Role of Augmented Reality in Architecture and Urbanism Education: Systematic Literature Review

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ABSTRACT
The use of technology in education has experienced a remarkable upswing in recent years, largely due to the integration of computer hardware into classrooms and the use of mobile devices such as smartphones. One aspect of this development is the proliferation of augmented reality (AR) in education, which has been shown to support teaching and learning processes in several areas by promoting engagement and motivation. This article, therefore, presents a systematic literature review of how AR-based experiences are created and implemented in didactic activities in undergraduate architecture and urbanism (AU) courses, highlighting the benefits of the learning process and the associated challenges. To achieve this, a bibliometric analysis, a quality assessment, and a literature review of articles were conducted. The results show that there are several approaches to developing and applying AR-based experiences in teaching AU that have numerous benefits.
KEYWORDS: Augmented Reality; Extended Reality; Teaching; Learning; Undergraduate Programs in Architecture and Urbanism.

INTRODUCTION
Augmented Reality (AR) systems enable the visualization of virtual objects superimposed on the physical world so that they can seamlessly coexist and interact in real time in three-dimensional environments (Azuma, 1997; Kipper & Rampolla, 2013; Milgram & Colquhoun, 1999; Schmalstieg & Höllerer, 2016). Thus, AR is not just a technology, but a system composed of a variety of technologies that work together to enhance our perception and interaction with digital information (Kipper & Rampolla, 2013).

Technology utilization in classrooms has witnessed a marked increase in recent times, primarily owing to the surge in computer equipment in schools and the employment of mobile devices such as smartphones and tablets. The proliferation of AR experiences in education is part of this evolution, which has proved advantageous for teaching-learning processes across diverse domains, including medicine (Cabero-Almenara, Barroso-Osuna, & Obrador, 2017; Kandasamy, Bettany-Saltikov, Cordry, & McSherry, 2021), product design (Tang, Au, & Leung, 2018), and pedagogy (Cabero-Almenara, Fernández-Batanero, & Barroso-Osuna, 2019).

Despite some research specifically addressing the adoption of AR-based didactic activities for undergraduate courses in Architecture and Urbanism (AU) and highlighting various benefits for teaching and learning (Chu, Chen, Hwang, & Chen, 2019; Domínguez, Escudero, Riera, & Delgado, 2017; Domínguez, RIERA, ESCUDERO, & Delgado, 2014; Fonseca, Redondo, & Villagrasa, 2015; Zhao, Pan, Gao, & Cheng, 2022), the investigation of this area remains limited. Furthermore, reports of difficulties associated with the use of AR systems have also emerged (Elmqaddem, 2019; Khan, Johnston, & Ophoff, 2019).

To explore and examine research employing AR systems to facilitate teaching and learning processes in undergraduate courses in AU, this article presents a systematic literature review (SLR) that addresses the development and application of these systems in didactic activities and elucidates the benefits and challenges encountered.

AUGMENTED REALITY IN EDUCATION
The idea of augmenting routine activities with artificial interactions with the physical world was first discussed in the 1930s (Schnabel, 2009). In the 1960s, Ivan Sutherland introduced equipment that served as an interface for AR (Azuma et al., 2001; Billinghurst & Kato, 2002). Since then, there have been several discussions on the

classification of reality spectra, leading to the emergence of different terms (Milgram & Kishino, 1994; Schnabel, Wang, Seichter, & Kvan, 2007).

Realities classified as Mixed Reality (MR) involve varying degrees of merging or replacing parts of the physical world (Schnabel, 2009). Virtual Reality (VR), on the other hand, is excluded from the MR spectrum, as it refers to an experience where the user is completely immersed in and interacts with a totally virtual and synthetic environment (Milgram & Kishino, 1994; Schmalstieg & Höllerer, 2016; Sherman & Craig, 2019; Stals & Caldas, 2020).

More recently, the term Extended Reality (XR) has been widely used (Al-Adhami, Wu, & Ma, 2019). XR is utilized to describe the spectrum that bridges the gap between MR and VR, covering all of these terms as an umbrella concept and encompassing the previously existing one hundred percent virtual environment of VR (Al-Adhami et al., 2019; Lee & Yoo, 2021; Stals & Caldas, 2020), as depicted in Figure 1.

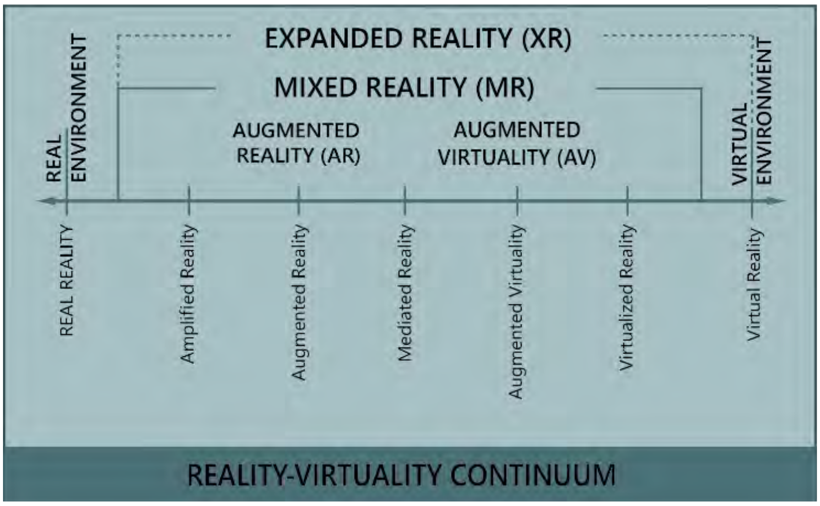

Fig. 1 – Junction of the main classifications of the spectrum of realities
Source: Adapted from (Al-Adhami et al., 2019; Milgram & Kishino, 1994; Schnabel et al., 2007)

AR environments were initially developed for Scientific Visualization and Games and later expanded to include Educational, Architecture, Engineering, and Construction (AEC), and Collaborative Design areas (Schnabel, 2009). AR experiences offer several benefits, such as improved collaboration, greater interactivity, integration of digital information, and computational mobility, according to the author.

