Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

User Experience of Augmented Reality Applications for Future Studies: A Thematic Review

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ABSTRACT

Augmented reality (AR) is the most remarkable interactive media version that integrates the latest media technology. Nevertheless, this technology is associated with several problems such as erratic lighting, which jeopardises the users' experience. Thus, this study aims to investigate the pattern and trends of user experience of AR applications for future research. Relevant articles retrieved from two databases (Scopus and Science Direct) were subjected to qualitative data analyses to identify the patterns and trends of users' experience of AR applications using Thematic Analysis. Overall, 24 articles were included in the final analysis. Results reflected users have a better user experience after using the AR applications. AR applications assisted users in understanding abstract and complex concepts while satisfying and encouraging users' interest in an object or a subject. The use of AR application was easy to learn, easy to use, interesting, and perceived to be useful. Future researchers can refer to the pattern analysis presented in this review, particularly in terms of users and the context of use. Users' perspectives need to be considered for the development of AR applications in the future to facilitate better user experience.

Keywords:
User experience; augmented reality; AR application; thematic review

1. Introduction

Augmented reality (AR) is currently experiencing widespread popularity. AR represents a significant advancement in interactive media, incorporating the latest technological innovations [1]. AR also is a variation of Virtual Environments (VE), or Virtual Reality (VR). The user can use AR to view the real world with virtual objects superimposed or blended into. Over the past few years, AR has drawn more attention and changed how people interact with technology [1]. For example, AR allows mobile devices to create compelling user experiences by overlaying digital information on real-world situations, thus AR application has the potential to capture the user's attention through their immersive environment [1]. It is estimated that there will be 1.7 billion mobile AR users worldwide by 2024 [2], thereby reflecting the growing usage of AR technology. AR is now a popular innovative

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https://doi.org/10.37934/araset.60.2.91102

method in various fields, such as manufacturing, industry, and academia. As a result, several AR-related studies have been conducted by researchers from various fields.

AR can be defined as a system that combines the real and virtual worlds, real-time interaction, and 3D models of virtual and real objects, which consists of the main components such as displays, input and tracking systems, and computers [3]. AR interaction technology is remarkably advantageous in the fields of education, healthcare, industry, office, and other scenarios [4]. The main types of displays for AR technology are head-mounted, handheld, and spatial. The concept of AR application can be related to real-time interactive environments, which combine real and virtual properties, and allow users to see objects in three dimensions [5]. Despite the numerous advantages of using AR technology in everyday life, there are still limitations when using the technology, which may result in a poor user experience.

User experience (UX) can be defined as all user interactions with an organisation's services and goods [6]. UX are the subjective experiences, attitudes, emotional reactions, and cognitive behaviours of users when they interact with products and services [7, 8]. It is one of the components of satisfaction felt by the users after interacting with the product or application [9]. Thus, the concept of UX needs to be understood to measure UX for the product or system and could achieve the user needs and expectations with efficiency [9].

The issue associated with using AR is the low knowledge of how to use the technology, as well as the low acceptance or adoption rate due to the lack of interaction and unfamiliarity with the technology [10, 11]. Siddiqui *et al.,* [12] also highlighted issues relating to AR or VR experience such as limited cost-effectiveness, in-depth design, technological evolution, and user acceptance. Among the pain points of using AR applications are poor user experience of the technology, lack of real feedback, and interaction of emotions by the users [4]. For example, users face the issue regarding unstable light conditions using AR applications in cultural heritage which jeopardizes users' experience [13]. Moreover, the potential for using AR or VR is endless and limited by human imagination [14]. Therefore, this review aims to investigate the patterns and trends of user experience of AR applications to provide guidelines for better experiences in the future. The research questions (RQ) addressed in this article are as follows:

RQ 1: What are the patterns of user experience of AR applications as reviewed in the literature for future studies?

