Synthesizing Evidence-Based AR Design Recommendations and Identifying Gaps in Practice

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Abstract

From handheld devices to head-mounted displays, augmented reality (AR) technologies are becoming commonplace in everyday settings, supporting tasks in education, healthcare, gaming, and beyond. Prior research has developed a number of evidence-based design recommendations for AR apps. However, these recommendations are often scattered across academic literature and differ in scope and focus. In addition, there are still open research questions about the degree to which existing guidelines are applied in practice, particularly in handheld AR contexts. To address these gaps, we synthesized AR design recommendations from academic literature and organized them into an integrated set of guidelines. We then empirically analyzed 52 commercial handheld AR apps to assess how well they align with these guidelines. We found that while most apps follow basic usability guidelines, such as using familiar UI layouts, many apps do not adopt context-aware features, offer limited support for multimodal interaction and feedback, and overlook key usability practices such as onboarding and navigational aids. In addition, we saw very few guidelines related to data privacy, collaborative AR, safety and accessibility. We contribute a synthesis of evidence-based AR recommendations and identify key areas of disconnect between recommendations and practice for handheld AR apps, which aids future designers and developers.

CCS Concepts

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

Keywords

Augmented Reality (AR), Handheld AR, Design Guidelines, User Interface Design, Accessibility, Multimodal Interaction, Spatial Navigation, Context-Aware Interfaces, AR App Evaluation

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1 Introduction

Augmented Reality (AR) is a technology that integrates computer-generated visuals with the real environment, aligning virtual elements with physical objects so they appear anchored in the real world and can be experienced and interacted with in real time [15]. AR supports an increasingly diverse set of tasks, ranging from interactive education and medical training to industrial maintenance and navigation [24, 34, 36, 50]. Over the past decade, researchers have explored the usability of AR systems across various domains. For example, Dey et al. [24] conducted a comprehensive review of 10 years of AR usability studies, highlighting trends, methodological practices, and gaps in application areas such as education, entertainment, and industrial use cases.

Researchers have developed design guidelines for AR apps, some of which are broadly applicable [22], while others are highly specialized, such as guidelines targeting AR assembly instructions [60]. However, these guidelines are scattered across academic literature, making the design and development of AR applications difficult [22]. The absence of an integrated set of AR design guidelines may contribute to gaps between what research recommends and how AR apps are developed in practice.

Although research-practice gaps have been observed in domains such as children's touchscreen apps [59] and mHealth apps [63], it is unclear to what extent the latest AR apps implement the recommended academic evidence-based practices. While researchers have identified usability challenges of AR (e.g. discoverability [52], user training [34]), few studies have checked whether these guidelines are followed by real-world applications [22]. This gap is especially relevant for handheld AR, in which the limitations of small screens, varied environments, and on-the-go use could significantly affect which design recommendations are feasible [23]. Understanding this gap between research and practice is important in informing design recommendations for future AR application development.

To address these gaps, we completed a two-part study. First, we performed a comprehensive synthesis of academic AR design guidelines from the existing literature. We collected recommendations, best practices, and design principles from prior AR research that covers diverse sets of devices (e.g., handheld devices, HMD) and contexts (e.g., assembly, education, entertainment, etc.). We organized these recommendations into an integrated set of 96 AR design guidelines, grouping them by 17 higher-level themes (e.g., *Instruction, Virtual Element Design, Context/Personalization*, etc.). Second, we systematically analyzed a dataset of 52 commercial handheld AR apps (spanning categories such as gaming, education, etc.) to evaluate their implementation in practice. We evaluated the design guidelines relevant to handheld AR by inspecting the app's features, user interface, interaction paradigms, and usability support. As our focus in this work was on synthesizing and evaluating guidelines from academic literature, we did not consult industry guidelines (e.g., ARCore, ARKit, HoloLens, Magic Leap). Our goal was to assess how well evidence-based academic design recommendations are reflected in current practice.

Our evaluation reveals two key trends. First, while most handheld AR apps follow basic usability and interaction guidelines, they rarely leverage AR-specific capabilities such as context-awareness, multimodal interaction techniques, and spatial and navigational aids that support users in complex environments. Second, several important areas are still underrepresented in both AR guidelines and practice; including user privacy, collaborative AR interactions, physical safety, and accessibility. By identifying these critical gaps, our work contributes to a grounded understanding of how AR development practices diverge from research and outlines future research directions for creating more usable, inclusive, and context-aware AR experiences.