The most commonly used devices for AR are smartphones, which require a camera and/or other optical sensors, as well as accelerometers, gyroscopes, compasses, or GPS systems for optimal performance (Kipper & Rampolla, 2013). Head Mounted Devices (HMDs), particularly smart glasses, are also relevant, but not as widely accessible as smartphones. The use of AR experiences in education is beneficial for teaching and learning processes in multiple areas (Akçayır & Akçayır, 2017; Arvanitis et al., 2009; Billinghurst & Dunser, 2012; Cabero-Almenara, Barroso-Osuna, & Martinez-Roig, 2021; Dunleavy, Dede, & Mitchell, 2009).

Several principles have been established to facilitate the effective planning of AR use in teaching-learning processes, such as the flexibility of AR systems to adapt to student's needs and the constraints of the institutional context in which they are employed (Kerawalla, Luckin, Seljeflot, & Woolard, 2006).

It is worth noting that within the classroom environment, AR enables students to collaborate in visualizing the same object in real space, thus enhancing collaborative capacity and face-to-face interaction (Billinghurst, 2002). This is unlike computer-based activities where students sit side by side, albeit working independently (Kiyokawa et al., 2002). The possibility of collective visualization combined with the debate is crucial for the development of design exercises in the AU course.

Smartphones offer an opportunity to extend the learning process beyond the classroom walls, utilizing AR apps that enable students to apply the knowledge acquired in class and solve problems in real-world situations (Cabero-Almenara & Barroso-Osuna, 2016).

AR facilitates the visualization of complex objects from multiple angles and scales, allowing for the continuity of the learning process outside the classroom. This type of visualization facilitates the understanding of AU students, who commonly face challenges in conceiving spatial relationships in their initial design exercises. Moreover, this enables the creation of virtual environments that are essential for higher education, such as laboratories and simulators, which encourage students to pursue their learning through engaging and dynamic experiences (Akçayır & Akçayır, 2017; Davila Delgado, Oyedele, Beach, & Demian, 2020; H. K. Wu, Lee, Chang, & Liang, 2013). The use of AR-based teaching and learning activities helps to develop technology-oriented skills and fosters an investigative, constructivist, and ubiquitous perspective creatively and dynamically. This, in turn, assists teachers in creating innovative and engaging didactics, which is an important demand in the university environment (Vázquez-Cano, Marín-Díaz, Oyarvide, & López-Meneses, 2020).

University students are currently drawn to new technologies such as AR because they demand stimuli for motivation and enthusiasm in the learning environment. They value the interactivity and opportunities for experimentation and simulation that the system offers (Bucea-Manea-Ţoniş et al., 2020). Hence, institutions need to promote technological innovation, which facilitates real-time communication and continuous interaction between students, universities, and the labor market. Additionally, institutions must support the development of AR-based activities by providing support centers for the production of innovative didactic activities (Cabero-Almenara et al., 2019).

METHOD

The implementation of a SLR constitutes a valuable contribution to scientific research, as it provides researchers with a comprehensive tool for mapping, evaluating, consolidating, and integrating relevant research findings on a specific research subject (Morandi & Camargo, 2015). As posited by these authors, the SLR methodology enables researchers to identify potential knowledge gaps and, ultimately, leads to the synthesis of relevant information.

The objective of this SLR is to survey and analyze research studies that have utilized AR systems to assist in teaching and learning processes related to undergraduate courses in the field of AU. Through this review, we aim to address questions regarding the development and application of AR systems in didactic activities, as well as to highlight the benefits of such systems for the learning process and the difficulties encountered in their implementation. To achieve this goal, the present study followed the methodology proposed by (Morandi & Camargo, 2015), which involves several steps, such as defining the central theme and research question (as stated above), establishing methodological procedures including the development of search strategies and criteria for inclusion and exclusion, conducting bibliometric analysis, assessing the quality of the studies, and performing a thorough analysis of the literature.

Methodological Procedures

A search was conducted on the Scopus and Web of Science (WOS) databases. The research utilized these databases due to their extensive collection of research articles and the capability to utilize unlimited Boolean operators, allowing for a more precise search. The search terms used were (("Augmented Reality") AND (educat* OR learn* OR teach* OR training OR student) AND (architect* OR urban*) AND (course OR undergraduate OR "higher educat*" OR postgrad* OR college OR school OR curric* OR syllabus OR degree)), just considering the abstract, title, and/or keywords of the articles, as shown in Figure 2. A total of 242 articles were found in Scopus, and 165 in WOS.

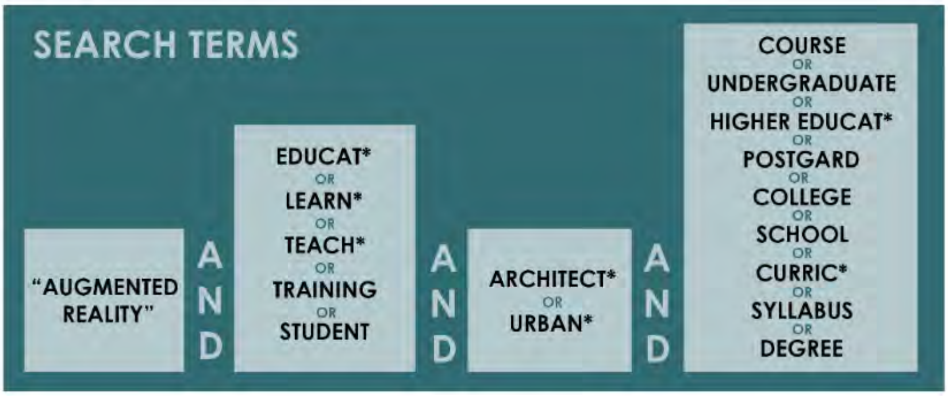

Fig. 2 – SLR search terms

The search in the databases utilized truncated words, indicated by an asterisk next to a part of the term. This method returns all variant words of the term. For example, when searching for the term teach*, the databases also searched for the terms teacher and teaching.

These filters included selecting only journal articles (excluding literature review articles), limiting the language to English, Portuguese, or Spanish, and setting the year of publication between January 01, 2013, and April 12, 2022. A total of 49 articles were found in Scopus, and 57 in Web of Science, resulting in 106 articles in total. To organize the articles, the researchers applied two exclusion criteria, which were to remove duplicate articles and articles that did not focus on the application of AR systems in teaching and learning activities in the field of AU.

