Indonesian Journal of Electrical Engineering and Computer Science
Vol. 39, No. 2, August 2025, pp. 1109~1120
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v39.i2.pp1109-1120

Systematic literature review of learning model using augmented reality for generation Z in higher education

Zulfachmi[1], Normala Rahim[2], Wan Rizhan[2], Puji Rahayu[3], Aggry Saputra[1]
[1]Department of Informatics Engineering, Sekolah Tinggi Teknologi Indonesia Tanjung Pinang, Tanjungpinang, Indonesia
[2]Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, Besut, Malaysia
[3]Faculty of Computer Science, Universitas Mercu Buana, Jakarta, Indonesia

Article Info

Article history:

Received Oct 7, 2024
Revised Mar 21, 2025
Accepted Jul 2, 2025

Keywords:

Augmented reality
Generation Z
Higher education
Learning model
Systematic literature review

ABSTRACT

Higher education is evolving with innovations aimed at enhancing the quality of learning, and one prominent innovation is the integration of augmented reality (AR) technology into the learning process. AR merges real-world and virtual elements in real-time, creating interactive and immersive educational experiences. This technology supports the display and interaction with virtual objects, enhancing engagement and comprehension among students. However, effective integration of AR in higher education faces challenges such as limited technological infrastructure, the need for skilled lecturers, and the adaptation of teaching methods to suit generation Z's learning preferences. Despite their technological proficiency, many educational institutions struggle to optimally implement innovations like AR. This systematic literature review aims to explore and identify an AR-based learning model suitable for generation Z in higher education. Findings suggest that AR technology can significantly enhance learning by offering engaging visualizations and interactive experiences, aligning well with generation Z's characteristics and learning styles. Effective AR implementation requires suitable platforms, such as mobile, desktop, wearable, and projection platforms, each offering unique benefits. By designing AR learning models that cater to generation Z, educational institutions can improve learning outcomes and experiences.

Corresponding Author:

Zulfachmi
Department of Informatics Engineering, Sekolah Tinggi Teknologi Indonesia Tanjung Pinang
29122 Tanjungpinang, Indonesia
Email: fahmi.stti@gmail.com

1. INTRODUCTION

Higher education has undergone a variety of changes and innovations, particularly in efforts to improve the quality of learning. One innovation that is increasingly receiving attention is the use of augmented reality (AR) technology in the learning process [1]. AR is a technology that combines real-world elements with virtual elements in real-time, thereby creating an interactive and captivating learning experience [2]. This technology allows the display and direct interaction of virtual objects like text, images, videos, or three-dimensional (3D) models with the user's physical environment [3]. This creates a learning experience that is not only more interactive and engaging but also more immersive, as students can see, hear, and even interact with educational content in a real-world context [4].

However, despite its potential, the integration of AR into higher education still faces significant challenges. One major issue is how to effectively incorporate this advanced technology into the curriculum, given obstacles such as limited technological infrastructure, the need for specialized lecturers, and the

adaptation of teaching methods to fit the learning characteristics of Gen Z [5]. The willingness of educational institutions to adopt AR and the ability to overcome these obstacles will greatly determine the success of using AR in improving the quality of learning [6].

Born between 1995 and 2010, generation Z or Gen Z has a deep familiarity with digital technology. The learning process in higher education presents a number of primary challenges for Gen Z, including issues with learning engagement and motivation, a preference for interactive and visual learning, the need for technology skills and adaptability to change, the need to balance online and face-to-face learning, and concerns about academic pressure and mental health [7]. Another characteristic of Gen Z is that they tend to require interactive and relevant learning methods to maintain motivation. Despite being proficient in using technology, not all educational institutions are able to utilize it optimally, and adaptation to new innovations such as AR still faces obstacles [8]. Gen Z's learning style is unique in that they prefer interactive, visual, and technology-based learning methods. As a result, the use of AR technology in higher education has become relevant and has the potential to meet the learning needs of this generation [9].

Despite the growing body of research on AR in education, several gaps remain in the existing literature. Most studies have focused on the general benefits of AR without specifically investigating its effectiveness for Gen Z students in higher education [10]. While prior research has examined AR-based learning applications, few studies have developed structured and comprehensive AR learning models tailored to Gen Z's unique learning characteristics, which emphasize engagement, interactivity, and digital integration [8]. Although research has explored AR's impact on student engagement and motivation, limited empirical studies have analyzed its effect on cognitive learning outcomes and skill development in higher education settings [11]. Specifically, the role of AR in fostering problem-solving skills, critical thinking, and knowledge retention in Gen Z students remains underexplored.

Prior studies have primarily addressed technical and infrastructural challenges, but there is a lack of research analyzing the readiness of lecturers and institutions in integrating AR into their curriculum [6]. Questions regarding pedagogical adaptation, faculty training, and institutional strategies for AR adoption are still open for investigation. While AR has been widely studied, research on its application across other disciplines in higher education remains limited [12]. Further studies are needed to determine how AR-based learning models can be adapted to various academic fields and effectively implemented to support different learning objectives. The aim of this systematic literature review (SLR) study is to explore and determine a learning model using AR that is suitable for Gen Z in higher education. It is hoped that this research can significantly enhance the quality of learning and offer practical advice to educational institutions on how to effectively implement AR technology.

2. METHOD

The researchers performed a SLR in this investigation. In this review, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement and flow diagram were utilized to facilitate the synthesis of pertinent journal articles. Generally, the process of SLR has three main stages: planning the review, identification, screening, eligibility, and data abstraction, and analysis [13]. These steps had an impact on the methodology used to perform this evaluation and describe the approaches used for data collecting.

2.1. Planning the review

In this section, the author collects a collection of research papers from the Scopus, PubMed, and Web of Science (WoS) databases. Therefore, the author deliberately chose to explore AR learning among Gen Z, especially within the framework of the third level learning model. Appropriate keywords extracted from the title to carry out the review include learning models, AR, Gen Z, and higher education. Next, those keywords are combined using the logical operators "OR" and "AND" to create a search string. This search string is used as a literature search strategy at the definition stage [14]. Table 1 presents the methodology used to conduct the literature search.

The keyword strings and combinations using the PRISMA statement, the next step in this phase is to keep looking for pertinent publications. By compiling pre-existing data from scholarly papers, this step improves the data collection tools [15]. Identification, screening, eligibility, and inclusion are the four phases of the PRISMA selection process [16].

