Mobile Augmented Reality: A Systematic Review of Current Research and the Untapped Potential of Interactive Marker-Based Games

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Abstract

Augmented Reality (AR) technology has transformed the gaming experience, providing players with distinctive and immersive experiences that integrate virtual elements with the physical world. Mobile Augmented Reality (MAR) has reshaped the use of AR technology by making it easily accessible to the general public through smartphones, significantly increasing user engagement and adoption that transcend traditional gaming paradigms. To evaluate the current state of mobile AR games research, we conducted a systematic literature review to analyse the landscape of mobile AR gaming. Our review identified three recurring themes: (1) recent advancements in mobile AR technology, (2) the effectiveness of marker-based games, and (3) the potential applications and innovations involving 3D interactive markers as the future direction for mobile AR. By highlighting these themes, we aim to bridge the gap between mobile AR games' potential and practical applications, setting the stage for future innovations and enhanced user experiences. Our findings underscore the necessity for ongoing research to uncover new opportunities with interactive markers in the mobile AR gaming domain.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**.

Keywords

augmented reality games, mobile devices, review

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1 Introduction

Augmented Reality (AR) has emerged as a groundbreaking technology in digital entertainment, blurring the boundaries between the virtual and physical worlds [13]. In this paper, we define AR as a technology that overlays digital content onto the real world in real-time through a mobile phone, enabling interactive and immersive experiences that enhance user perception and engagement. AR games blend digital interactivity with real-world elements, providing users with immersive experiences that go beyond conventional gaming norms. As AR technology continues to evolve and increase, so does the landscape of AR gaming. The rich and dynamic study areas are developed for exploration and analysis. AR technology has seen significant progress in recent years, impacting multiple facets of human life, including entertainment [24], education [69], and commerce [6]. However, the disparity between AR technology's potential and its practical integration, particularly in educational settings, underscores the need for further research into overcoming implementation barriers and developing effective adoption strategies [38].

Among the innumerable applications of AR like AiR-hockey [50], AR Worms [49], and outdoor AR games like ARQuake [2], we find one domain that has garnered significant attention, i.e., mobile gaming. Mobile Augmented Reality (MAR) games seamlessly merge virtual elements with the real world, providing players with engaging and immersive experiences. As mobile gaming continues to grow, fueled by the widespread adoption of smartphones and the increasing availability of AR technology, developers and researchers are exploring MAR games' potential to revolutionise the gaming industry [12]. While AR gaming spans various platforms, our study intentionally focuses on MAR games due to their increasing accessibility [16] and widespread adoption [9]. Unlike broader AR applications, MAR games leverage smartphone-based AR capabilities, making them a distinct and rapidly growing subfield that requires dedicated investigation. However, despite the growing interest in this emerging field, there remains a need for a comprehensive synthesis of existing literature to explain the current state of research, identify trends, and pinpoint areas for future investigation. While there were three reviews in total, namely educational mobile AR games [33], mobile AR serious games [47], and mobile AR for individuals with Autism Spectrum Disorder (ASD) [37], there is no comprehensive review that synthesises the overall MAR gaming landscape. This study aims to address that gap by providing a structured analysis of advancements, trends, and future directions in mobile AR gaming.

This literature review examines the diverse aspects of AR technology as applied to mobile gaming and proposes opportunities for future investigations. We synthesised our findings by searching for mobile AR games, analysing interactions and gameplay and evaluating user experience while designing mobile AR games. In addition to exploring technical advancements, this review emphasises the role of Human-Computer Interaction (HCI) and User Experience (UX) in shaping MAR games. Understanding player interactions, immersion, and engagement mechanics is crucial for designing compelling MAR experiences, making HCI and UX key aspects of our analysis. The current systematic review aims to address the following three research questions (RQs):

- RQ1: What are the current mobile augmented reality technology advancements identified in recent research?
- RQ2: How effective are marker-based games in enhancing user engagement and learning outcomes?
- RQ3: What potential applications and innovations could marker-based AR games offer?

These questions aim to: (1) examine the latest technological advancements in mobile augmented reality gaming, highlighting key innovations and emerging trends; (2) evaluate the role of marker-based interactions in enhancing user engagement, learning and gameplay experiences; and (3) investigate the potential applications and future developments of marker-based AR games, uncovering new opportunities for innovation in interactivity, collaboration, and immersive gameplay. Through this literature review, we intend to offer researchers, developers, and practitioners a comprehensive understanding of the current state-of-the-art AR mobile gaming landscape and direct future opportunities for expanding mobile AR towards marker-based games. The results show that marker-based technology could further enhance the augmented reality experiences that promote communication, collaboration, and connectedness among players. This direction could serve as one of the foundations for advancements in mobile AR games and provide opportunities for future exploration, especially in developing digital games in the mental health care landscape and 3D interactive markers.

2 Related Work

AR technology has experienced a remarkable evolution since its inception, shaping how we interact with the world and revolutionising various industries. In its early stages, AR was primarily confined to research laboratories, with pioneering efforts such as Ivan Sutherland's "Sword of Damocles" laying the groundwork for overlaying computer-generated graphics onto the real world in 1968 [63]. The unique characteristic of AR is the augmentation of the real world with computerised information instead of reconstructing it entirely in a virtual environment.

AR games have evolved from entertainment to educational tools and immersive experiences that engage players through imagination, social interactions, and authentic learning environments. The exploration of AR games across different research studies showcases augmented reality's diverse applications and benefits in gaming and learning contexts [21, 32, 61]. The emphasis on skills development, immersive experiences, and user engagement underscores the continuous development and innovation in AR gaming [31]. AR games have the potential to offer authentic, memorable experiences to players. This enables players to feel deeply connected to the game environment, promoting a sense of realism and captivating experiences that transcend traditional gaming boundaries [62]. The significance of AR games to players emphasises the roles of imagination and social experience [32]. It delves into the importance of player imagination and social relationships in enhancing the gameplay experience, suggesting that AR games can support human imagination without replacing it [32]. AR games can potentially teach interpretation, multi-modal thinking, problem-solving, teamwork, and civic engagement [31].

