) employed the development of physical artifacts directly within the VR environment, while Jimeno-Morenilla et al. (2016) made use only of the platform's visualization feature.

As for the Experiments, only Chaniaud et al. (2023) did not involve the design of an artifact, focusing solely on the 3D construction of objects originally presented in 2D representations. All studies report short task durations in the VR environment, starting at 10 minutes and not exceeding 40 minutes.

Regarding the incidence of control groups, it can be verified in Chart 2 that they were present in 100% of the Quasi-experiments, while 80% of the Experiments included them, and only 20% of the Case Studies did so.

Research type	Control group (n)	%	Mean number of participants (n)	References
Quasi-Experiment	Yes (8)	100%	54.5	(Rahimian e Ibrahim, 2011; Jimeno-Morenilla *et al.*, 2016; Shih *et al.*, 2019; Halabi, 2020; Henrich *et al.*, 2021; Jalil *et al.*, 2022; Rossoni *et al.*, 2024; Díaz González *et al.*, 2025)
Experiment	Yes (4)	80%	31.0	(Huang, Lin e Cai, 2021; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023; Díaz González *et al.*, 2025)
	No (1)	20%	50.0	(Huang e Lee, 2022)
Case Study	No (8)	80%	38.0	(Dorta, Kinayoglu e Boudhraâ, 2016; Camba, Soler e Contero, 2017; González, 2018; Damgrave, Lutters e Putnik, 2019; Koohgilani et al., 2019; Evans e Soderlund, 2020; Hamurcu, Timur e Rizvanoglu, 2023; Liao, 2024)
	Yes (2)	20%	16.5	(Zhang e Ranscombe, 2021; Díaz González et al., 2025)

Chart 2: Use of comparison/control groups in experimental approaches
Source: The authors

In the Quasi-experiments, Rahimian and Ibrahim (2011), Shih et al. (2019), Halabi (2020), and Díaz González et al. (2025) employed traditional sketching methods as a comparison element, while Jimeno-Morenilla et al. (2016), Henrich et al. (2021), and Rossoni et al. (2024) used traditional CAD software, and Jalil et al. (2022) utilized only lectures for this purpose.

In the Experiments, Huang and Chen (2019), Huang, Lin and Cai (2021), and Banerjee, Chowdhury and Yein (2023) employed a comparison with development using traditional CAD software, while Chaniaud et al. (2023) adopted conventional sketching as a comparative element; only Huang and Lee (2022) did not employ a control group, noting that the initiative was an exploratory study intended to explore factors within the VR environment.

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In the Case Studies, only Zhang and Ranscombe (2021) and Díaz González et al. (2025) reported using control groups. However, although most authors did not report employing them, only González (2018), Damgrave, Lutters and Putnik (2019), and Evans and Soderlund (2020) did not present any other type of comparison related to the analyzed intervention, as the remaining authors utilized comparison within the study groups themselves, sometimes evaluating participants at different times. Regarding comparative methods, the studies mentioned comparing tasks in the VR environment with those performed on conventional devices (laptops), traditional teaching methods (lectures, presentations, videos, etc.), manual sketching, and conventional digital modeling in CAD software.

Regarding the number of participants, the overall mean is approximately 41, with Quasi-experiments being the study type that employed the highest number (mean of 54.5), while Case Studies with control groups recorded the lowest mean (16.5). It is important to highlight that the different data collection methods and research approaches employed have a direct impact on the number of participants, with studies conducted over longer periods and involving undergraduate/graduate course subjects tending to present a higher number of participants.

As previously pointed out, another relevant point is the analysis of the tools and data collection mechanisms employed in the studies (Chart 3).