The contribution of this study is the analysis of the UX of AR applications which is identifying patterns and trends from 2017 to 2023. This article is organised as follows: Section 2 presents the methodology of the study, Section 3 discusses the results and discussion in terms of quantitative and qualitative analysis, and Section 4 provides the conclusion and future work.

2. Methodology

Many methods are used to analyse the previous works of literature for example a systematic literature review using the PRISMA protocol [15]. This article employed a thematic review (Figure 1). A term that entails applying thematic analysis procedures in a literature review using the ATLAS.ti tool [16]. Thematic analysis is a process to identify the pattern and recognise the themes (construct) of a specific subject [17]. This research was also conducted to analyse and interpret the findings, as well as provide recommendations for future research on user experience and AR. The selection of previous literature was performed based on the selection criteria presented in Table 1.

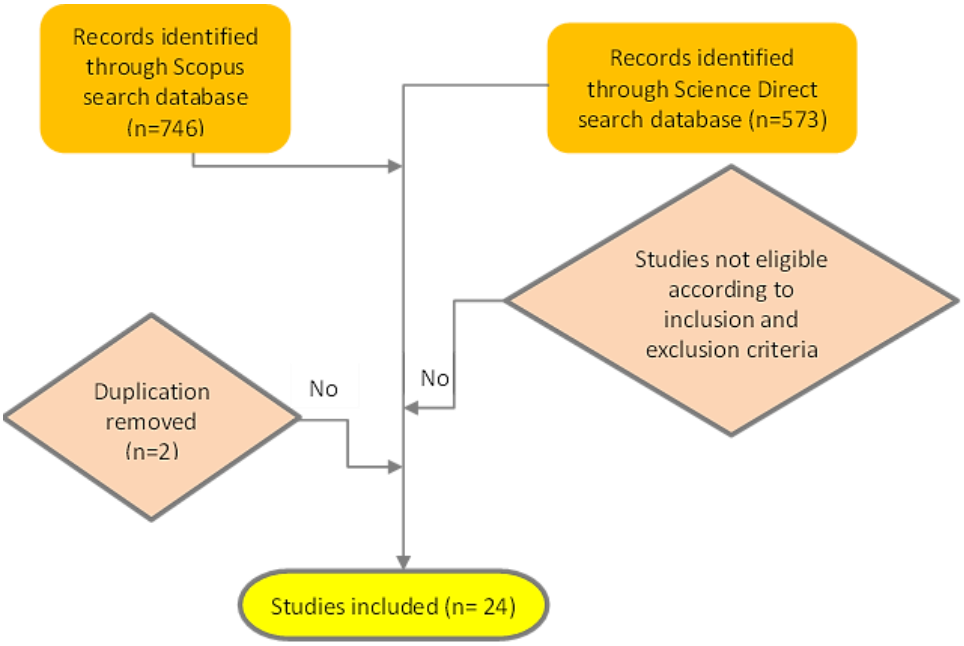

Fig. 1. Inclusion and exclusion criteria in the thematic review

Table 1
Inclusion and exclusion criteria adapted from previous study [9]

Criteria	Inclusion	Exclusion
Publication timeline	1 Jan 2016-28 Feb 2023.	2015 and before.
Document type	Article (research journal, conference proceeding).	Chapters in a book, book series, books etc.
Language	English.	Non-English.
Nature of the study	Focused on user experience and related to AR application.	Not focused on user experience and related to AR application.

Based on Table 1, the publication was derived from 2016 until 2023 (from 1 January 2016 – 28 February 2023). The selection criteria for document types were journal articles and conference proceedings, while articles from book series, books and chapters in a book were excluded. Furthermore, the titles, abstracts and keywords of all the articles were reviewed. Only the articles written in English and related to user experience and AR applications were considered. Besides, the researchers also removed articles that were not associated with the keyword of the study.