Furthermore, while reviewing the previous literature, we can portray the evolution and diverse applications of AR games, showcasing their potential in education [61], entertainment [2], mental state examination [21], and immersive gaming experiences [31] both indoors and outdoors. Advancements in AR technology have enabled diverse AR game scenarios through devices that engage users in interactive and location-based gaming experiences, showcasing the evolving landscape of AR gaming over the years. These advancements in AR technology have led to the development of headsets like Microsoft HoloLens [54] and the exploration of mobile AR [12] to visualise content and enhance user experiences. The use of AR in different contexts has diversified, enabling innovative solutions and experiences tailored to specific needs and disciplines.

Mobile AR games have advanced by utilising handheld devices such as smartphones and tablets to deliver interactive and immersive gaming experiences. Progress in Handheld Augmented Reality (HAR) showcases the enhanced processing power that have made these devices well-suited for AR applications. Dubois et al. [13] emphasised the dual needs of the users who have to benefit from computers while interacting with the real world, leading to the emergence of augmented reality as a solution. Montola et. al. [45] emphasises the blending of real and virtual experiences, as seen in their exploration of Alternate Reality Games (ARGs) that integrate everyday life into interactive narratives, enhancing player engagement through social and physical contexts. Korhonen et. al. [29] further highlights the importance of understanding playful user experiences and the role of technology in shaping these interactions, ultimately advocating for a more holistic view of game design that encompasses both digital and non-digital elements. A design approach that prioritises the enjoyment of body games, driven by the interplay between technology and physical play, can further enrich both the corporeal experience and the social environment [41]. The collaboration interface in mobile AR supports network connections across multiple devices for enhanced user interactions [68]. The integration of mobile AR with education has enabled users to interact with virtual objects in real-time, providing immersive and meaningful experiences. Mobile AR games have transformed how players perceive and engage with their physical surroundings, creating a more interactive and enjoyable learning process. Through pairwise interactions in AR games, players interact via smartphones in an augmented reality space, highlighting the evolution of AR technology in gaming experiences towards interactive and engaging gameplay scenarios [58]. Using mobile augmented reality learning-based systems for educational purposes provides methodological guidelines for developing serious games to increase students' Quality of Experience (QoE) [66]. Mobile AR games enhance the learning process for players in an engaging and meaningful way [66].

While there are various systematic reviews on AR games [36, 42, 53, 67], we have only been able to analyse three literature reviews on mobile AR games, namely in education [33], serious games [47] and healthcare [37]. The lack of reviews on the overall landscape of mobile AR games indicated shortcomings that justify this study. Moreover, these three reviews became one of the primary sources for analysing the landscape of mobile AR games. While these reviews specifically focus on learning in education or rehabilitation in healthcare, they do not provide a comprehensive overview of the overall landscape of mobile AR games. Thus, to fill this research gap, this systematic review provides a comprehensive review of mobile AR games' current state of the art. Understanding the current state of the art in mobile AR games is crucial for identifying emerging trends, challenges, and opportunities, which can inform future research and development in this innovative area.

3 Methods

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines [52]. Figure 1 displays an overview of the selected publications' identification, screening and eligibility. The review process was conducted in five phases: defining keywords, determining the database, screening, preliminary analysis, data synthesis, and the coding process. We selected six literature databases known for their broad coverage of research in diverse fields and their interdisciplinary: ACM Digital Library, IEEE Xplore, ScienceDirect, Web of Science, SpringerLink and Scopus. These databases are also the six most cited HCI venues according to Google Scholar [1]. Inclusion and exclusion criteria were established to refine the scope of the systematic review of mobile augmented reality games by selecting studies focusing on mobile platforms and incorporating key mobile AR elements. Based on this, the Inclusion Criteria (IC) and Exclusion Criteria (EC) are outlined below.

- IC 1: The paper has one of the following terms in the title, abstract or keywords: "Mobile Augmented Reality" OR "MAR" OR "Mobile AR" along with one of the terms: "Game" OR "Games"
- IC 2: The paper only focuses on Mobile Augmented Reality games.
- IC 3: The paper is written in English.
- IC 4: The paper is a journal article, proceedings or conference article, book or book chapter.

Similarly, the exclusion criteria were:

- EC 1: The paper does NOT focus on Mobile Augmented Reality games.
- EC 2: The paper is NOT available.
- EC 3: The paper focuses on MAR, Extended Reality (XR), and Virtual Reality (VR).

[1]https://scholar.google.com/citations?view_op=top_venues&hl=en&vq=eng_humancomputerinteraction

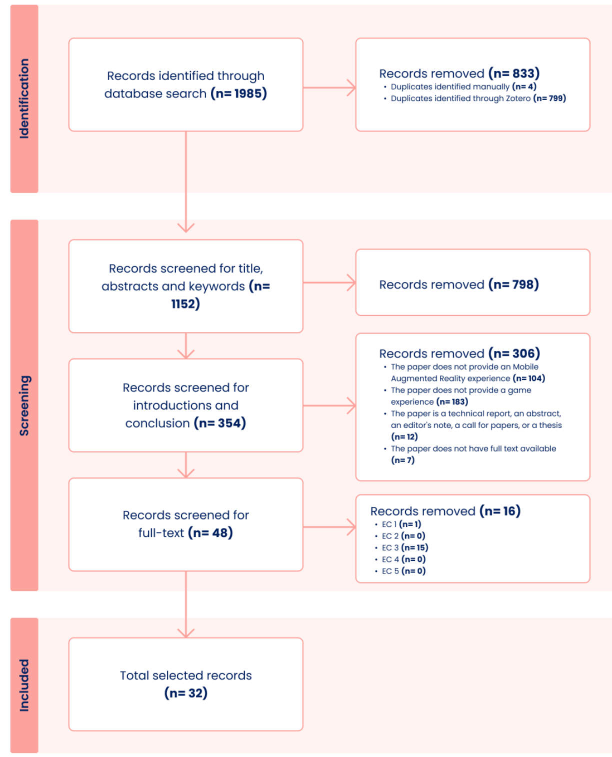

Figure 1: Summary of the identification, screening, eligibility, and inclusion of studies

- EC 4: The paper is a technical report, an abstract, an editor's note, a call for papers, or a thesis.
- EC 5: The paper does NOT have full text available.