The software Mendeley was used to remove duplicate articles, resulting in a total of 72 unique documents. After that, the researchers manually applied the exclusion criterion of articles that did not focus on the application of AR systems in teaching and learning activities in the field of AU. As a result, 18 articles remained, as shown in Figure 3.

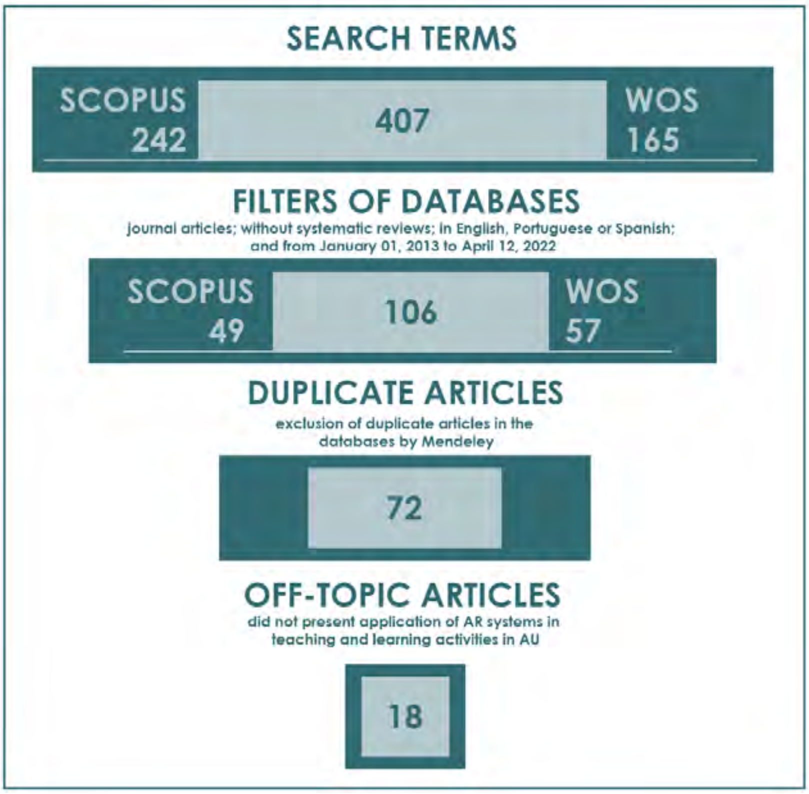

Fig. 3 – Number of articles found before and after exclusion criteria

To conduct bibliometric analysis, quality assessment, and literature analysis, the 18 selected articles were classified according to the following categories: database; year of the article; journal; country of the first author; level of education of the students involved; relevance of AR in teaching activities; main activities (modeling/visualization); topics of study involved in AR activity; development mode of experience in AR; platform/tool used for development; tracking mode; devices used; and benefits and difficulties pointed out.

Bibliometric Analysis

To conduct a quantitative synthesis of the selected studies, a bibliometric analysis was performed. It was found that eleven articles were common to both the Scopus and WOS databases, as depicted in Figure 4.

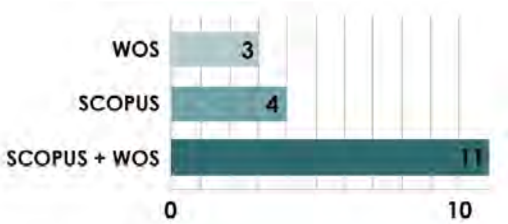

Fig. 4 – Number of articles found in each search database

Concerning to the years of publication, it was observed that there was a gradual increase in the number of articles on the topic over time, as depicted in Figure 5. Notably, no publications were found in 2013, but in subsequent years, between 1 and 3 publications were identified annually, indicating a nascent field that is ripe for further exploration.

Fig. 5 – Number of articles published per year

Regarding the journals, the articles were found to be distributed across 15 different publications, as shown in Figure 6. The results suggest that the topic of AR is of significant interest to a diverse range of journals in fields such as Technology, Education, Architecture and Urbanism, Engineering, Construction, and others. Although only one journal (Architecture, City and Environment) focuses specifically on Architecture, five of the publications relate to related areas such as Engineering and Construction. Nonetheless, a common goal that is shared among all of these journals is a focus on the study of technology and innovation.

JOURNAL	ARTICLES
Applied Sciences Research In Learning Technology Universal Access In The Information Society	2
Advanced Engineering Informatics Advances In Engineering Education Architecture, City and Environment Computers In Human Behavior Construction Innovation Education And Information Technologies Intelligent Automation And Soft Computing International Journal Of Interactive Design And Manufacturing International Journal Of Simulation And Process Modelling Journal Of Construction Engineering And Management Journal Of Visualization Revista Iberoamericana De Educacion A Distancia	1

Fig. 6 – Number of articles published per journal

To conduct a geographical analysis of the articles, the country of the first author was taken into consideration. The results indicate that Spain stands out with a total of 6 articles (33%), demonstrating a strong commitment to the application of AR for teaching AU, as depicted in Figure 7.

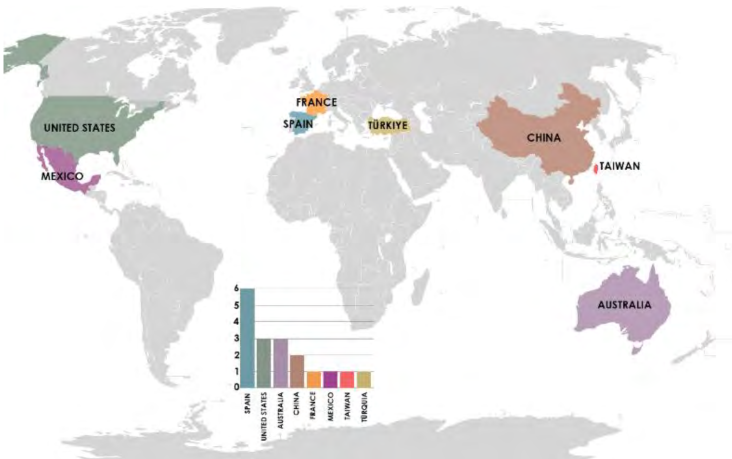

Fig. 7 – Number of articles by country of the first author

Regarding the level of education of the students involved in the studies, it was found that the majority of research (66.5%) was applied to undergraduate students, as shown in Figure 8. This finding suggests that activities using AR can be developed for students with little or no specific knowledge of AU.