2.2. Identification

The identification stage begins by looking for relevant articles to review. A search was conducted on Scopus, PubMED, and WoS using the keywords listed in Table 1, specifically "learning model" or "learning methods," "augmented reality" or "AR," "generation Z" or "Gen Z," and "higher education" or "education".

The search for this topic yielded 609 results from Scopus, 79 from PubMED, and 27 from WoS [17]. On June 12, 2024, the last search was conducted, and a total of 715 results were filtered. Figure 1 displays the PRISMA protocol flow.

Table 1. Literature search strategy

Keyword	The word strings and their combinations
Learning model	("Learning model" OR "learning methods") AND
AR	("Augmented reality" OR "AR") AND
Gen Z	("Generation Z" OR "Gen Z") AND
Higher education	("Higher education" OR "education")

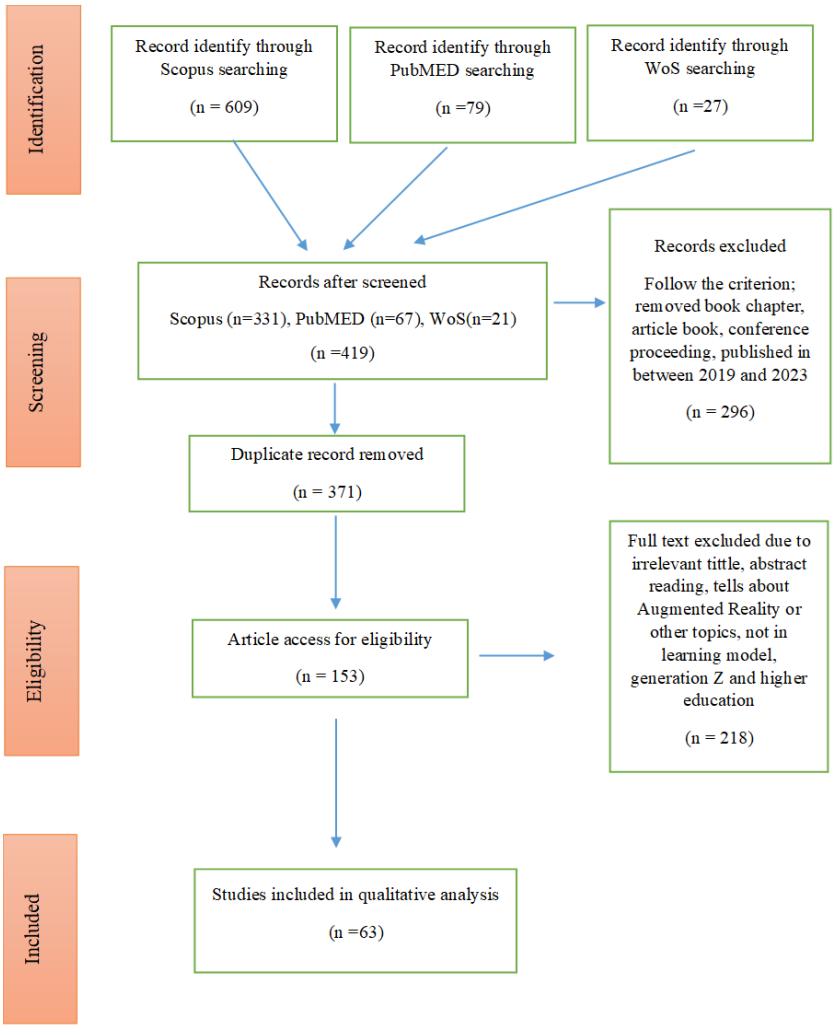

Figure 1. Diagram of the PRISMA flow used in the article selection procedure

2.3. Screening

Sorting data based on article title, year of publication, document type, language, and article accessibility completes the filtering stage. The topic, specifically learning models using AR for Gen Z in higher education, must align with the title of the article. The publication year between 2019 and 2024 to gather relevant and up-to-date studies. The selected document type is only for original research published in scientific journals. Trade journals, magazines, books, newspapers, and conference papers were excluded [18]. The language was set to English to standardize the research, and accessibility was restricted to full-text articles with free access only. The screening process yielded 296 articles unrelated to the research under investigation. In the next stage, eliminate duplication between identification results [19]. A total of 371 duplicate results from other journal database sources were found in the list of search results.

Table 2. Inclusion and exclusion criteria

Requirement	Included	Exclude
Title and substance of the article	Appropriate title that complied with the study's requirements	Irrelevant title and failed to comply with the study's requirements
The publication year	Publications between 2019 and 2024	Publications outside of the designated range
Kind of publication	Only original research and journal article format	Editorials, reviews, and research that lack empirical data
Language	English	Others

2.4. Eligibility

This stage requires the collaboration of all authors to manually verify the information based on the paper abstract. To optimize efficiency and assure comprehensive coverage of our review requirements, the papers were distributed equitably among the authors [20]. Titles that are pertinent, correlated with the subject matter, and appropriate for our intended sample are sought. Subsequently, other criteria that failed to satisfy our review standards were established, including titles that were not pertinent, studies that concentrated on virtual reality instead of AR, research that was unconnected to higher education and learning models, and other factors [21]. During this stage, a total of 153 papers met the criteria for being included in review, as indicated in Figure 1.

2.5. Data abstraction and analysis

Total of 63 studies to include in the previous stage of this systematic literature review, based on our specific criteria for inclusion. These selections are detailed in Table 2. The validity and reliability of studies are contingent upon the calibre of the articles and the rigour of the review techniques. The incorporation criteria and the stringent framework of the PRISMA protocol enhance the quality and dependability of the data, hence mitigating the potential for bias [22]. These specific publications were examined to determine the comprehension of AR, its benefits and drawbacks in the context of education, and to aid authors in analyzing research inquiries for discoveries in the reporting section [23]. This study employs meta-analysis techniques to examine research findings. The meta-analysis approach involves the synthesis and examination of data from multiple studies that have been undertaken on related research issues [24]. Pertinent findings and data from prior studies were compiled to finalize the literature review. Primarily, the acquired data or findings will be utilized to address research inquiries. This review aims to synthesize and integrate information from multiple studies, with the goal of enhancing earlier research. In addition, thematic analysis, a recognized approach for discerning patterns or themes in qualitative data, was utilized [25]. Data were extracted from previously conducted investigations, resulting in a total of 63 articles.