These criteria ensured that only high-quality, relevant research was included, filtering out studies that either lacked a focus on mobile AR, were outdated, or did not meet the methodological standards necessary for a comprehensive analysis. The next section will delve into the keywords chosen to define the scope of the literature review, explaining their relevance and how they guided the research process.

3.1 Defining Keywords

To define the scope of the review, we included broader keywords: augmented reality mobile games, AR smartphone games, gamification with mobile augmented reality, and mobile AR games. In contrast, we omitted keywords such as virtual reality games, AR tabletop games, and augmented reality games. We intentionally omitted the broader term 'augmented reality games' to ensure our review remained focused on mobile-specific implementations. While this term encompasses a wide range of AR gaming applications, it includes non-mobile platforms such as AR tabletop games and head-mounted display experiences, which fall outside our study's scope. By refining our keyword selection, we aimed to capture research explicitly addressing mobile augmented reality games and their unique gameplay elements. We used this scope to guide our search to collect a broad sample of mobile augmented reality games research covering different aspects of mobile AR gaming that primarily use some form of gameplay elements in mobile devices and accordingly used them to define the keywords. This scope helped define our keywords, which consist of the names of mobile AR game types. These keywords were modified, and variations were used through the application of wildcards [2].

The resulting database search query was formulated as follows: (“augmented reality mobile game*” OR “mobile augmented reality game application*” OR “MAR game*” OR “MAR based game*” OR “AR mobile gamification”) AND (“serious game*” OR “game-based learn*” OR “mobile platform” OR “smartphone*” OR “board game*” OR “collaborative game*” OR “social game*”). To capture variations of common words of mobile augmented reality games, the wildcards allowed us to use terms like games and gaming by using game* and so on. The search string was modified on different databases.

3.2 Determining Database

We selected six databases: ACM Digital Library, IEEE Xplore, Scopus, ScienceDirect, SpringerLink, and Web of Science. These databases are the most common sources of high-quality publications in computer science and cover a comprehensive range of research articles. The date range for this study is from 2004 to May 2024, giving us an overview of the advancements made in mobile AR games in the last twenty years. The keywords search produced 1985 research papers imported into Zotero Reference Manager [8]. 799 duplicates were removed using Zotero Reference Manager, and 4 were manually removed before the screening phase.

3.3 Screening

1152 papers were eligible for the screening after the duplicates were removed. The initial screening phase followed a two-step process to adequately handle the quantity of results. The first step followed a review of screening the title, publication keywords, and abstracts. To screen the papers based on the abstracts and the titles, we used the defined inclusion and exclusion criteria based on the aims and objectives of the review. The screened papers were categorised into relevant (354) and irrelevant (798) based on the inclusion and exclusion criteria. The second step involved reviewing the paper's introduction and conclusion sections. Based on the introductions and conclusions of the papers, 306 papers were excluded from the study as they did not meet the scope of the research. The resulting collection included 48 papers for full-text screening.

The inclusion and exclusion criteria were re-visited during the full-text screening phase to assess the eligibility of the 48 papers. 16 papers were removed after revisiting the exclusion criteria. The most common reason for excluding these papers was that the study focused on using mobile AR technology, XR, and VR for designing games (EC 3). This left us with a final set of 32 publications for the preliminary analysis.

[2]The wildcard is an advanced search technique that can be used to maximise the search results in library databases.

3.4 Preliminary Analysis

We conducted a preliminary analysis to categorise and answer the three research questions: (RQ1) What are the current mobile augmented reality technology advancements identified in recent research? (RQ2) How effective are marker-based games in enhancing user engagement and learning outcomes? (RQ3) What potential applications and innovations could marker-based AR games offer?

Our review of 32 papers examined research methodologies in mobile AR games, categorising studies into qualitative and quantitative analyses. This provided insights into HCI principles such as user interaction, engagement, immersion, and user experience [7, 27, 34]. We also identified gameplay elements that maximise impact and reveal potential opportunities. In a deeper investigation, we analysed methodologies like questionnaires and interviews used to evaluate UX interactions in mobile AR games. We explored how design elements—realism, narrative, and emotional engagement—enhance user interaction and gameplay in marker-based games [10, 22]. Additionally, we examined mobile AR's role in mobile game-based learning across industries to assess its adoption and benefits [44]. These investigations provided a clearer understanding of AR's technological advancements and potential.

3.5 Data Synthesis and Coding Process

Once we collected a corpus of publications, we employed an iterative coding process. The final set of 32 papers was reviewed in detail, with coding repeated until consensus was reached. Each paper was categorised along three independently developed dimensions: Research Focus, Methodological Approach, and Type of AR Feature.

3.5.1 Research Focus. We classified papers based on whether they addressed technical advancements, user experience, educational applications, or mobile AR game effectiveness. If a focus was not explicitly stated, we assigned the most relevant category based on study objectives. For example, papers discussing mobile AR in education were coded under educational applications, even if they included broader technological discussions.

3.5.2 Methodological Approach. To ensure consistency, we grounded our coding in established HCI and AR research methods, referencing "*Ways of Knowing in HCI*" [51]. Papers were categorised into quantitative experiments, qualitative case studies, mixed-methods approaches, or user testing. This framework captured the diverse methodologies across studies.

