Systematic mapping study on High-level Content Design Frameworks for Augmented Reality

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***Abstract*—Augmented Reality (AR) is expected to be one of the technologies that will have a high impact on different areas such as education, maintenance or game development. One of the main drawbacks of using this technology has been the complexity for users without programming skills to create AR applications. The use of High-Level Content Design Frameworks (HCDF) is proposed as a solution to facilitate the process of developing AR applications.**

There are different types of HCDF, but it is necessary to classify them so further research would fill gaps in the current literature. To the best of our knowledge, no research has been done focusing on analyzing the articles related to HCDF. As a solution to these problems, we have proposed a systematic method to classify and find current trends in research focused on HCDF.

***Index Terms*—systematic mapping study, augmented reality, authoring tool, content design framework**

I. Introduction

Augmented Reality (AR) has obtained a strong interest in research for more than a decade and has led to interdisciplinary research in fields such as education, architecture, medicine, entertainment and marketing which have achieved positive results [1].

For instance, there is an increase in the development of tools for the creation of AR applications (*augmented reality authoring tools*), which can be used both by expert users through a programming framework and by non-expert users through a content design framework [2]. Content design frameworks for AR can be classified in low-level content design frameworks or high-level content design frameworks (HCDF), where the HCDF commonly includes a visual editor that facilitates the creation of applications focused on AR.

For this reason, we have carried out a systematic mapping study on HCDF based on the process established in [3], and the update proposed by [4]. For this research, the HCDF stakeholders have been defined as shown in Figure 1 and described as following:

- HCDF developer: The HCDF programmer who use AR programming frameworks.
- HCDF user / AR application author: The non-programmer user that uses the HCDF to add custom AR content.
- AR application user: The target end-user which uses AR applications.

The rest of the paper is organized as follows: section II gives an overview of related works, section III describes in detail how the research method was carried out, section IV shows the results obtained by answering the research questions, and finally, section V synthesizes and concludes the systematic mapping study.

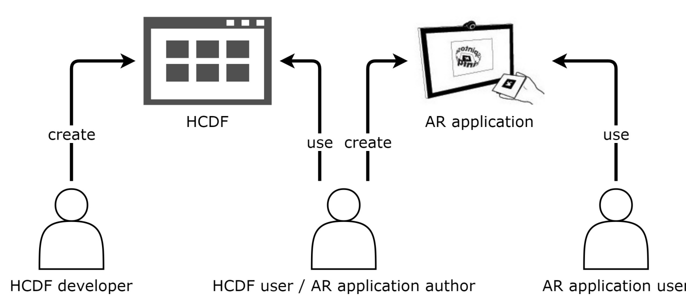

Fig. 1. HCDF stakeholders

II. Related Works

Two articles collect AR authoring tools, both of them propose new taxonomies. Reference [2] showed at least one example per each classification focused on AR frameworks. On the other hand, [5] found 14 primary studies about content

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design frameworks and their classification is made according to authoring paradigms (stand-alone or plug-in) and deployment strategies (platform-specific or platform-independent).

However, none of these investigations have focused specifically on HCDF. Also, both articles use a non-systematic procedure to identify primary studies, so we did not find any articles that have carried out a systematic review or systematic mapping on this topic.

Therefore, the present work seeks to update and cover the totality of existing articles about HCDF through a systematic mapping of the literature.

III. Research Method

The goal of our work is to identify how HCDF are developed and used. Therefore, we propose a set of research questions which serve as guidelines for our research.

A. Research Questions

We chose a systematic mapping study because the objective of the paper is to explore state of the art on HCDF. Also, we seek to find out what sub-areas exist on this topic through a classification.

