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Survey: Using Augmented Reality to Improve Learning Motivation in Cultural Heritage Studies

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Abstract: Cultural Heritage (CH) refers to the representation of historical places and traditional customs of a specific city or country. Its principal aim is to transmit to future generations how their ancestors lived, and what their customs and buildings were like, etc. Nowadays, there are different technology systems and research investigations that are focused on CH education that use augmented reality (AR), virtual reality (VR), and mixed reality (MR). The aim of this document is to specifically identify if the use of AR improves students' motivation to learn about topics related to CH. To this end, studies from different databases and specific journals, along with those concerning technology systems, were evaluated, and comparisons were made between them. Additionally, the aspects that should be considered in future research to improve student motivation and technology systems were identified.

Keywords: adaptive information; augmented reality; content co-creation; cultural heritage; inclusive learning; mixed reality; virtual reality

1. Introduction

Cultural Heritage (CH), "is the legacy of physical artifacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present, and bestowed for the benefit of future generations" [1] (p. 1). According to the UNESCO International Convention of Cultural Heritage, there are 1,007 relevant places in 161 countries that are at risk due to their physical conditions and are extremely important to preserve [2]. CH is twofold—tangible and intangible. Tangible CH refers to elements such as paintings, sculptures, monuments, structures, etc., while intangible CH considers aspects such as oral traditions and expressions, music, social practices, rituals, festive events, knowledge of previous generations, etc. [2–4]. A synonym of CH in virtual environments is Virtual Heritage (VH), where electronic media is used to reconstruct cultural elements from the past and the present [5,6].

Nowadays, the use of different technologies such as AR, VR, and MR, are reliable methods with which to preserve CH [7]. In this survey, of the three technologies employed for CH education, only AR is considered because the general aim is to analyze whether the use of AR in CH education enhances student motivation. Another more specific goal is to investigate if it is possible to motivate students providing a stimulus that enables them to do different activities without being aware of the time it takes or the difficulty involved [8]. For instance, Yoon [9] shows that using AR in learning environments could provide a better experience compared to that encountered in classrooms. Above all, this paper attempts to answer the following research questions about student motivation when studying CH:

- What advantages, disadvantages, limitations, and challenges do AR technologies have for the subject of CH?
- What advantages and disadvantages do AR technologies have compared to other technologies such as VR and MR?
- What tools or frameworks for developing applications in AR are used to create CH content?
- Does the use of AR improve student learning motivation in topics related to CH?
- To improve student motivation, what characteristics are considered in applications currently available, and which ones are missing?

These research questions were proposed to determine whether digitalizing content (using AR) improves student motivation when studying CH compared with more traditional methodologies and, furthermore, which aspects of the digitalization are relevant to consider for future research and system development. Although the focus is on the use of AR, Section 2 defines the AR, VR, and MR technologies and highlights the differences between them. Section 3 shows the importance of implementing AR in CH study programs. Section 4 presents the methodology for the research and the five investigation questions posed concerning the use of the AR in CH education. In Section 5, a taxonomy with the classifications applied to the articles found in databases and scientific journals is defined, and the five research questions presented in Section 4 are answered. Finally, Section 6 lists the conclusions and notes some considerations concerning the literature review presented in this work.

2. The Reality-Virtuality Continuum

Milgram and Kishino [10] define what AR, VR, and MR are, based on the Milgram and Kishino Reality-Virtuality Continuum scale they developed (Figure 1). The real world is represented on the left and the virtual world on the right. Thus, AR is closer to the real world, VR to the virtual world, and MR in between as it is the mixture of both AR and VR.

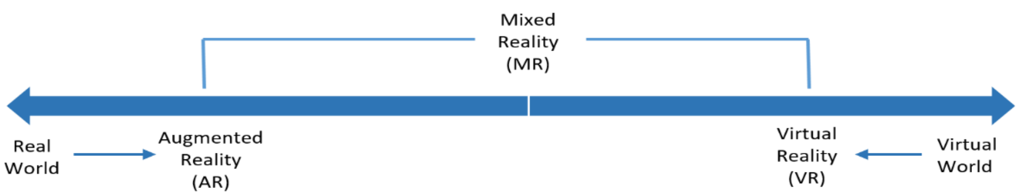

Figure 1. The Milgram and Kishino Reality-Virtuality Continuum.

One of the most accepted definitions for AR is given by Azuma, who defines AR as a system that [11]:

1. Combines or overlays virtual objects in the real or physical world
2. Executes in real-time
3. Allows user-interaction with the virtual and real objects

Although when talking about AR it is common to mention the use of virtual objects like texts, images, and videos, it is also possible to expand the contents to human senses (sight, smell, taste, hearing, and touch) and it can be used to improve or replace senses that the user may have lost [12].

At first, AR was used only in professional applications such as medical visualizations or repairing complex equipment because initially, it was very expensive in terms of money, implementation, and development, and the only users who were able to invest in this technology were some companies and governments [13]. Nowadays, a number of companies have invested in developing applications for AR (for example, ARToolKit, ARCore, Vuforia, Layar, etc.) which has, in turn, simplified its access for all parties [13,14] and ensured that AR technology would be even bigger than VR in the future [13].

Unlike AR, VR creates totally computer-generated digital environments generated in which a user is immersed, and the environment has similarities to reality [15]. In this case, the users are immersed inside a virtual environment that allows them to manipulate what they perceive as real objects—just as they would in the real world [15].

MR, on the other hand, refers to the mixture of the two technologies (AR and VR) mentioned above, i.e., there is an interaction between virtual and real objects [10]. To understand the difference between AR and MR, AR overlays virtual objects onto the real world, whereas in the case of MR, the user can not only interact with virtual objects but also with those from the real world as well.

Although these three technologies are available, from here on, the article will only discuss AR approaches.

3. Why Consider AR for CH Education?

UNESCO considers CH preservation to be essential and also differentiates CH into tangible and intangible elements [2]. Tangible elements are physical artifacts such as masterpieces, buildings, monuments, etc., and intangible elements are social and cultural practices, knowledge, skills, expressions, and so forth. Accordingly, implementing virtual technologies such as AR, allows educational institutions and museums to support the learning process through the digitalization of educational content. Virtual technologies offer tools that generate positive changes in student learning processes and motivation because they encourage students to be interested in learning for learning's sake, i.e., without the 'carrot' of receiving prizes or recognition [16].

In European countries, CH education has typically relied on traditional learning methods such as textbooks and presentations. In other words, lessons where face-to-face interaction is involved [17].

A clear example of the first system in AR for CH education is the ARCHEOGUIDE (Augmented Reality-based Cultural Heritage On-site GUIDE) [18–21] project launched in 2001. This system generates information for the user about the history of Olympia, Greece, and it gives that information using positional and orientation sensors [22,23]. To use it, a laptop and special lenses (Head Mounted Display—HMD) are employed to superimpose virtual models of the Greek ancient warriors onto the real world. It also adds buildings, monuments, masterpieces, etc., that have been destroyed or that are structurally degraded.

