Criteria for the incorporation of software in architectural education

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HIGHLIGHTS

- Virtual reality is a positive tool with a high-impact in architectural education
- Constructivist, cognitive, and holistic approaches support incorporation of software in architectural education
- Technology and software in architectural education require a strategic structuring for their incorporation

ABSTRACT

The integration of technology has been a constant fact in various areas of architecture. Currently there are innovative tools to be used both in the architectural design process and in professional practice, so its incorporation in architectural education is necessary for the preparation of future professionals. However, the incorporation of technology in architectural education is a process that involves various factors, so this article aimed to analyze the technologies and software that have been incorporated into architectural education to establish criteria in this regard, in addition to identifying the pedagogical approaches used for their incorporation. A systematic review was carried out through three online scientific databases and a quantitative-qualitative analysis was performed. The results suggest that the most incorporated technology and software are Virtual Reality and Rhinoceros respectively. The main reason for integrating a certain technology or software is the need to encourage the adaptation of these to the current demands of the area. Four main criteria used for the incorporations were identified: selection of learning resources, learning design, implementation and degree of success and evaluation. In terms of pedagogical approaches, the constructivist approach was found to be the most used. The incorporation positively influence the teaching-learning process in architecture education, however, there are limitations to their complete satisfaction, so studies on the subject are necessary, especially in specific contexts.

Keywords: *architectural education, software, technology, incorporation, criteria, pedagogical approaches*

1. INTRODUCTION

Currently, both professionals and students in the field of architecture use various types of software as a common practice for the conceptualization, projection and materialization of an architectural project.

The integration of computer-aided design (CAD) was a paradigm shift in terms of representation techniques for architecture, since its use implies less manual work time, greater precision and the possibility of collaborative work worldwide, such that digital applications and tools for design have been developed alongside global technological innovation and development.

Such is the case of building information modeling (BIM), which has gained popularity in the discipline for more than 40 years since its emergence in the 1970s. [1]. BIM is a technology distributed through various software that integrates all the information of the architectural project in a virtual model [2]. In addition to BIM, other software is found in the active discourse of digital tools in architecture: virtual reality, augmented reality, big data, robotic tectonics, parametric design, 3D printing, geographic information systems (GIS) and artificial intelligence. All these applications are being explored in architecture, in its different fields, and even some are already consolidated within professional practice.

For this reason, as mentioned by various studies [2]–[4], the preparation of future professionals in the areas of architecture and design must provide the knowledge and tools to face current and future challenges in terms of design, construction, sustainability, quality of life and city planning.

The number of design and architecture schools concerned with implementing study plans and courses that integrate technologies that provide students with the necessary elements to practice in the job field are increasing daily. However, the implementation of new technologies in education is a complex process due to various factors such as accessibility to media and digital tools, integration with a pedagogical approach, the complexity, in itself, of the design process and its adaptation to a specific software, or the selection of the software according to the level of knowledge of the student, among others.

The main problem is that there is no clarity about what technologies to use in the different architecture subjects and programs, or under what conditions to use them to fulfill educational purposes. In addition, it is required that the inclusion of these technologies as teaching-learning tools address clear pedagogical approaches. In this way, the systematic review had the following aims:

1. To analyze what technologies have been incorporated into architectural education and related disciplines, in order to establish appropriate criteria for their implementation.

2. Identify the type of pedagogical approach that supports the incorporation of software in architectural education to assess the results.

The documentary research of the specialized literature available in the scientific databases aims to answer the following research questions:

1. What types of software have been incorporated into architectural education and under what criteria?

2. What pedagogical approaches support the incorporation of software in architectural education?

The importance of answering these questions lies in proposing educational strategies appropriate to the current demands of the labor market, higher education, industry, the environment and society. Otherwise, by not taking into account technical aspects, such as pedagogical and methodological ones in the integration of ICT in the classroom, "the possibilities of the technologies are notably reduced" (own translation) [5].

The widespread use of technologies by beginning architecture students could have a negative effect on creativity and learning of the basic principles of architecture [6] if there is no implementation plan from the pedagogical approach of architecture.

Pedagogy is essential to guide the use of technology, its expectatives and its integration in educational processes, because "no technological resource would make sense if it is introduced into the classroom without first thinking what for, for whom, how it will be used what learning and competencies are intended to be achieved with it” (own translation) [5].

2. METHOD

Systematic review is a documentary research method that provide the state-of-the-art on a specific topic. Through these method it is possible to identify the cutting edge knowledge. That is, everything that is known about solving a problem and what is not yet known about it [7].

To answer the research questions raised, an information search was carried out using three electronic scientific databases specialized in education and technology: *Science Direct*, *Dialnet* and *AULIMP*. The information search strategy was based on the principles of the PRISMA 2020 declaration [7], which are accepted by the academic community to carry out social or educational research.

2.1. Review process and search strategy

The review was carried out between August 7 and September 2, 2022 with the following formula ((software) AND (architectural education OR educación arquitectónica)). Search terms included keywords in Spanish and English. 772 results were obtained. After a review of duplicates, seven documents were discarded. The total documents admitted to the process of review were 765.

Subsequently, an analysis of the relevance of these 765 documents was made by reading the titles and abstracts. Only 84 documents were relevant for the analysis. Finally, inclusion and exclusion criteria were applied, which are explained later in this text. The final result was 23 documents as a unit of analysis (Figure 1).