Data collection method	**N**	**%**	**References**
Questionnaire	18	45.0%	(Jimeno-Morenilla *et al.*, 2016; Huang e Chen, 2019; Shih *et al.*, 2019; Evans e Soderlund, 2020; Halabi, 2020; Henrich *et al.*, 2021; Huang, Lin e Cai, 2021; Bernardo e Duarte, 2022; Huang e Lee, 2022; Jalil *et al.*, 2022; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023; Hamurcu, Timur e Rizvanoglu, 2023; Liao, 2024; Rossoni *et al.*, 2024; Siena *et al.*, 2024; Díaz González *et al.*, 2025)
Project Evaluation	14	35.0%	(Dorta, Kinayoglu e Boudhraâ, 2016; Jimeno-Morenilla *et al.*, 2016; Camba, Soler e Contero, 2017; González, 2018; Damgrave, Lutters e Putnik, 2019; Huang e Chen, 2019; Shih *et al.*, 2019; Evans e Soderlund, 2020; Halabi, 2020; Henrich *et al.*, 2021; Huang, Lin e Cai, 2021; Chaniaud *et al.*, 2023; Lee e Chen, 2024; Díaz González *et al.*, 2025)
Scales	14	35.0%	(Hamurcu, 2018; Huang e Chen, 2019; Shih *et al.*, 2019; Evans e Soderlund, 2020; Halabi, 2020; Henrich *et al.*, 2021; Huang e Lee, 2022; Jalil *et al.*, 2022; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023; Hamurcu, Timur e Rizvanoglu, 2023; Rossoni *et al.*, 2024; Siena *et al.*, 2024; Díaz González *et al.*, 2025)
Interviews	10	25.0%	(Hamurcu, 2018; Henrich *et al.*, 2021; Zhang e Ranscombe, 2021; Huang e Lee, 2022; Jalil *et al.*, 2022; Mohamed e Sicklinger, 2022; Hamurcu, Timur e Rizvanoglu, 2023; Taylor, 2023; Zhang *et al.*, 2023; Liao, 2024)
Systematic Literature Review (SLR)	10	25.0%	(Berni e Borgianni, 2020; Hamurcu, Timur e Rızvanoğlu, 2020; Liu *et al.*, 2021; Hamad e Jia, 2022; Mohamed e Sicklinger, 2022; Jindal, Mittal e Bansal, 2023; Jiawei, Mokmin e Shaorong, 2024; Lee e Chen, 2024; Nazlidou *et al.*, 2024)
Observation	7	17.5%	(Rahimian e Ibrahim, 2011; Camba, Soler e Contero, 2017; González, 2018; Koohgilani *et al.*, 2019; Henrich *et al.*, 2021; Huang, Lin e Cai, 2021; Taylor, 2023)

Chart 3: Data collection methods employed in the studies

Source: The authors

The most employed method was the Questionnaire (45%); these are typically administered in the form of online forms with open-ended and closed-ended questions, through which participants provide self-reported data regarding their perceptions of the usability of the employed systems, specific knowledge prior to and after the performed tasks, as well as engagement and satisfaction.

Next is Project Evaluation (35%), whose artifacts consist of deliverables resulting from tasks performed by participants, characterized by posters, presentations, reports, sketches, and 3D projects, which are then evaluated regarding their conceptual and execution quality according to parameters defined in each study. It is quite common to form Expert Panels to conduct this evaluation, as evidenced in the studies by Jimeno-Morenilla et al. (2016), Huang and Chen (2019), Huang, Lin and Cai (2021), and Chaniaud et al. (2023).

A total of 35% also employed Scales to operationalize data collection from participants, always in conjunction with another instrument aimed at measuring performance levels, perception, cognitive loads, and other types of variables. Specific scales are highlighted, such as NASA-TLX – Task Load Index (Banerjee, Chowdhury and Yein, 2023), SUS – System Usability Scale (Huang and Chen, 2019; Huang, Lin and Cai, 2021; Huang and Lee, 2022; Chaniaud et al., 2023), KPSI – Knowledge and Prior Study Inventory (Jalil et al., 2022), and UTAUT – Unified Theory of Acceptance and Use of Technology (Zhang et al., 2023), with the Likert Scale being cited as the most employed instrument to capture variations in completeness and intensity in evaluations and/or responses.

Regarding the use of Interviews (25%), these are typically organized as open-ended questions with structured and/or semi-structured scripts, with their predominant use taking the form of group discussions.

Observation (17.5%) tends to be direct, exclusively qualitative, and recorded in the form of notes regarding specific phases of the activities performed. However, Rahimian and Ibrahim (2011) emphasize that this type of analysis demands the establishment of a highly detailed coding scheme to ensure it is reflected in clear objectives and quantifiable data. The remaining reported methods serve as a complement to those mentioned.