For some years now, mobile devices have been an ideal tool for developing AR applications. In addition, MIT (Massachusetts Institute Technology) considers AR to be one of the ten principal technologies to have emerged and can be used not only by students learning about CH but also researchers and artists [24].

Several papers mention that interest in the use of AR for education has increased [9,25] and show that in educational institutions, this technology generates greater motivation and participation in the content that is being taught for both teachers and students alike. When AR is used, students become more involved in the explanations, and interactive learning is extended, thus improving the perception and understanding of the real world through the use of virtual information [26–28].

The article by Di Serio [29] considers that, "motivation provides a source of energy that is responsible for why learners decide to make an effort, how long they are willing to sustain an activity, how hard they are going to pursue it, and how connected they feel to the activity" [8]. In addition, when comparing traditional teaching methods (such as the use of slides) in relation to AR, the article shows that the use of AR encourages students to be more motivated in their learning process [29].

AR can be applied not only in formal learning environments like the classroom but also in informal learning environments like museums, parks, archeological sites, etc. [30,31]. Employing AR in internal environments like museums has the considerable advantage of motivating users to learn about the resources they have been presented with. For example, Damala's article [32] evaluates AR applications in museums and shows that this technology provides intuitive and discrete ways of interaction with the objects presented. In addition, AR allows exhibitions to be presented virtually in places where space is limited or restricted [33], without invading physical space [34] and thus avoiding any possible physical discomfort [35].

AR systems can also be applied to creating, distributing, and providing access to learning resources [24], thus improving interactivity with and immersion in the virtual content, which, in turn, enhances student motivation and the skills involved in the learning process [29].

On the other hand, it is also important to consider how AR can provide users with disabilities the opportunity to interact with the elements. For example, a possible strategy to help visually-impaired users interact with elements and access information presented in museums would be through music and sounds [36]. Another example from the literature is mentioned in the article by Albouys-Perrois [37], where a tool called PapARt (Paper Augmented Reality ToolKit) is used to make and explore interactive maps using electronic boards with audio.

In general, AR allows users to have better experiences in the services offered, since it allows access to relevant information, and thus, helps improve participants' knowledge about different places they can visit [38–41]. For instance, an application called AudioNear [39] uses an AR system with audio on public transport and generates information about a monument or interesting place based on the user's position.

One of the difficulties mentioned in the literature concerning AR implementation in external places are environmental conditions because optimum environmental conditions are required for AR to operate well. For instance, Angelopoulou [24] shows where the user-experience could be affected, while Azuma and Van Krevelen [13,42] outline various difficulties related to the technical aspects of AR implementation such as pixel-accurate registration for tracking large environments and weather conditions [13]. Van Krevelen's article [42] also mentions that it is important to bear in mind that screens can generate low levels of light in the real world and impede the content being seen correctly. Thus, when developing any AR application, external factors such as the amount of light, reflections off objects, the position of the user, screen resolution, contrast, and color depth, etc., must all be taken into consideration.

Another issue considered in most of the studies, and also mentioned in the article by Radu [43], is the usability of AR compared to other kinds of technologies such as computers. Radu mentions that this problem is generated because AR is a relatively new technology in the classroom, and so only some students and teachers know how it works. For example, the article by Tzima [44] shows that AR is not well-known by students, and teachers who have used it found that its implementation is difficult when creating 3D content. Generally, the creation of these models is done by scholars. However, as described in the article by Wu [45], teachers can modify content in a simplistic way. Meanwhile, Tzima's [44] article develops a study about the effectiveness of applying AR in education by taking into account teachers' points of view. They claimed that employing AR is not advisable because many applications that currently exist not only often require some kind of payment, but they also undergo constant change. Similarly, the article from Akçayır [46] also mentions that one of the challenges to implementing AR in education, on account of it being such a new technology, is that not many teachers and students know how to use its functions. Thus, if current learning methods are to be changed, a greater amount of time will need to be dedicated to explaining exactly how AR works and how it is used.

Using mobile devices can also be considered to be a drawback for students because the device itself could become a distraction and increase the time that they spend on carrying out tasks [45] and, as it also includes virtual information that may be unrelated to the task, the technology itself may become intrusive in the learning process [25]. However, Wu [45] describes possible solutions or methods (e.g., notifications) that could be used to capture student interest once again.

4. Questions Posed and Research Methodology

For UNESCO, museums, and research studies are highly relevant in the effort to preserve CH, in that many buildings have structural risks and limited access [2]. Likewise, UNESCO considers it important to use technological tools for learning (but only if used in an appropriate way [16]) because through these tools CH and places can be preserved for future generations. From this, the following research questions were framed:

- What advantages, disadvantages, limitations, and challenges do AR technologies have for the subject of CH?
- What advantages and disadvantages do AR technologies have compared to other technologies such as VR and MR?
- What tools or frameworks for developing applications in AR are used to create CH content?
- Does the use of AR improve student learning motivation in topics related to CH?
- To improve student motivation, what characteristics are considered in applications currently available, and which ones are missing?

Research Methodology

For the exploration carried out into articles related to CH education, and based on the research questions mentioned above, the different kinds of techniques and examples described in the articles by Rozo, Olson, and Silva [47–49] were considered for the literature review. Figure 2 shows the methodology proposed, and below, the steps are explained in more detail.

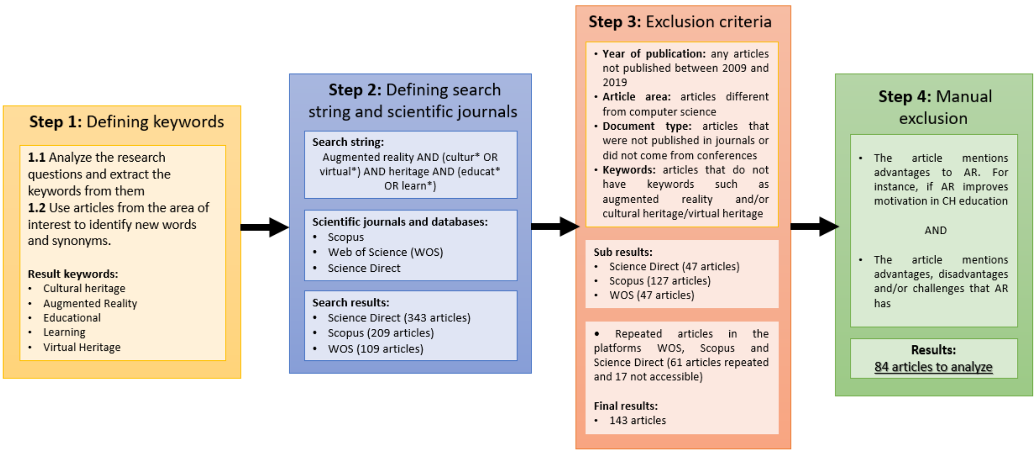

Figure 2. Steps for article evaluation.