3. RESULTS AND DISCUSSION

3.1. Result

The findings in this section were organized by different years, distinct database sources, and the research designs and subjects that motivated our review and analysis, using a systematic review approach [26]. According to the total number of learning model analysis studies employing AR for Gen Z in higher education published between 2019 and 2024 [27]. The following subsections provide responses to the specified research topics. This section presents the analysis of the data extracted from the studies in accordance with the three defined research questions.

3.1.1. RQ1: what are the characteristics of Gen Z students?

Gen Z students who were born in the mid-1990s to the early 2010s have different characteristics from previous generations. They are digital natives, raised in an era of the internet and advanced technology that defines almost every aspect of their lives [28]. These young people are adept at using smartphones and social media to socialize, find information and learn [29]. Due to being used to fast and immediate information, Gen Z tend to have short attention spans and prefer visual and interactive content. From an educational perspective, flexible and interactive learning methods, such as e-learning and blended learning, are preferred over conventional methods by them [30].

In addition, Gen Z has a high social and environmental awareness, often carrying out activities related to sustainability and social justice [31]. Gen Z also known as a more open and inclusive generation, and have an attitude that is more accepting of diversity. Gen Z students typically seek a balance between academic and personal life and place a high value on mental health and emotional well-being [32]. Collaborative in nature, they often work in teams and prioritize collaboration and extensive networking to achieve their goals [33]. Researchers identified several ways to explore the characteristics of Gen Z students,

as presented in Table 3. Based on the review results from Table 3, there are characteristics of Gen Z, which are presented in Figure 2.

Table 3. Characteristics of Gen Z students

Authors	Statement	Abstraction
Dhinakaran *et al.* [29]	Gen Z exhibits pragmatic, self-reliant, and global perspective as agents of change, along with a strong emphasis on health consciousness. These attributes signify notable shifts in student conduct when compared to earlier generations, resulting in the emergence of a generation gap. These modifications highlight the necessity for adaptations in educational methodologies and intergenerational engagements to cater to the distinct requirements of Gen Z.	Gen Z is realistic, independent, global-minded, change-makers, and health-conscious, which completely changes student behavior and creates a generation gap.
Khalid *et al.* [31]	Gen Z has unique characteristics. The age difference between educators or instructors and Gen Z students can sometimes cause misunderstandings and easily make the students stressed.	Gen Z students are more likely to get stressed easily if their teachers are quite far apart in age.
Hegade and Shettar [32]	Gen Z has early exposure to the internet, possesses a high level of technological proficiency, and maintains a harmonious presence on both social media platforms and traditional media. Gen Z pupils necessitate an educational strategy that prioritizes conceptual design and motivation rather than a straightforward delivery of lessons.	Gen Z students are more comfortable using technology and visuals than conventional learning.
Yu and Suny [30]	Gen Z students exhibit a preference for online communication, adaptable timetables, multimedia materials, and diverse applications. Nevertheless, students from Gen Z are increasingly requesting increased opportunities for immediate and interactive engagement with both their teachers and fellow students.	Gen Z students prefer online communication and use various multimedia applications for learning.
Etheredge and Waliczek [5]	Gen Z students have been acquainted with technological advancements such as the internet, cellphones, personal computers, and laptops from an early age, which has made them highly adept at using technology and proficient in multitasking. I have a preference for blended learning.	Gen Z students have multitasking characteristics and like hybrid learning models

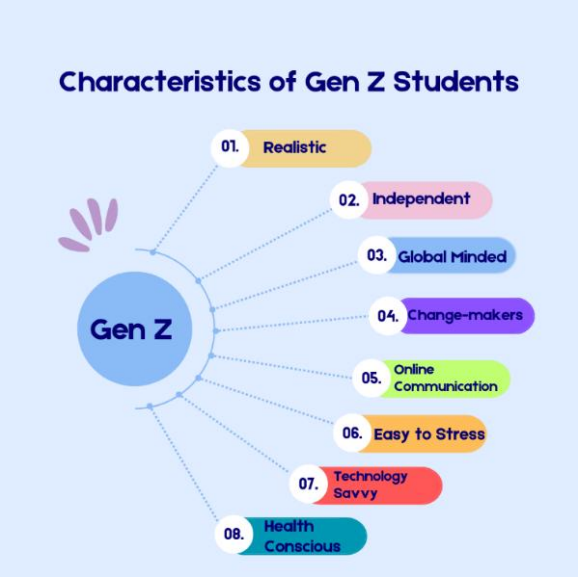

Figure 2. Characteristics of Gen Z students

3.1.2. RQ 2: how does the learning model using AR in higher education relate to Gen Z students?

AR technology has opened up new opportunities in the world of education, especially in higher education [34]. By utilizing AR, students can see three-dimensional visualizations of concepts that are difficult to understand only through text or static images [35]. In addition, AR supports rapid and flexible learning, in line with Gen Z's need for flexibility in learning, as well as increasing collaboration and communication through virtual environments that support teamwork and joint problem solving [36]. Systematic analysis was carried out on sixty-three (63) selected articles, which resulted in six learning models using AR, namely game-based learning (n=17), collaborative learning (n=12), visual learning (n=21), interactive learning (n=9), contextual learning (n=2), and remote learning (n=2). AR learning models for higher education are presented in Figure 3.

The findings of this study align with existing research on AR in game-based learning, which emphasizes its effectiveness in enhancing students' active participation and understanding of complex concepts through interactive simulations [37]. Similar to previous studies, the implementation of game elements in AR-based learning is observed to significantly increase students' motivation and interest in learning [38]. Furthermore, collaborative learning in an immersive virtual environment has been shown to improve communication and teamwork skills, supporting the findings by Cabero-Almenara *et al.* [39]. The ability of AR to facilitate joint visualization and collaborative problem-solving is consistent with the visualization learning model proposed by Neffati *et al.* [40], which highlights the benefits of three-dimensional and interactive displays in strengthening students' understanding of complex materials. This aligns with research by Halim *et al.* [41], which demonstrates that virtual object manipulation enhances retention and comprehension.