Relevant articles on the research topic were extracted from the databases using the following keywords: "user experience" AND "augmented reality" OR "AR" AND "application". A total of 746 articles were retrieved from Scopus and 573 from Science Direct articles. However, 1293 articles were removed because they were not focused on user experience and AR applications. In addition, incomplete and inaccessible articles were removed. Upon removing the duplicated articles (2 articles) from the Scopus database, 24 articles were included in the final analysis. The articles were then transferred to ATLAS.ti tool as primary documents. Subsequently, the articles were analysed based on the year of publication and discussion patterns for seven years (1 Jan 2016 - 28th Feb 2023). The findings are presented in two parts: quantitative and qualitative results.

3. Results

3.1 Quantitative Analysis

This section discusses the results obtained upon analysing the quantitative data on user experience and AR applications.

As shown in Table 2, there is an upward trend in the publications related to UX and AR applications in countries such as China and Malaysia. Moreover, other countries share the same number of publications included Italy, Indonesia and Germany. The trends of publication in many countries depict that UX and AR application has received remarkable attention among researchers. This situation can be seen in the related publications from countries such as Greece, UK, Saudi Arabia, Poland, Turkey, Paris, Taiwan, Spain, Morocco, Columbia, Finland, Sweden, Greece, Peru and Denmark.

Table 2
Number of publications from 2016-2023 based on countries

Countries name	2016	2017	2018	2019	2020	2021	2022	2023	Total
Greece							1		1
China							2	1	3
UK							1		1
Saudi Arabia							1		1
Malaysia		1				1	1		3
Italy							2		2
Poland							1		1
Turkey			1						1
Paris							1		1
Taiwan							1		1
Spain				1					1
Morocco								1	1
Indonesia			1		1				2
Columbia							1		1
Finland			1						1
Sweden			1						1
Germany							2		2
Peru							1		1
Denmark							1		1

Table 3 presents the publishing trend of the articles that focused on user experience of AR applications in 2016. However, AR-related publications began to be conducted in 2017 and continued to increase until 2022. Meanwhile, only found two publications were published in 2023, which is as a result of the literature search process to retrieve studies published until February 2023.

Table 3
Journal for study review

Journal Name	2016	2017	2018	2019	2020	2021	2022	2023
Cognitive Systems Research								1
International Journal of Electrical and Computer Engineering								1
International Journal of Advanced Computer Science and Applications							2	
Heritage							1	
Journal of Computing and Information Science in Engineering							1	

Table 3. Continued
Journal for study review

Journal Name	2016	2017	2018	2019	2020	2021	2022	2023
Proceedings of the Nordic Human-Computer Interaction Conference							1	
IEEE Access							1	
Proceedings of the International Conference on Internet and E-Business							1	
Multimedia Tools and Applications							1	
Journal of Sensors							1	
Proceedings of 8th International Conference of the Immersive Learning Research Network							1	
Frontiers in Virtual Reality							1	
Proceedings of the ACM on Human-Computer Interaction Information							1	
Information							2	
Proceedings of the International Conference on Web Information Systems and Technologies							1	
The International Journal of Advanced Manufacturing Technology						1		
Bulletin of Electrical Engineering and Informatics					1			
Virtual Reality				1				
Procedia Computer Science			1					
Computers			1					
International Journal of Instruction			1					
International Journal on Advance Science Engineering Information Technology		1						
Total	0	1	3	1	1	1	15	2

3.2 Qualitative Analysis

This section discusses the research question highlighted in Section 1*: What are the patterns of user experience of AR applications as reviewed in the literature for future studies?* The qualitative findings in this study were extracted from ATLAS.ti tool and presented based on two UX perspectives: users and context of use.

3.2.1 UX perspective in terms of users

Perspective is the main element that is used to build the definition of user experience and it assists in identifying those or an individual who has been affected by the changes in UX [18]. UX perspectives can be divided into four namely organisation, users, the context of use, and product [18]. The detailed description of UX perspective are presented as follows:

i. Organisation: An organisation's goal is to provide valuable products for the users.
ii. User: The users look for a valuable and suitable use of the product.
iii. The context of use: This serves as the intermediary link between an organisation and users, it impacts both elements.
iv. Product: Focusing on how to design the product and improve the user experience.