We address the following research questions:

- RQ1. Where and when are the academic articles on HCDF published?
  - RQ1.1. What is the publication trend of HCDF articles by year?
  - RQ1.2. In which conference or scientific journal are HCDF articles published?
- RQ2. How are HCDF developed?
  - RQ2.1. What are the AR programming frameworks used by the *HCDF developer*?
  - RQ2.2. In which development platform does the *HCDF user* create AR applications?
  - RQ2.3. What interface projection platform of the HCDF does the *AR application user* use to view the content in AR?
- RQ3. What type of user interface does the *AR application author* use with the HCDF?
- RQ4. How are the HCDF classified according to the general models proposed by [5]?
- RQ5. What is the application field in which the HCDF are focused?
- RQ6. What are the methods used to validate the HCDF?

B. Search

To determine the keywords, it is necessary to take into consideration the scope of the investigation. We generated our search string by using the PICO strategy [6]:

- Population: The population is the applications of AR or mixed reality (MR). The keywords that identify the population are: “augmented reality”, “AR”, “mixed reality” and “MR”.
- Intervention: The intervention or technology are the HCDF; however, this term is not widely used. For this reason, it has been chosen to use the term AR authoring tool which includes the HCDF. The keywords that identify the intervention are: “authoring tool”, “authoring software”, “authoring system”, “authoring platform” and “authoring toolkit”.
- Comparison: This research does not make comparisons with other methods to create AR applications.
- Results: The results from using the HCDF is the usability for the creation of AR applications.

We determined that the population and intervention criteria are the most relevant items in our context.

Another important point is to eliminate the keywords that are acronyms of the population criterion because they generate unnecessary results. Regarding the criterion of intervention, the most used word is “authoring ’, which comprises the other keywords. Finally, the search string to apply is (“augmented reality” OR “mixed reality”) AND “authoring”.

Then a search was done on January 2018 in the following academic databases: ACM Digital Library, IEEE Xplore Digital Library, ScienceDirect and Scopus. The following Table I shows the results.

TABLE I
RESULTS IN EACH ACADEMIC DATABASE

Academic database	Search field	Number of articles obtained
ACM Digital Library	Title, abstract and keywords	120
IEEE Xplore Digital Library	Title, abstract and keywords	123
ScienceDirect	Title, abstract and keywords	47
Scopus	Title, abstract and keywords	311
	Total	601

We validated our search strategy by comparing our results with the articles obtained by [5].

C. Study Selection

The inclusion and exclusion criteria were obtained through the process proposed by [7] and were applied to the metadata, titles, and abstracts of the articles. When in doubt, we proceeded to full-text reading. At least two different authors reviewed each article and decided if it was uncertain, relevant or irrelevant according to our topic.

1) Inclusion Criteria:

- The article was published until 2017.
- The article is digitally available and was published as part of a conference, scientific journals or workshop.
- The language of the article is English.
- The article describes an HCDF.
  - The HCDF must have a visual editor.
  - The HCDF is independent or part of a system.
  - The HCDF allows augmenting visual, audio or haptic content.

– The HCDF can be part of a layered authoring tool[1]. If the framework has a visual editor and is self-sufficient, then the framework will be included.
– The HCDF can use embedded pre-designed content or external content. The user can add custom content (multimedia objects or text) to the application without the need to write lines of code.

2) Exclusion Criteria:

- The article describes an AR programming framework, that is, it requires the user to program[2].
- The article does not propose a HCDF but uses or validates an existing HCDF. Only articles that describe their own frameworks are included.
- The article proposes a HCDF in which visual content is not used, For example, if the framework only uses audio content[3], the article will not be included.
- The article is a duplicate of another article.

Since there is no systematic review or systematic mapping related to the area previously proposed, our investigation covers the totality of articles available up to the proposed date.

We then applied the decision rules and used the strategy D5 [7] as suggested by [4]. With the remaining set of articles, we proceeded to read each article entirely and emit a final opinion. Finally, we eliminated articles that describe the same HCDF, giving priority to articles with the most recent publication date and from scientific journals.