The preference for interactive learning models in higher education as research by Marks and Thomas [42], supports the observation that AR-based learning fosters active student engagement with the subject matter. Additionally, AR enables direct interaction with virtual objects, allowing students to test hypotheses and conduct experiments that may not be feasible in a real-world setting, as noted by Sanderasagran *et al.* [43]. Despite the limited number of studies, the potential of contextual learning models for bridging theoretical knowledge with real-world practice is evident, confirming the conclusions drawn by Chanjaradwichai *et al.* [44]. The ability of AR to immerse students in realistic virtual experiences is also in line with findings by Kamarudin *et al.* [45], which emphasize its role in deepening contextual understanding. Lastly, the implementation of remote learning as discussed by Gupta *et al.* [46], aligns with the growing trend of using technology to enhance accessibility and flexibility in education. Although research in this area remains limited, findings suggest that remote learning serves as an effective solution for overcoming geographical barriers.

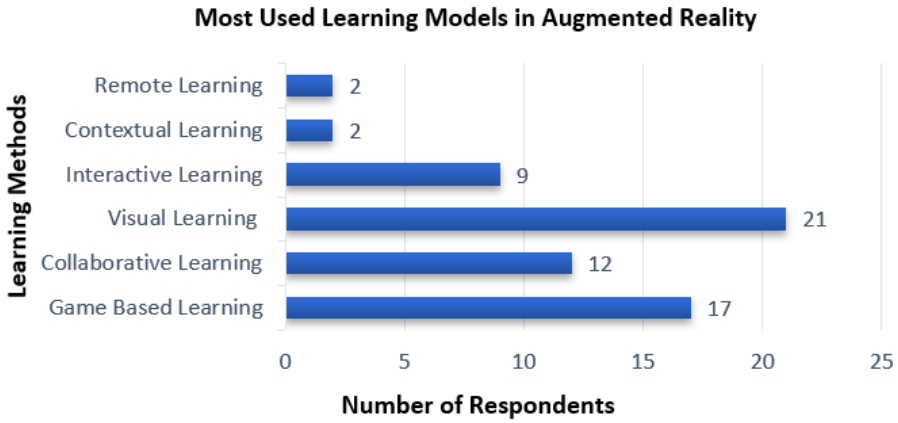

Figure 3. Type of learning using AR

3.1.3. RQ 3: what type of platform is most widely used to support learning models using AR?

The results of this study align with existing research on the use of various tools and platforms in supporting AR-based learning models. Similar to findings by Martin *et al.* [47], this study confirms that both hardware and software play a crucial role in AR implementation. The categorization of AR applications based on device type, as discussed by Lu *at al.* [48] is also reflected in this study, which highlights the prevalence of mobile-based AR (n=45) solutions, followed by wearable devices (n=10), desktops (n=7), and

projection-based AR (n=1). These variations in AR technology align with the findings of Suryani *et al.* [49], who emphasize that each device type has distinct advantages and limitations, making them suitable for specific learning contexts and user needs. Furthermore, the study supports the conclusions of Eldokhny and Drwish [50], demonstrating that a combination of multiple AR platforms enhances the effectiveness of learning models. The integration of these platforms not only improves interactivity but also ensures a more engaging and practical learning experience for students. These findings reinforce the growing recognition that AR, when implemented strategically across different devices, can significantly enhance educational outcomes. From the results of the systematic analysis of the platforms most widely used as learning media using AR can be seen in Figure 4.

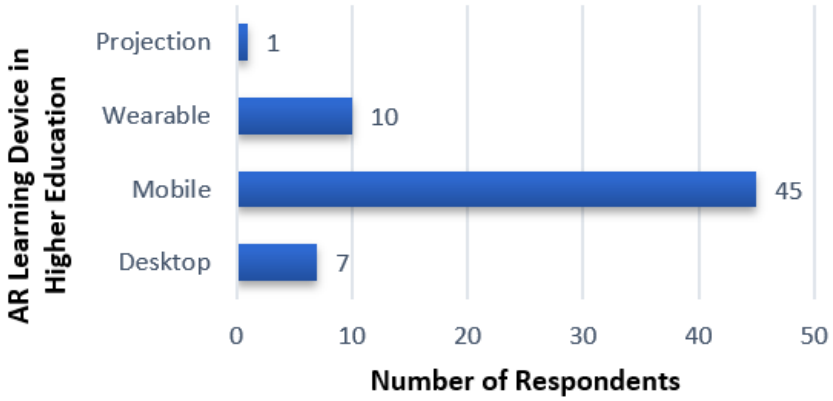

Figure 4. AR learning platform in higher education

3.2. Discussion

Gen Z students, characterized by their realism, independence, global insight, changemaking abilities, online communication skills, technological proficiency, and health consciousness, demonstrate a strong correlation with AR-based learning models in higher education [31]. Given these unique traits, AR presents a significant opportunity to enhance their learning experiences [32]. Specifically, game-based learning, which incorporates game elements to boost engagement and motivation, aligns well with Gen Z's digital familiarity and affinity for interactive experiences [51]. Beyond engagement, AR also fosters collaborative learning, allowing students to work together in immersive virtual environments, thereby strengthening their social and teamwork skills in line with their global mindset and preference for online communication [52].

Building on this, AR's ability to deliver vivid and immersive visualizations enhances comprehension of complex concepts, making it particularly beneficial for students with a practical mindset and strong technological adaptability [53], [54]. The interactive nature of AR further facilitates direct engagement with learning materials, improving both student involvement and conceptual understanding [55]. Additionally, AR supports contextual learning by integrating educational content into real-world settings, reinforcing its significance and practical applications, which is especially advantageous for students with a global perspective and a passion for creating change [56], [57].

In the context of remote learning, AR has the potential to create more immersive and interactive experiences, addressing some of the limitations of conventional distance education while catering to Gen Z's independent nature and digital communication skills [58]. Furthermore, the engaging and dynamic nature of AR can help mitigate student stress, making learning more enjoyable and in line with the generation's tendency to experience high stress levels [59]. By recognizing this alignment, higher education institutions can develop AR-based learning models that cater to Gen Z's specific needs, ultimately improving their overall learning experience [60].