Therefore, this study focused and discussed the UX of AR applications based on the users' and the context of use perspectives [18]. As shown in Figure 2, the researchers' categorised the UX perspectives of AR applications in terms of the user's side into positive and negative. The users demand for the product that they can use and are valuable to them. The findings revealed that the UX of AR applications can improve users' experience [19, 20]. The users also have a better user experience after using the AR applications, such as AR applications for Cultural Heritage in Archaeological Museums [21], AR Applications for the 1st, 5th, and 6th Grade of Primary School [2], and machine-learning based AR for learning applications [22].

AR applications assist the users to understand the abstract concepts in the classrooms regarding the layout design [23]. The finding shows that AR applications assist students to understand complex concepts, thus improving their efficiency in education learning [22]. This study also revealed that the users feel engaged in the experience with the products such as using HoloLens with a virtual interface design and acceptability of sensory experience [3]. The users do not need to use the user manual of the product when using the AR application, such as those employed for online shopping processes [24]. However, engagement with the AR application is a crucial learning component given its significant impact on the learner's motivation to keep interacting with a system and the course material [3].

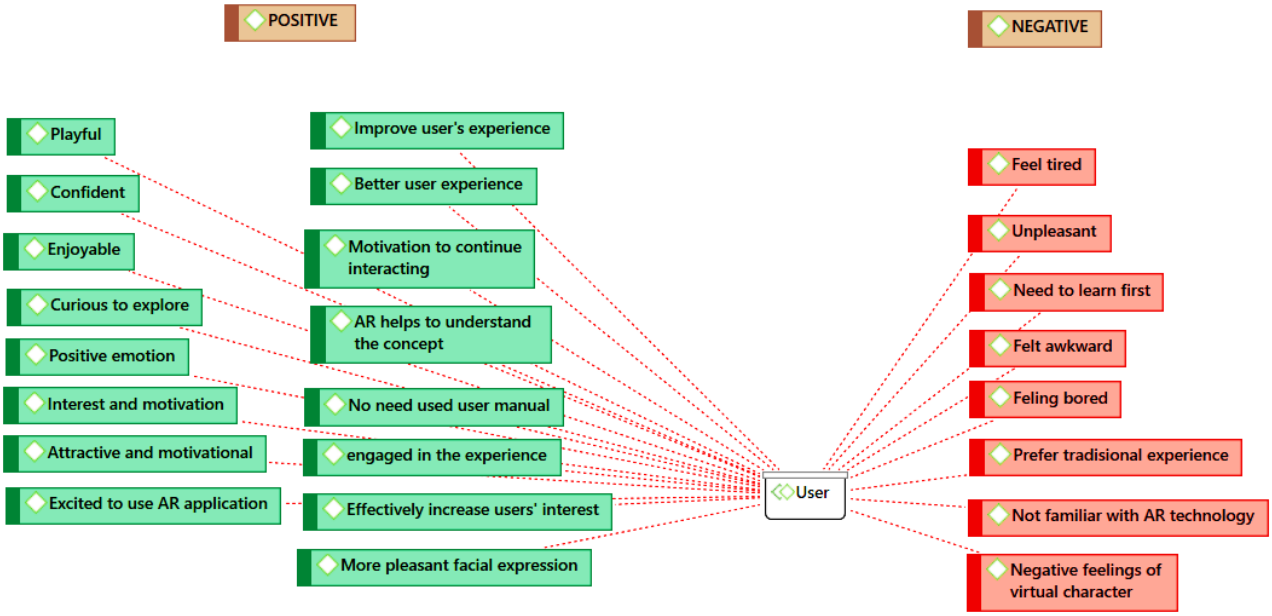

Fig. 2. UX perspective in terms of 'user'