D. Quality Evaluation

To ensure there is necessary information for the data extraction form (see section III-E), we applied a quality evaluation to the remaining articles. During this stage, each article was assigned a score of 0 - 6 based on the quality criteria of Table II. Each criterion has the value of 1 point. An article can pass the quality criteria if it has at least 4 points.

TABLE II
QUALITY CRITERIA

	Description
QC1	The article shows the AR tracking method
QC2	The article shows the development platform
QC3	The article shows the interface projection platform
QC4	The article shows the authoring user interface
QC5	The article shows enough information to classify the HCDF according to the taxonomy of [5]
QC6	The article shows clearly at least one validation method of the HCDF

This systematic mapping of the literature is based on the 74 articles that passed this stage. The number of articles included and excluded for each stage is shown in Figure 2. Appendix A shows the list of included articles (primary studies), as well as those excluded by the quality evaluation.

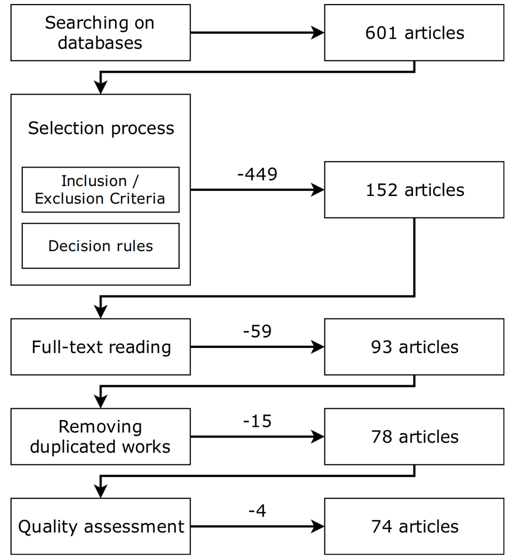

Fig. 2. Overview of the article selection process

E. Data Extraction

For each article, the necessary data are extracted to complete the form shown in Table III. The following are a detailed definition of the fields used in the data extraction form:

1) AR programming framework or method: The framework has to identify where to augment the content. We were careful not to confuse with 3D rendering libraries.

2) AR tracking method: Provided by the AR programming framework and abstracted by the HCDF to end-users.

3) Development platform: Platform used by *HCDF user*.

4) Interface projection platform: Platform used by the *AR application user*.

5) Authoring user interface: Interface type used by *HCDF user*.

6) General models: Taxonomy proposed by [5].

7) Domain: Field of application the HCDF is focused on.

8) Validation method: Evaluation process used to validate the HCDF.

IV. RESULTS

We summarize our findings and discuss them on this section. These are organized by our proposed research questions in III-A.

A. Frequency of Publication (RQ1)

The publication trending by year on Figure 3 shows an increasing interest in this topic. Since this topic appeared in 2002, there is little research done until 2007. From this year on, the trending has increased reaching a peak in 2016.

Regarding the venue of publication, if the HCDF is domain-specific applied then the research article is submitted to a venue related to that domain. Most of the HCDF are not focused on a specific field, but a general use. As shown in Table IV, most academic events are related to AR.

[1]A layered framework can support different levels of complexity to engage different users.

[2]We refer “to program” as writing lines of code in a programming language.

[3]There are augmented reality systems based only on audio, we do not consider them because they would present a disadvantage when compared with frameworks that allow visual content.