Chart 4 presents a list of the variables identified, categorized into Usability and Satisfaction, Engagement and Attitudes, Performance and Project Quality, Design Process and Learning, Cognitive Load, Usage and Interaction Metrics, and Technology Acceptance.

Variables measured	N	%	References
Usability and Satisfaction	17	42.5%	(Huang e Chen, 2019; Koohgilani *et al.*, 2019; Shih *et al.*, 2019; Huang, Lin e Cai, 2021; Zhang e Ranscombe, 2021; Huang e Lee, 2022; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023; Jindal, Mittal e Bansal, 2023; Rossoni *et al.*, 2024; Siena *et al.*, 2024; Díaz González *et al.*, 2025)
Engagement and Attitudes	13	32.5%	(González, 2018; Hamurcu, 2018; Koohgilani *et al.*, 2019; Henrich *et al.*, 2021; Hamad e Jia, 2022; Mohamed e Sicklinger, 2022; Banerjee, Chowdhury e Yein, 2023; Hamurcu, Timur e Rizvanoglu, 2023; Taylor, 2023; Jiawei, Mokmin e Shaorong, 2024; Nazlidou *et al.*, 2024; Rossoni *et al.*, 2024)
Performance and Project Quality	11	27.5%	(Jimeno-Morenilla *et al.*, 2016; Camba, Soler e Contero, 2017; González, 2018; Damgrave, Lutters e Putnik, 2019; Halabi, 2020; Huang, Lin e Cai, 2021; Pan *et al.*, 2021; Bernardo e Duarte, 2022; Chaniaud *et al.*, 2023; Zhang, 2023b; Díaz González *et al.*, 2025)
Design Process and Learning	10	25.0%	(Lin e Hsu, 2017; González, 2018; Damgrave, Lutters e Putnik, 2019; Evans e Soderlund, 2020; Jalil *et al.*, 2022; Zhang, 2023a; Lee e Chen, 2024; Liao, 2024)
Cognitive Load	6	15.0%	(Rahimian e Ibrahim, 2011; Liu *et al.*, 2021; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023; Rossoni *et al.*, 2024)
Usage and Interaction Metrics	6	15.0%	(Dorta, Kinayoglu e Boudhraâ, 2016; Henrich *et al.*, 2021; Bernardo e Duarte, 2022; Banerjee, Chowdhury e Yein, 2023; Chaniaud *et al.*, 2023)
Technology Acceptance	2	5,0%	(Banerjee, Chowdhury e Yein, 2023; Zhang et al., 2023)

Chart 4: Variables measured in the studies

Source: The authors

The majority of studies (42.5%) adopted variables related to "Usability and Satisfaction" of the system employed, in which information was collected regarding perceived usability, satisfaction, experience, interactivity, preferences, accuracy, usage demand, knowledge retention, learning, expectations, accessibility, and user loyalty.

In the "Engagement and Attitudes" group (32.5%), variables comprising opinions, subjective impressions, understanding of concepts, collaboration, interest, creativity, motivation, skills, and presence were listed.

In "Performance and Project Quality" (27.5%), the collected data refer to project quality, academic performance, design accuracy, and the quality and rendering time of the projects.

In the "Design Process and Learning" group (25%), the variables were problem-to-solution conversion, project understanding, spatial perception, collaboration, efficiency, and initiative. Regarding this specific topic, Chaniaud et al. (2023) employ the Mental Rotation Test – MRT, focused on recording and analyzing the study participants' spatial perception ability, while Jimeno-Morenilla et al. (2016) make use of the Torrance Test of Creative Thinking – TTCT, with the intention of collecting standardized data regarding the participants' creativity.

Regarding "Cognitive Load and Usage and Interaction Metrics" (10%), data were obtained concerning execution time, number of errors, cognitive actions, performance, movements, and participant involvement.

Finally, "Technology Acceptance" (5%) was composed of performance expectancy, effort, social influence, and facilitating conditions.