Despite these advantages, several challenges must be addressed to optimize the effectiveness of AR-based learning. Accessibility and affordability remain key concerns, as high-performance AR devices such as headsets and smart glasses may not be widely available to all students [61]. Additionally, successful integration of AR into academic curricula requires educators to develop new teaching strategies, which may be hindered by a lack of technical expertise [62]. Another challenge is cognitive overload while AR enhances engagement, excessive interactivity could overwhelm students and hinder learning rather than support it [53]. Furthermore, the long-term impact of AR-based learning on knowledge retention and student adaptability remains an area that requires further exploration. Future research should focus on developing adaptive AR

learning models that accommodate different learning styles while also providing comprehensive training for educators to facilitate effective implementation.

To ensure smooth and effective adoption, choosing the right AR platform is essential [62]. Mobile platforms are the most widely used due to their accessibility and flexibility [61], [63], yet desktops, wearables, and projection-based AR each contribute to different aspects of the learning experience [64]. Mobile AR, accessible through smartphones and tablets, is the most popular due to its portability and compatibility with various educational applications such as Google Expeditions and AR Flashcards [40], [65]. Meanwhile, desktop-based AR applications, which require high computing power and large screen displays, are commonly developed using tools like Unity3D and Vuforia [66]. Wearable devices, such as Microsoft HoloLens, Google Glass, and Magic Leap, provide highly immersive experiences by projecting 3D content directly into the user's field of view, facilitating hands-on interactive learning [67].

Additionally, projection-based AR, which uses projectors to display AR elements onto physical surfaces, is particularly useful for classroom demonstrations and laboratory experiments [68]. Although mobile AR is the most widely used due to its flexibility, each platform whether desktop, wearable, or projection-based plays an important role depending on the educational context. However, despite the advantages of these platforms, challenges such as internet connectivity issues, device compatibility, and user adaptability must be addressed to ensure AR's successful implementation in remote learning environments [58]. While AR can enhance learning engagement and reduce stress, its potential drawbacks, including screen fatigue and digital dependency, require further investigation [59].

Future research should explore hybrid learning models that integrate AR with traditional face-to-face instruction to maximize learning outcomes. Additionally, further studies are needed to assess the effectiveness of different AR platforms mobile, desktop, wearable, and projection in enhancing student engagement and comprehension. By addressing these challenges, AR can be more effectively integrated into higher education, providing Gen Z students with an innovative, engaging, and sustainable learning experience that aligns with their unique characteristics and learning preferences.

4. CONCLUSION

AR presents a promising approach to enhancing learning experiences for Gen Z students in higher education. Given their digital proficiency, preference for interactive learning, and global mindset, AR-based learning models align well with their needs by fostering engagement, collaboration, and comprehension. The immersive nature of AR enables students to visualize complex concepts, work together in virtual environments, and integrate learning into real-world contexts, ultimately improving motivation and knowledge retention. However, despite its advantages, the adoption of AR in higher education faces challenges such as accessibility, affordability, educator training, and cognitive overload. Ensuring the successful implementation of AR requires careful selection of platforms, whether mobile, desktop, wearable, or projection-based, each contributing uniquely to the learning process. Additionally, concerns related to internet connectivity, device compatibility, and screen fatigue must be addressed to optimize AR's effectiveness in remote learning.

Future research should focus on developing adaptive AR learning models that accommodate diverse learning styles while integrating AR with traditional instructional methods. By addressing these challenges and refining AR-based approaches, higher education institutions can create an engaging, effective, and sustainable learning environment that meets the needs of Gen Z students and prepares them for the future.

ACKNOWLEDGEMENTS

The authors wish to express their sincere gratitude to Universiti Sultan Zainal Abidin (UniSZA) for providing excellent research facilities and a conducive environment that greatly supported this study. Their invaluable support in offering the necessary space and resources was instrumental in the completion of this research.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Zulfachmi	✓		✓	✓		✓		✓	✓				✓	
Normala Rahim		✓				✓		✓	✓		✓	✓		
Wan Rizhan	✓		✓	✓			✓			✓	✓		✓	
Puji Rahayu					✓									
Aggry Saputra					✓		✓			✓		✓		✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] N. Utami, A. Setiawan, and I. Hamidah, "A bibliometric analysis of augmented reality in higher education," *Journal of Engineering Science and Technology*, vol. 18, no. 3, pp. 1599–1613, 2023.

[2] S. Al-Megren and A. Almutairi, "Analysis of user requirements for a mobile augmented reality application to support literacy development amongst hearing-impaired children," *Journal of Information and Communication Technology*, vol. 18, no. 1, pp. 97–121, 2019, doi: 10.32890/jict2019.18.1.8283.

[3] G. Papanastasiou, A. Drigas, C. Skianis, M. Lytras, and E. Papanastasiou, "Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills," *Virtual Reality*, vol. 23, no. 4, pp. 425–436, 2019, doi: 10.1007/s10055-018-0363-2.

[4] A. Sofianidis, "Why do students prefer augmented reality: a mixed-method study on preschool teacher students' perceptions on self-assessment AR quizzes in science education," *Education Sciences*, vol. 12, no. 5, pp. 1–20, 2022, doi: 10.3390/educsci12050329.

[5] C. L. Etheredge and T. M. Waliczek, "Comparative analysis of Generation Z era students' overall grades and course satisfaction of a basic floral design course taught fully face-to-face versus an online hybrid format," *HortTechnology*, vol. 31, no. 6, pp. 709–714, 2021, doi: 10.21273/HORTTECH04900-21.

[6] G. Kaisara and K. J. Bwalya, "Mobile learning in higher education: insights from a bibliometric analysis of the body of knowledge," *International Journal of Learning, Teaching and Educational Research*, vol. 22, no. 6, pp. 152–174, 2023, doi: 10.26803/ijlter.22.6.9.

[7] A. L. Marshall and A. Wolanskyj-Spinner, "COVID-19: challenges and opportunities for educators and Generation Z learners," *Mayo Clinic Proceedings*, vol. 95, no. 6, pp. 1135–1137, 2020, doi: 10.1016/j.mayocp.2020.04.015.

[8] L. Pombo, "Exploring the role of mobile game-based apps towards a smart learning city environment – the innovation of EduCITY," *Education + Training*, vol. 65, no. 2, pp. 253–264, 2022, doi: 10.1108/ET-06-2022-0238.

[9] B. Onecha, C. Cornadó, J. Morros, and O. Pons, "New approach to design and assess metaverse environments for improving learning processes in higher education: the case of architectural construction and rehabilitation," *Buildings*, vol. 13, no. 5, 2023, doi: 10.3390/buildings13051340.