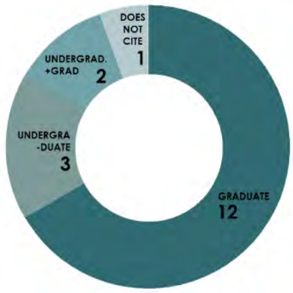

Fig. 8 – Number of research applied by the level of education

Quality Analysis

To assess the relevance of the selected studies to the review issue, which is one of the dimensions used to evaluate the quality of primary studies (Morandi & Camargo, 2015), a classification was conducted based on the applicability of AR in teaching activities, as shown in Figure 9. To achieve this, three classifications were created: intense for studies where AR was the primary visualization system in didactic activities, moderate when AR shared equal importance with another system such as VR, for instance, and subtle when AR was not the main focus. Although AR was not the only system or technology applied in some of the studies, it was the main focus in eight studies, which were classified as intense, representing the dominance of the research.

As an example of moderate relevance, a study by (Guray et al., 2021) aimed to promote teaching activities related to building design and construction through the use of projects and the modeling of building information for visualization of its elements in AR. In this study, Building Information Modeling (BIM) was found to be equally important as visualization in AR and was thus classified as having moderate relevance.

Another study (Birt & Cowling, 2018) investigated different ways of understanding the lighting comfort of a building. The activity included visualization of the design using: (i) 2D documentation; (ii) virtual reality (VR) with a HMD; (iii) VR with a smartphone and Google Cardboard (GOOGLE, 2022); (iv) AR using the HoloLens HMD (MICROSOFT, 2021); and (v) visiting the building for on-site analysis. In this study, AR was only a small part of the systems and technologies studied and was thus classified as having subtle relevance.

Relevance	Article
Intense	ALVAREZ; PARRA; TUBIO, 2017
	CHU et al., 2019
	DOMINGUEZ et al., 2014
	DOMINGUEZ et al., 2017
	FONSECA; REDONDO; VILLAGRASA, 2015
	SHIRAZI; BEHZADAN, 2015
	TURKAN et al. 2017
	ZHAO et al., 2022
Moderate	ALMENARA; OSUANA; ROIG, 2021
	FONSECA et al., 2016
	GONZALEZ et al., 2020
	GURAY et al., 2021
	VASILEVSKI; BIRT, 2020
Subtle	BIRT; COWLING, 2018
	GONZALEZ, 2018
	SEPASGOZAR, 2020
	WU et al., 2019
	XU; ZHANG, 2022

Fig. 9 – Number of articles and the relevance of AR in studies

Literature Analysis

This section endeavors to establish correlations among the texts to address the initial question, while identifying lacunae and potential areas for future research within the domain of study (Morandi & Camargo, 2015).

The main activities applied in the classroom in the research were examined, and two primary activities were identified: (i) visualization, which was present in all studies, and (ii) modeling of a three-dimensional element followed by its visualization, which was observed in half of the studies (Figure 10). While the visualization activity is inherent to AR, it is noteworthy that the modeling activity was incorporated into a significant number of studies.

In the studies analyzed, the modeling activity for visualization in AR was proposed to the students for various elements, such as the building in the urban context (Domínguez et al., 2014), new proposals for urban furniture to reorganize a local market (Fonseca, Valls, Redondo, & Villagrasa, 2016), sculptures to be inserted in urban space (Domínguez et al., 2017), land for the study of topography (Alvarez, Parra, & Tubio, 2017), parts and volumes of buildings for the development of spatial skills (González, 2018), urban sculptures and a building that dialogues with the surroundings (González, Suarez-Warden, Milian, & Hosseini, 2020), building elements (Guray et al., 2021), and steel structures (Xu & Zhang, 2022).

Activity	Articles
Visualization	ALMENARA; OSUANA; ROIG, 2021
	BIRT; COWLING, 2018
	CHU et al., 2019
	SEPASGOZAR, 2020
	SHIRAZI; BEHZADAN, 2015
	TURKAN et al. 2017
	VASILEVSKI; BIRT, 2020
	WU et al., 2019
	ZHAO et al., 2022
Modeling and Visualization	ALVAREZ; PARRA; TUBIO, 2017
	DOMINGUEZ et al., 2014
	DOMINGUEZ et al., 2017
	FONSECA; REDONDO; VILLAGRASA, 2015
	FONSECA et al., 2016
	GONZALEZ, 2018
	GONZALEZ et al., 2020
	GURAY et al., 2021
	XU; ZHANG, 2022

Fig. 10 – Number of articles per main activity

To conduct a qualitative analysis of the themes of study involved in the AR activity, they were distributed among the various curricular components of the AU courses as defined by the National Curricular Guidelines (DCNs) of the AU courses, Resolution No. 2 of June 17, 2010 (BRASIL, 2010). The main themes identified in each research were then associated with these curricular components (Figure 11).

Fig. 11 – Number of articles with main activity related to the themes of the curricular components of the Brazilian DCNs.

AR-based activities have been widely applied to the study of Architecture, Urbanism, and Landscape Design, as evidenced by the recurrent proposals found in the surveyed articles. These proposals include modeling of building designs for visualization in AR in the real urban context (Domínguez et al., 2014); design and modeling of new proposals for urban furniture aimed at reorganizing local markets (Fonseca et al., 2016); design and modeling of sculptures for urban intervention proposals (Domínguez et al., 2017); AR visualization of house designs with a small useful area, used to experiment and study accessibility issues (W. Wu et al., 2019); project design of urban sculptures and religious buildings aimed at studying the local context and creating a dialogue with the surroundings (González et al., 2020); and design and modeling of residential building designs using BIM, with a focus on the organization of documentation (Guray et al., 2021).