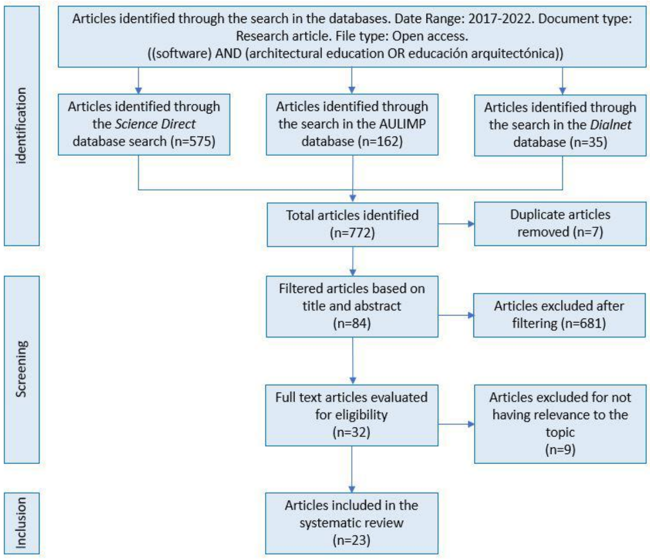

***Fig. 1:** Flowchart of the article search and selection strategy. Own elaboration based on* [8]

2.2. Inclusion criteria

The inclusion criteria were: open access research articles, written in any language and from any country of origin, with full text availability, on educational topics, published between 2017 and 2022. Due to these broad inclusion criteria, it was possible to know the cutting edge knowledge in several world regions.

2.3. Exclusion criteria

Studies with poor methodology were excluded. Also, those that addressed the following topics, which are not strictly educational: the patterns or guidelines that help build a software program, specific software engineering topics, learning computer programming, information architecture, which is a discipline key in the information retrieval process.

Items such as urban planning, smart cities, internet of things in buildings, smart buildings, energy efficiency and climate change were also excluded. Studies that addressed the use of new technologies in the professional practice of architecture were also excluded.

In some cases, the inclusion and exclusion criteria were applied after reading the entire article, because the terminology used in design and architecture is very similar to that used in software architecture in the computer science area.

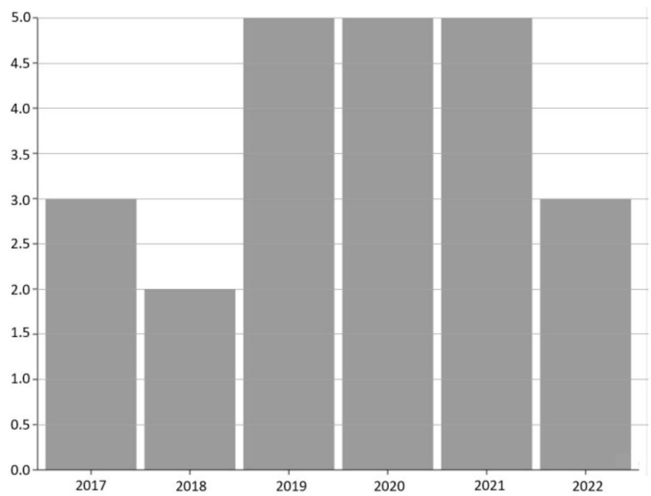

***Fig. 2:** Number of articles included in the review per year.*

3. RESULTS AND DISCUSSION

Germany is the country with the highest number of publications on the incorporation of software in architectural education and related disciplines (4 articles). From this reference, in descending order, the following countries and the total number of articles on the subject are: China (3), Turkey (3), Japan (2), USA (2), Spain (2), and Denmark, United Arab Emirates, Canada, Portugal, Greece, Indonesia, South Korea, Bangladesh, Cyprus, Russia, Norway, Liechtenstein, United Kingdom, Singapore, Austria, Jordan, and Kosovo with only one publication. It stands out that the USA and Canada are the only American countries with a publication on the subject.

In the history of design and architecture, Germany stood out for the creation of the Bauhaus, which established the foundations of modern design. Therefore, the skills of students in these disciplines are highly influenced by these bases [9]. This explains the preponderant role of Germany in the results of this documentary research.

Table 1 presents the articles included in this systematic review. They have been listed in alphabetical order, with the full title, author's name, year of publication and country of origin. The years with the highest number of research (Figure 2) were 2019, 2020 and 2021. It is inferred that in the last two years there was an increase in research on virtual education, online education and distance education as a result of the COVID-19 pandemic. It can be said, then, that this provoked the analysis of the deficiencies and opportunities of architecture education in these modalities. The production of publications in 2022 is scarce because it was the year in which this research was carried out.