TABLE III
DATA EXTRACTION FORM

Data item	Values	RQ
Study ID	Integer	-
Article title	Name of the article	-
Author name	Names of the authors	-
Year of publication	Year of publication	RQ1.1
Venue type	Journal, conference or workshop	RQ1.2
Venue name	Name of the publication venue	RQ1.2
AR programming framework or method	Name of the AR programming framework or method	RQ2.1
AR tracking method	Marker-based, feature-based, location-based or other	RQ2.1
Development platform	Desktop PC, hand-held device (HHD), head-mounted display (HMD) or web	RQ2.2
Interface projection platform	Desktop PC, hand-held device, head-mounted display or web	RQ2.3
Authoring user interface	2D, non-immersive 3D, tangible or immersive 3D	RQ3
General models [5]	• Model 1: Stand-Alone + PS • Model 2: Stand-Alone + PI • Model 3: All in one • Model 4: Plug-in + PI	RQ4
Domain	Education, maintenance/assembly, games, other or general	RQ5
Validation method	Usability evaluation, empirical evaluation (user testing, use case or technical evaluation) or unknown	RQ6

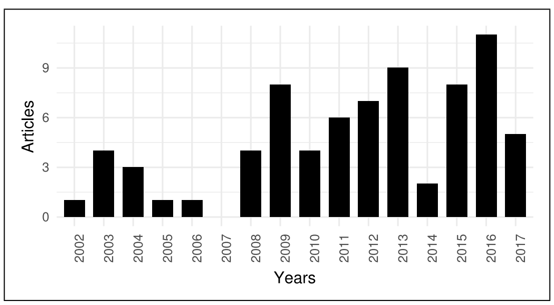

Fig. 3. Frequency of publication by year

B. HCDF Architecture (RQ2)

Most of the HCDF allow the end-user to create interactions using AR marker-based tracking method (see Figure 4) since *HCDF developers* frequently use marker-based AR programming frameworks (see Figure 5). Table V and Table VI from Appendix B show the articles classified by AR programming framework and AR tracking method.

For a long time, the development platform most used was the desktop PCs. However, this has changed in the last three years in favor of web, HHD, and HMD (see Figure 6).

As can be seen on the timeline of Figure 7, there are three periods related to the interface projection platform.

- 2002 - 2007: The most used platform at this stage is the HMD, while HHD hardware is still improving.

TABLE IV
VENUE OF PUBLICATION OF HCDF

Venue type	Venue name	Total
Conference	International Symposium on Mixed and Augmented Reality (ISMAR)	6
Conference	International Conference on Virtual-Reality Continuum and Its Applications in Industry (VRCAI)	4
Conference	International Conference on Virtual Environments, Human-Computer Interfaces and Measurement Systems	2
Conference	Virtual Reality (VR)	2
Conference	International Conference on Distributed, Ambient, and Pervasive Interactions (DAPI)	2
Journal	IFIP Advances in Information and Communication Technology	2
	Others	56

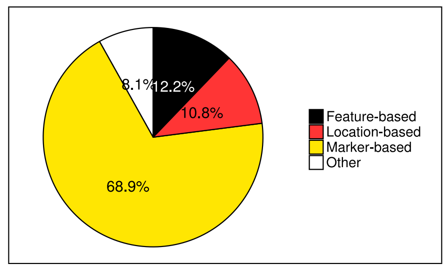

Fig. 4. Distribution of the AR tracking method

- 2008 - 2011: HMD is replaced with desktop PC since this is most widely used.
- 2012 - 2017: Due to the technological development of the HHD, most of the HCDF are focused on HHD as an interface projection platform.

Based on this three periods, we noticed a relation between the development platform and the interface projection platform as shown in Figure 8.

During the first period (2002 - 2007), if the AR application created with the HCDF is going to be viewed on an HMD or a desktop PC, then frequently the development platform was the desktop PC. In the second period (2008 - 2011), the desktop PC stands out both as a development platform and as an interface projection platform.