3.5.3 Type of AR Feature. Papers were coded based on the AR technologies they employed, with multiple codes assigned if applicable: *Location-Based Augmentation:* Virtual content tied to physical locations using GPS, enhancing experiences through real-world positioning (e.g., games with interactive outdoor elements). *Marker-Based Augmentation:* AR triggered by physical markers (e.g., QR codes, printed images), serving as anchors for digital content in 2D or 3D formats. *Projection-Based Augmentation:* Digital content projected onto surfaces, creating interactive experiences where virtual elements appear within the physical environment. *Mixed Methods Augmentation:* Studies integrating multiple AR techniques (e.g., combining location-based and marker-based AR for enhanced gameplay). This classification allowed us to analyse how different

AR techniques enhance user interaction and engagement across the literature.

4 Results

Of the initial 1985 records identified, 32 were included in the review. The search covered all years from 2004 up to May 2024. This systematic review provides a thorough understanding of the current state-of-the-art in AR mobile gaming and highlights future opportunities for expanding marker-based mobile AR games. This section presents the results of the systematic review, which are divided into two parts: quantitative analysis and qualitative analysis. The included publications are also listed in Table 1.

4.1 Quantitative Analysis

The quantitative analysis highlights 7 major themes: the year of publication, the countries, the disciplines, the aim of the study, the target audience, the methodologies, and the use of augmentation. Figure 2 displays a summarised overview of the publications between 2012 and 2024, slightly leaning towards more publications from 2018. 2018 and 2023 display the highest studies on mobile AR games, with an evident dip in 2019. Since 2019, there has been a gradual increase in the articles published each year, which indicates an active interest in this field. The national distribution of studies displays a focus on the Global North, with the most studies developed in Europe (with the most articles in Germany and three articles each in Portugal and Greece), followed by Asia (two articles in Indonesia, two articles in China and one as a collaboration between two countries) and North America (six articles in California, Washington, Texas, South Carolina, Massachusetts and Colombia) as seen in Figure 3.

Of the 32 publications in the review, 16 articles focused on education as a discipline to use mobile augmented reality games, as seen in Figure 4. 11 articles focused on the human-computer interaction discipline and various usage aspects of mobile AR technology. While three articles focused on the medical usage of mobile AR, only two presented the usage of mobile AR in psychology. Figure 5 indicates that more than half of the studies aim to understand user experiences, and most of these articles use surveys to measure quantitative data and analyse user behaviour. Additionally, nine articles solely use qualitative methods or combine them with quantitative methods as a mixed method to analyse user experience through their studies. Among the qualitative methods, some of the most common methods of collecting data were interviews, observation of user behaviour and note-taking. The target audience mainly focused on data collection with children, teachers, professionals, health care providers and parents, and through co-design workshops. While eight publications presented a detailed process of their studies, the other four articles presented the impact of their studies.

Figure 6 indicates that most studies focused on school adolescents. While 4 studies focused on a specific age group, these were targeted at children between 5-14 years. 2 studies targeted university students, while the other 11 articles focused on a much larger age group (20-28 year-olds, mixed-age groups and older adults). 14 studies employed co-design methods, and 11 collected user feedback during development. 7 publications either did not document any involvement of the target group or stated the involvement of