As the articles by Rozo, Olson and Silva [47–49] mention, it is important to define the main research questions for a literature review. To do so, the aspects that the researchers want to answer must be taken into consideration. Here, as a **first step**, the research questions were generated based on the premise of identifying whether implementing AR technologies in CH education would enhance student motivation in the learning environments or not. Once the five research questions had been defined, the next step was to define the keywords, as stated in the article by Silva [49]. The steps to identifying these keywords are as follows:

1. Analyze the research questions and extract the keywords from them.
2. From the keywords extracted, use papers from the area of interest to find synonyms or new words.

Based on the research questions, the initial keywords were heritage, augmented reality (AR), educational, and learning. Later, when searching through papers from the area of interest, articles mentioning the use of technologies (such as AR in heritage), also defined virtual heritage and that the learning process of heritage is known as Cultural Heritage (CH). With the steps mentioned above, the subsequent keywords were considered:

- Cultural Heritage
- Augmented Reality
- Educational
- Learning

- Virtual Heritage

As a **second step**, the definition of the search string is important [47–49], i.e., separating each keyword and linking synonym words with the OR connector and using the connector AND to link those words that have some relationship to the research. The search string generated was:

- Augmented reality AND (cultur* OR virtual*) AND heritage AND (educat* OR learn*)

Next, as mentioned in the work by Rozo, Olson, and Silva [47–49], and using the search string, different scientific journals and databases related to computer science were selected. The journals and databases selected were:

- Scopus
- Science Direct
- Web of Science (WOS)

As a result, 209 articles from Scopus, 343 from Science Direct, and 109 from WOS were acquired. As a **third step**, the following exclusion criteria were applied to the results:

- **Year of publication:** any articles not published between 2009 and 2019
- **Article area:** articles different from computer science
- **Document type:** articles that were not published in journals or did not come from conferences
- **Keywords:** articles that do not have keywords such as augmented reality and cultural heritage/virtual heritage

After applying these exclusion criteria, there were 127 eligible articles from Scopus, 47 from Science Direct, and 47 from WOS. Next, the titles were analyzed and any repeated articles deleted, i.e., articles that appeared on more than one of the WOS, Scopus, or Science Direct platforms. This resulted in 61 repeated articles and 17 others being discarded as there were not accessible. In total, 143 articles were obtained.

The **fourth step**, was to carry out a manual exclusion of articles. In other words, only articles that satisfied some of the following were considered:

- The article mentions the advantages of AR. For instance, if AR improves motivation in CH education.
- The article mentions the advantages, disadvantages, and challenges that AR has.

In relation to the first criterion, articles that mentioned that AR improved motivation in CH education were considered because it is important to know if the digitalization of educational content into AR improves student motivation in their learning process and if it has a positive change compared to the traditional education methods.

Likewise, articles that mentioned the advantages, disadvantages and/or challenges that AR has, were also considered as this criterion complements the first criterion because it identifies the viability and difficulties than need to be considered when developing or implementing AR applications that improve student motivation in topics related to CH education.

After this manual exclusion (**fourth step**), 84 articles remained. These were then analyzed in detail to identify how AR had been implemented and if it had improved motivation in CH.

5. System Classification

In the 84 articles selected, different systems are mentioned, These systems can be classified using the classifications presented in the articles by Ardissono, Azuma, Bekele, Milgram, and Čopič [10,11,14,50,51] along with the categories motivation, content co-creation, and type of adaptation (Figure 3). Motivation, content co-creation, and type of adaptation were considered and included because in the inspection of the articles and systems, these characteristics were mentioned as being able to improve the student's learning process in topics related to CH.

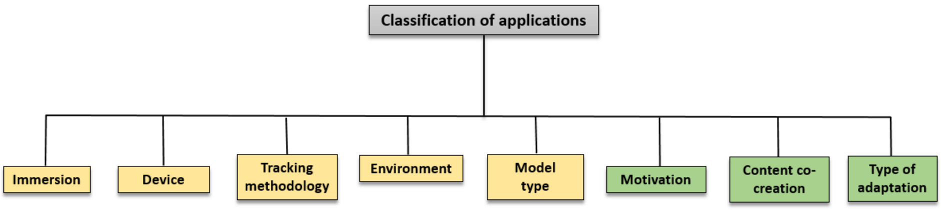

Figure 3. Classification of applications.

Immersion: The kind of technology that uses (AR, VR, MR, another) systems. To this purpose, the different types of realities mentioned in the article of Milgram [10] are considered:

- **AR:** complements the real world with virtual objects
- **VR:** immerses the user in a totally virtual world
- **MR:** mixes AR and VR technology
- **Another:** uses another technology

VR and MR systems were considered so as to compare the advantages and disadvantages these two systems have over AR technology and to determine how AR can improve the learning process in CH. Note that Table 1 depicts the systems that implement MR with a + in the options AR and VR because MR uses both technologies.

Device: identify if the system needs to use a special device such as a head-mounted display (HMD), handheld devices, computers, etc. The classification selected is based on the article by Azuma [11], and the option GUI was also added because there are systems in which content can only be obtained through a web server, and they do not use technologies such as AR or VR.

- **Head-Mounted Display (HMD):** a special device that is used (e.g., goggles or helmets) for AR and VR.
- **Handheld devices:** mobile devices such as tablets, mobile phones, PDAs, etc.
- **SAR (Spatial Augmented Reality) devices:** augment objects in the real world without special displays such as monitors, i.e., projectors to show information about the physical objects of the real world.
- **GUI:** refers to the use of technologies other than AR and VR.

Tracking methodology: refers to how the system executes the AR content in the device. As mentioned in Ardissono, Azuma, Bekele and Čopič [11,14,42,50,51], the tracking methods can be:

- **Based on the location: the** content is generated by the location of the user.
    - **Global Positioning System (GPS):** tracking is generated by geo position.
    - **Sensors:** tracking uses the device's own sensors such as accelerometers, gyroscopes, Near-Field Communication (NFC), Bluetooth, etc.
- **Based on images:** content in AR is generated by the recognition of targets or images
    - **Quick Response Codes (QR codes):** a bi-dimensional barcode (square barcode).
    - **Recognition of 2D images or 3D models:** recognizes images through 2D or 3D patterns.

Environment execution: this category was considered in the articles by Ardissono and Čopič [50,51]:

- **Internal environments:** systems are executed in internal environments such as museums, classrooms, excavations, etc.
- **External environments:** systems are executed in external environments such as parks, public transport, archeological sites, etc.
- **Virtual environments:** systems are executed in a virtual way, in other words, VR applications.

Table 1. Comparative table systems.