2 Related Work

2.1 AR Design Guidelines and Principles

Prior work has examined design guidelines for augmented reality (AR) systems [14, 17, 27, 28, 42–44, 46, 54, 57, 61]. For example, Gabbard et al. [28] examined how to design AR interfaces in outdoor environments, with a particular focus on improving text readability. With the rise of smartphone augmented reality, Ko et al. [42] established a set of usability principles developed for handheld AR apps. In recent years, researchers have undertaken broader syntheses of augmented reality/ mixed reality (MR) guidelines. Endsley et al. [27] organized 97 design statements from the existing AR literature and further refined 84 heuristic principles into nine high-level heuristics for AR interaction. Vi et al. [61] built on the work of Endsley et al. [27] and other sources by synthesizing insights from research, industry, and traditional UX principles to formulate 11 user experience guidelines for designing XR applications with head-mounted displays (HMD). Although earlier studies mostly focused on head-mounted AR/MR devices and general UX principles, our work goes further by bringing together a broad set of AR guidelines from established literature that apply across different contexts. We also examine whether these guidelines are implemented in practice by systematically reviewing real-world handheld AR apps.

Krauß et al. [44] compared mixed reality (MR) academic design recommendations from 89 papers to industry-based guidelines (e.g., Apple, Google), and found key differences in focus, abstraction, and applicability. For example, while industry guidelines tended to be more concrete and device-specific, academic recommendations were often abstract. Industry guidelines, such as Google's ARCore [37] and Apple's ARKit [8], mainly serve their own platforms instead of offering universal design principles [14]. Design guidelines often vary widely in scope, from highly specific, device-oriented heuristics [43], to domain-focused suggestions such as those for educational or gaming AR contexts [17, 46]. While prior studies provide design guidelines for handheld AR apps [54, 57], it is unclear if these guidelines are applied in current commercial apps.

2.2 Evaluation of HCI Guidelines in Practice

In HCI, design guidelines are often evaluated by examining whether they are actually reflected in real-world applications (apps), which reveals gaps between ideal best practices and practical implementation. Previous research has demonstrated that even when evidence-based guidelines are available, their implementation in commercial apps is often inconsistent or incomplete [27, 59, 63]. Endsley et al. [27] and Vi et al. [61] proposed well-known AR and XR heuristics based on prior literature and domain knowledge. While their work organizes and refines existing recommendations, it does not evaluate the extent to which real-world AR apps implement these guidelines. Prior work has begun to explore evaluating evidence-based guidelines in other domains [59, 63]. For instance, Soni et al. [59] conducted a literature review to create a set of design recommendations for children's touchscreen apps, which they used to evaluate commercial apps. The authors found gaps between research findings and actual design practice, such as apps not following guidelines to use clear touch feedback [59].

Studies have evaluated AR apps using heuristic-based analysis. For example, Labrie and Cheng [45] evaluated handheld AR apps focused on interior and home design tasks, such as furniture placement and room visualization, using Nielsen's usability heuristics [51]. They found recurring AR-specific usability issues, such as unclear surface tracking feedback, and argued that general HCI heuristics should be adapted for the AR context. Herskovitz et al. [35] analyzed 105 handheld AR apps and identified common tasks users perform, focusing on accessibility challenges. They found that many AR interactions, such as placing or exploring virtual content, present unique usability barriers, especially for blind users.

Despite growing interest in evaluating guideline adoption, few studies offer empirical insights at scale for handheld AR. While Soni et al. [59] and Herskovitz et al. [35] offer useful foundations, they focus on specific audiences or tasks, such as children's touchscreen apps and accessibility challenges in AR apps. Ashtari et al. [14] interviewed AR/VR creators and found that creators sometimes have difficulty applying academic design guidelines, finding some of the guidelines too broad. On the other hand, industry guidelines are typically developed for platform-specific ecosystems that limit their generalizability [14]. Academic guidelines, though sometimes broad, are developed through systematic research methodologies that prioritize cross-platform applicability. By synthesizing evidence-based academic recommendations, we identify design principles that can solve platform-specific constraints and can inform AR development across different contexts and application domains.