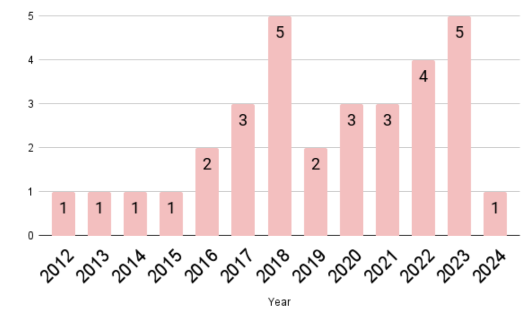

Figure 2: Year of Publication

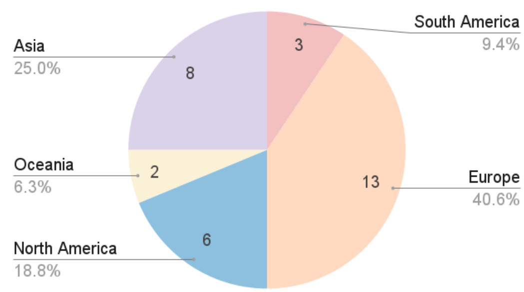

Figure 3: Country of Publication

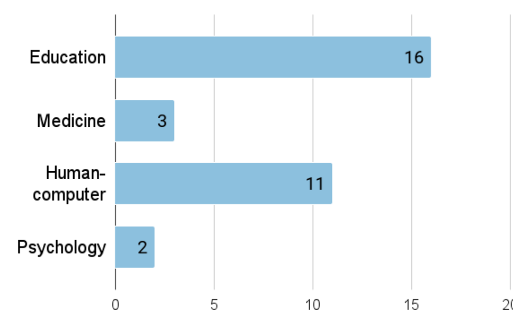

Figure 4: Discipline

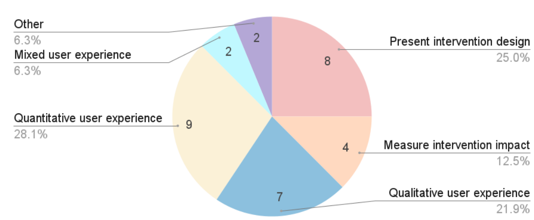

Figure 5: Aim of Study

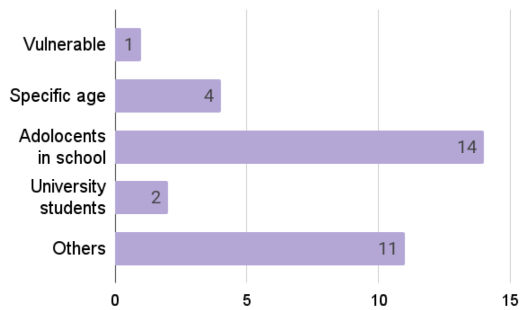

Figure 6: Target population

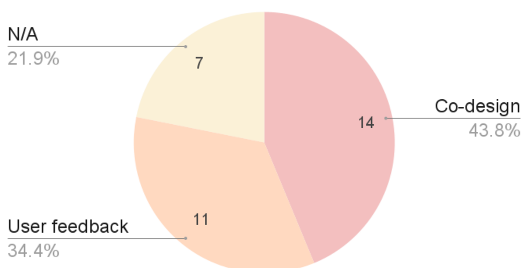

Figure 7: Co-design methodology

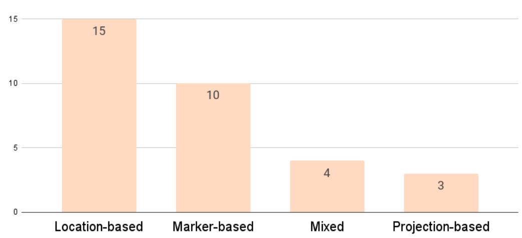

Figure 8: Type of AR Feature

the target group in future work. Co-design is valuable when designing games for a specific target group because it ensures that the solutions are tailored to the specific needs and preferences, especially among vulnerable people.

Finally, more than half of the studies focused on using location-based augmentation while designing mobile AR games. Aside from the 15 articles that solely relied on location-based augmentation, 4 articles that used mixed augmentation (location-based and/or projection/marker-based) majorly used location tracking as a primary feature. 10 articles used marker-based articles to design mobile AR games, while 3 studies displayed projection-based mobile AR games.

The findings show that this field has been active for at least 8 years. It mostly focuses on designing mobile AR games in the education discipline, and the studies are designed mainly for children. While co-design and user feedback are majorly used as a development methodology, there is space for further involvement of users in the pre-development, during and after the post-development process of designing studies. Mobile AR technology is less common in the medical and psychology disciplines, and its applications to vulnerable audiences are also marginal. Moreover, the findings show that the field heavily relies on location-based augmentation while designing mobile AR studies compared to other types of AR features.

4.2 Qualitative Analysis

The publications in the review indicate various approaches to designing games with mobile augmented reality, focusing on various types of AR features and their implementation of mobile AR in the literature genre.

4.2.1 Use of Mobile AR games for Learning. Sixteen publications provided detailed discussions on using mobile AR games in education. Four of these demonstrated using mobile AR games to teach elementary school children about math, geography and science [25, 28, 43, 64]. Three publications discussed teaching primary school children about learning about their city [30], encouraging collaborative learning [39] and designing guidelines for creating mobile AR games for education [35]. Xue et al. [7] compared three educational approaches: traditional english education, an AR tool developed using Scratch, and an iPad-based approach. AR tools and iPad applications significantly improved students' motivation to learn and knowledge acquisition. The articles stated that AR content's interactive and visual nature made learning materials more appealing and easier for preschool children to remember. Similarly, Syamsudin et al. [64] suggested that mobile AR games can be tailored to various educational needs, including different educational levels and subjects. This adaptability makes AR games a versatile tool in the educational landscape. While some articles [11, 27, 30, 59] focused on individual learning, Faican et al. [39] focused on using mobile AR games to increase collaborative learning among children. The author emphasised that the quality of communication in collaborative play is superior, facilitating mutual understanding, dialogue management, and information pooling. This aspect is crucial for developing effective communication skills in educational settings. Ferrer et al. [18] derived design guidelines for future serious AR games, emphasising the importance of balancing usability and engagement to optimise learning outcomes.

Eleven publications discussed the use of AR technology and the direction towards the advancement in the HCI field. Rachman et al. [56] applied a collision detection algorithm to detect interactions between the virtual characters. This algorithm was crucial for determining when characters collide, triggering health point calculations for the player and the enemy. Buhion et al. [5] focused on using technology to make users align slices of 3D models to form recognisable virtual models, thus engaging users in an interactive experience with AR technology. The study highlighted the differences in user interaction and effectiveness between the two AR approaches, with early testing indicating that the 2D marker-based AR is more effective in showcasing anamorphic illusions. Morschheuser et al. [46] emphasised using HCI principles and cooperative game features to positively associate with "we-intentions," which refer to the intention of players to work together as a group. This association was mediated by various group dynamics, including group norms, social identity, joint commitment, attitudes toward cooperation,

Author	Year	Aim of study	Users	AR type
Blum et al. [4]	2012	Analysis of quantitative user experience	Not specified	Location
Ferrer et al. [18]	2013	Analysis of user experience mixed methods	School and college students	Marker
Garcia et al. [20]	2014	Measure study design	Practitioners and patients	Marker
Koutromanos et al. [30]	2015	Analysis of qualitative user experience	Primary school children	Location
Bhadra et al. [3]	2016	Present study design	Young kids	Mixed
Cortes et al. [19]	2016	Analysis of quantitative user experience	University students	Location
Gilbert et al. [22]	2017	Measure study design	Patients	Mixed
Maia et al. [40]	2017	Analysis of qualitative user experience	Mixed	Location
Meekaew et al. [43]	2017	Analysis of quantitative user experience	Elementary school children	Marker
Morschheuser et al. [46]	2017	Analysis of quantitative user experience	Not specified	Location
Ekonomou et al. [15]	2018	Present study design	Secondary school children	Location
Felka et al. [17]	2018	Analysis of quantitative user experience	Not specified	Location
Hammadi et al. [1]	2018	Analysis of qualitative user experience	Age 6-11	Projection
Herpich et al. [25]	2018	Present study design	Elementary school children	Location
Kim et al. [28]	2019	Analysis of quantitative user experience	Elementary school children	Marker
Rachman et al. [56]	2019	Analysis of quantitative user experience	Young children	Marker
Attaway et al. [26]	2020	Present study design	Children	Location
Faican et al. [39]	2020	Present study design	Primary school children	Location
Lehto et al. [34]	2020	Measure study design	Children age 9-11	Location
Qin [55]	2020	Analysis of quantitative user experience	Not specified	Location
Santos et al. [11]	2021	Other	Children in school	Mixed
Reisinho et al. [57]	2021	Analysis of qualitative user experience	Young children	Projection
Buhion et al. [5]	2022	Analysis of qualitative user experience	Age 20-28	Marker
Li et al. [35]	2022	Analysis of user experience mixed methods	Primary school children	Mixed
Mittmann et al. [44]	2022	Present study design	Age 10 - 13	Marker
Syamsudin et al. [64]	2022	Analysis of quantitative user experience	Elementary school children	Marker
Chen et al. [10]	2023	Present study design	Not specified	Marker
Hammad et al. [24]	2023	Measure study design	Not specified	Location
Hussain et al. [27]	2023	Present study design	Vulnerable	Marker
Schlesener et al. [59]	2023	Analysis of qualitative user experience	University students	Location
Xue et al. [7]	2023	Analysis of qualitative user experience	Age 5-6	Projection
Schlomann et al. [60]	2024	Other	Older Adults	Location