Application	Device				Immersion			Tracking Methodology				Environment			Model Type			*Motivation*			*Type of Adaptation*		
								Based on Location		Based on Images													
	HMD	Handheld	SAR	Desktop	AR	VR	Another	GPS	Sensor	QR Code	2D Image/ 3D Model	Internal	External	Virtual	Museums	Cultural Heritage Sites	Art Galleries	*Intrinsic*	*Extrinsic*	*Content Co-Creation*	*Context*	*Individual*	*Group*
Hybrid ICT [52]		+			+					NA	NA		+			+							
Sutton Hoo [24]		+			+					+		+	+		+								
AudioNear [39]		+			+			+					+			+							
Re-experiencing History in Archaeological Parks [30]		+			+			+			+	+	+			+			+				
Painting appreciation [26]		+			+						+	+					+	+				+	
MARCH [33]		+			+						+	+			+								
Virtual exhibitions and museums [32]		+			+						+	+			+								
Auxie [36]		+				+			+					+	+			+				+	
EvoGuide [53]		+			+				+			+				+							
VisAge [54]		+			+			+			+		+			+				+			
Virtual Heritage of the territory [55]		+			+			+		+		+	+			+				+			
Visual Art Course [29]		+			+						+	+					+	+					
ARIES [56]		+			+					+		+			+			+					
Augmented reality in science museum [9]		+			+				+			+				+							
Exploring spatial narratives [57]		+			+			+					+			+		+				+	
ARIS [7]		+			+					+		+				+			+				
TaggingCreaditor [7]		+			+			+	+			+	+		+	+			+			+	
ArtSense [58]		+			+				+			+			+			+				+	
AR museum guide [59]		+			+						+	+			+			+					
AR presentation system [60]		+	+		+						+	+			+			+					
integrative framework for extending the boundaries of the museum visit experience [61]		+		+	+						+	+			+			+				+	+
ARtifact [62]		+			+						+	+					+						
AR Nagasepaha [63]		+			+						+	+				+							
AR in education and training [23]	+	+			+			+		+		+	+			+		+					
Digital research and education [64]		+			+			+			+		+			+			+				
Easy Perception Lab [65]	+	+			+	+		+			+	+		+	+			+					
Interactive tourist guide [66]		+			+					+			+			+							
Mobile augmented reality for CH [22]		+			+			+			+		+			+		+					

Table 1. *Cont.*

Designing an immersive tool experience [41]	+				+						+	+	+		+			+		
Tangible Past [67]	+			+	+	+				+		+				+				
A flexible platform for the creation of 3D semi-immersive environments [68]	+					+			+			+		+	+					
Reviving the past [69]	+					+			+					+	+					
Virtual Heritage: living the past [5]	+					+			+					+	+			+		
Access to complex reality-based 3D models [70]	+					+			+					+		+				
Design of information landscapes [71]	+			+		+	+					+		+			+			
Development of a low-cost application of VR [72]	+					+			+			+			+					
Exploring CH using VR [73]	+					+			+					+		+				
Meta-museum [74]	+					+			+					+	+			+		+
Building virtual and AR exhibitions [34]				+		+			+					+	+		+			
HIPS [75]				+			+		+			+			+			+		+
LoCloud [7]				+			+	NA	NA	NA	NA	+			+			+		
Detailed 3D reconstruction of large-scale heritage sites [76]				+		+	+		+				+	+		+				
AR using Kinect [35]			+		+				+	+		+				+				
A tracking framework for AR tours on cultural heritage sites [77]			+		+						+	+	+		+	+				
The buildings speak about our city [78]		+			+			+		+		+				+			+	
systematic design for serious heritage games [79]				+	+						+	+			+					
Virtual tour of Geological Heritage [80]		+				+				+				+		+				
SKILLS [81]	+				+						+	+				+				
AR Book [82]		+			+						+	+					+			
Cañari AR application [83]		+			+					+		+			+					
MARS [84]				+	+				+			+				+				
PON DiCet Project [85]		+			+			+					+			+				
Learning tacit artisan skills [86]			+		+				+			+				+				
Temple of Debod [87]		+			+					+			+			+				
CHESS project [88]	+				+				+			+			+					
Batlló Museum [89]		+			+			+				+			+					
Industrial Heritage [90]	+					+		+						+		+				
Malolos City [90]	+				+	+		+			+		+			+				
Cova dels Cavalls [91]		+			+					+			+				+			
Malolos Kameztizuhan [6]		+			+						+		+			+				
History Learning support system: Ancient Japanese architectures [92]	+				+	+		+		+				+		+				
SOMARA [93]		+			+						+	+			+					+

Table 1. *Cont.*

Development of spatiotemporal information system using MR [94]	+				+	+			+				+	+	+	+							
Digital Heritage: Progress in Cultural Heritage [95]		+			+			+					+		+								
Distributed, Ambient and Pervasive Interactions [96]	+					+			+					+	+								
Cala Minnola [97]		+			+			+					+			+							
Cala Minnola VR app [97]	+					+			+					+		+							
E-Pumapunku [4]		+			+					+		+			+								
Evaluation of learning outcomes iphone game vs traditional game [98]		+			+						+	+					+						
Lonja Valencia [99]			+		+						+	+			+								
ARCO [100]		+			+					+		+			+								
Complete workflow for CH visualization and experience [101]	+				+	+		+				+				+							
SPIRIT		+			+			+					+		+	+							
Guidelines for designing a smart and ubiquitous learning environment [102]		+			+			+					+			+							
Habanapp [103]		+			+			+					+			+							
Argon Project: the lights of St. Etienne [104]		+			+				+			+				+							
Argon Project 1: Campus Tour [104]		+			+			+					+			+							
Argon Project 1: InfraestructAR [104]		+			+			+					+			+							
Argon Project 2: Auburn Avenue [104]				+	+						+	+				+							
Argon Project 2: Neptun [104]		+			+			+				+			+						+		
Argon Project 2: Midtown Buzz [104]		+			+			+					+			+							
OR.C.HE.S.T.R.A: Caruso [105]		+			+			+					+			+					+		
OR.C.HE.S.T.R.A: E.Y.E.C.U. [105]			+		+				+			+					+					+	
OR.C.HE.S.T.R.A: Smart Floor [105]			+		+				+			+			+							+	
Total	**21**	**52**	**7**	**10**	**67**	**21**	**4**	**27**	**25**	**16**	**26**	**50**	**30**	**17**	**35**	**45**	**9**	**17**	**5**	**2**	**2**	**11**	**1**

Model type: this takes as its reference to the article by Čopič [51]. It considers the systems used in:

- **Museums:** systems are executed in museums
- **Art galleries:** systems are executed in art galleries
- **Cultural Heritage sites:** systems are executed in different places to museums and art galleries.

Motivation: the type of motivation considered came from the article by Garris [106]. This category is created to identify the type of motivation that is generated by each system and if it is focused on improving it.