The topic of Structural Systems is prevalent in AU courses, as well as in three studies in courses focused on Engineering and Construction. These studies propose activities such as the visualization and interaction with structural elements to comprehend their behavior under the application of various forces (Turkan, Radkowski, Karabulut-Ilgu, Behzadan, & Chen, 2017), visualization of diverse building construction processes with emphasis on foundations (Sepasgozar, 2020), and the study of steel frames for building structures (Xu & Zhang, 2022).

The use of AR as a tool for aiding Drawings and Means of Representation and Expression highlights the significance of spatial visualization in comprehending design concepts. One study utilized AR visualization to read assembly guides of physical models for the understanding of design representation (Shirazi & Behzadan, 2015). Additionally, the visualization of 3D parts and built volumes through AR was employed for the development of spatial skills (González et al., 2020; Xu & Zhang, 2022).

Two studies focused on the Theory and History of Architecture, one of which modeled and presented an existing design through AR (Fonseca et al., 2015), while the other involved the study of design elements of a cathedral by reading markers on a physical model of the building located in a museum (Chu et al., 2019). Environmental comfort was the subject of two studies that used AR visualization to analyze the lighting performance of buildings (Birt & Cowling, 2018; Zhao et al., 2022).

Moreover, Aesthetics and Art History were incorporated into AR activities in the form of visualizing art pieces in AR complemented with audio information for the study of Indigenous works of art in Australia (Vasilevski & Birt, 2020), as well as the geometric and mathematical information of a religious building for the study of Construction Technology (Almenara, Osuana, & Roig, 2021). Finally, Topography was studied through the modeling and visualization of the terrain under analysis (Alvarez et al., 2017).

As for the development of the AR experience, half of the studies created customized AR apps using applications or software that required programming knowledge. Another eight articles developed customized experiences using no-code programming platforms (NCPP), which do not require users to create or edit codes. Only one study did not specify the form of development and was classified as "does not cite/demonstrate" (Figure 12).

The AR apps created for these experiences include the U-AR (Urban Augmented Reality) for Android, designed for urban study (Domínguez et al., 2017); the Corrigan Walking Tour, for the study of Indigenous Art History in Australia (Vasilevski & Birt, 2020); and the FBE Piling AR (PAR), for the study of foundation structures (Sepasgozar, 2020).

Development Mode	Articles
No-code programming platforms (NCPP)	ALMENARA; OSUANA; ROIG, 2021
	ALVAREZ; PARRA; TUBIO, 2017
	DOMINGUEZ et al., 2014
	FONSECA et al., 2016
	FONSECA; REDONDO; VILLAGRASA, 2015
	GONZALEZ, 2018
	GONZALEZ et al., 2020
	GURAY et al., 2021
	SHIRAZI; BEHZADAN, 2015
Customized AR application (APP)	BIRT; COWLING, 2018
	CHU et al., 2019
	DOMINGUEZ et al., 2017
	SEPASGOZAR, 2020
	TURKAN et al, 2017
	VASILEVSKI; BIRT, 2020
	WU et al., 2019
	ZHAO et al., 2022
Does not cite/demonstrates	XU; ZHANG, 2022

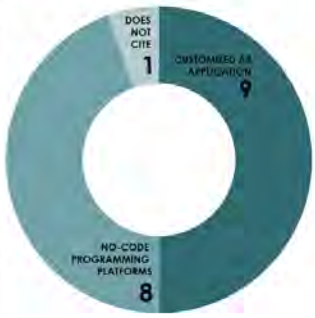

Fig. 12 – Number of articles with different development modes for AR use

In terms of the platforms or tools utilized for the development of the experiments, various options were mentioned (as shown in Figure 13). Among these, Unity 3D was cited in four articles (Birt & Cowling, 2018; Vasilevski & Birt, 2020; W. Wu et al., 2019; Zhao et al., 2022), while the ARmedia plugin was utilized in two studies (Domínguez et al., 2017; Fonseca et al., 2016). The remaining platforms or tools were only mentioned once each. However, four articles did not provide any details regarding the tools utilized (Chu et al., 2019; González, 2018; Sepasgozar, 2020; Xu & Zhang, 2022).

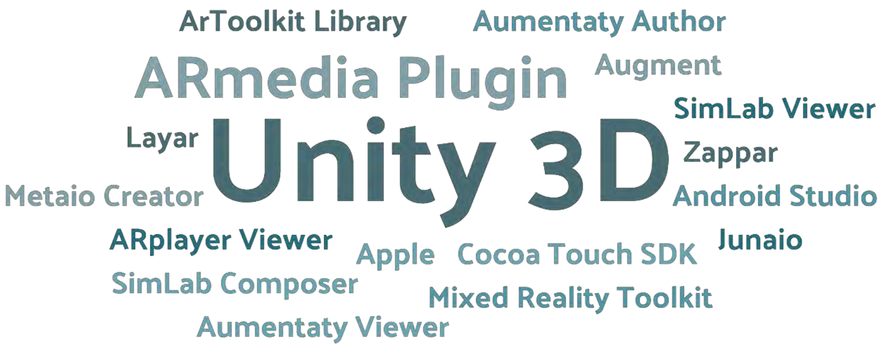

Fig. 13 – Tools cited in development research

In addition to Unity 3D, other software tools were used for the development of AR applications. The Apple Cocoa Touch SDK, which is a Software Development Kit for IOS platforms, was utilized in one study. ArToolkit Library, a software library for AR development, was used in another study to define the tracking of objects (Turkan et al., 2017). Android Studio, an integrated development environment for applications, was mentioned in one study, but its specific usage was not clearly explained (Almenara et al., 2021). It is noteworthy that Unity 3D, initially developed for game production, has become a popular engine for creating AR experiences.

In addition to Unity 3D, other tools have been mentioned for AR development. Microsoft's Mixed Reality Toolkit was used by (Sepasgozar, 2020), which is a collection of packages that support development on platforms such as Unity 3D or Unreal (MICROSOFT, 2022). Some studies utilized no-code programming platforms such as Augment (González et al., 2020), Zappar (Almenara et al., 2021), Layar (Domínguez et al., 2014), and Aumentaty (Alvarez et al., 2017), for AR development and hosting, using them for viewing applications such as Aumentaty Viewer. Other softwares like Metaio Creator (Fonseca et al., 2015) and SimLab Composer (Guray et al., 2021) were also used for this purpose, with the latter employing the SimLab Viewer app for AR visualization. One study cited the use of the ARmedia plugin tool for Sketchup and the ARplayer viewer app for visualizing three-dimensional AR models created by students (Fonseca et al., 2016). Another study used the Junaio application to visualize informative content for the assembly of a physical building model, although it was deactivated in 2014 (Shirazi & Behzadan, 2015).