Table 1: Summary of the analysed records

and anticipated positive emotions. The results indicated that cooperative game features foster community and collaboration among players, essential for effective HCI. Only one study focused on using mobile augmented reality games on mental health [44]. The study involved the participation of 91 early adolescents and evaluated the game's usability and preliminary efficacy. Results indicated high acceptability and positive feedback regarding the game's ability to foster social connections and improve class climate.

4.2.2 Target Users of Mobile AR games. More than half of the publications focused on using mobile AR for children between 5-14 years specifically [1, 3, 7, 11, 15, 25–28, 30, 34, 35, 39, 43, 44, 56, 57, 64]. These studies demonstrate how mobile AR technology can effectively create engaging educational experiences for children, fostering learning in history, literacy, sustainability, and nutrition through interactive and immersive gameplay. Reisinho et al. [57] focused on a nutrition-themed serious game that combined tangible interfaces with AR to teach cooking skills to children. The game aims to motivate kids to make healthy food choices through interactive gameplay that simulates culinary processes. While Santos et al. [11] used a location-based AR game that encourages learning through a treasure hunt format. The study is designed to motivate children by incorporating competitive elements and collaborative learning opportunities while promoting physical activity. Two publications [15, 34] employ mobile AR to engage children in exploring cultural heritage sites and historical monuments through a location-aware game format. The game allows children to interact with historical characters and narratives, fostering imagination and a sense of immersion. Bhadra et al. [3] used a scanning mode that allowed children to interact with letters and associated 3D objects, promoting letter recognition and vocabulary development.

Eleven publications provided detailed discussions on using mobile AR games for users like older adults, 20-28 year old's, health care providers, patients and mixed age groups [5, 20, 40, 60]. Schlomann et al. [60] discussed the use of mobile AR games by older people and older adults for health-related purposes. The study deduced the readiness of this age group to use augmented reality games on mobile devices in their everyday lives and for health promotion. Garcia et al. [20] discussed using a mobile AR game designed for therapeutic support to assist physiotherapists and patients on ankle sprain rehabilitation. Four publications [10, 17, 24, 46] either did not specify their user group or vaguely mentioned them.

4.2.3 Co-Design Methodology in Mobile AR. Two-thirds of the publications used co-design methodology while designing their studies or actively collected feedback from the target user groups in their design process. Schlesener et al. [59] discussed how there were multiple brainstorming sessions, both in-person and online, that would be most beneficial for society, ultimately deciding on active bystander awareness training. The game design included scenario selection, storyboarding, and scripting, refined through team discussions. Feedback from these discussions informed the design choices, ensuring that the game effectively addressed the challenges of creating iterations of their studies. Mittmann et al. [44] discussed how the study was created through an interdisciplinary collaboration involving psychologists, software developers, and artists, ensuring that it reflects the needs and voices of early adolescents.

Faican et al. [39] investigated the relationship between various game elements in existing studies and players' enjoyment, sense of presence, and need satisfaction. The study used a data collection method that involved an online survey administered to participants who had played that game. A total of 719 participants filled out the survey, designed to examine the associations among various constructs related to game enjoyment, presence, and need satisfaction. Buhion et al. [5] compared two augmented reality (AR) mobile applications designed to solve anamorphic illusion puzzles: 2D printable markers and 3D physical items as markers. The study involved user testing with 15 participants, divided into experienced and naive users. A self-administered questionnaire was used to gather data on user preferences and effectiveness ratings. The remaining one-third of the publications [20, 28, 30, 56] were work-in-progress articles or short papers intending to involve more stakeholders and target groups to develop their prototypes further.

4.2.4 Augmentation in Mobile AR. Fifteen articles used location-based augmentation while designing mobile AR games. Three articles [26, 34, 46] aimed at the subjectivity of the visiting experience by allowing players, particularly children, to engage with historical narratives through interactive gameplay. Similarly, two publications [19, 30] highlighted the effectiveness of AR in creating an engaging learning environment, emphasising the integration of educational content with interactive gameplay. In the case of integrating virtual 3D objects into real-world locations, Blum et al. [4] emphasised the importance of using real locations effectively to enhance player presence and engagement, suggesting that the spatial attributes of the augmented world significantly impact the overall experience. The AR technology enhanced the learning experience by allowing users to interact with 3D virtual organisms in real-world museum settings in another study [43]. The museum's location was a backdrop for educational activities, facilitating a hands-on learning experience about biodiversity. Similarly, Herpich et al. [25] described an orientation activity for players incorporating location-based elements. The study required players to navigate their school environment using mobile devices equipped with AR features. The activity was designed to teach geographical concepts such as cartography and cardinal points, with students physically moving to different locations to complete tasks and challenges.