The apparent lack of use of HHD and web are common in both periods. This changes on the third period (2012 -

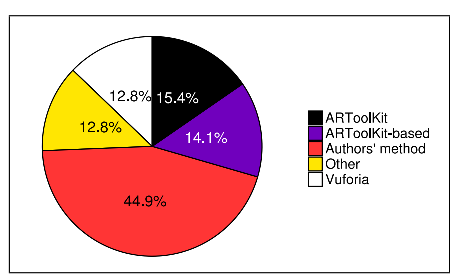

Fig. 5. Distribution of the AR programming framework or method

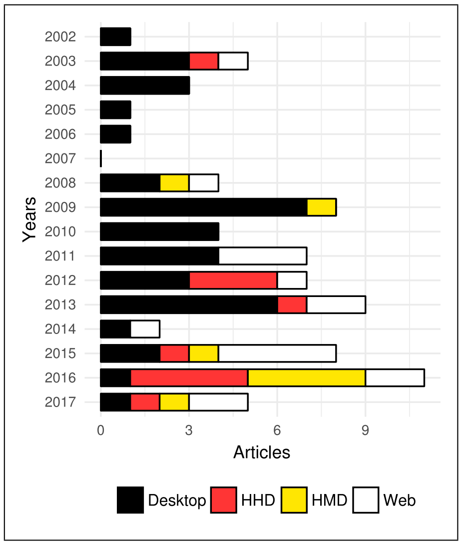

Fig. 6. Development platform by year

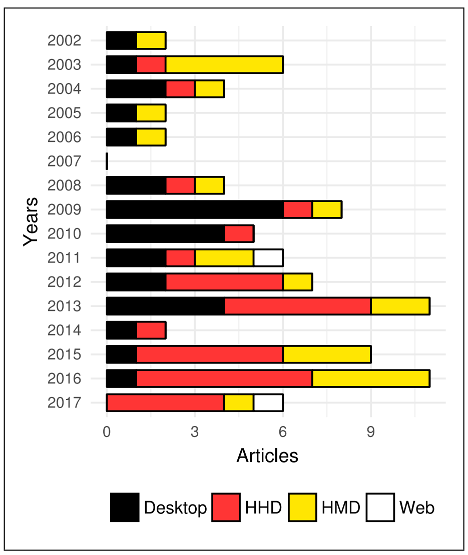

Fig. 7. Interface projection platform by year

2017), the web and the HHD are the development platform and interface projection platform most used, respectively.

Table VII and Table VIII from Appendix B show the articles classified by development platform and interface projection platform.

C. Authoring User Interface (RQ3)

The most common authoring user interfaces are 2D and Non-immersive 3D (see Figure 9). There is an increasing interest in immersive 3D user interfaces, though there is not any work related to them during the first period. Such an immersive experience is obtained by using HMD. Table IX from Appendix B shows the articles classified by user interface.

D. Classification by general models (RQ4)

According to Figure 10, we can confirm the conclusions of [5], model 2: Stand-alone + PI is the most used. We could

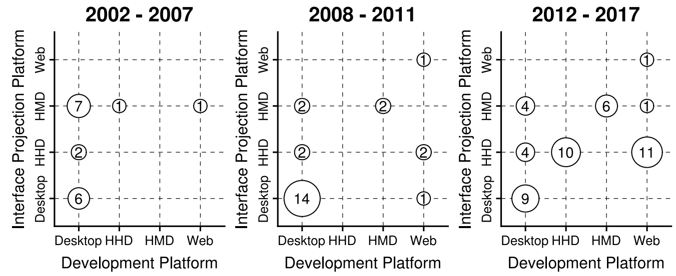

Fig. 8. Development platform and interface projection platform for three periods

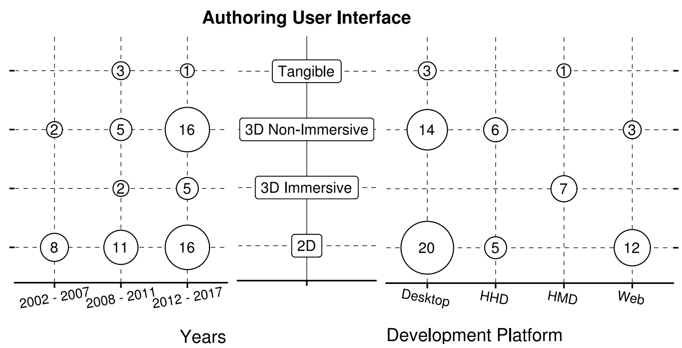

Fig. 9. Mapping showing the distribution of the authoring user interface during three periods depending on the development platform

not find any HCDF that fits the description of the model 1: Stand-alone + PS.