3 Methodology

Our methodology involved two main phases. First, we conducted a comprehensive review of peer-reviewed literature to collect AR design recommendations across both handheld and HMD contexts. We synthesized these recommendations using affinity diagramming, merging overlapping ideas and structuring them into distinct themes to produce a unified set of guidelines. Second, we evaluated commercial handheld AR apps against these synthesized guidelines to assess how well they align with evidence-based design practices.

3.1 Synthesis of AR Design Guidelines

Similar to prior work [64], the first three authors of this paper followed the guidelines of Kitchenham and Charters [41] and Soni et al. [59] for collecting the design recommendations from academic literature. We excluded papers that were not written in English, had not been peer reviewed, and only included papers that addressed AR design recommendations (i.e., not VR). In line with our aim to assess academic guidelines in practice, we limited our literature search to academic research and did not include industry guidelines.

We began our first iteration of a literature search between November 2023 and February 2024. During this period, we searched for peer-reviewed literature on augmented reality design guidelines using Google Scholar and the ACM Digital Library. We used Google Scholar because it aggregates results from major repositories (ACM Digital Library, SPIE, IEEE Xplore) and other scholarly sources. We used keywords "AR design recommendations," "AR design guidelines," and "Augmented Reality design guidelines/recommendations." We reviewed each paper to extract specific AR application guidelines. We extracted the design guidelines as they appeared in the original papers and, when needed, added brief context from the source (e.g., noting when a recommendation applies specifically to an educational app). By the end of this first phase, we identified 21 relevant papers, which provided 144 design recommendations.

Later, from May to June 2025, we conducted a second round of literature review to ensure that our guidelines reflected the most recent developments. In this follow-up search, we found 6 additional papers that matched our initial search keywords and selection approach, which yielded 31 new design recommendations. Combining both iterations, we ultimately reviewed a total of 27 papers to build a comprehensive collection of 175 design recommendations.

After completing the literature review and compiling the initial list of design guidelines, we organized and refined these guidelines using affinity diagramming, a method for analyzing large-scale qualitative data through a bottom-up, inductive approach [16]. We adopted affinity diagramming because it provides a straightforward, bottom-up way to cluster varied recommendations and organize them into themes [16, 33]. The first two authors and the last author built the affinity diagram from the design recommendations extracted from the existing literature. We used affinity diagramming to add clarification context when necessary, group similar ideas under broader themes, and merge overlapping recommendations. For example, we merged the following two recommendations: maintaining sufficient contrast between overlay text and background for improved visibility [21] and visual overlays should have sufficient contrast between text and background [19]. We used Lucidchart [10], an online whiteboard tool that supported remote, iterative collaboration to facilitate this process. Through multiple iterations of grouping and discussion, we categorized all design recommendations into 17 distinct themes, which covered *Field-of-view, Virtual Element Design, and Make It Usable,* among others (see Table 1 for all themes). We remained open to creating new themes whenever they emerged naturally during this process and merged themes if there was overlap. The affinity diagramming process resulted in a comprehensive set of 96 finalized design recommendations, grouped into 17 themes, which were distinct from each other. Table 1 presents one representative guideline per theme to illustrate the breadth of the recommendations; the full design recommendation table is included in Supplementary Material.

3.2 Evaluation of Existing AR Applications

From June to July 2025, we evaluated how well current handheld AR applications follow our synthesized design recommendation list. Since we focused on handheld AR, we chose to examine Android apps available on the Google Play Store; we did not test iOS apps because the Google Play Store offers a wide variety of freely accessible Android AR apps for general audiences [4], and to avoid any platform-specific differences (SDKs and store policies). To build our dataset, we searched the Google Play Store using keywords such as "Augmented Reality" and "AR." We then filtered the results based on explicit criteria: the apps had to be free, rated for everyone, and had an average user rating above three stars. These criteria are consistent with prior research, such as Schmidt-Kraepelin et al. [57], who defined *successful* apps as those with three or more stars to ensure a focus on apps that have demonstrated at least moderate user satisfaction. Similar to prior work [57, 63], we restricted our analysis to free handheld AR apps to avoid the potential bias introduced by the higher expectations of users towards the apps they have to pay for. These aforementioned criteria helped us select a set of handheld AR apps that are both broadly representative and generally well-received by users. In the end, we compiled a list of 100 handheld AR applications for our analysis, such as *ARLOOPA: AR Camera 3D Scanner* [6], *AR Flashcards by PlayShifu* [5], and *SkyView Lite* [12]. The apps were divided among the first two authors for evaluation. After installation and testing, we excluded apps that lacked an AR component, required payment to access AR features, or had critical implementation issues (e.g., SDK errors, freezing). This filtering resulted in a final dataset of 52 apps (see Supplementary Material for list of apps), which spanned a range of domains, such as education and entertainment (see Table 2).