Num.	Article title	Author's name	Year	Country
1	A Didactic Pedagogical Approach toward Sustainable Architectural Education through Robotic Tectonics	Xinyu Shi, Xue Fang, Zhoufan Chen, Tyson Keen Phillips and Hiroatsu Fukuda	2020	China, Japan and USA
2	Collaboration and Dialogue in Virtual Reality	Camilla Gyldendahl Jensen	2017	Denmark
3	Collage digital y tics, nuevas herramientas para la Historia y Teoría de la Arquitectura	Rubén García Rubio and Annarita Cornaro	2019	USA y UAE
4	Construction of xapi-based Multimedia Interaction Technology in Architectural Design Teaching	Haiou Wang	2017	China
5	Data-Driven Design as a Vehicle for BIM and Sustainability Education	John Benner and J. J. McArthur	2019	Canada
6	Design thinking as digital transformative pedagogy in higher sustainability education: Cases from Japan and Germany	Sadaf Taimur and Motoharu Onuki	2022	Japan
7	Developing an Integrated VR Infrastructure in Architectural Design Education	Serdar Aydin and Begum Aktas	2020	Turkey
8	Establishing the Architectural Talents Cultivating System of Practice and Innovation Ability Under the Background of New Engineering	Yang Chengdong and Liang Shuang	2019	China
9	GIS in Architectural Teaching and Research: Planning and Heritage	Bertha Santos, Jorge Gonçalves, Ana M. Martins, Maria T. Pérez-Cano, Eduardo Mosquera-Adell, Despina Dimelli, Apostolos Lagarias, and Pedro G. Almeida	2021	Spain, Portugal and Greece
10	Impact of simple virtual technology application in architectural education	Bramasta Putra Redyantanu and Altrerosje Asri	2021	Indonesia
11	Integrating 3D Printing Technologies into Architectural Education as Design Tools	Hemza Boumaraf and Mehmet İnceoğlu	2020	Turkey
12	Integrating simulation into design: an experiment in pedagogical environments	Sungeun Lee, Bokgiu Choi, Camilla Cavalcante Maia, Jaewan Park, Sang Hoon Youm and Sangwon Lee	2021	South Korea
13	Introducing BIM in Outcome Based Curriculum in undergraduate program of architecture: Based on students' perception and lecture-lab combination	Sharif Tousif Hossain and KM Ulil Amor Bin Zaman	2022	Bangladeshi
14	Learning with augmented reality: Impact of dimensionality and spatial abilities	Jule M. Krüger, Kevin Palzer and Daniel Bodemer	2022	Germany
15	Mandatory Virtual Design Studio for All: Exploring the Transformations of Architectural Education amidst the Global Pandemic	Aminreza Iranmanesh and Zeynep Onur	2021	Cyprus
16	"Mobility game": interactive technology for urban planning education	N V Danilina and R Harder	2020	Russia and Germany
17	More than experience? - On the unique opportunities of virtual reality to afford a holistic experiential learning cycle	Jennifer Fromm, Jaziar Radianti, Charlotte Wehking, Stefan Stieglitz, Tim A. Majchrzak and Jan vom Brocke	2021	Germany, Norway and Liechtenstein
18	Out of "touch"? – An experiential pedagogical approach to daylighting in architecture and interior design education	Gillian Treacy	2019	United Kingdom
19	The 'Urban Elements' method for teaching parametric urban design to professionals	Aurel von Richthofen, Katja Knecht, Yufan Miao and Reinhard König	2018	Singapore, Germany and Austria
20	The application of virtual reality technology in architectural pedagogy for building constructions	Ahmad K. Bashabsheh, Hussain H. Alzoubi and Mostafa Z. Ali	2019	Jordan

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Num.	Article title	Author's name	Year	Country
21	The concept of "modelarium" and its impact on creativity and artistic education	Bajçinovci, Bujar and Jerliu, Florina	2017	Kosovo
22	Urban data and urban design: A data mining approach to architecture education	Francesc Valls, Ernesto Redondo, David Fonseca, Ricardo Torres-Kompen, Sergi Villagrasa and Nuria Martí	2018	Spain
23	VR-Based Interactive Learning in Architectural Education: A Case on Safranbolu Historical Bathhouse	Eray Şahbaz	2020	Turkey

Table 1: *Number of articles included in the review by year and country.*

3.1. Embedded technologies and software

Table 2 presents various technologies implemented with different software. In some cases, the incorporation was for the presentation of a product created with software and the subsequent evaluation of the reaction, behavior and knowledge of the user. In other cases, the user used the tool from scratch to build a product or project. And, in other cases, the user used elements previously made with software, as well as interaction with digital tools to generate a project, propose a solution to a problem, or create a product.

Figure 3 presents the most incorporated technologies. First, there is the creation of virtual reality (VR) through various software. Among the most used software are Unity Game Engine, Rhinoceros, Autodesk Revit, Blender and Oculus rift (Figure 4). This diagram presents, in the first order, the technologies and, where appropriate, the implemented software; secondly, the specific software used for each technology.