On the other hand, Gan *et al.,* [25] reported that the analysis shows that the use of AR applications such as AR Intelligent Virtual Agents (IVAs) on smartphones with more pleasant facial expressions can increase users' interest and motivation. Besides, the positive side for users when using AR products is the fun, and feeling playful [2, 26], enjoyable [27], confident [2, 27], and curious to explore new things [3]. In addition, Volioti *et al.,* [2] stated that AR applications in education are attractive and motivational for learning. As a result, all teachers, including those with lower computer literacy levels, expressed interest in AR technology and willingness to integrate it as a supporting tool in teaching processes. Thus, AR technology makes users excited to use a product and concurrently encourages them to develop positive emotions toward the use of AR applications [2].

While UX perspective in terms of users' negative side revealed that users feel tired after using the AR/VR systems due to the artificial visual movements [12] and unpleasant experiences when using

mobile AR applications [28]. The users need to learn first before they can use it since this AR technology is still very new to most people [29]. The investigation from this analysis also revealed that several participants feel awkward [3] and bored while using the AR applications [25, 28]. This situation occurs because the users cannot absorb information about a display and are easily distracted. Moreover, the current study reflects that users who are not familiar with AR technology [2], have unpleasant experiences. The work by Siddiqui *et al.,* [12] mentioned that people still prefer the real traditional experience rather than virtual experiences for example using Virtual Tourism and Digital Heritage applications which used VR/AR technologies. Furthermore, the finding shows that the user tends to have negative feelings when interacting with virtual characters of AR applications [3]. Therefore, this study concludes that the UX of AR applications could be categorised into positive and negative sides. The positive user experience outweighs the negative experience for users of AR technology. However, it cannot be denied that AR technology is able to improve the user experience for the better if used for a certain period. Therefore, improvements in user experience are necessary for the effectiveness of a product or platform used [30].

3.2.2 UX perspective in terms of the context of use

This section also discussed UX of AR applications but in terms of 'the context of use' from literature. As mentioned earlier, UX perspectives in terms of 'the context of use' which the intermediary link between organisation and user and has an impact on both elements. Based on Figure 3 below, thirteen categories are related to 'the context of use" for AR applications. When an organisation develops a product or system with AR technology, then it is able to have an impact on the users who use it. The findings revealed that the usage of AR applications by the users made them become more satisfied for example, using AR games in the domain of Geography [2]. With the developed AR games, it helps the school to encourage students' interest in the subject as well as the students' academic improvement. When users are satisfied using a product or system with AR technology, it also gives satisfaction to an organization. Moreover, if the user has an enjoyable experience with the product, then the user experience becomes better [31]. However, the level of user knowledge using new technology applications may provide insufficient UX to users who do not have prior knowledge [11]. The user emotion may influence the user satisfaction of the products [1].

The findings also revealed that the use of AR applications is easy to learn [2], easy to use [2,24, 29], the interaction feedback of AR was interesting [3], and perceived usefulness [32]. For instance, the users perceived usefulness of using game-based learning and AR to support and enhance their learning experiences in educational institutions. The usage of AR applications in teaching Physics can facilitate students without requiring any technical support [2]. On the other hand, the analysis revealed that the users have high acceptance and positive user experience when using the AR of mobile applications [33]. Therefore, the use of AR technology in any field is not only beneficial to users but also to an organization, for example having an impact in terms of student academic improvement. The current study also revealed that users are willing to use the product or system more frequently that has AR technology [2]. Thus, animation technology and VR are related to each other [34]. Technology-based digital learning also enables student learning to be more effective [35].