After location-based augmentation, ten publications used marker-based augmentation for their studies. Xue et al. [7] used the AR Spot tool to integrate markers that children can interact with to reveal virtual objects and corresponding vocabulary. The markers serve as triggers for the AR content, allowing children to engage with the learning material more interactively and enjoyably. Rachman et al. [56] used a marker-based tracking technique, which involved detecting specific markers to determine the location and orientation of the camera. This allowed the system to project two-dimensional (2D) or three-dimensional (3D) virtual objects into the real-world environment in real-time. Buhion et al. [5] utilised 2D marker-based AR printable markers, while 3D marker-based AR employs physical items as markers. This variety allowed for different interaction techniques, such as moving and rotating markers, which can lead to more intuitive and natural user interactions with digital content. Chen et al. [10] used transparent AR markers central to their study's gameplay mechanics. Players manipulate these markers, which can be stacked to create new inputs for the study. The publication highlighted the innovative use of stacking mechanics to enhance tangible interaction.

Other types of augmentation included creating digital projections in the real world. In their study, Hammadi et al. [1] used AR features designed to simulate real-world interactions, making the learning experience more immersive and interactive by allowing players to build a sustainable city using culturally relevant buildings. A study by Xue et al. [7] allowed users to interact with virtual objects overlaid on the real world by integrating cameras that enable this interaction, making it more intuitive and engaging.

5 Discussion

Our results show two mobile AR game discourses in the existing literature: the current state of mobile augmented reality games and the advancements of marker-based games. Concerning the first observation, mobile augmented reality games represent a relatively new and developing field within the broader landscape of gaming and technology. The current body of research is characterised by 16 work-in-progress studies and short papers, with only a few comprehensive long papers available. The variance here shows the continuous research and experimentation within the field as researchers proceed to further explore and expand on the potential of mobile augmented reality gaming. Because this is a novelty-natured field, it characterises rapid growth through growing interest in its applications and implications. The second finding regarding the evolution of marker-based augmentation in mobile augmented reality gaming is important, pushing the boundaries of this field further open and testing new prospects. Enhanced marker technology can enable more complex interactions and richer user experiences, opening innovative gameplay mechanics and applications. However, it is through the investigation into current limitations that the true progress of researchers and developers can unlock new, untapped potential in further shaping mobile AR games. This progress will refine existing experiences and inspire novel approaches and applications within this field.

In summary, the existing research addresses the potential of AR technology in mobile games (1) through the type of AR features (location-based, projection-based, marker-based, mixed augmentation) and (2) the opportunities for further development of mobile AR gaming (tangible markers, 3D interactive markers, use of mobile AR in psychology). Our results align with these insights and provide a deeper discussion about the knowledge obtained from developing these studies. In the following subsection, we critically analyse the findings derived from the results concerning the research questions.

5.1 RQ 1: Mobile AR Games

Location-based augmentation in mobile AR games relies on the user's geographical position to overlay virtual content onto specific real-world locations, creating experiences tied to physical places. Pokémon GO [55] revolutionised AR technology by bringing it to mainstream audiences, demonstrating its potential for large-scale, location-based interactive experiences. It shifted AR from a niche technology to a widely recognised and engaging tool for immersive, real-world gameplay. A study by Qin [55] on 719 participants discussed Pokémon GO's impact on players, encouraging them to explore their physical environment to catch virtual creatures and collect items at designated locations. Similarly, many articles explored location-based augmentation in physical health and education. Ekonomou et al. [15] elaborated on how AR can augment the experience of visiting historical sites by providing contextual information tied to specific locations. Similarly, Cortes et al. [19] focused on a location-based AR game designed to engage students in discovering institutional landmarks.

In contrast, projection-based augmentation directly overlays digital elements onto surfaces or objects within the user's immediate environment, allowing for dynamic interactions with virtual content that appears physically present in the space around them. Xue et al. [7] discussed integrating AR technology with Scratch to create an interactive learning environment. The AR tool, AR Spot, allowed users to observe virtual objects superimposed on real-world scenes captured via a video camera. This setup enabled users to interact with virtual elements by manipulating physical objects seamlessly. Three publications [3, 22, 35] also highlight location-based and marker-based augmentation techniques, allowing virtual content to be anchored to specific geographical locations and physical markers within the environment. Rachman et al. [56] stated that using 2D card markers is essential for detecting the location and orientation of virtual objects in the game. This allows for interactive gameplay where players can engage with augmented elements in real-time, demonstrating the importance of physical markers in enhancing the overall game experience and immersion.

5.2 RQ 2: Effectiveness of Marker-Based Games

Marker-based augmentation represents a relatively new and emerging area of research, particularly when compared to a more established augmentation type of location-based AR games. The review highlighted that out of the 10 publications on marker-based games, only two were full papers [27, 44], while the remaining eight were either short papers or works in progress [5, 10, 18, 20, 28, 43, 56, 64].

Despite the limited number of studies, the findings consistently suggest that markers are highly effective in mobile AR games, particularly in anchoring virtual content to the physical world. For instance, Ferrer et al. [18] explored various AR interfaces, including single and multi-marker systems. The study stated using multiple markers can improve user interaction and learning outcomes in educational games. It highlighted the importance of usability in marker design and implementation, as it directly influences user motivation and learning effectiveness.

Moreover, markers contribute to intuitive and immersive user experiences by seamlessly integrating digital elements with real-world environments, making mobile AR games more engaging and accessible. Hussain et al. [27] further underscore the effectiveness of marker-based AR in educational settings, particularly in engaging children with learning difficulties. Their study demonstrated how markers could be used to recognise 3D alphabet characters, helping to maintain children's attention and motivation during learning activities. This emphasises the value of markers in creating interactive and engaging educational experiences, particularly for young learners. While still in its early stages, the research on marker-based games in mobile AR highlights their effectiveness in enhancing user interaction, engagement, and learning outcomes.