[10] A. D. Rahmat, H. Kuswanto, I. Wilujeng, and R. Perdana, "Implementation of mobile augmented reality on physics learning in junior high school students," *Journal of Education and e-Learning Research*, vol. 10, no. 2, pp. 132–140, 2023, doi: 10.20448/jeelr.v10i2.4474.

[11] D.-C. Claros-Perdomo, E.-E. Millán-Rojas, and A.-P. Gallego-Torres, "Application of augmented reality, gamification and m-learning," *Metaverse*, vol. 1, no. 2, p. 8, 2020, doi: 10.54517/met.v1i2.1775.

[12] S. M. Alnajdi, "The effectiveness of using augmented reality (AR) to enhance student performance : using quick response (QR) codes in student textbooks in the Saudi education system," *Educational technology research and development*, vol. 70, no. 3, pp. 1105–1124, 2022, doi: 10.1007/s11423-022-10100-4.

[13] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "Computers & education a systematic review of immersive virtual reality applications for higher education : design elements, lessons learned, and research agenda," *Computers & Education*, vol. 147, no. July 2019, p. 103778, 2020, doi: 10.1016/j.compedu.2019.103778.

[14] M. Z. Iqbal, E. Mangina, and A. G. Campbell, "Current challenges and future research directions in augmented reality for education," *Multimodal Technologies and Interaction*, vol. 6, no. 9, pp. 1–29, 2022, doi: 10.3390/mti6090075.

[15] M. Asadullah, M. Yeasmin, A. F. Alam, A. Alsolami, N. Ahmad, and I. Atoum, "Towards a sustainable future: a systematic review of mobile learning and studies in higher education," *Sustainability (Switzerland)*, vol. 15, no. 17, pp. 1–17, 2023, doi: 10.3390/su151712847.

[16] S. Mystakidis, A. Christopoulos, and N. Pellas, "A systematic mapping review of augmented reality applications to support STEM learning in higher education," *Education and Information Technologies*, vol. 27, no. 2, pp. 1883–1927, 2022, doi: 10.1007/s10639-021-10682-1.

[17] S. Rashid, A. Khattak, M. Ashiq, S. U. Rehman, and M. R. Rasool, "Educational landscape of virtual reality in higher education: Bibliometric evidences of publishing patterns and emerging trends," *Publications*, vol. 9, no. 2, 2021, doi: 10.3390/publications9020017.