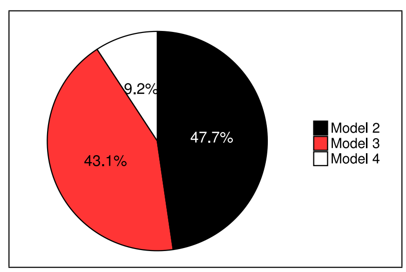

Fig. 10. Distribution of general models proposed by [5]

Another issue to consider is the platforms used by each model (see Figure 11). The development platform most used with model 2 are the desktops PCs and the web. Also, the interface projection platform most used with model 2 is the HHD, even though this model supports platform independence (it can be extended to support other platforms).

Table X from Appendix B shows the articles classified by the general models.

E. Domain of application (RQ5)

Nearly to 59% of HCDF are designed for a specific domain (see Figure 12). The most common fields of application are education and maintenance/assembly, but it is also possible to use HCDF in game development, urban planning [8], military [9], [10] or cultural heritage [11].

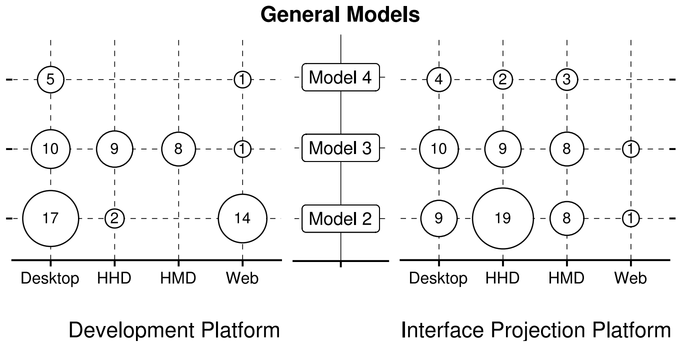

Fig. 11. Mapping showing the general models distribution depending on the development platform and the interface projection platform

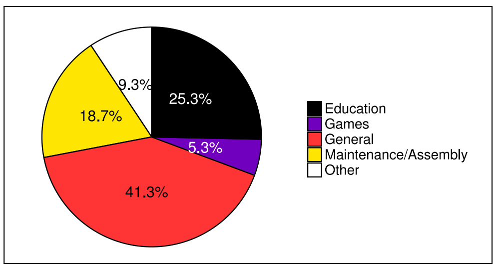

Fig. 12. Domain distribution

In the maintenance/assembly field, it is preferred the desktop PCs as a development platform because the experts are already familiar with it, and as an interface projection platform, it is preferred the HMD because it offers freedom of movement to the maintenance staff to perform their tasks.

On the other hand, in the education field, there are not many HMD available, so it is preferred widely used platforms such as the desktop PCs or HHD (see Figure 13).

Table XI from Appendix B shows the articles classified by domain.

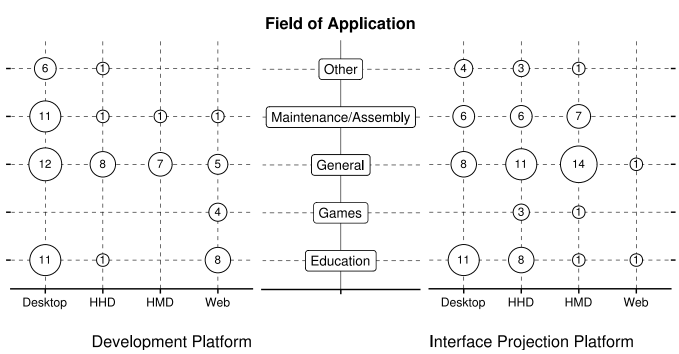

Fig. 13. Mapping showing the domain distribution depending on the development platform and the interface projection platform

F. Validation method (RQ6)

There is not a general approach to validate the HCDF. Since what matters is the value to end-users, we recommend to validate them with a usability evaluation. Most of the articles offer more details of the development stage than the validation stage as can be seen in Figure 14.