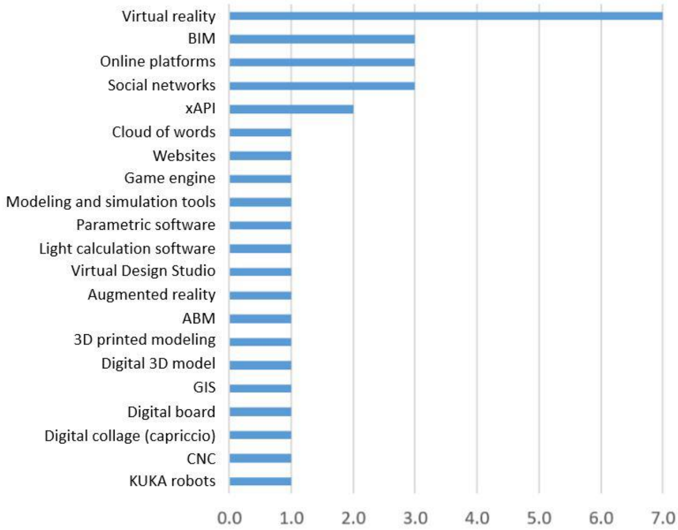

Fig. 3: *Used technologies in architectural education.*

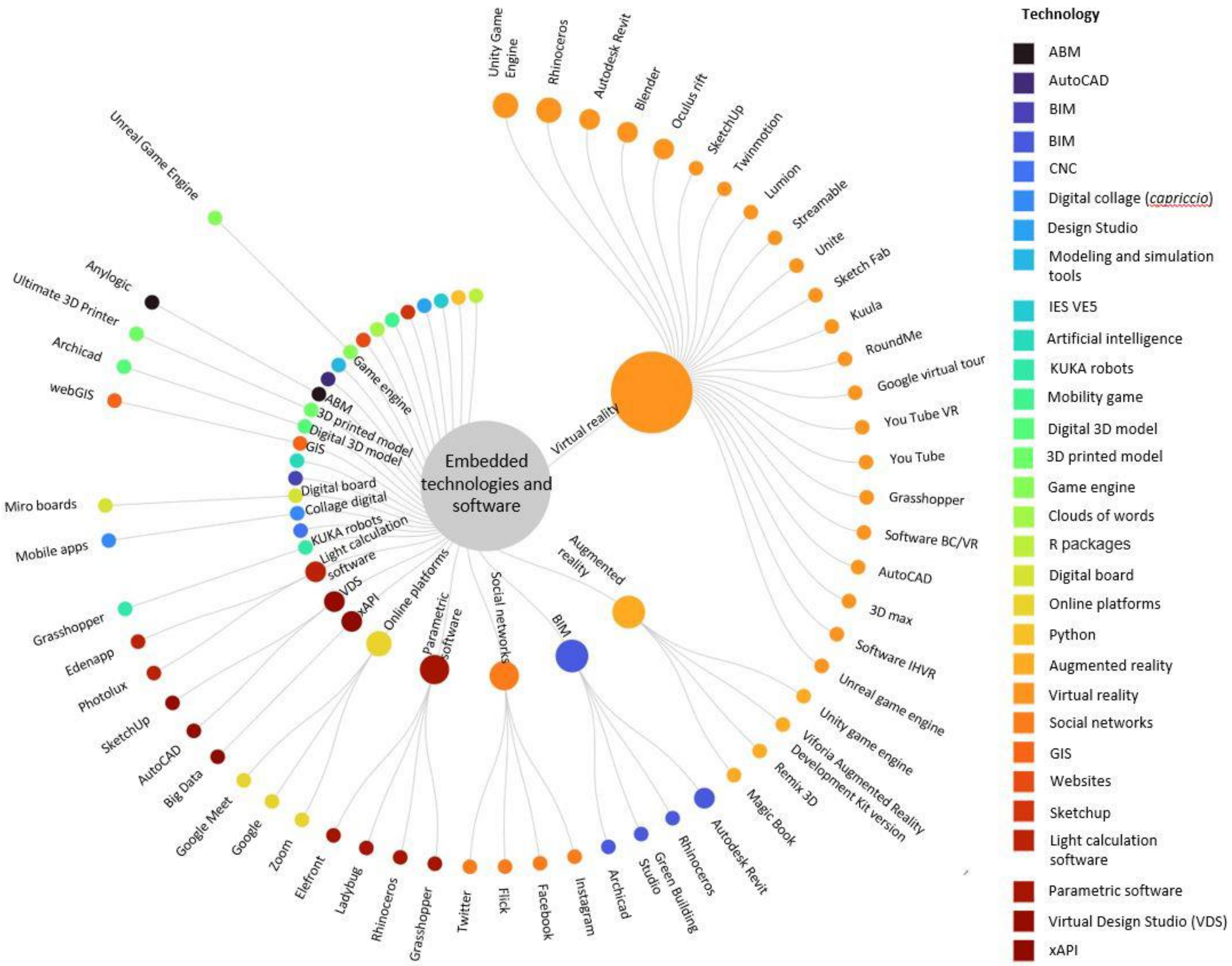

***Fig. 4:** Diagram of embedded technologies and software in architectural education.*

Article	Technologies	Software
1	KUKA robots	Grasshopper
	CNC	NI*
2	Virtual reality	Autodesk Revit Unity Game Engine Oculus Rift
3	Digital collage (*Capriccio*)	NI*
	Mobile apps	NI*
	Social networks	Instagram
4	xAPI	Big Data
5	BIM	Autodesk Revit Green Building Studio
6	Online platform	Zoom
	Digital board	Miro boards
7	Virtual reality	Blender Rhinoceros Autodesk Revit
	Online platforms	Google
	Social networks	Facebook
	BIM	Autodesk Revit Rhinoceros
	Virtual reality	Unity Game Engine Rhinoceros Grasshopper
8	Virtual simulation	NI*
	Building performance simulation	NI*
	BIM	NI*
	Virtual reality	NI*
	Augmented reality	NI*
	Artificial intelligence	NI*
9	GIS	webGIS
10	Virtual reality	SketchUp Rhinoceros Twinmotion Lumion You Tube Streamable Unite Sketch Fab Kuula RoundMe Google virtual tour You Tube VR
11	Digital 3D model	Archicad
	3D printed model	Ultimate 3D Printer
12	ABM	Anylogic
13	BIM	Archicad
	CAD drawing	AutoCAD
14	Augmented reality	Unity Game Engine Vuforia Augmented Reality Development Kit version Remix 3D Magic Book