[18] A. Kumar, R. Dey, G. M. Rao, S. Pitchai, K. Vengatesan, and V. D. A. Kumar, "3D animation and virtual reality integrated cognitive computing for teaching and learning in higher education," *Advances in Parallel Computing*, vol. 39, pp. 615–620, 2021, doi: 10.3233/APC210252.
[19] E. Vázquez-Cano, V. Marín-Díaz, W. R. V. Oyarvide, and E. López-Meneses, "Use of augmented reality to improve specific and transversal competencies in students," *International Journal of Learning, Teaching and Educational Research*, vol. 19, no. 8, pp. 393–408, 2020, doi: 10.26803/ijlter.19.8.21.
[20] A. A. Ziden, A. A. A. Ziden, and A. E. Ifedayo, "Effectiveness of augmented reality (AR) on students' achievement and motivation in learning science," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 4, pp. 1–12, 2022, doi: 10.29333/ejmste/11923.
[21] Y. S. Lin, S. Y. Chen, C. W. Tsai, and Y. H. Lai, "Exploring computational thinking skills training through augmented reality and AIoT learning," *Frontiers in Psychology*, vol. 12, no. February, pp. 1–9, 2021, doi: 10.3389/fpsyg.2021.640115.
[22] Z. S. See *et al.*, "Playable experiences through technologies: opportunities and challenges for teaching simulation learning and extended reality solution creation," *Journal of Information Technology Education: Innovations in Practice*, vol. 22, pp. 67–90, 2023, doi: 10.28945/5121.
[23] S. Cai, C. Liu, T. Wang, E. Liu, and J. C. Liang, "Effects of learning physics using augmented reality on students' self-efficacy and conceptions of learning," *British Journal of Educational Technology*, vol. 52, no. 1, pp. 235–251, 2021, doi: 10.1111/bjet.13020.
[24] H. D. Ariessanti, H. Prabowo, F. L. Gaol, and M. Liana, "Factors shape the success of implementing AR models for stem learning," *Journal of Theoretical and Applied Information Technology*, vol. 102, no. 2, pp. 619–630, 2024.
[25] K. Móga, Á. Hölgyesi, Z. Zrubka, M. Péntek, and T. Haidegger, "Augmented or mixed reality enhanced head-mounted display navigation for in vivo spine surgery: a systematic review of clinical outcomes," *Journal of Clinical Medicine*, vol. 12, no. 11, 2023, doi: 10.3390/jcm12113788.
[26] R. Castaño-Calle, A. Jiménez-Vivas, R. Poy Castro, M. I. Calvo Álvarez, and C. Jenaro, "Perceived benefits of future teachers on the usefulness of virtual and augmented reality in the teaching-learning process," *Education Sciences*, vol. 12, no. 12, 2022, doi: 10.3390/educsci12120855.
[27] Y. O'Connor and C. Mahony, "Exploring the impact of augmented reality on student academic self-efficacy in higher education," *Computers in Human Behavior*, vol. 149, no. March, p. 107963, 2023, doi: 10.1016/j.chb.2023.107963.
[28] D. Dong, "A probe into the psychological mechanism of Generation Z College students using network buzzwords in the internet era," *Frontiers in Psychology*, vol. 12, no. August, pp. 1–10, 2021, doi: 10.3389/fpsyg.2021.663728.
[29] V. Dhinakaran, P. Partheeban, R. Ramesh, R. Balamurali, and R. Dhanagopal, "Behavior and characteristic changes of Generation Z engineering students," *2020 6th International Conference on Advanced Computing and Communication Systems, ICACCS 2020*, pp. 1434–1437, 2020, doi: 10.1109/ICACCS48705.2020.9074322.
[30] E. Yu and C. Suny, "Student-inspired optimal design of online learning for generation Z," *Journal of Educators Online*, vol. 17, no. 1, 2020.
[31] N. M. Khalid, F. Senom, A. S. Muhamad, N. M. F. Mansor, and N. H. Saleh, "Implementation of PERMA model into teaching and learning of Generation Z," *International Journal of Learning, Teaching and Educational Research*, vol. 22, no. 9, pp. 423–441, 2023, doi: 10.26803/ijlter.22.9.23.
[32] P. Hegade and A. Shettar, "Elevate-Z: a model to create learning spaces for Generation Z students," *Journal of Engineering Education Transformations*, vol. 35, no. Special Issue 1, pp. 175–180, 2022, doi: 10.16920/jeet/2022/v35is1/22025.
[33] Faith Marcel, "Mobile augmented reality learning objects in higher education," *Research in Learning Technology*, vol. 27, no. 1–10, pp. 1–10, 2019.
[34] M. Lazo-Amado and L. Andrade-Arenas, "Augmented reality for anatomy course for children with autism," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 34, no. 2, pp. 1246–1257, 2024, doi: 10.11591/ijeecs.v34.i2.pp1246-1257.
[35] F. T. Kurdi, E. Lewandowicz, J. Shan, and Z. Gharineiat, "Three-dimensional modeling and visualization of single tree LiDAR point cloud using matrixial form," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 17, pp. 3010–3022, 2024, doi: 10.1109/JSTARS.2024.3349549.
[36] U. Cahyana, I. Lestari, I. Irwanto, and J. Suroso, "Development of a mobile learning network for science with augmented reality and its impact on students' literacy and numeracy," *International Journal of Innovative Research and Scientific Studies*, vol. 7, no. 2, pp. 576–586, 2024, doi: 10.53894/ijirss.v7i2.2685.
[37] W. S. Wan Husain, S. N. Wan Shamsuddin, and N. Rahim, "A conceptual framework for road safety education using serious games with a gesture-based interaction approach," *Pertanika Journal of Science and Technology*, vol. 30, no. 1, pp. 621–640, 2022, doi: 10.47836/PJST.30.1.34.
[38] N. Nordin, N. R. M. Nordin, and W. Omar, "The efficacy of REV-OPOLY augmented reality board game in higher education," *International Journal of Emerging Technologies in Learning*, vol. 17, no. 7, pp. 22–37, 2022, doi: 10.3991/ijet.v17i07.26317.
[39] J. Cabero-Almenara, C. Llorente-Cejudo, and R. Martinez-Roig, "The use of mixed, augmented and virtual reality in history of art teaching: a case study," *Applied System Innovation*, vol. 5, no. 3, 2022, doi: 10.3390/asi5030044.
[40] O. Saidani Neffati *et al.*, "An educational tool for enhanced mobile e-Learning for technical higher education using mobile devices for augmented reality," *Microprocessors and Microsystems*, vol. 83, no. January, p. 104030, 2021, doi: 10.1016/j.micpro.2021.104030.
[41] F. A. Halim, W. H. N. Wan Muda, N. Zakaria, and N. H. B. A. Samad, "The potential of using augmented reality (AR) technology as learning material in TVET," *Journal of Technical Education and Training*, vol. 12, no. 1 Special Issue, pp. 119–124, 2020, doi: 10.30880/jtet.2020.12.01.012.
[42] B. Marks and J. Thomas, "Adoption of virtual reality technology in higher education : An evaluation of five teaching semesters in a purpose - designed laboratory," *Education and Information Technologies*, vol. 27, pp. 1287–1305, 2022, doi: 10.1007/s10639-021-10653-6.
[43] A. N. Sanderasagran, A. A. Aziz, and D. M. N. D. Idris, "Real-time computational fluid dynamics flow response visualisation and interaction application based on augmented reality," *Journal of Information and Communication Technology*, vol. 19, no. 4, pp. 559–581, 2020.
[44] S. Chanjaradwichai, J. Na-Songkhla, and T. Chiasiriphan, "A trackable augmented learning media system for a higher education level," *International Journal of Emerging Technologies in Learning*, vol. 14, no. 13, pp. 129–144, 2019, doi: 10.3991/ijet.v14i13.10177.
[45] S. Kamarudin, H. M. Shoaib, Y. Jamjoom, M. Saleem, and P. Mohammadi, "Students' behavioural intention towards e-learning practices through augmented reality app during COVID-19 pandemic in Saudi Arabia," *Interactive Learning Environments*, vol. 31, no. 9, pp. 5715–5731, 2023, doi: 10.1080/10494820.2021.2016863.