The articles that detailed the validation stage agreed to the validation method: it needs to be related to the end-users, whether it is assessed with a formal method or an empirical method. It is not practical to assess them using a technical evaluation.

Table XII from Appendix B shows the articles classified by validation method.

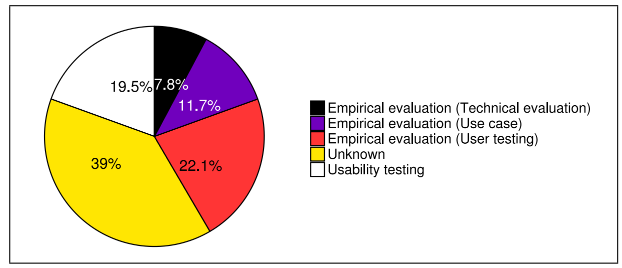

Fig. 14. Validation method distribution

V. Conclusions

This work carried out a systematic mapping study on the HCDF. Through this study, we could identify the following challenges for the future which are closely related to the proposed research questions RQ2, RQ3 and RQ6:

RQ2. Part of the increasing trending on HCDF is because AR programming frameworks allow *HCDF developer* to focus only on developing new interactions and not to worry about low-level procedures. As we said, the web stands out as a development platform, but not as an interface projection platform. One of the advantages of the web is the massively use. If an HCDF is developed with the web as a target, then we can bring AR applications nearly everywhere.

RQ3. 3D immersive user interfaces are a hot topic, not well explored and needs more research. These allow to creating AR content through a WYSIWYG editor as seen in the related articles in Table IX.

RQ6. We can not evaluate and compare all HCDF under the same criteria due to the difficulty of defining common testing tasks for end-users. However, it can be defined common tasks to HCDF with the same authoring user interface (2D, non-immersive 3D, tangible, immersive 3D). This way, we can finally compare HCDF as [12] did. There is a need for usability evaluation standards for HCDF.

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APPENDIX A
LIST OF ARTICLES INCLUDED AND EXCLUDED IN THE SYSTEMATIC MAPPING OF LITERATURE

Our selected primary studies are [8]–[81]. We excluded the following articles by the quality evaluation: [82]–[85].

APPENDIX B
DETAILED RESULTS OF DATA EXTRACTION

TABLE V
AR PROGRAMMING FRAMEWORK OR METHOD

Value	**Articles**
ARToolKit	[9], [16], [18], [19], [27], [28], [35]–[37], [49], [52], [66]
ARToolKit-based	[8], [17], [24]–[26], [30], [33], [39], [41], [46], [71]
Vuforia	[49], [54], [55], [65], [68], [69], [72], [73], [78], [80]
Authors' method	[10], [12]–[15], [20], [21], [23], [29], [31], [32], [34], [38], [40], [43]–[45], [47], [48], [50]–[53], [56]–[60], [62], [67], [70], [74]–[76], [79]
Other	[11], [22], [39], [42], [61], [63]–[65], [77], [81]

TABLE VI
AR TRACKING METHOD

Value	**Articles**
Marker-based	[8], [9], [12], [13], [16]–[19], [22], [24]–[28], [30], [32], [33], [35]–[37], [39], [41], [44]–[46], [49], [51]–[55], [57]–[62], [64]–[69], [71]–[75], [77], [78], [80]
Feature-based	[29], [34], [42], [47], [48], [52], [56], [63], [70]
Location-based	[10], [14], [15], [38], [42], [43], [50], [79]
Other	[20], [23], [31], [40], [76], [81]