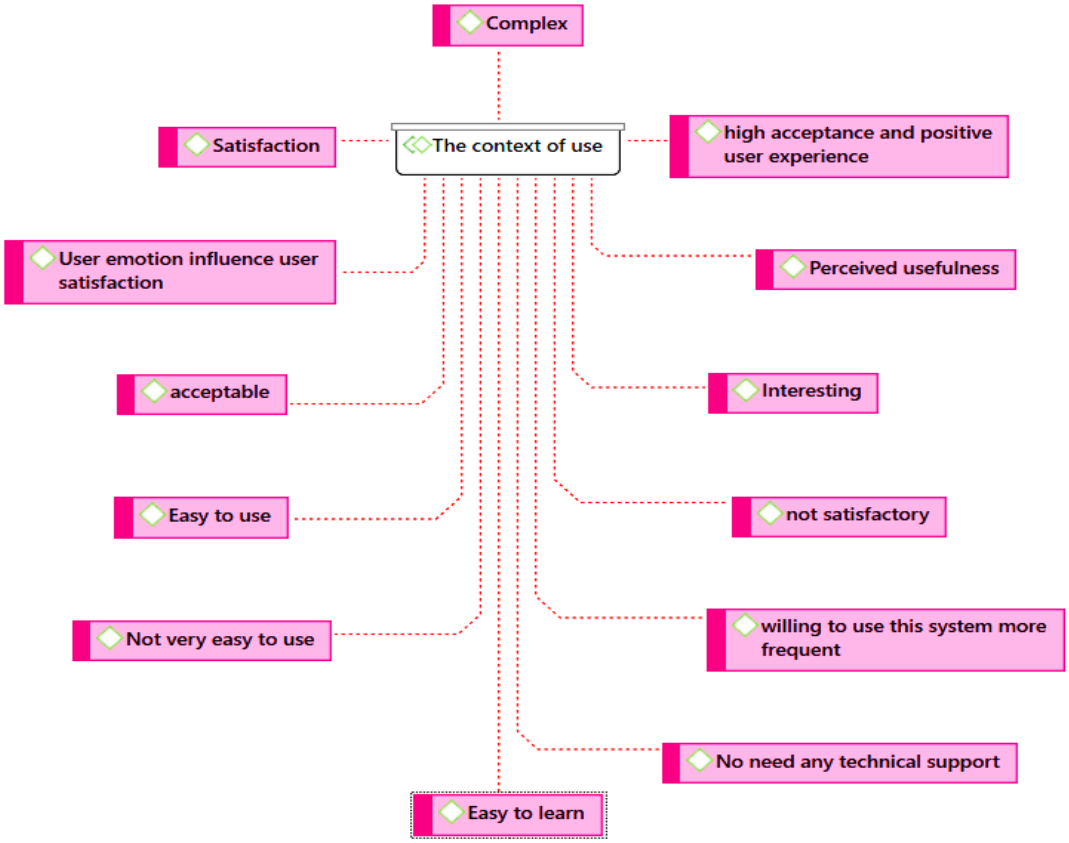

Fig. 3. UX perspectives in terms of "the context of use"

Nevertheless, Volioti *et al.,* [2] stated there are several users who find AR applications complex and not very easy to use. This situation occurs due to students not having a suitable space to use AR applications. Besides, the users also find it difficult to use the AR application if they have to simultaneously use two QR codes. The analysis revealed that several users are not satisfied with AR narrative, for example using HoloLens with a virtual interface design [3]. This might be due to the mismatch of virtuality and reality experiences. However, the use of AR applications using HoloLens is still acceptable to users [3]. Therefore, a suitable space should be considered for the use of AR applications and requires a match between the virtual experience and reality so that a positive UX can be enhanced.

Therefore, based on the analysis that has been conducted, the types of AR applications from the literature can be categorised into terms of AR learning apps, AR/VR systems, machine learning-based AR, and AR game-based learning. There is a need to study the user experience on specific types of AR applications that can be used for future AR application development and future studies by researchers. Additionally, future researchers can use bibliometric analysis to identify user experience patterns of AR applications because the analysis is displayed graphically [36]. The findings summary for future AR application development and studies is illustrated in Figure 4 below.