Regarding the most employed devices and systems, there is a wide variety; regarding the hardware employed, Head Mounted Displays – HMDs represent the most common type – totaling 26 HMDs: HTC Vive (5), HTC Vive Pro (2), Oculus Rift (4), Oculus Quest (1), Oculus/Meta Quest 2 (4), Microsoft HoloLens (3), Microsoft HoloLens 2 (1), Oculus Touch (1), HP Reverb G1 (1), and unspecified HMDs (4). It is common to observe the use of the same type of device in multiple studies involving the same group of researchers, evidencing the intention to optimize institutional investments.

Regarding software, an even greater variety is observed, often due to the multiplicity of study objectives, which leads to their selection based on the intended tasks and interactions. However, five software applications can be highlighted: Unity (8), Gravity Sketch (5), Autodesk 3dsMax (4), Autodesk VRED (3), and SolidWorks (3). All these systems are geared towards 3D creation, modeling, and rendering, with Gravity Sketch being the only one among them exclusive to VR platforms.

Finally, Asian countries account for the highest concentration of studies, with 13 – Taiwan (6), China (3), India (1), Malaysia (1), and Asia-Pacific (1); Europe comes in second place, with 10 – United Kingdom (2), Turkey (2), Germany (1), Spain (1), France (1), Italy (1), Norway (1), and Europe (1); in third place, the Americas represent 7 studies – USA (3), Mexico (2), Brazil (1), and Canada (1); and the remaining studies are divided between Middle Eastern countries and Oceania.

Discussion

The predominant research methodology reveals a maturing field of study, as the significant number of studies with experimental approaches (57.5%) signals a shift beyond exclusively theoretical exploration of the topic, seeking hypothesis validation to generate robust evidence related to the application of VR in the design teaching-learning process. An example of this methodological complexity, with the adoption of different investigation instruments, is provided by works such as that of Díaz González et al. (2025), who reported the combined use of Case Study and Quasi-experiment to enrich their analyses.

Regarding **Population (P)**, the analysis reveals that studies typically employ participants from both undergraduate and graduate programs to investigate the impact of interventions. The number of participants varies considerably among different research types – the overall mean was approximately 41, with

Quasi-experiments utilizing the highest number of participants (mean of 54.5), while Case Studies with control groups recorded the lowest mean (16.5). It is important to highlight that data collection methods and research approaches had a direct impact on this number – studies that extended over longer periods and were integrated into undergraduate or graduate course subjects tended to have a higher number of participants.

Regarding **Intervention (I)**, in experimental studies, it is possible to identify certain patterns and particularities: the adopted procedures are structured around specific tasks, with controlled durations and, in most cases, compared to conventional methods.

In Experiments and Quasi-experiments, the main focus was on the creation of artifacts directly within the VR environment: for instance, Banerjee, Chowdhury and Yein (2023) assigned the task of developing a water bottle; Chaniaud et al. (2023) required the development of a shelf and a sideboard based on 2D images; Huang, Lin and Cai (2021) involved the design of a computer mouse; Halabi (2020) asked participants to develop a wheelchair-accessible kitchen; Huang and Chen (2019) employed the creation of a toy car; and Shih et al. (2019) focused on the design of a set comprising a table, a chair, and a cup.

Case Studies explored different facets of the design process in VR: some investigated the visualization features of the immersive environment (Hamurcu, 2018; Koohgilani et al., 2019; Liao, 2024), sometimes in comparison with traditional mechanisms; while others delved into the creation process (Dorta, Kinayoglu and Boudhraâ, 2016; Damgrave, Lutters and Putnik, 2019), with some employing collaborative environments (Evans and Soderlund, 2020), and others analyzing more complex design processes that integrated VR with other techniques, such as traditional sketching and 3D modeling (Dorta, Kinayoglu and Boudhraâ, 2016; González, 2018; Díaz González et al., 2025).

A consistent finding in the experimental studies was the short duration of tasks performed in the VR environment: interventions typically started at 10 minutes and commonly did not exceed 40 minutes. This limitation may reflect a deliberate strategy to mitigate cognitive load and the potential physical discomfort associated with prolonged use of the devices.