We evaluated each app against the guidelines that apply to handheld AR or to both handheld and HMD use, excluding recommendations meant only for HMD, using a coding scheme with four

Table 1: This table shows one example recommendation for each of our 17 themes to illustrate the scope of our synthesized design guidelines. We list out each guideline's theme, recommendation number, context (e.g., general, education, assembly, etc.), citations, and relevant device(s) (i.e., handheld, head-mounted display (HMD)). See Supplementary Material for all 96 recommendations in detail.

Theme	Rec #	Example Guideline and Context	Devices
Context / Personalization	1	Intelligently tailor and filter visual elements and information based on users' current context, such as location, viewing angles, activity, or environmental conditions, as well as users' preferences and interests to provide relevant, timely, and engaging content; General [27], Travel [43].	Handheld, HMD
Use Common Interactions / Metaphors	16	Designers should respect existing preconceived expectations for UI placement (e.g., menus top-left in tablets) rather than breaking norms; Collaborative XR Interfaces [31].	Handheld, HMD
Virtual World Interacting with Real World	18	If virtual elements are aligned with physical objects, this alignment should be continuous over time and viewing perspectives; General [27].	Handheld, HMD
Safety / Accessibility	26	Design AR interactions to be physically accessible and safe, ensuring actions are easy to perform, not dangerous and do not require excessive coordination. Designers should consider users' varying physical capabilities; General [27], Assembly [18].	Handheld, HMD
Text / Labels	28	Ensure text and labels maintain sufficient contrast and readability against varied backgrounds. Use distinct, bold, and bright textual information that is distinct enough from the physical environment. Consider luminance contrast ratios and utilize text boxes when necessary; General [29, 30], Language Interpreting [20].	Handheld, HMD
Field-of-View	30	AR experiences should not present information outside of an intended user's perceptual thresholds or field of view. If the information does fall outside of the user's field of view, then it should be easy to find or recall; General [27].	Handheld, HMD
Virtual Element Design	41	Considering the device power's limitation of hardware, adapt the size of 3D models based on the capabilities of the device while keeping the details of the models sufficiently high to make them recognizable and appealing; General [25], Outdoors [48].	Handheld, HMD
Reducing Complexity	54	To prevent user overload, gradually introduce options; Serious Games [47].	Handheld
Do Not Obscure Real World Elements	58	Ensure that presented information (e.g., text labels) do not obscure or occlude the user's focus of interest; General [30], Games [62], Assembly [18].	Handheld, HMD
Collaborative	60	Allow multiple users to simultaneously access content and consider replicating existing information. Calibrate the experience based on users' roles and expertise; Education [54].	HMD
Privacy Features / Transparent Data	61	Addressing user privacy concerns through the implementation of privacy-enhancing features and transparent data handling practices. By prioritizing user privacy and security, mobile AR (MAR) applications can build trust among users, therefore enhancing overall user satisfaction and engagement; Travel [43].	Handheld, HMD
Instructions	62	Include introductory tutorials or UI elements that allow users to gain further information on the application's purpose and how to use it. Dedicate time to educating users what can be done in the AR application; Navigation [56], Tourism [58], Education [54].	Handheld, HMD
Feedback	69	Provide real-time feedback to guide users, such as if users are proceeding correctly, what must be changed, and its impact on outcomes to allow users to take physical action and observe rapid feedback in order to promote learning and prevent repeated errors; Instructions [55, 67], Education [54].	Handheld, HMD
Mimic Real World	72	Provide familiar visual, haptic, and auditory cues that mimic real-world elements to improve usability and user experience. Designers should also utilize constraints, like preventing the hand from going through certain virtual objects; Travel [43], Medical Game [19].	Handheld, HMD
Make it Usable	74	For mobile applications, divide the help menu in multiple steps for more usability, comprehension, and recall. Navigation and signposts should be direct and clear so that users can navigate in a straightforward way; General [38, 42], Tourism [58], Assembly [18].	Handheld
Direct User Focus / Designing POI	83	Update text labels to inform selection of POIs (Point of Interests) and shrink exploration space to present the detail of POI and draw user attention, addressing the issues with users not noticing textual distance; Navigation [56], Tourism [58].	Handheld
Design Phase	89	AR experiences should be designed to accommodate for the capabilities and limitations of the hardware platform; General [27], Collaborative XR Interfaces [31].	Handheld