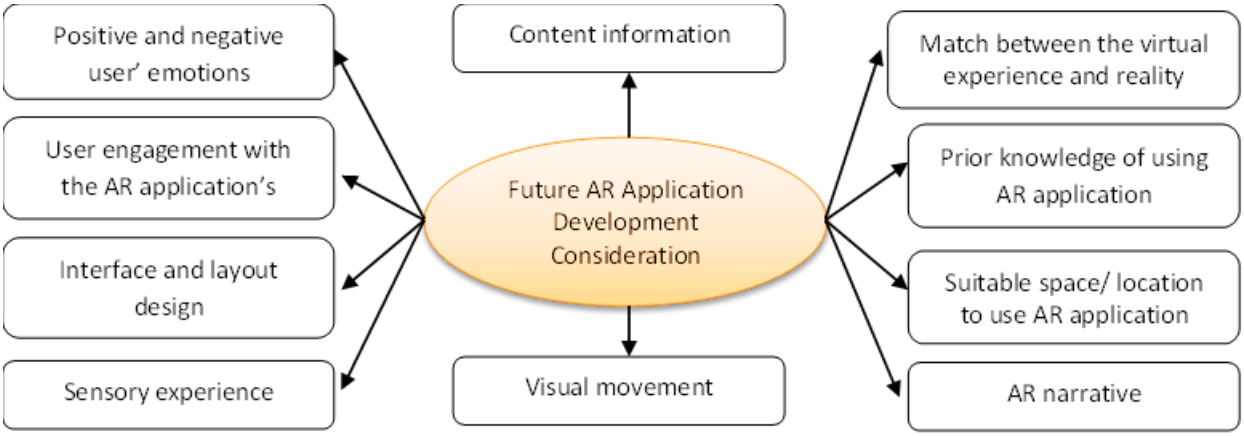

Fig. 4. Future AR applications development consideration

4. Conclusions and Future Work

This article reviewed the user experience of AR applications from past literature. The results discussed the UX perspective in terms of 'users' and 'the context of use' which refers to the UX definition from the previous study [18]. The result on UX perspectives in terms of 'users' were categorised into positive and negative sides. The UX of using AR applications can be improved after the usage of the products [19, 20]. Moreover, the use of AR applications in life also could increase users' interest and motivation [25]. Conversely, the UX perspective in terms of users from the negative side is the users feel tired after using the AR/VR systems due to the artificial visual movements [12] and have unpleasant experiences [28]. While the result of UX perspectives in terms of 'the context of use' revealed that the user is satisfied with the use of AR applications. The study also found that the use of AR applications by the users are easy to learn [2], easy to use [2, 24, 29] interesting [3], and perceived usefulness [32]. Furthermore, the users have high acceptance and positive user experience when using AR technology [33]. In addition, the experience of users also could be one of the measurement dimensions of learning.

Therefore, this paper has contributed to the analysis of the UX of AR applications by identifying patterns and trends from 2017 to 2023 which can be used by practitioners and future researchers. However, based on the findings of this study, it can be concluded that there is still a huge research gap where there is a lack of detailed discussion in previous studies related to the UX perspective that has an impact on organizations and industries. As the articles retrieved within 8 years back are limited (24 publications) and the publications started actively from 2022, it shows a limitation in the sources of this study. Future research should consider studies that discuss guidelines for designing products or systems with AR technology so that the user experience becomes better. Designers must consider all facets of technology, experience, and innovative applications to improve user stickiness and personalized experiences [4]. Besides, future studies can also use the application of the Fuzzy Delphi Method (FDM) to determine the important dimensions of user experience using AR applications [37, 38].

Acknowledgment

This research was supported by the Ministry of Higher Education (MoHE) of Malaysia through the Fundamental Research Grant Scheme (FRGS/1/2019/ICT01/UUM/02/4). The authors would also like to thank the Department of Polytechnic and Community Colleges Education (Hadiah Latihan Persekutuan) and Politeknik Balik Pulau, Penang for their support.

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