[46] Y. P. Gupta, Mukul, and N. Gupta, "Deep learning model based multimedia retrieval and its optimization in augmented reality applications," *Multimedia Tools and Applications*, vol. 82, no. 6, pp. 8447–8466, 2023, doi: 10.1007/s11042-022-13555-y.
[47] E. Martin, J. Castéra, H. Cheneval-Armand, and P. Brandt-Pomares, "The use of augmented reality for inquiry-based activity about the phenomenon of seasons: effect on mental effort and learning outcomes," *Frontiers in Education*, vol. 8, no. July, pp. 1–11, 2023, doi: 10.3389/feduc.2023.1223656.
[48] A. Lu, C. S. K. Wong, R. Y. H. Cheung, and T. S. W. Im, "Supporting flipped and gamified learning with augmented reality in higher education," *Frontiers in Education*, vol. 6, no. April, pp. 1–11, 2021, doi: 10.3389/feduc.2021.623745.
[49] S. Machala, N. Chamier-Gliszczynski, and T. Królikowski, "Application of AR/VR technology in industry 4.0," *Procedia Computer Science*, vol. 207, pp. 2984–2992, 2022, doi: 10.1016/j.procs.2022.09.357.
[50] A. A. Eldokhny and A. M. Drwish, "Effectiveness of augmented reality in online distance learning at the time of the COVID-19 pandemic," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 9, pp. 198–218, 2021.
[51] S. Lawrence, "Gen AI – Gen Z : understanding Gen Z ' s emotional responses and brand experiences with Gen," no. July, 2025, doi: 10.3389/fcomm.2025.1554551.
[52] A. Jovanović and A. Milosavljević, "VoRtex metaverse platform for gamified collaborative learning," *Electronics (Switzerland)*, vol. 11, no. 3, 2022.
[53] H. Mohammad, T. Almarabeh, and L. Rajab, "A rapid review of learning using hologram in higher education," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 12, pp. 242–248, 2023.
[54] A. Alejandro Alvarez-Marin, J. A. Velazquez-Iturbide, and M. Castillo-Vergara, "The acceptance of augmented reality in engineering education: the role of technology optimism and technology innovativeness," *Interactive Learning Environments*, vol. 31, no. 6, pp. 3409–3421, 2023, doi: 10.1080/10494820.2021.1928710.
[55] D. Allcoat, T. Hatchard, F. Azmat, K. Stansfield, D. Watson, and A. von Mühlenen, "Education in the digital age: learning experience in virtual and mixed realities," *Journal of Educational Computing Research*, vol. 59, no. 5, pp. 795–816, 2021, doi: 10.1177/0735633120985120.
[56] A. Álvarez-Marín, J. Á. Velázquez-Iturbide, and M. Castillo-Vergara, "Technology acceptance of an interactive augmented reality app on resistive circuits for engineering students," *Electronics (Switzerland)*, vol. 10, no. 11, 2021, doi: 10.3390/electronics10111286.
[57] I. Schorr, D. A. Plecher, C. Eichhorn, and G. Klinker, "Foreign language learning using augmented reality environments: a systematic review," *Frontiers in Virtual Reality*, vol. 5, no. February, pp. 1–15, 2024, doi: 10.3389/frvir.2024.1288824.
[58] C. Rodríguez-Abad, A. E. Martínez-Santos, J. del C. Fernández-de-la-Iglesia, and R. Rodríguez-González, "Online (versus face-to-face) augmented reality experience on nursing students' leg ulcer competency: Two quasi-experimental studies," *Nurse Education in Practice*, vol. 71, no. July, 2023, doi: 10.1016/j.nepr.2023.103715.
[59] D. Hendricks, "Applications of augmented reality as a blended learning tool for architectural education," *SOTL in the South*, vol. 6, no. 1, pp. 79–94, 2022, doi: 10.36615/SOTLS.V6I1.247.
[60] K. Sabbah, F. Mahamid, and A. Mousa, "Augmented reality-based learning: the efficacy on learner's motivation and reflective thinking," *International Journal of Information and Education Technology*, vol. 13, no. 7, pp. 1051–1061, 2023, doi: 10.18178/ijiet.2023.13.7.1904.
[61] G. Gómez-García, F. J. Hinojo-Lucena, S. Alonso-García, and J. M. Romero-Rodríguez, "Mobile learning in pre-service teacher education: Perceived usefulness of AR technology in primary education," *Education Sciences*, vol. 11, no. 6, 2021, doi: 10.3390/educsci11060275.
[62] C. Wyss, A. Degonda, W. Bührer, and F. Furrer, "The impact of student characteristics for working with AR technologies in higher education—findings from an exploratory study with Microsoft HoloLens," *Information (Switzerland)*, vol. 13, no. 3, 2022, doi: 10.3390/info13030112.
[63] Y. A. Daineko, D. D. Tsoy, A. M. Seitnur, and M. T. Ipalakova, "Development of a mobile e-learning platform on physics using augmented reality technology," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 5, pp. 4–18, 2022, doi: 10.3991/ijim.v16i05.26961.
[64] Y. Koumpouros, "Digital horizons: enhancing autism support with augmented reality," *Journal of Autism and Developmental Disorders*, Feb. 2025, doi: 10.1007/s10803-024-06709-4.
[65] S. H. Hadi *et al.*, "Developing augmented reality-based learning media and users' intention to use it for teaching accounting ethics," *Education and Information Technologies*, vol. 27, no. 1, pp. 643–670, 2022, doi: 10.1007/s10639-021-10531-1.
[66] S. Norzaimalina, A. Majid, A. R. Salam, and J. Bahru, "A systematic review of augmented reality applications in language learning," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 10, pp. 18–34, 2021.
[67] L. Fu, "Research on the teaching model of animation professional class based on AR/VR technology and 5G network," *Wireless Communications and Mobile Computing*, vol. 2021, p. 10, 2021, doi: 10.1155/2021/1715909.
[68] J. W. Lai and K. H. Cheong, "Adoption of virtual and augmented reality for mathematics education: a scoping review," *IEEE Access*, vol. 10, pp. 13693–13703, 2022, doi: 10.1109/ACCESS.2022.3145991.

BIOGRAPHIES OF AUTHORS

Zulfachmi received his master's degree in electrical engineering with concentration on computer and management information systems, Universitas Udayana, Indonesia. He is a lecturer in the informatics engineering department, Sekolah Tinggi Teknologi Indonesia Tanjung Pinang. Expertise in internet of things, software engineering, and website programming. He can be contacted at email: fahmi.stti@gmail.com.

Normala Rahim received the Ph.D. degree in information science and technology from Universiti Kebangsaan Malaysia, Malaysia. She is a Senior Lecturer at the Multimedia Studies Center, Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin. Her expertise is in UI/UX, virtual reality technology, augmented reality, and mixed reality. She can be contacted at email: normalarahim@unisza.edu.my.

Wan Mohd Rizhan Wan Idris received the Ph.D. degree in information science and technology from Universiti Kebangsaan Malaysia, Malaysia. She is a senior lecturer at the Multimedia Studies Center, faculty of informatics and computing, Universiti Sultan Zainal Abidin. His expertise is in UI/UX, virtual reality technology, augmented reality, and mixed reality. He can be contacted at email: wmrizhan@unisza.edu.my.

Puji Rahayu born in Jakarta, completed her doctoral studies in computer science in 2019 at the faculty of computer science, University of Indonesia. Currently carrying out her duties as a lecturer at Universitas Mercu Buana, with specifications in the field of computer science with more than 7 years of experience in education and research with a focus on the field of information science with the topic of e-governance and software engineering. There are more than 18 scientific papers that have been published in national and international journals, indexed by Scopus and WoS, as well as several intellectual property rights certificates obtained. She has received several research grants from the Ministry of Education and Culture, and she is now actively involved in several research collaborations with national and international researchers. Currently, she has involved in the IEEE and ACM professional associations as a member of the Asia Pacific region. She can be contacted at email: pujisekar@gmail.com.

Aggry Saputra received his master's degree in electrical engineering with concentration on computer and management information systems, Universitas Udayana, Indonesia. He is a lecturer in the informatics engineering department, Sekolah Tinggi Teknologi Indonesia Tanjung Pinang. Expertise in HCI, robotics, and software engineering. He can be contacted at email: aggry@sttindonesia.ac.id.