- **Intrinsic:** motivation is generated willingly. In the systems analyzed intrinsic motivation was considered because students can select different options to look up information in AR.
- **Extrinsic:** motivation is generated by prizes or external rewards. In the systems analyzed, extrinsic motivation was considered for those that use games to attract student interest.

Content co-creation: identifies if the systems allow users access to the creation of content without any previous knowledge of the technology used.

Type of adaptation: this takes as its reference to the article by Ardissono [50]. The content could be adapted by:

- **Context:** user location.
- **Individual:** specific user.
- **Group:** group characteristics.

The article by Challenor and Ma [107] mentions a review of AR applications for history education and heritage visualization, where the purpose of the study is to identify if using an AR system enhances the teaching of topics such as the Holocaust in history. The review studied a list of AR systems for education, and classified these systems into subject area, the authenticity of the augmented content, photorealism, impact on learning, and emotional impact. Comparing this study with this review, we found that aspects such as content co-creation, type of adaptation, environment, tracking methodology, motivation, device, and immersion are important factors to consider in AR systems in order to improve the learning process of the students in CH education.

Even though the research proposal did not originally include content co-creation and type of adaptation, these aspects have been included in Table 1 and Figure 3 as a consequence of the literature review carried out.

Some disadvantages to implementing AR in CH education in terms of content co-creation are that teachers and students cannot create their own content because they need to acquire specialized knowledge to be able to use the software [44]. In the case of an adaptation, the systems need to have appropriate content, because in some of the systems analyzed, showing all the content had been found to (possibly) produce an overwhelming amount of information which could, in fact, be irrelevant to student's interest [50]. For that reason, adaptation is an important element and the personal aspects of the user and their context (e.g., interest, preferences, personal characteristics, time available, and so on) must be considered. The article by Damala [58] mentions that adaptation/personalization can enable the same content to be shown in different ways depending on the user's preferences (e.g., videos, text, audio, etc.). Furthermore, adaptation allows potential users who may have a disability, access to this technology. For example, the article by Dulyan [36] mentions a system available to the visually-impaired in galleries and art museums that uses audio AR.

Table 1 compares the systems evaluated for each one of the previously defined categories. The plus symbol (+) indicates that the system considers that specific characteristic. In the case that (NA) appears, this means that the article in question does not specifically mention that characteristic. For example, the article by Alitany [52] mentions that they use image methodology tracking, but they do not specify if it is with QR codes, 2D images, or 3D models. The fields left blank, mean that the character has not been mentioned at all. In the case of immersion, those who implement MR have a + in both the AR and VR options because MR uses both technologies.

In the case of devices, from the 84 articles studied, 52 (61.9%) use handheld devices for the AR systems, which coincides with the article by Čopič [51]. The systems focus on this type of device since access to this is becoming easier and easier nowadays [24,108]. In addition, these devices have sensors such as gyroscopes, GPS, Bluetooth, and so on, which can be readily employed, as well. [55]. There are also some articles that mention VR, for instance the system described by Esclapes [72], where they used low-cost devices like Google's CardBoards or GO from VRelia.

In terms of tracking methodology, most of the AR systems were observed to focus on the recognition of 2D images/3D models and the use of the GPS, however, some of them also use other sensors like the NFC in TaggingCreaditor [7], Bluetooth [59,109], laser scanners [76], etc.

In Table 1, a relationship between the tracking methodology that the system uses and the model type (museums, art galleries, cultural heritage sites) is observed. In the case of cultural heritage sites, most of the systems' tracking methodology works through location, and 2D image/3D model recognition, and the majority are implemented in external environments. On the other hand, in the museums and art gallery categories, most of the systems focus on internal environments and use tracking methodologies like sensors and 2D image/3D model recognition.

From the literature review and the elements mentioned above, few systems consider the aspects of adaptation, which agrees with what was mentioned in the article by Ardissono [50]. In the case of content co-creation and motivation, few systems allow students and teachers to adapt and create content for CH education, nor do they focus on improving student motivation. As both aspects are important to consider for future research, and when developing applications, they were included in Table 1.

From the analysis of the 84 articles selected (as well as the others that were considered in the literature review), the research questions previously proposed could now be answered.

What Advantages, Disadvantages, Limitations and Challenges do AR Technologies have for the Subject of CH?

The main advantage of using AR for CH education is that it improves learning performance, generates motivation [26], provides interaction with physical resources [11,35], and encourages collaboration between users [26,83]. It avoids being isolated from others [110], enhances user-perception of the surrounding environment by providing superimposed additional information using 2D and 3D graphics [3], develops a student's cognitive process [111], has an impact on learning retention [107] and is a highly reliable technology because it copies physical elements through digital files that can be used in conservation work [112] such as preserving buildings, masterpieces, ruins, etc. In other words, AR improves the user's experience by making reconstructions and exploring and managing the CH information [14].

Nowadays, Information and Communication Technologies (ICT), coupled with the evolution of smartphones, make AR applications attractive to CH sites like museums because they can be used to show different types of content to a wider audience [83]. As such, the number of AR applications used in CH is on the increase, and future predictions suggest this will be accompanied by an exponential increase in the numbers of AR technology users [91]. Chang [26], for example, describes a study designed to identify the experience the user has with AR in an art appreciation class and concludes that employing AR is more effective compared to the use of audio guides in an art museum. This is because AR makes the information easier to digest through its audio and visual material. Chang [26] also shows that in different studies, AR offers visitors interesting, fun, and challenging experiences, as well as immersive sensations. In educational applications, it also generates motivation and participation by attracting students and teachers through additional information. By integrating images between the real and virtual worlds, it diminishes the chance of students becoming overwhelmed by the amount of information available and, in turn, enhances their learning process [63]. AR is a useful learning platform for CH education because it motivates both students and researchers to understand historical events [28].

In addition, AR improves the human perception of [35] and interaction with the real world, and it could be applied to human senses such as hearing, taste, smell, touch, and vision [11,12] to improve on them or even replace them [12]. Meanwhile, the article by Bolestis [40] mentions that using audio AR reduces any distraction mobile devices can cause because the user, is focused on the audio content. They describe an application called AudioTransit, which is an AR audio tour guide used on public transport to provide commuters/users with free information about cultural points of interest they may be passing.

For CH education, AR allows the focus to be on the user, because it provides navigation, interaction, and orientation when the museums do not have enough space or resources to present their collections, thus improving the user's experience by reconstructing heritage information [14]. Furthermore, it allows users like researchers or artists, to exploit its applications to teaching cultural and artistic elements, and allows interactive learning that could be extended and enhanced in terms of distribution, creation, collaboration, time allocation and access to learning resources [24]. In addition, AR is a valuable tool for CH because it can reconstruct (and thus retain) archeological sites that are in poor condition or no longer exist, i.e., they can be seen virtually by future generations [28,35,70,100]. In fact, nowadays, the latest mobile technologies mean that users can learn about CH in informal learning environments like museums, parks, archeological sites, etc., [30].