Article	Technologies	Software
15	VDS	AutoCAD Sketchup
	Online platform	Google Meet
16	NI*	Mobility game
17	Virtual reality	NI*
18	NI*	Sketchup
	NI*	Design Studio
	NI*	IES VE5
	Light calculation software	Photolux Edenapp
19	Parametric software	Grasshopper Rhinoceros Ladybug Elefront
20	Virtual reality	Software BC/VR AutoCAD 3D max Unity Game Engine
21	Modeling and simulation tools	NI*
22	Social networks	Flick Twitter
	Game engine	Unreal game engine
	xAPI	NI*
	NI*	Python
	NI*	R packages
	Websites	NI*
	Cloud of words	NI*
23	Virtual reality	Software IHVR Blender Unreal Game Engine Oculus rift

Table 2: *Technologies and software incorporated in the reviewed articles. NI* not indicated in the article.*

Perez *et al*. [10] proposes a definition of virtual reality and augmented reality: "Virtual Reality (VR) and Augmented Reality (AR) are the three-dimensional (3D) representation of things through electronic means". Both allow you to see the result of a project before it is carried out.

Some research has analyzed the integration of VR and its effectiveness in education [4], [11]–[15]:

In its incorporation by ecosystems, according to aspects of innovation and efficiency, it shows a successful trend, but the selected software (Blender, Rhinoceros and Autodesk Revit, Unity Game Engine and Grasshopper), had an unexpected degree of difficulty in its use for the students; a determining factor was that the programs were in English, for Turkish-speaking students.

On the contrary, when incorporating VR was proposed in a simple way, there was a good understanding of the concepts and the application of the technology. The VR was considered, by the students, as a positive tool for the communication of the architectural project. They also stated that it contributed to their learning process.

Students and teachers proposed the combination of VR and artificial intelligence in the development of VR prototypes, to obtain holistic experiential learning.

In another case, the VR-based BC/VR software was rated as more enjoyable, with more potential to provide information to students, and more implementable in courses, than the traditional way of teaching. Another study regarding its effectiveness, in relation to traditional methods, showed that VR achieved the expected success in teaching the principles of historic building design, since student learning was more effective than with the traditional way.

In second place, BIM was identified as the most incorporated technology, also generated through various software. Among the most used software are Autodesk Revit, Rhinoceros, Green Building Studio y Archicad.

The results of the incorporation of BIM [2], [11], [16] indicate a good participation of the students, the acquisition of the capacity to model, simulate and evaluate design iterations from BIM, the acquisition of knowledge about design concepts and the need to incorporate them into the curriculum from the first year at its basic level to achieve a gradual introduction according to the learning process in the following years.

The most incorporated software were Rhinoceros, Unity Game Engine, Autodesk Revit, Grasshopper, AutoCAD, Sketchup, Blender, Oculus Rift, Unreal Game Engine y Archicad (Figure 5). These programs were used in more than one study in different technologies.

Some studies hypothetically explored the incorporation of certain software. One of them

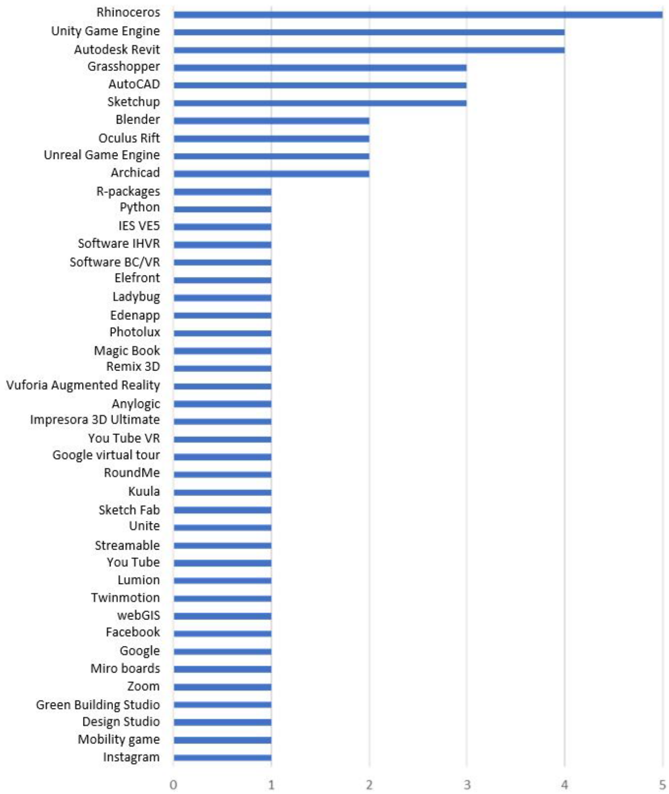

Fig. 5: *Incorporated software.*

[13] analyzed the incorporation of VR through experiential learning through Design thinking, where students created three prototypes to use this tool in their design process.

The research of Chengdong and Shuang [4] raised the construction of a talent cultivation mechanism as a practical teaching platform of production, study and research, where the integration of technologies based on virtual simulation, building performance simulation, BIM, VR, RA, artificial intelligence, computing and smart construction.