Comparison (C) with conventional teaching methods was a crucial methodological element in most experimental studies, with the most common control strategies including comparison with methods and tools already established in design (sketching or 3D modeling in CAD software). Traditional sketching methods were employed as a comparison mechanism in studies such as those by Rahimian and Ibrahim (2011), Shih et al. (2019), and Díaz González et al. (2025), while research such as those by Jimeno-Morenilla et al. (2016), Henrich et al. (2021), and Rossoni et al. (2024) used CAD software as a comparative element.

The evaluation of **Outcomes (O)** was multifaceted: Questionnaires (45%) were widely used to capture self-reported data on students' perceptions, aligning with the most investigated set of variables, "Usability and Satisfaction" (42.5% of studies); Project Evaluation focused on tangible results, analyzing the conceptual and execution quality of artifacts, such as sketches and 3D models, frequently relying on the evaluative rigor of Expert Panels, as evidenced in the works of Jimeno-Morenilla et al. (2016) and Chaniaud et al. (2023), among others.

To measure outcomes quantitatively, various standardized scales were employed, such as the NASA Task Load Index (NASA-TLX), used to measure cognitive load; the System Usability Scale (SUS), to assess usability; and the Knowledge and Prior Study Inventory (KPSI), to measure the study participants' prior knowledge inventory (Huang and Chen, 2019; Jalil et al., 2022; Banerjee, Chowdhury and Yein, 2023).

Other important variables collected included "Engagement and Attitudes" (32.5%) and "Performance and Project Quality" (27.5%), with the search for standardized data on cognitive processes being reinforced by the use of validated tests, such as the Mental Rotation Test (MRT), employed by Chaniaud et al. (2023), and the Torrance Test of Creative Thinking (TTCT), employed by Jimeno-Morenilla et al. (2016).

Conclusions

The convergence of VR with education and society is perceived as a contemporary trend, with the analyzed literature indicating that immersive technologies find a vast growth area in this context, with the potential to increase productivity and quality across all stages of product development (Shih et al., 2019; Berni and Borgianni, 2020; Liu et al., 2021; Bernardo and Duarte, 2022; Zhang, 2023b, 2023a; Liao, 2024; Nazlidou et al., 2024).

A possible integration between human aspects and technology promises to optimize not only productivity but also creative methods, consolidating the role of VR across different stages of the design process (Shih et al., 2019; Berni and Borgianni, 2020; Liu et al., 2021; Bernardo and Duarte, 2022; Zhang, 2023b, 2023a; Liao, 2024; Nazlidou et al., 2024). VR presents itself as a highly valuable pedagogical tool, especially when integrated into project-based and student-centered learning approaches (Dorta, Kinayoglu and Boudhraâ, 2016; Jimeno-Morenilla et al., 2016; Camba, Soler and Contero, 2017; Damgrave, Lutters and Putnik, 2019; Koohgilani et al., 2019; Evans and Soderlund, 2020; Halabi, 2020; Hamurcu, Timur and Rızvanoğlu, 2020; Jalil et al., 2022; Mohamed and Sicklinger, 2022; Taylor, 2023; Rossoni et al., 2024).

Pedagogical approaches that combine traditional methods with VR tools can enhance the development of spatial skills in design students (González, 2018; Hamurcu, 2018; Zhang and Ranscombe, 2021; Hamurcu, Timur and Rizvanoglu, 2023; Jindal, Mittal and Bansal, 2023; Zhang, 2023b; Jiawei, Mokmin and Shaorong, 2024; Díaz González et al., 2025). Such approaches grant students significant responsibility in the teaching-learning process, enhancing their competencies in dealing with the complexities and uncertainties inherent to the design process while, at the same time, improving their abilities to develop high-quality solutions of relevance to society (Dorta, Kinayoglu and Boudhraâ, 2016; Jimeno-Morenilla et al., 2016; Camba, Soler and Contero, 2017; Damgrave, Lutters and Putnik, 2019; Koohgilani et al., 2019; Evans and Soderlund, 2020; Halabi, 2020; Hamurcu, Timur and Rızvanoğlu, 2020; Jalil et al., 2022; Mohamed and Sicklinger, 2022; Taylor, 2023; Rossoni et al., 2024).