The use of mobile games with AR could be beneficial in formal and informal environments because, as AR is not limited to any type of technology and can be used in different environments [78], it allows learners and instructors to collaborate and communicate remotely about topics related to CH and they can also share different virtual material with each other [82]. Puyuelo's article [99] presents an example of an AR design application using interactive resources for the Gothic Silk Market Building, called the "Lonja de la Seda", in Valencia, issues such as poor lighting, difficult access, etc., are resolved, and AR is demonstrated as being an effective tool in CH for accessibility and communication because it is non-intrusive and supplements additional information that enhances the user's visual experience.

In addition, AR is an interesting tool because it engages [87,88] and enhances [3,90] the user's perceptions through virtual content overlaid with additional information in 2D or 3D. The use of markers to show AR content increases the robustness and reduces the computational requirements of the system [81].

However, AR also has some shortcomings and limitations depending on who is using it because, as learners have constant access to a variety of immersive technologies, using AR does not necessarily mean that students will learn better compared to more traditional methods and for that reason AR should be focused on the content rather than entertainment [107]. Nonetheless, the role of educational institutions and museums should be to motivate the student learning process [82], and AR may be one way to achieve this. Bustillo [68] comments that the use of AR through games can alter the learning process of abstract concepts in CH if it is not used in an appropriate way. For example, Champion [113] describes that using emblematic game interaction in topics related to CH could, depending on the implementation and content of the game (for instance, first-person shooter games), encourage violence. To avoid any negative experiences, the content available should be useful and appropriate [14] contain interactive subject matter [50], and the technologies in physical museums and heritages sites must stimulate the user in order to educate future generations to understand their past [113]. Another disadvantage in AR is that the tracking methodology based on markers could be intrusive in some scenarios [81]. In the same vein, it is important to consider different aspects that might affect the user's experience; for example, in [91], they mention that in their application, the virtual content takes too much time to appear in the mobile device. An article by Martinetti [114] mentions that the main factors for the lack of AR pervasiveness are technological/technical limitations (image recognition, internet connection, responsiveness), human interaction (distraction and ergonomic devices) and organizational limitations (handling AR projects, IT infrastructure and financial resources).

Challenges for AR include precision, user-tracking, and registering 3D models in a real environment. As Bostanci [35] notes, these aspects are important to bear in mind when developing an application. In external environments, such as excavations, AR applications could be affected by the light conditions, and therefore, it is fundamental to consider this kind of aspect if the application is to work properly [24]. The success of an AR application also depends on the content available, and it could be affected by aspects such as resolution, illumination, contrast, latency, calibration of the virtual objects with the real world [14], geometric precision, capture of details, photorealism, portability, efficiency, etc. [76]. For example, the articles by Blanco-Pons and Chang [91,115] mention that perceived usefulness is a factor that determines the use of AR applications [91], and that the popularity of an exhibition is not dependent on the museum, but rather on the content offered and the device used [115]. Azuma [13] notes another point that is important to work on when using AR in CH, namely, choosing places that are important for current and future generations to remember. Furthermore, [44] mentions that other factors to consider in CH AR applications are the characteristics of the urban environment, the constant changes this kind of technology undergoes, which means teachers and students will need (re)training, and keeping the information updated.

What Advantages and Disadvantages do AR Technologies Have Compared to Other Technologies Such as VR and MR?

AR allows interaction with the real world to take place and is enriched by superimposing virtual information in real-time, thus enhancing human perceptions of CH by reconstructing physical archeological sites and preserving them for future generations [35]. It does not replace the user's reality [11], but it does allow for on-site construction, thus avoiding physical difficulties [35]. Neither does it generate isolation among users [38] but rather generates interaction with other users, thus improving the CH learning experience [35]. Furthermore, AR reduces the time consumed in recreating virtual objects [81] because the user perceives both realities simultaneously [91]. It also avoids problems such as motion sickness [81]. Ardito [30] describes an application they refer to as 'edutainment', that uses AR in archaeological parks where students are encouraged to more involved in the learning process through games.

As AR only manipulates part of the real environment, it is a viable technology in terms of technological and economic cost, as well as for creating content [15,41].

Unlike VR, where everything is a virtual object, AR replicates the authenticity of the artifacts and does not require specialized hardware to operate an application [107]. In VR, the user's location is not important, but the problem is that these environments are synthetic and do not offer real artifacts, and so the authenticity of the CH elements are lost [57]. AR also provides real augmented visual perceptions of the information or content because, unlike VR, AR does not change the real world at all [41], thus allowing users the opportunity to experiment with real objects [23]. For example, Challenor and Ma [107] mention that VR creates complete immersive environments but lacks the stimulation of senses like the smell because the environment is not real. AR has the potential to transform the ways we learn about our world and the places and elements around us. Choudary [33] mentions that, in the case of prehistoric caves where their access is restricted, AR allows the user to visit the real places virtually. For museums, the use of AR provides thoughtful and intuitive interaction with the objects on display to the public [32].

The disadvantage that AR has compared to VR is that the objects from the real and virtual worlds must coexist and be aligned; thus AR needs to have greater precision [11] than VR. As well, [116] mentions that there is evidence that many of the AR devices and some of the content in AR can generate confusion, dissatisfaction, physical fatigue, etc. External aspects such as illumination, reflections, shadows, and weather are also noted as being able to affect the workings of the applications. For example, [87] describes an application used in the exterior and interior of a temple. When there is too much light or too many shadows on the engravings, the functionality is affected at the moment the user wants to watch the augmented content.

Fällman [15] mentions that Winn [117] identifies a number of the advantages VR has over AR: (i) in its virtual world, VR allows changes to be made to the relative size of the objects, (ii) the user can interact with, and design all of the virtual world themselves, (iii) objects that are difficult to represent in the real world can be created and visualized and (iv) user experiences are more secure and safer than in places where interaction with real objects could affect other users [5]. For example, article [70] shows that VR helps engineers to visualize different techniques in a 3D environment for military training that feigns emergency situations but avoids possible damage or accidents because it all takes place in a virtual world. However, that said, if in VR the virtual world is more interactive in content, the users might want to manipulate or sabotage it [118].

MR, on the other hand, provides the user with the advantages of both the AR and VR technologies [14,119], but its drawback is that it currently uses expensive devices (for example, Hololens from Microsoft) to show content [51].

What Tools or Frameworks for Developing Applications in AR are Used in the Creation of CH Contents?

To determine which tools or frameworks for developing applications in AR can be used, a comparative table was drawn up (Table 2) depicting the characteristics that each has. The systems analyzed in Table 2 were evaluated to identify which would be the most suitable for resolving the challenges mentioned before, on technological and economic levels, and by taking into account the analysis presented in Table 1.