Similarly, another research [17] examines the teaching and learning process of students and proposes the concepts of *Modelarium* as a learning tool and space, which focuses on educational competencies and communication skills, considering the introduction of teaching tools modeling and simulation.

Other studies analyzed how software integration has been carried out in universities, for example, with GIS systems [18].

The reasons for the incorporation of the software or technology is relevant in this analysis, but not all the studies mentioned the reasons for the choice of the software. The results found are detailed below:

- The need to promote adaptation to technology (robots, BIM, VR) due to the current and future demands of the construction industry, including the design and construction of sustainable buildings [2], [4], [14], [16], [19].
- The correspondence between the pedagogical approach and the selected technology, in terms of the characteristics of the software [14], [20], [21].
- According to the approach established by the author (Design Thinking, VR), considering the digital tools that could support the elements of his approach [13], [22].
- Adapt traditional artistic techniques, such as *Capriccio*, to digital tools, and promote student participation through the use of technology [23].
- The authors find useful (xAPI and VR) in making teaching more interesting and engaging students [13], [24].
- The interest in the area for the integration of technologies, specifically for integrating simulation in the design process [15], [16].
- The use and exploration of software in architectural education is scarce, so the authors present their analysis in this regard [12], [16], [18], [25].
- For the impact it has had on architectural design (VR, VDS) and the dilemmas facing its integration into architectural education [3], [14], [26]–[28].
- For the recent recognition of the potential of the digital tool in the area of architecture or related areas [18], [25], [27], [29].
- Relatively low cost as one of the main advantages of using certain technology [18].
- Due to the characteristics offered by the digital tool in terms of design, the use of which could improve the development of educational materials for architectural education [15], [28], [30], [31].
- Software was selected to perform an alternative scan to existing comparison studies [29].

3.2. Criteria used for the incorporation of software and technology

Through a comparative analysis of the texts, the most used elements for the incorporation of technology or software were identified, which were grouped into four categories of analysis.

1) Selection of learning resources.
    - Pedagogical approach or creation of a pedagogical framework.
    - Thematic content.
    - Context (physical and social).
    - Digital tools. Its selection was due to: adaptation to technology in the area, according to the pedagogical approach, interest in its integration, usefulness, to explore its use in education, its impact on architecture, its accessibility and its own characteristics.
2) Learning Design.
    - Previous knowledge, previous experience or level of knowledge about the technology incorporated.
    - Students' perspectives on embedded technology or software.
    - Guide, teaching role.

- Explanation on the handling of the software, detailed guide, introduction of the basic concepts of the technology, importance of its use and presentations.
- Course Objectives and Course Learning Objectives.
- Student profile.
- Construction of the curricular system, curricular plan or program, construction of the teaching environment (virtual and real in some cases).
- Learning material. Preparation of teaching material for students. Definition of the project or activity to be carried out.

3) Implementation.

- Acquisition of skills and knowledge.
- Problem solving.
- Explore the tool, period of habituation to handling the software, become familiar with the technology.
- Mastery level that the student acquires from the digital tool.
- Use, simulation of the tool.
- Presentation or exposition of the tool before the students.
- Time to carry out the activity, the project or the interaction with the tool.

4) Degree of success and evaluation.

- Impact. Effects of mastery or handling of the tool by students.
- Expectation and perception of the student about the technology incorporated.
- Achievement of program learning outcomes: evaluation of the results, that is, the degree of success of the students in completing the task, activity or project and their demonstrated understanding that it has to do with the use of the software and the thematic content. And the evaluation of the process that means to measure the incorporation and achieved the pedagogical objectives.
- Knowledge evaluation. That is, evaluation of course content and cognitive level.

The results indicate that the incorporations made through the identified criteria contribute to improving skills, contribute to the development of sustainable designs and projects, contribute to the acquisition of knowledge, improve academic performance, motivate and stimulate students, provide new approaches to design and contribute to the visualization of ideas.

It was also found that the incorporation of software and technology requires a strategic structuring so that the development of its incorporation is adequate, and in some cases, with better contextual planning.

3.3. Pedagogical approaches

Of the 23 articles analyzed, 87% (20 articles) clearly indicated a pedagogical approach to incorporate some technology in education (Figure 6). Some authors created their own pedagogical framework, or based themselves on other examples that have been used in the area to use them as educational methods.

The constructivist approach was the most used, with 12 investigations that implemented it. Among the most used models are Problem-Based Learning, Project-Based Learning and Experiential Learning. The findings, according to the categories of analysis, are presented below.

Constructivism. In architectural education it is common to handle constructivism because, in terms of design, this form of teaching and learning allows students to learn by doing simulations of professional practice. In general, the evaluations are carried out with projects and the students expose their learning by solving certain problems through one or various products, such as architectural plans, sketches,