Regarding the tracking methods for visualizing AR experiences, eight studies have reported using markers, while others eight have not. However, one study reported using solely GPS tracking, while another noted employing both marker and GPS tracking methods (Figure 14). The authors of one study suggest that incorporating multi-markers, which refers to the utilization of more than one marker with the same function printed on the student's activity reading page, can help minimize instability in AR visualization. This is because such an approach ensures that at least one of the markers will always be within the line of sight of the device's camera (Turkan et al., 2017). Additionally, the authors of another study commented that GPS tracking of a three-dimensional model was challenging at distances of less than 25m from the insertion site (Domínguez et al., 2014).

Tracking Mode	Articles
Marker	ALMENARA; OSUANA; ROIG, 2021
	ALVAREZ; PARRA; TUBIO, 2017
	DOMINGUEZ et al., 2017
	FONSECA; REDONDO; VILLAGRASA, 2015
	GURAY et al., 2021
	SHIRAZI; BEHZADAN, 2015
	TURKAN et al. 2017
	VASILEVSKI; BIRT, 2020
Does not cite	BIRT; COWLING, 2018
	CHU et al., 2019
	GONZALEZ et al., 2020
	GONZALEZ, 2018
	SEPASGOZAR, 2020
	WU et al., 2019
	XU; ZHANG, 2022
	ZHAO et al., 2022
GPS	DOMINGUEZ et al., 2014
GPS and Marker	FONSECA et al., 2016

Fig. 14 – Number of articles per tracking mode for AR visualization

In terms of the devices used for the AR experience, the smartphone was the most commonly cited device, used in 12 studies. This can be attributed to its widespread accessibility among students. The tablet was used in nine studies, often provided by educational institutions. HMD appeared in three articles, all of which cited the HoloLens model (MICROSOFT, 2021). One article mentioned the use of a computer in addition to the smartphone, and one did not specify any device. In one study, headphones were also used in conjunction with the smartphone to enhance the experience during the activity (Figure 15).

Device	Articles
Smartphone	ALMENARA; OSUANA; ROIG, 2021
	ALVAREZ; PARRA; TUBIO, 2017
	DOMINGUEZ et al., 2014
	DOMINGUEZ et al., 2017
	FONSECA; REDONDO; VILLAGRASA, 2015
	FONSECA et al., 2016
	GONZALEZ et al., 2020
	GURAY et al., 2021
	SEPASGOZAR, 2020
	SHIRAZI; BEHZADAN, 2015
	VASILEVSKI; BIRT, 2020
	XU; ZHANG, 2022
Tablet	ALMENARA; OSUANA; ROIG, 2021
	CHU et al., 2019
	DOMINGUEZ et al., 2017
	FONSECA et al., 2016
	FONSECA; REDONDO; VILLAGRASA, 2015
	GONZALEZ et al., 2020
	GURAY et al., 2021
	TURKAN et al, 2017
	XU; ZHANG, 2022
HMD (Hololens)	BIRT; COWLING, 2018
	WU et al., 2019
	ZHAO et al., 2022
Computer	ALVAREZ; PARRA; TUBIO, 2017
Headphone	VASILEVSKI; BIRT, 2020
Does not cite	GONZALEZ, 2018

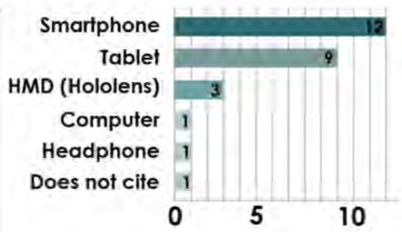

Fig. 15 – Number and types of devices cited for the AR experience

After analyzing the conclusions of the articles, two-word clouds were created to represent the recurrence of words related to the benefits and difficulties encountered during the AR implementation process. Several studies highlighted the benefits of AR, including improvement in learning (9), engagement (8) and motivation (8), interaction (4), satisfaction (3), and collaboration (2). Some studies also pointed out that students showed improvements in analytical skills and critical thinking (González et al., 2020) and communication (Shirazi & Behzadan, 2015). The authors highlighted the importance of fun as an essential part of AR activities (Vasilevski & Birt, 2020). The ubiquity of mobile devices, such as smartphones, makes learning accessible anytime and anywhere, which is another important benefit of AR (Domínguez et al., 2014). Additionally, AR allows for fast and realistic visualization of three-dimensional models during teaching activities (Guray et al., 2021).

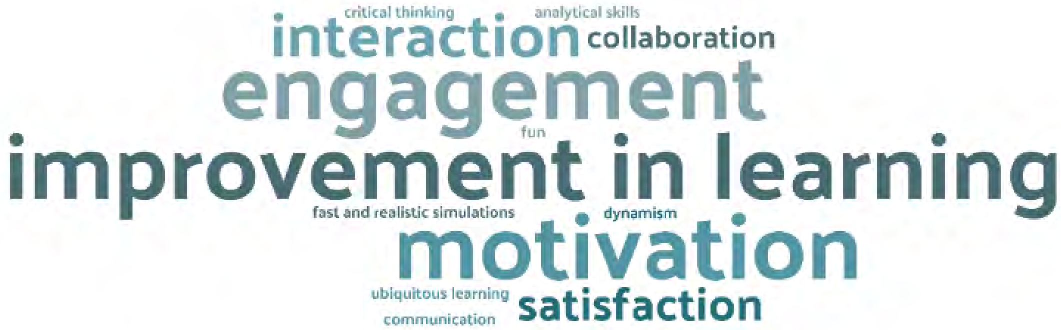

Fig. 16 – Word cloud of the benefits pointed out with the use of AR for teaching and learning activities

The present studies suggest that several difficulties are associated with the use of AR in educational settings (Figure 17). Among these challenges, authors have mentioned the difficulty of modeling 3D objects for visualization in AR (4), the AR system itself (4), the low performance of the devices used by students (2), the instability during the presentation of virtual content (2), and the planning of teaching activities (2). Several educators and students have experienced technical issues and slow response times when using the AR system (Alvarez et al., 2017; Domínguez et al., 2017, 2014; Shirazi & Behzadan, 2015; Vasilevski & Birt, 2020). Additionally, the weight of the devices was mentioned as a challenge for students during extended activities (Vasilevski & Birt, 2020). Some authors have reported that students have shown digital dependence when visualizing digital representations for understanding a study object (González, 2018). Furthermore, the lack of support from educational institutions in the application of AR by professors has also been identified as a significant challenge (Almenara et al., 2021). These difficulties represent significant barriers to the successful implementation of AR activities in the classroom.