Table 1 reveals that most of the systems use handheld devices, and most of the AR content is executed in internal and external environments with tracking methodologies such as QR codes, 2D images/3D models, GPS, and sensors. Nevertheless, in the case of QR codes and 2D images/3D models, these systems are focused on internal environments while GPS and sensors are used in external environments. Table 2 contains information about the version, the tracking methodologies that can be implemented, where a + symbol indicates the characteristics that can be used or—if it does not have that characteristic, the platforms that support AR (Unity, Android, and IOS) if it is open source, if it needs a license to use it, if it is available commercially and how much each license costs.

Does the Use of AR Improve Student Learning Motivation in Topics Related to CH?

From the analysis, it is deduced that AR improves the learning experience [23,82] and extends it interactively [24] because it can be used as an auto guide for CH resources. For instance, the application described in [30], which was used by middle school students from Michelangelo (Bari, Italy). The application consists of a game with 4-5 players where they have to formulate hypotheses and discuss them in order to discover and learn about the culture of Ancient Rome. Thanks to this technology, the children who participated were more involved with the 3D visualization and the physical models that can be printed in 3D. Compared to traditional methods, student motivation to understand the topics was enhanced, and it also developed their skills and encouraged social relationships to be built between their peers [28]. Using games with AR stimulates an understanding of history in students that can be difficult to engender. It is a fun way for students to enjoy the subject, and they can learn better compared to traditional methods because the activities require different abilities that can be developed simultaneously and also boost collaboration between partners [30]. However, it is important to distinguish between entertainment and education because simply using games, in general, will not mean that students learn effectively [118]; educational objectives also need to be included. For example, [29] shows that AR has a positive impact on student motivation when the Instructional Materials Motivation Survey (IMMS) is included. This is an evaluation of satisfaction and motivation that considers four factors of motivation: attention, relevance, satisfaction, and confidence. Scientists, researchers and teachers alike agree that when students feel motivated to learn, they retain more information about the topic(s) and are more involved in finishing the proposed activities, thus allowing for a student to interact with their classmates and teachers and improve their abilities and performance [29].

For educational purposes, the process becomes easier in museums and classrooms because conventional methods fail to engage and motivate students [82]. The museum and classroom environments are not as effective as AR is in helping students to imagine historical scenes and to understand what happened in those places [89]. Recently, mobile AR applications have been successfully integrated into museums, heritage sites, tourism, and learning environments and AR has proven to be a promising technology because it increases the appreciation of the CH content, attracts new users, increases motivation, and promotes participation [89]. Moreover, the use of AR in learning environments generates more interest because students have better experiences in their learning process as it is fluid, sporadic, and participative [9] and methods based on textbooks are less effective in helping students to understand historical events. Nevertheless, it is important to mention that the use of technologies like AR does not replace classes and traditional methods; it only improves the student's learning process [82].

Similarly, AR not only allows participation between students but also between teachers [26], generating collaborative environments where they can work together simultaneously, thus allowing the students to take control of their learning experience by attracting them with additional information that this technology overlays [29] as is described in Kerawalla [120].

To Improve Student Motivation, What Characteristics are Considered in Applications Currently Available, and Which Ones are Missing?

The characteristics that were considered from the applications analyzed include the device used, the type of technology used, the tracking methodologies, the environment it is used in, etc. These characteristics only focus on software and hardware, albeit some of them consider the environment (internal and external) where they are executed.

So, very few applications consider students to be an important focus. In [50], it is shown that for adaptation/personalization, it is essential to consider student interest, knowledge, personal characteristics, etc. since this allows for the most appropriate content to be selected and avoids overloading the user with content that is of no interest to them. A good example of considering the user is the application HIPS [75], which uses infrared sensors in a museum, and the user can select a tour prepared by the curator, design their own tour, or select one that has been designed by other users. An evaluation of a project [118], shows that aspects such as interactivity and adaptation/personalization might be more important than realism because CH has a lot of information that is not relevant for all users. Besides, [50] shows that in the case of tourism, as it is a social activity, the system adapts the content to groups of users that have similar interests, experiences, and needs because each of them requires different types of information and different levels of detail. For example, [75] shows that the information selected and presented depends on location, level of interest, knowledge, and user preferences (i.e., users can select how they would like the information to be presented (video, audio, text, etc.). AR also offers to users who have a disability, the opportunity to visit places like museums and galleries [36].

Thanks to the technological advances in mobile devices, these now have sensors such as barometers, gyroscopes, accelerometers, and so forth, which allow new tools to be created for learning and knowledge assessment, thus generating two new methodologies in education known as ubiquitous learning (u-learning) and mobile learning (m-learning) [55]. In [58], the information provided about a masterpiece can be complemented by selecting different types of content (videos, audios, texts, etc.) and by considering the user's interests. The system is developed for different kinds of visitors (school groups, children, families, adults, etc.).

On the other hand, few applications take into account the type of student's motivation (extrinsic or intrinsic), and if students and teachers can create content. Applications will function only if the content generated is useful and interesting [14]. Nowadays, education is related to the evolution of the student and their personal skills because these skills will define who they are in the future and will improve aspects such as critical knowledge, responsibility, passion, motivation, enthusiasm, confidence, etc., [121]. This is why in CH education, it is important to take into account factors that can enhance and improve the learning process. For example, the article by Wu [45] mentions three elements that should be considered for active learning: (i) using the AR system is fun, (ii) the system offers interesting challenges to complete, and (iii) it generates curiosity about the new topics.

In addition, future applications in AR will need to consider usability and content co-creation [122] as some of the AR systems were found to be difficult for students to use because of technical problems such as size screen, network speed, battery life, etc., and because of a lack of knowledge about how to use this technology [44]. Another study shows that an aspect of improving is in the creation of CH AR applications because creating content currently consumes a lot of time [122]. For instance, constructing 3D monuments demands time be spent on collecting data, on re(training) (because of the constant changes the technology undergoes) and on implementation (because AR content for CH needs skilled software developers, designers accomplished in 2D imaging and 3D modeling, video editing, etc., [44]).

6. Conclusions and Considerations

Through the categories defined for this study and the evaluation of the systems, it was observed that using AR for CH education generates a positive impact on motivation for topics related to art, history, the sciences, etc. AR can be applied in formal environments like classrooms and informal environments such as museums, parks, archeological sites, cultural heritage sites, public transport, and so forth. Based on this, it is observed that the use of this technology allows information that is relevant to a student to be complemented, and it improves the student's learning experience in topics related to CH.