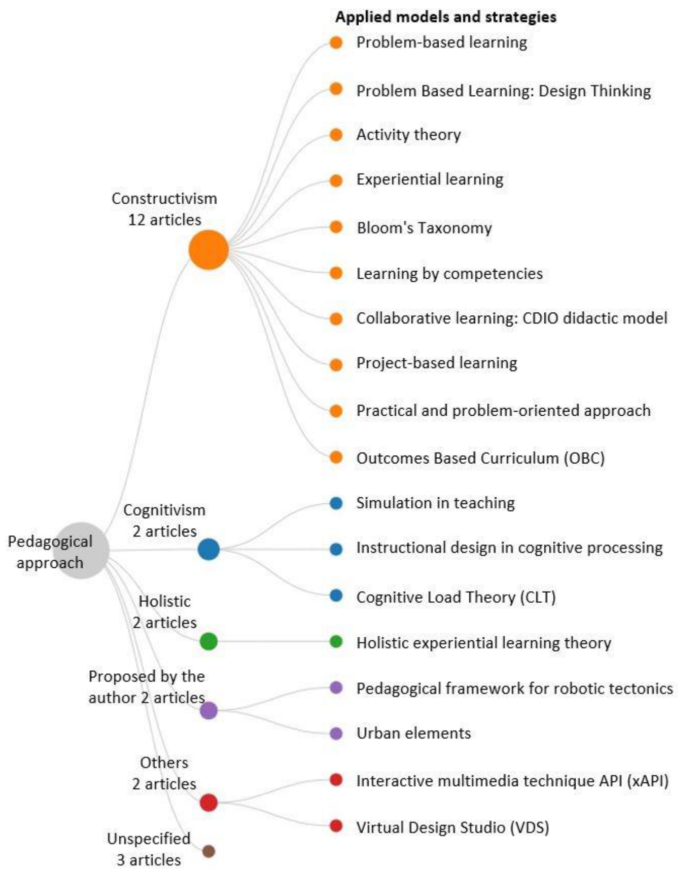

Fig. 6: *Pedagogical approaches used in the studies.*

physical models, virtual models, among others. Then, the teacher or jury provides the feedback and the qualification. “Studio and the critique session stand at the heart of architectural pedagogy”, so the process of having one's work critiqued in front of peers is a regular ritual for architects [27].

Currently, education demands the development of skills closely linked to the design of significant learning experiences where students are the center of the teaching-learning process [5]. That is to say, today the constructivist approach is one of the most used and with various possibilities to create the change that education and, in turn, contemporary society demands, in terms of the integration of ICTs in the classroom.

Cognitivism. Some investigations mention that there is a lack of standardized models for teaching architectural design. This is a consequence of the diversity of perspectives, educational approaches and design methods [25]. Added to this is the emergence of new intelligent design tools, which have not been sufficiently studied regarding their impact and pedagogical application. One of these tools is simulation-based design. Therefore, agent-based modeling (ABM) has been used to study its impact on learning.

The characteristics of the use of simulations in teaching correspond to a cognitive approach because learning consists of adding meanings to modify cognitive structures, which are defined as the set of previous learning that the individual has about his environment [32].

The article *Learning with augmented reality: Impact of dimensionality and spatial abilities* states that the authors used instructional design in cognitive processing based on cognitive load theory (CLT). This decision was based on the fact that they consider cognitive load to be a significant aspect in 3D object learning and in AR learning. And, as their evaluation in this field is still scarce, they investigated how and under what conditions, a 3D representation in AR can be more suitable for learning, compared to a 2D representation in AR. Hence the importance of relying on the CLT to measure cognitive load.

Holistic. Improving the quality of teaching requires an integrated and holistic approach, both for teachers and students, point out Bajçinovci and Jerliu [17]. His research reflects on the implementation of study plans to impact the quality and diversity of teaching, as well as the understanding of trends and background in a given context.

Fromm *et al.* [13] found that design-oriented studies of VR in higher education are not grounded in learning theories, so their research sought to identify VR design elements that could be implemented to enable a holistic experiential learning process. As a result, the authors revealed seventeen positive effects of VR-based learning, ranging from better learning outcomes, increased motivation and interest in learning, to the possibility of enabling learning through "live experience". The authors concluded that virtual reality is suitable for a flipped classroom and ubiquitous learning activities.

Proposed by the author. Shi *et al*. [19] propose a pedagogical framework for the integration of robotic tectonics in architectural education. This is because the development of automated Japanese building construction, used mainly by industrial manufacturers, could be implemented in professional practice. For this reason, there is an interest in integrating robotic tectonics into the teaching of architecture in a simple and understandable way so that students acquire the required skills, both for this tool and for the discipline.

On the other hand, universities still do not have adequate facilities to provide courses related to robot-based architectural design. Therefore, it is not possible to study its integration satisfactorily. Since 2016, DAMlab (Digital Fabrication and Architecture Laboratory) created an experimental teaching platform that explores digital tools, including robots. Since the last three years, the pedagogical approach to robotic tectonics has emerged, which focuses on the digital and the sustainable. Therefore, his research is dedicated to testing the proposed pedagogical approach and demonstrating how robotic tectonics can improve architectural education for sustainability.

Another approach is described in the article *The 'Urban Elements' method for teaching parametric urban design to professionals*, where the authors state that, currently, despite advances in research and availability of tools, the integration of the concepts of parametric urban design is lacking. As a consequence, parametric urban design has not been widely adopted in practice. That is why they proposed a pedagogical method to teach urban design concepts and convert them into parametric urban design definitions. They called this proposal the method of urban elements. The study was carried out through a course, where all the participants had a master's degree in architecture. The results suggest that the implementation of the method increases the acquisition of knowledge about urban design and ensures its application in other environments. However, it was difficult for the participants to understand the applicability of the parametric design and method in a real-life context and in their daily practice [3].