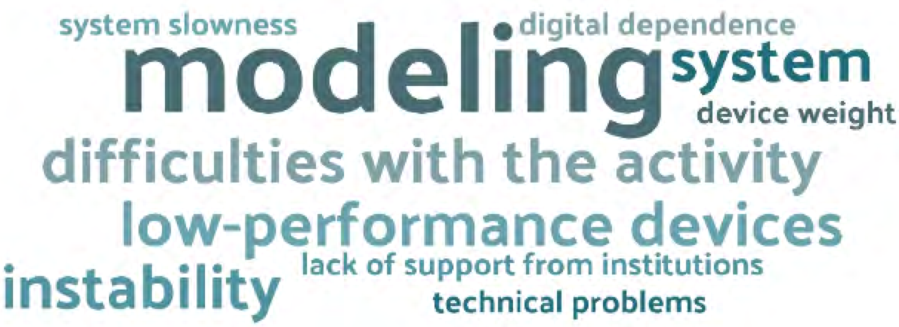

Fig. 17 – Word cloud of the difficulties pointed out with the use of AR for teaching and learning activities

Finally, to compile the data worked in the literature analysis, Table 1 was developed, which presents the information organized by article and the corresponding classification category.

Table 1. Compilation of literature analysis data

Article	**Rele-vance**	**Acti-vity**	**Subject of Study**	**Deve-lopment**	**Platforms / Tools**	**Tra-cking**	**Device**	**Benefits in using AR**	**Difficulties in using AR**
	I = intense M = moderate	**M = modeling**		**APP = application**		**G = GPS M =**			
(Almenara et al., 2021)	M	V	Construction Technology	APP	Zappar; Android Studio	M	smartphone; tablet	motivation	lack of support from institutions
(Alvarez et al., 2017)	I	M V	Topography	NCPP	Aumentaty Author; Aumentaty Viewer	M	smartphone; computer	engagement; motivation; improvement in learning	the slowness of the system; modeling
(Birt & Cowling, 2018)	S	V	Environmental Comfort	APP	Unity3D	-	HMD HoloLens	-	-
(Chu et al., 2019)	I	V	Theory and History of Architecture	APP	-	-	tablet	engagement; motivation	activity
(Domínguez et al., 2014)	I	M V	AU and Landscape Design	NCPP	Layar	GPS	smartphone	ubiquitous learning, satisfaction, motivation	system; activity; modeling; low performance devices

Article	Rele-vance	Acti-vity	Subject of Study	Deve-lopment	Platforms / Tools	Tra-cking	Device	Benefits in using AR	Difficulties in using AR
	I = intense M = moderate	M = modeling		APP = application		G = GPS M =			
(Domínguez et al., 2017)	I	M V	AU and Landscape Design	APP	ARmedia Plugin	M	smartphone; tablet	engagement; motivation; improvement in learning	system; instability; low performance devices
(Fonseca et al., 2016)	M	M V	AU and Landscape Design	NCPP	ARmedia Plugin; ARplayer Viewer	GPS; M	smartphone; tablet	collaboration; interaction; engagement; motivation; improvement in learning	modeling
(Fonseca et al., 2015)	I	M V	Theory and History of Architecture	NCPP	Metaio Creator	M	smartphone; tablet	improvement in learning; satisfaction; motivation	modeling
(González et al., 2020)	M	M V	AU and Landscape Design	NCPP	Augment	-	smartphone; tablet	satisfaction; critical thinking; analytical skills; improvement in learning	-
(González, 2018)	S	M V	Drawing and Means of Rep. and Expression	NCPP	-	-	-	dynamism; interaction	digital dependency
(Guray et al., 2021)	M	M V	AU and Landscape Design	NCPP	SimLab Composer; SimLab Viewer	M	smartphone; tablet	fast and realistic simulations	-
(Sepasgozar, 2020)	S	V	Structural Systems	APP	-	-	smartphone	engagement; improvement in learning	-
(Shirazi & Behzadan, 2015)	I	V	Drawing and Means of Rep. and Expression	NCPP	Junaio	M	smartphone	engagement; communication; motivation; collaboration	system
(Turkan et al., 2017)	I	V	Structural Systems	APP	Apple Cocoa Touch SDK; ArToolkit Library	M	tablet	improvement in learning; interaction	-
(Vasilevski & Birt, 2020)	M	V	Aesthetics and History of Art	APP	Unity 3D	M	smartphone; headphones	engagement; interaction; fun; improvement in learning	technical problems; instability; device weight
(W. Wu et al., 2019)	S	V	AU and Landscape Design	APP	Unity3D	-	HMD HoloLens	engagement	-

Article	Rele-vance	Acti-vity	Subject of Study	Deve-lopmen t	Platforms / Tools	Tra-ckin g	Device	Benefits in using AR	Difficulties in using AR
	I = intense M = moderate	M = modeling		APP = applicatio n		G = GPS M =			
(Xu & Zhang, 2022)	S	M V	Structural Systems	-	-	-	smartphone ; tablet	-	-
(Zhao et al., 2022)	I	V	Environmenta l Comfort	APP	Unity 3D; Mixed Reality Toolkit	-	HMD HoloLens	engagement; improvement in learning	-
(-) Does not cite									

SUMMARY OF RESULTS AND DISCUSSIONS

This SLR aimed to investigate the development and application of AR-based experiences in teaching and learning activities related to subjects in AU, as well as to identify the benefits and difficulties associated with this process. The review revealed that the use of AR-based experiences is highly beneficial for enhancing the teaching and learning processes for students, despite some difficulties reported by the authors.