The points below, summarize the findings from the literature review carried out:

- Most of the systems, nowadays, focus on CH education through AR and VR. Both have advantages and disadvantages, depending on the context in which they are executed.
- CH education is focused on complementing the student's learning process principally with the use of AR in informal environments such as museums, parks, public transport, art galleries, etc.
- Most of the studies show that for museums and their curators/managers, the underlying motivation to implement these technologies is to attract the public and encourage them to visit their galleries and presentations.
- Few systems consider the adaptation/personalization of the content when they use the content for the students. Context is adapted based on the location and time available, while individual adaptation considers interests, ways of presenting the content (video, audio, text), and in some systems, helping those with disabilities or fears (for example [104] mention users with claustrophobia). Meanwhile, group adaptation considers those users that have similar interests in a specific topic.
- It has been observed that, over time, most of the AR systems use handheld devices (tablets, smartphones, laptops, etc.) because access to such devices is much easier these days.
- When developing future systems, it will be important to consider the usability and technical aspects such as the environment in which it will be executed, the type of content that will be shown, the tracking methodologies that will be used, etc.
- Most of the systems in AR focus on learning topics related to art and history. In addition, many of them use GPS and 2D image recognition, 3D models, and tracking methodologies.
- Systems that use intrinsic motivation focus on student learning and allow them to choose what they want to learn, while systems with extrinsic motivation use other ways to motivate students, for instance, by using games.

- Depending on the environment where the systems are executed, they use a specific tracking methodology. For example, most of them use sensors, QR code recognition, and 2D image recognition and 3D models in internal environments and GPS in external environments.
- Few systems consider content co-creation by the student or the teacher.
- Few systems consider the student's motivation since they generally focus on the user's experience in terms of the content and technology it uses.

As was found in the literature, implementing AR in CH learning improves a student's learning experience and motivation, but to do this, the systems must develop useful content by considering the type of application, tracking methodologies, environment, devices, etc. In addition, it must be remembered that most of the systems focus on handheld devices since these days it is easier to have access to them.

However, from the observations mentioned in the previous sections, some of the challenges to implementing AR in education are (i) usability- since AR is a relatively new technology and few users know how it works, (ii) content creation -as this is difficult for a non-expert user, (iii) the overload of information, which is not relevant for the students, and (iv) the improper use of the technology. Finally, technical aspects such as lighting, the reflection of objects throw out, the type of visual device, tracking methodologies, etc., are factors that must also be taken into account when developing applications.

One way of overcoming these challenges is to include the student as part of the system where they can create their own content collaboratively with classmates and teachers and show that information in different ways such as video, audio, texts, and so forth. The goal here is to help improve student motivation as they themselves are the ones creating the activities related to CH education through the medium of AR.

Co-creation allows the user to be a participant in the content generated, so the information used should be suitable for the student's age and the topics explained by the teacher. At the same time, content adaptation/personalization means that the student has the opportunity to learn in a better way. However, in this case, it is necessary to create a user and context profile that allows the student to be to identified and thus avoid cognitive overload with information that is not important for that particular student and select the augmented content by considering that student's specific preference(s) (audio, video, text, etc.).

Motivation can be intrinsic or extrinsic. In the case of intrinsic motivation, the student performs the activities without expecting any reward as they are interested and motivated to learn regardless of the time spent on the activities. On the other hand, extrinsic motivation focuses on rewards so that learning is to reach a specific objective, and for that reason, it is a characteristic that is important to consider when generating content in AR.

From the analysis of Table 2, it is possible to deduce that complete frameworks with which to develop AR applications that are currently being used are Vuforia, ARKit (Apple), ARCore (Google), and Wikitude. In future applications, these frameworks could also be used since they support most of the tracking methodologies and handheld devices currently available. Besides, the developer can also find detailed information about how to create the AR content. Moreover, these frameworks can be used to develop an AR system that improves motivation in CH education by considering not only student characteristics but also content co-creation because these allow AR content to be created for external and internal environments, and most of them support different platforms and devices.

Table 2. Comparative table of AR frameworks.

Framework	Version	Tracking Methodology					Supports AR/VR	Platform	Open Source	Commercial	Free	Price
		QR Code	Image	Model	Multiple Images	GPS						
Vuforia	8.1	+	+	+	+	+	+	iOS, Android, Unity	no	yes	yes. Developer version	Standard – 500$/y Cloud – 100 $/m Pro – By contact
Wikitude	8.5	+	+	+	+	+	+	iOS, Android, Unity	no	yes	Yes (trial and limit characteristics)	Pay 1 time/ subscription demo—499 € sdk pro—1990 €/ 2490 €/y sdk pro 3D—2490 €—2990 €/y cloud—4490 €/y
ARKit (Apple)	2.0	+	+	+	+	+	+	iOS	no	yes	yes (limit number of projects in the week)	Developer account 100 $/y
ARCore (Google)	1.9.190422066	+	+	+	+	+	+	iOS, Android	yes	no	yes	Does not specify
Kudan	1.5	+	+	+	+	+	+	iOS, Android, Unity	no	yes	yes (with watermark)	AR business – 1500$/y AR enterprise – By contact
ARToolKit	5.3.2	+	+	-	+	+	+	iOS, Android, Unity	yes	no	yes	Does not specify
ARmedia	Does not specify	+	+	+	-	+	+	iOS, Android	no	yes	yes (no commercial license)	By contact
Maxst	4.1.1	+	+	+	-	+	-	iOS, Android, Unity	no	yes	yes (with watermark and no commercial license 1 month)	Pro—39 $/m Enterprise – by contact
droidAR	3.0	-	+	+	+	+	-	Android	yes	no	yes	Does not specify
LayAR	Does not specify	+	-	-	-	+	+	iOS, Android	no	yes	no	By contact
Aurasma (HP Reveal)	2.0	+	+	-	-	-	-	iOS, Android	no	yes	no	SDK in development
Xzimg	Does not specify	-	+	+	-	-	-	iOS, Android, Unity	no	yes	yes (limit characteristics)	Professional – By contact
Augment	Does not specify	-	+	+	-	-	-	iOS, Android	no	yes	yes (14 days)	Essential—9 € per dispositive Professional—25 € per dispositive Enterprise—59 € per dispositive
EasyAR	2.0.0	-	+	-	+	-	-	iOS, Android	no	no	yes (limit characteristics)	By contact
simpleCV	1.3	-	+	-	-	-	+	Android	yes	no	yes	Does not specify
BlippAR	Does not specify	-	+	-	-	-	-	iOS, Android	no	yes	yes (30 days)	By contact
CraftAR	3.4.1	-	+	-	-	-	-	iOS, Android	no	yes	no	Indie—9 € per page Pro – By contact
PixLive	Does not specify	-	+	-	-	-	-	iOS, Android	no	yes	yes (demo 30 days)	Indie—9 €/m Pro – By contact
DeepAR	Does not specify	-	+	-	-	-	-	iOS, Android, Unity	no	yes	yes (30 days)	By contact
NyARToolKit	5.0.8	+	-	-	-	-	-	iOS, Android	yes	no	yes	Does not specify

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