Others. Wang [24] identified a weakness in online courses in the lack of real-time student-teacher interactivity. Therefore, she proposed the application programming interface (xAPI) experience standard as a suitable instrument for recording and analyzing learning activities in architectural design teaching. xAPI is "a specification for learning that makes it possible to collect data on the wide range of experiences a person has (online and offline)"(own translation) [33]. The result of Wang's research was that the designed system based on xAPI has the potential to stimulate students' interest and enthusiasm to study and learn, as well as guide their learning process.

On the other hand, because the COVID-19 pandemic forced educational programs to move to the virtual environment, Iranmanesh and Onur [27] consider the year 2020 as the consolidation of the virtual design studio (VDS) as an educational method. The study of design is the central pedagogical focus for most architecture schools, therefore the authors proposed to explore the mandatory implementation of VDS during the pandemic in an architecture school, in view of the fact that VDS has proven pedagogical merits in other studies.

Unspecified. The articles that did not define any approach, theory, model or strategy in particular, such as the research carried out by Rubio and Cornaro [23], some experiences of interaction with digital tools in the elaboration of collages of the concepts and content of the subject are mentioned. Therefore, they can be assumed as an experiential learning whose approach is constructivism.

The *Impact of simple virtual technology application in architectural education* research was carried out in a Virtual Reality Architecture curricular course that manages learning by competencies. It takes a constructivist approach and started from the idea that the ideal tools for architectural education are not yet available, so students use the simplest available options. The results indicate a positive impact on the acquisition of skills and presentation of the students' work, for which the authors propose a formal integration of learning as a main course in the architecture study program.

In the study carried out by Şahbaz [15] on the use of virtual reality simulations to learn about historical buildings, the author emphasizes that the purpose of interactive tools is to allow students to *learn by doing*, lessen the limitations of the classroom and help students to experience the spaces in a more real way without having to travel to the location of the building. In addition, he emphasizes that virtual reality by itself does not define the learning process, what is to be learned, the characteristics of the student, the learning experience and the experience when interacting with said technology. In general, he implicitly approaches the constructivist approach through experiential learning.

Although a pedagogical approach was not specified in these three articles, with the analysis of each text, characteristic elements of a certain approach were identified. The three studies coincide in the constructivist approach, which is why it is confirmed as the predominant approach in the area.

4. CONCLUSIONS

This systematic review identified the technologies and software that have been incorporated into architectural education. Virtual reality, BIM, online platforms and social networks stand out. Rhinoceros, Unity Game Engine, Autodesk Revit, Grasshopper, AutoCAD, Sketchup, Blender, Oculus Rift, Unreal Game Engine and Archicad were the most incorporated software.

Regarding the criteria with which these technologies were incorporated into architectural education, four general criteria for incorporation were proposed: selection of learning resources, learning design, implementation and degree of success and evaluation.

Based on these criteria, it was found that software incorporations positively influence the teaching-learning process of architectural education. However, most of the studies agree that the incorporation of software and technology requires well-planned strategies to achieve the expected success. There were cases where the use of digital tools was difficult for students to understand. Other cases report that the data produced by the program was difficult to assimilate and integrate into the design. In addition, better contextual planning is also necessary in the incorporation of technology or software.

An important finding of the research was that the majority of the studies analyzed (87%) were based on a pedagogical approach to carry out the incorporation of software or technology. Constructivism, cognitivism and the holistic proposal were the most consolidated approaches in education, in general. The most widely used approach in architectural education is constructivism. In some cases, the authors made their proposal by creating their own pedagogical framework or strategy; others took as reference techniques that have already been tested in related areas such as Design Thinking, xAPI and VDS. Some that did not clearly specify any approach, framework, theory, model or specific strategy, but through analysis it was found that due to their characteristics they belonged to the constructivist approach.

The results regarding the use of these approaches suggest that the constructivist approach offers several possibilities to cover the current educational demands of architecture. However, it also highlights the lack of models for teaching architecture, and the scarcity of studies that continue to explore the incorporation of technologies with high potential in the area from a pedagogical perspective.

The main limitations on the incorporation of software and technology found were: 1) accessibility to the appropriate tools, either due to the lack of facilities in the universities or due to their complexity in terms of software and hardware; 2) ignorance of digital tools and their use, and their use gradually based on the learning process. The investigations recommend for future studies to continue exploring the approaches and methodologies used for the incorporation of technology, in order to validate its effectiveness, as well as to continue investigating in depth the potential of technologies and their impact on the architectural design process, since in some cases the technology did not meet the expectations of students and researchers. In addition, there is a lack of studies on the subject. The analyzed studies also suggest early teaching about technologies to achieve an adequate understanding and take advantage of the tool's potential as main courses in the curriculum.

Most studies seek to demonstrate the impact and applicability of technologies and software in the teaching-learning process of architectural education. Others study its incorporation in the study plans. Both cases wish to respond to the current demands of architectural practice, education and sustainability.

Taking into account these results, models with strategic planning of technologies and software could be proposed to be incorporated with defined criteria and pedagogical approaches, in relation to the application context. Likewise, implement a model in the curricular courses and evaluate its results to have a demonstrative framework applicable in various subjects of the architecture curriculum. The context is decisive in the success of any implementation.

In this regard, the lack of studies on the subject is notable, especially in Latin America. It is essential that educators, educational authorities, institutions and researchers get more involved so as not to be overwhelmed in the use of technology in the same areas. In this way, it is possible to contribute to the training of future professionals capable of facing the technological challenges of the labor field worldwide.

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