5.3 RQ 3: Potential Applications

While the review has predominantly focused on the reliability of 2D markers, there is a growing recognition of the need to prioritise tangible interactions and the balance between physical and virtual realities in mobile AR games. One of the key innovations in this domain is the exploration of both 2D and 3D marker-based approaches, as highlighted in recent studies. Buhion et al. [5] emphasised the functional significance of markers in mobile AR studies, comparing the capabilities of 2D and 3D markers. The authors argued that 2D markers, typically printable, offer flexibility in scaling and interaction, making them accessible and adaptable for various gaming scenarios. In contrast, 3D markers involving physical objects provide a richer, more immersive user experience by incorporating tangible elements into the gameplay. This distinction between 2D and 3D markers points to a future where the choice of marker type can be strategically aligned with the desired user experience, whether flexibility and accessibility or immersion and tangibility. Chen et al. [10] explored this further by introducing stacking transparent AR markers, representing a significant leap in interactive marker-based mobile AR games. The stacking mechanics allow for the creation of new inputs, enabling more complex interactions and the generation of creative outputs, such as musical compositions. This innovation enhances the creative possibilities for users and fosters social interaction, as the gameplay mechanics encourage collaboration and shared experiences.

The expansion of marker-based mobile AR games lies in the continued exploration and integration of 3D objects and tangible markers, coupled with a focus on enhancing user engagement through HCI-driven design. This evolution will likely yield new forms of interaction that blend physical and virtual realities more seamlessly, creating immersive and engaging experiences beyond traditional gaming. This review suggests expanding mobile AR games' creative and educational potential and fostering new forms of social interaction and collaboration in virtual and physical spaces.

Future Work. Our findings indicate that mobile AR games predominantly emphasise location-based augmentation, with a notable lack of studies focused on 2D and an absence of 3D marker-based games. Only one paper involving a 2D marker-based game has been identified in psychology and vulnerable groups. While 3D marker-based AR games remain underexplored, their integration with XR and VR technologies could enhance spatial interactions, object tracking, and immersion. This suggests a potential opportunity to investigate the influence of mobile AR games on psychology, similar to their impact on education. Additionally, Gyory et al. [23] contributes to this discourse by advancing tangible interaction design, providing practical tools that enhance user engagement and accessibility in AR environments. By borrowing from XR/VR advancements, 3D marker-based mobile AR games could incorporate more dynamic and persistent digital overlays, improving player immersion and spatial awareness. Similarly by expanding research on how blending real and virtual experiences through ARGs enhances player engagement by embedding interactive narratives into social and physical contexts could further expand investigation on 3D marker based mobile AR games. Another promising direction for future research involves exploring tabletop AR games, which utilise 3D markers to create interactive, shared experiences. These games offer new mechanics for collaborative play, educational simulations, and hybrid digital-physical interactions. Based on the conclusions of our review, we will advance to the next phase of the literature review. The subsequent step involves processing all the remaining data in our collection. We will employ thematic analysis to handle the substantial amount of qualitative data. Our research aims to explore various characteristics of study systems that have been understudied in previous work. Lastly, throughout the review, we only screened mobile AR games through academic papers and cannot draw any insights about the progress made in the gaming industry.

Limitations. First, we excluded publications that had VR and XR along with mobile AR from this literature review to maintain a focused scope specifically on mobile AR games, as each technology presents distinct user experiences and technical challenges. Including publications that use VR and XR along with mobile AR would have introduced complexity and variability, potentially diluting the findings relevant to mobile AR. Additionally, VR and XR have separate, well-established research bodies that could overshadow the unique aspects and advancements in mobile AR gaming. However, we acknowledge that the intersection of 3D marker-based AR games with VR and XR presents exciting opportunities for expanding the capabilities of mobile AR gaming. Advancements in XR and VR technologies can enhance the responsiveness and immersion of mobile AR experiences. The inclusion of 3D marker tracking could further support object permanence and realistic physics simulations, making mobile AR games more engaging and lifelike. While our review primarily focused on mobile AR, future research should explore how these advancements from VR and XR can be integrated into mobile AR gaming. Second, the results reported are based on descriptive statistics and preliminary analysis. Considering the wide range of HCI principles, such as interactions, user experience, immersion, and emotional design, to name a few, our methodology to find and screen literature could not reach every element that contributes to the HCI principles while designing mobile AR games. Third, our review was only limited to mobile AR games. With this, we excluded work like Thomas et al. [65], where the author delves into different gaming experiences that leverage AR technology, such as interactive storytelling, game-based learning, physical interaction with virtual elements, and collaborative gameplay utilising augmented environments.Similarly, Nguyen et al. [48] present a new type of trading card (Stereo Cards) designed for a table-top augmented reality game environment, which is also ready for AR applications and games. Blast Theory's projects, such as Uncle Roy All Around You and Rider Spoke, blur the boundaries between art and gaming, creating pervasive hybrid play experiences that foster a deeper sense of presence [14]. While these works illustrate the broader potential of AR for interactive storytelling and immersive experiences, our review remains focused exclusively on mobile AR games. While the models and processes mentioned in the studies can help design experiences for mobile AR, such approaches cannot be directly applied to improve mobile AR games.

6 Conclusion

This systematic review aims to map out the existing landscape of mobile AR gaming and provide opportunities for future exploration. In our analysis of 32 publications, we found a diverse range of articles, which we categorised based on the type of AR features, the discipline of study, user groups and co-designing methodology. Our findings underscore how more than half of the articles heavily rely on location-based augmentation in mobile AR games to analyse and evaluate user experience. From this perspective, location-based augmentation can be seen as a popular medium for measuring studies across different fields of discipline. To conclude, these findings highlight the untapped potential of 2D and 3D marker-based augmentation, which will aid the progression of the field. By addressing these research questions, we intend to lay the groundwork for future studies on interactive markers in mobile AR games. Our efforts will facilitate advancements in the field, allowing researchers to build upon each other's findings.

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