Table 2: Google Play Store categories for the 52 apps.

Category	Count	Category	Count
Education	11	Adventure	2
Entertainment	9	Health & Fitness	2
Tools	7	Action	1
Art & Design	4	Travel & Local	1
Medical	2	Arcade	1
Business	2	Productivity	1
Photography	2	Video Players & Editor	1
Simulation	2	Education & Language	1
Maps & Navigation	2	Social	1

options: *Yes, No, Maybe,* and *Not Applicable.* We used *Yes* when an app fully meets a recommendation and *No* when it does not meet it at all. *Maybe* was used when an app partially followed a recommendation or the coder was unsure how to assign a code. We discussed all *Maybe* cases as a group to reach consensus and ensure consistent final labels. We used the *Not Applicable* option for recommendations that do not apply to the specific context of an app. For example, some recommendations are relevant only for embodied social AR experiences involving multiple co-located users; when an app does not include social or co-located interaction, we mark such recommendations as *Not Applicable* to avoid penalizing the app for features outside its intended scope. Before evaluating any guidelines, we interacted with each app for at least 5–10 minutes to understand its basic features and how it worked. During this time, we explored the interface, placed virtual objects, used any available AR modes, and completed onboarding steps if needed. Testing was conducted on Samsung Galaxy Tab A8 devices [11] to ensure consistency in hardware and user experience. After the initial exploration, we reviewed each app carefully against the relevant design recommendations. To evaluate context-aware recommendations (such as those based on location, activity, or user preferences), we tested the apps in both indoor and outdoor settings, changed the device's position and angle, and looked for any content that changed based on context. For outdoor apps, we tested them between 3pm–6pm to keep lighting conditions consistent.

4 Results

We analyzed 52 handheld AR apps using the structured coding approach described in the methodology. Figure 1 presents the distribution of coding responses (*Yes*, *No*, *Maybe*, *Not Applicable*) across the 17 design recommendation themes. While Figure 1 provides a theme-level overview, the following subsections group related themes into broader categories and discuss how specific recommendations were implemented in practice. We highlight which design recommendations were commonly followed and which were frequently overlooked. We refer to individual design recommendations using their assigned numbers (e.g., Rec #28 refers to recommendation 28 in our design guideline table; see Table 1 and Supplementary Material for all 96 design recommendations). Each recommendation is also linked to its original source citations. Figure 2 shows example screenshots illustrating both implementation and non-implementation of AR design recommendations.

4.1 Usability and Interface Design Practices

Several apps demonstrated adherence to basic usability practices for interfaces, such as clear text presentation and reduced visual clutter. For example, the majority of apps maintained clear and readable text, with 76.92% of apps (n=40) meeting text clarity and size guidelines (Rec #28 [18, 19, 29, 30, 39, 48, 58, 65]), and 78.85% of apps (n=41) using familiar UI conventions by placing interface elements in expected locations (Rec #16 [31]). Most apps also followed principles to avoid visual overload; 73.08% apps (n=38) minimized on-screen text and distractions (Rec #53 [27, 43, 54, 65]) and 69.23% apps (n=36) ensured sufficient contrast for text and labels in varying backgrounds (Rec #29 [20, 29, 30]). When it came to directing user focus to POIs (Point of Interests) in complex and cluttered environments, 44.23% (n=23 apps) utilized salient visual elements and indicators such as colors, shapes, and icons (Rec #37 [18, 65]). For example, *Lego Technic AR* [9] highlights POIs with distinctive UI indicators in a cluttered environment (Figure 2d). However, none of the apps optimized their interfaces for one-handed use on a handheld device, which goes against Rec #43 [42], and one-handed operation can be critical for comfort in handheld AR. In practice, handheld AR UIs mostly require two-handed interaction (one hand to hold the device, another to perform interaction), and no app was found to adapt UI elements to be reachable with a single hand.