VR-based 3D modeling tools offer a more engaging, enjoyable, and collaborative experience when compared to traditional CAD, improving usability and user creativity, showing promise for the conceptual phases of the design process (Rahimian and Ibrahim, 2011; Lin and Hsu, 2017; Huang and Chen, 2019; Henrich et al., 2021; Huang, Lin and Cai, 2021; Pan et al., 2021; Hamad and Jia, 2022; Huang and Lee, 2022; Banerjee, Chowdhury and Yein, 2023; Chaniaud et al., 2023; Lee and Chen, 2024; Siena et al., 2024).

The adoption of VR in design education faces significant challenges – VR sketching and modeling are inherently more complex than traditional methods, demanding more developed visuospatial skills and a steep learning curve for new users (Rahimian and Ibrahim, 2011; Lin and Hsu, 2017; Huang and Chen, 2019; Henrich et al., 2021; Huang, Lin and Cai, 2021; Pan et al., 2021; Hamad and Jia, 2022; Huang and Lee, 2022; Banerjee, Chowdhury and Yein, 2023; Chaniaud et al., 2023; Lee and Chen, 2024; Siena et al., 2024). Students and instructors express concerns regarding the potential negative impact on the development of essential manual skills and material knowledge, in addition to barriers such as tool usability and the lack of physical interaction provided by the devices (González, 2018; Hamurcu, 2018; Zhang and Ranscombe, 2021; Hamurcu, Timur and Rizvanoglu, 2023; Jindal, Mittal and Bansal, 2023; Zhang, 2023b; Jiawei, Mokmin and Shaorong, 2024; Díaz González et al., 2025). Given this, it becomes essential that students master fundamental design skills, such as traditional sketching, before delving into the complexity of digital tools (Rahimian and Ibrahim, 2011; Lin and Hsu, 2017; Huang and Chen, 2019; Henrich et al., 2021; Huang, Lin and Cai, 2021; Pan et al., 2021; Hamad and Jia, 2022; Huang and Lee, 2022; Banerjee, Chowdhury and Yein, 2023; Chaniaud et al., 2023; Lee and Chen, 2024; Siena et al., 2024).

Regarding the technical aspects related to VR, issues such as precision (in which traditional CAD still outperforms), costs, technical difficulties, and motion sickness represent significant challenges to be overcome (Rahimian and Ibrahim, 2011; Lin and Hsu, 2017; Huang and Chen, 2019; Henrich et al., 2021; Huang, Lin and Cai, 2021; Pan et al., 2021; Hamad and Jia, 2022; Huang and Lee, 2022; Banerjee, Chowdhury and Yein, 2023; Chaniaud et al., 2023; Lee and Chen, 2024; Siena et al., 2024).

Finally, the educational experience plays a crucial role in shaping the attitudes of future design professionals; it is, therefore, fundamental that Higher Education

Institutions (HEIs) provide adequate access to and training in VR tools, thereby enabling students to achieve the level of proficiency required by the demands of the professional environment (González, 2018; Hamurcu, 2018; Zhang and Ranscombe, 2021; Hamurcu, Timur and Rizvanoglu, 2023; Jindal, Mittal and Bansal, 2023; Zhang, 2023b; Jiawei, Mokmin and Shaorong, 2024; Díaz González et al., 2025). In this context, there is a need for the development of well-structured curricula and the formulation of robust methodological proposals capable of objectively measuring the impact of VR (Dorta, Kinayoglu and Boudhraâ, 2016; Jimeno-Morenilla et al., 2016; Camba, Soler and Contero, 2017; Damgrave, Lutters and Putnik, 2019; Koohgilani et al., 2019; Evans and Soderlund, 2020; Halabi, 2020; Hamurcu, Timur and Rızvanoğlu, 2020; Jalil et al., 2022; Mohamed and Sicklinger, 2022; Taylor, 2023; Rossoni et al., 2024), with the ultimate goal of consolidating it as a platform that enables collaboration and offers the necessary balance between interactions in the physical and virtual worlds (Shih et al., 2019; Liu et al., 2021; Bernardo and Duarte, 2022; Zhang, 2023b, 2023a; Liao, 2024; Nazlidou et al., 2024).

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