TABLE VII
DEVELOPMENT PLATFORM

Value	**Articles**
Desktop PC	[8]–[11], [13], [15]–[22], [24], [26], [27], [29]–[37], [39], [40], [44], [46], [49], [51]–[54], [56], [58], [60], [66], [71], [78]
HHD	[14], [42], [43], [45], [55], [65], [68], [70], [73], [75], [80]
HMD	[12], [23], [28], [62], [72], [74], [76], [81]
Web	[14], [25], [37], [38], [41], [47], [48], [50], [57], [59], [61], [63], [64], [67], [69], [77], [79]

TABLE VIII
INTERFACE PROJECTION PLATFORM

Value	**Articles**
Desktop PC	[8], [9], [13], [16], [18], [19], [21], [22], [24], [26], [27], [29]–[37], [44], [46], [51]–[53], [56], [58], [60], [71]
HHD	[11], [17], [20], [25], [34], [38], [42], [43], [45], [47]–[50], [54], [55], [57], [60], [61], [63]–[65], [67]–[70], [73], [75], [77]–[80]
HMD	[10], [12]–[17], [19], [21]–[23], [28], [39], [40], [52], [56], [59], [62], [66], [72], [74], [76], [81]
Web	[41], [77]

TABLE IX
AUTHORING USER INTERFACE

Value	**Articles**
2D	[11], [13], [14], [16], [18]–[22], [26], [29]–[31], [36]–[41], [46], [47], [50], [53], [57]–[59], [61], [64], [66], [68]–[70], [73], [75], [79]
Non-immersive 3D	[8], [15], [17], [24], [27], [32], [34], [42]–[45], [48], [49], [51], [52], [55], [56], [60], [65], [67], [71], [77], [80]
Tangible	[9], [33], [35], [62]
Immersive 3D	[12], [23], [28], [72], [74], [76], [81]

TABLE X
GENERAL MODELS

Value	**Articles**
Model 2: Stand-Alone + PI	[10], [11], [13]–[15], [17], [18], [21], [25], [29], [32], [36]–[38], [42], [47]–[50], [52], [54], [57], [60], [61], [63], [64], [66], [67], [77]–[79]
Model 3: All in one	[8], [9], [12], [23], [24], [26]–[28], [30], [31], [33], [35], [41], [43], [45], [55], [58], [62], [65], [68], [70], [72]–[76], [80], [81]
Model 4: Plug-in + PI	[19], [22], [34], [40], [44], [69]

TABLE XI
DOMAIN

Value	**Articles**
Education	[27], [29]–[31], [33], [35]–[37], [43], [51], [53], [57], [59]–[61], [64], [67], [69], [77]
Maintenance/Assembly	[13], [17], [21], [32], [49], [52], [54], [56], [62], [63], [66], [70], [71], [78]
Games	[25], [38], [59], [79]
Other	[8]–[11], [26], [34], [80]
General	[12], [14]–[16], [18]–[20], [22]–[24], [28], [39]–[42], [44]–[48], [50], [55], [58], [65], [68], [72]–[76], [81]

TABLE XII
VALIDATION METHOD

Value	**Articles**
Usability evaluation	[12], [16], [28], [35], [49], [52], [58], [61], [63], [65], [72], [74], [75], [78], [79]
Empirical evaluation (User testing)	[8], [15], [19], [23], [30], [33], [36], [37], [41]–[43], [46], [51], [61], [62], [66], [69]
Empirical evaluation (Use case)	[21], [22], [25], [26], [38], [44], [50], [59], [67]
Empirical evaluation (Technical evaluation)	[31], [34], [39], [46], [47], [49]
Unknown	[9]–[11], [13], [14], [17], [18], [20], [24], [27], [29], [32], [40], [45], [48], [53]–[57], [60], [64], [68], [70], [71], [73], [76], [77], [80], [81]