4.2 Context-Aware Personalization

Handheld AR applications made limited use of context-aware or user-tailored content delivery; only 15.38% of apps (n=8) dynamically tailored content or visuals to the user's context (e.g., location, activity, or preferences), as recommended by contextual adaptation guidelines (Rec #1 [27, 43]). Similarly, just 13.46% of apps (n=7) allowed flexible interaction modes based on context (e.g., the ability to pause or switch interaction techniques in different environments), despite recommendations to do so (Rec #6, [19, 30, 48]). We found that only 8 apps (15.38%) provided filters or content controls based on distance and visibility, meaning 84.62% of apps (n=44) went against Rec #93 [30] and offered no distance-based filtering for augmented content. These low adoption rates indicate that context-aware personalization is lacking in current handheld AR design. Most AR apps deliver static content, offering little to no adaptation based on user context.

4.3 Multi-Modal Interaction and Feedback

Current AR apps underutilize multimodal interaction and feedback mechanisms. For example, only 30.77% of apps (n=16) supported multiple interaction modalities (such as speech or gesture input alongside touch) (Rec #13 [25, 56]), meaning a large portion (67.31%, n=35) relied solely on basic touchscreen input. Multimodal feedback and rich interaction cues were scarce. For instance, only 6 apps (11.54%) followed Rec #70 [19, 48, 56] and provided clear visual and auditory feedback for user interactions or tracking events, and just 13 apps (25%) followed Rec #69 [48, 55, 62] and gave users real-time feedback or guidance on whether they were performing tasks correctly. Haptic, visual, and auditory cues were also rare; only 21.15% of apps (n=11) employed familiar tactile and visual cues or enforced physical constraints (like preventing the user's hand from passing through certain objects) to make interactions