Several studies did not provide details regarding the development of the AR experiences, such as the involvement of programming specialists (Birt & Cowling, 2018; Vasilevski & Birt, 2020; W. Wu et al., 2019) or the technologies used (Chu et al., 2019; Xu & Zhang, 2022). Thus, it appears that their focus was on evaluating the use of AR in teaching activities and its benefits for the learning process, regardless of the development mode of the apps used.

Other studies considered it important to present the development process, and some researchers chose to develop their own and customized applications. Still, platforms that do not require programming knowledge were the most used. Therefore, it is emphasized that this is an alternative for professors who do not know how to develop or edit codes.

It is worth noting that some studies conducted on these platforms were limited to the insertion of three-dimensional models for visualization in AR (Alvarez et al., 2017; Domínguez et al., 2014; Fonseca et al., 2015, 2016; González et al., 2020; Guray et al., 2021). This particular activity yielded several benefits, such as improved learning (Alvarez et al., 2017; Fonseca et al., 2015, 2016; González et al., 2020), motivation (Alvarez et al., 2017; Domínguez et al., 2014; Fonseca et al., 2015, 2016), satisfaction (Domínguez et al., 2014; Guray et al., 2021), engagement (Alvarez et al., 2017), collaboration and interaction (Fonseca et al., 2016). We highlight that the modeling of the study object linked to visualization in AR enhances the learning process in digital modeling (Guray et al., 2021).

Some studies utilized designs created by students (Domínguez et al., 2014; Fonseca et al., 2016; Guray et al., 2021), which may explain why the themes of architecture, urbanism, and landscape design were the most commonly addressed. In this specific activity, the following benefits were mentioned: improved learning and motivation (Domínguez et al., 2014; Fonseca et al., 2016); satisfaction (Domínguez et al., 2014); collaboration and interaction (Fonseca et al., 2016); and the ability to visualize designs in fast and realistic simulations (Guray et al., 2021).

Other research, even if not involving modeling and design of projects, also reinforced the importance of visualization in AR for the teaching and learning processes, with the study of building performance in lighting comfort and structural systems (Sepasgozar, 2020; Vasilevski & Birt, 2020; Zhao et al., 2022).

It is known that it is up to the teacher to plan how to insert AR-based activities into their teaching plans to promote classroom learning (Kerawalla et al., 2006). However, to do so, it is important to overcome barriers such as three-dimensional modeling, system handling, the use of low-performance devices, problems with the activities, instability of the virtual element regarding markers, and lack of institutional support. To this end, institutions could offer training to teachers or even specialized financial or human resources for the development of AR-based activities.

It is worth noting that the most commonly used devices were the students' smartphones, and some studies mentioned the low performance of these devices as a difficulty (Domínguez et al., 2017, 2014). The slowness of the system (Alvarez et al., 2017) and technical problems (Vasilevski & Birt, 2020) were also mentioned, possibly due to the use of smartphones with different configurations. The difficulty of using GPS as a tracking mode was also noted, due to the low accuracy of the students' smartphones (Domínguez et al., 2014).

Markers were the most frequently used tracking mode, but the instability of the virtual element was observed during their use (Domínguez et al., 2017; Vasilevski & Birt, 2020). Surveys utilizing HoloLens did not cite difficulties with the use of the system. However, it is worth noting that the cost of HMDs may pose a barrier to their adoption in other studies.

The utilization of ready-to-use apps has facilitated the development of certain didactic activities (Almenara et al., 2021; Alvarez et al., 2017; Domínguez et al., 2014; González et al., 2020), while others necessitated significant effort for the creation of customized applications (Birt & Cowling, 2018; Vasilevski & Birt, 2020; W. Wu et al., 2019; Zhao et al., 2022). This could potentially present an obstacle to the integration of AR-based activities by educators who have limited time and/or institutional support. Nevertheless, the analyzed studies have demonstrated the pertinence of academic research to the proposed topic, with benefits outweighing difficulties, although a limited number of studies have not shown the benefits of AR utilization (Birt & Cowling, 2018; Xu & Zhang, 2022).

CONCLUSIONS

This SLR enabled a deep analysis of research that studied the application of AR-based experiences, specifically in didactic activities addressing AU themes in undergraduate and postgraduate courses. Despite this specific focus, it was observed that some studies applied other modeling and visualization systems and technologies in conjunction with AR, such as VR and digital fabrication, indicating that researchers seek to diversify the study of systems and technologies for teaching and learning practices.

It is worth noting that students' widespread access to smartphones can be leveraged by teachers in the planning of AR-based didactic activities, with the caution of designing experiences that are compatible with the students' device configurations. The SLR revealed that, in some cases, students showed engagement in developing three-dimensional models for AR visualization. Since this is already a recurring activity in AU courses, it presents a good option for involving students in the development of AR experiences for classroom activities.

Different forms of application development used by teachers and students were identified. As some studies utilized platforms that do not require programming knowledge, these represent an important alternative for teachers with limited or no experience in coding. Additionally, they offer an option for teachers who wish to create innovative, customized activities in less time. Also, existing applications can be seen as a viable option for teachers with limited available time but who still wish to adopt AR in their classroom practices (although, in this situation, it is not possible to customize the experience).

Studies identified numerous benefits on using AR for teaching and learning processes, with improvements in learning outcomes, engagement, and motivation being notable. Another significant advantage of AR is its ability to enable attractive and innovative activities outside the classroom, fostering ubiquitous learning. However, challenges were also indicated, such as modeling, system instability, the use of low-performance devices, and difficulties with the activity itself. This suggests that the adoption of AR in undergraduate and postgraduate education still requires considerable effort from those involved. Hence, it is essential for educators to undergo training in order to develop their own innovative AR-based activities, taking into account their proficiency in AR systems.

The number of articles analyzed in this SLR highlights the need for further research in this specific field. Thus, new studies could provide greater support for teachers who wish to incorporate innovative AR-based didactic activities in their classes.

The main challenge encountered in conducting this SLR was the time required for the in-depth analysis of highly technical articles. Future studies could expand the SLR to include a more thorough analysis of the tools used for application development.

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