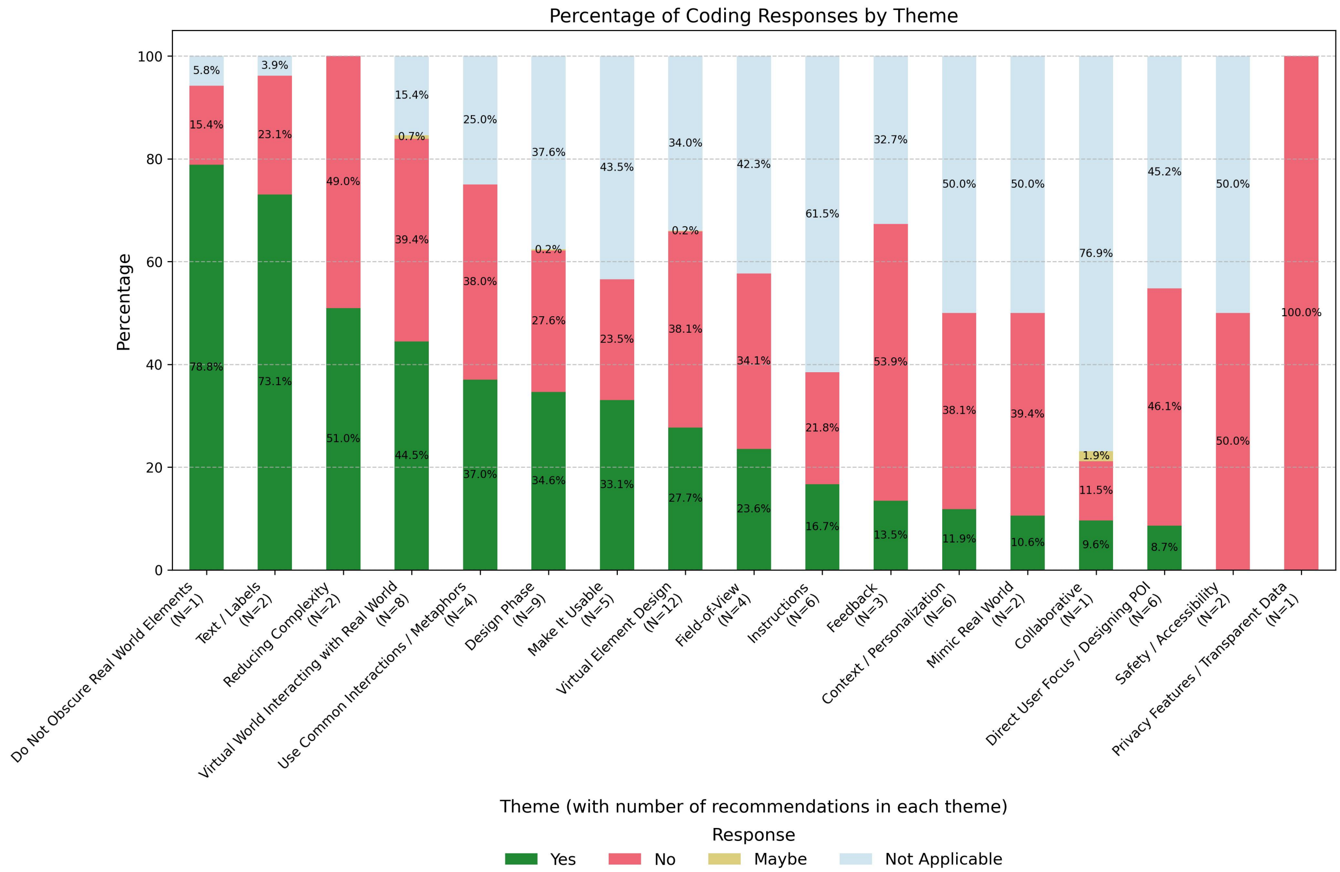


Figure 1: Percentage distribution of app responses (*Yes, No, Maybe, Not Applicable*) across 17 handheld AR design recommendation themes. Each theme aggregates multiple design recommendations, with the total number of recommendations shown beneath each theme label as N. Bar segments represent the proportion of responses within each theme, normalized to 100%. The rounded percentage values are overlaid within each bar segment to indicate the distribution of coding responses per category.

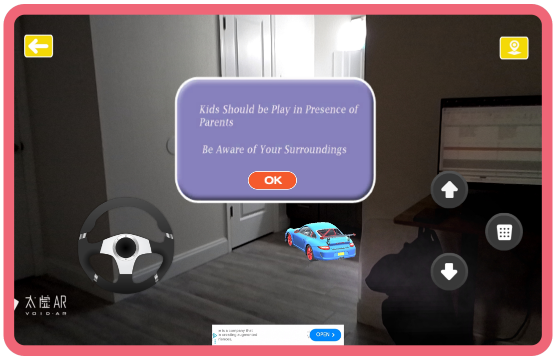
more natural (Rec #72 [19, 43]). The vast majority of apps did not incorporate the multimodal interaction techniques promoted in the literature. Most apps were limited to simple touch interaction and basic on-screen visuals, with little use of sound, haptics, or contextual cues. This suggests that AR developers have not widely adopted these interaction enhancements, which may hinder user engagement and usability improvements.

4.4 Spatial and Navigational Aid

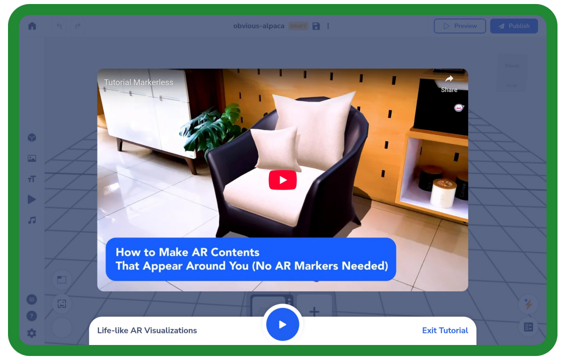
We observed low adoption of guidelines aimed at improving spatial awareness and navigation in handheld AR experiences. A total of 30.77% of apps (n=16) followed the guideline to manage field-of-view (FOV) limitations. These apps either kept visual information within the user's FOV or ensured that information outside the FOV was easy to find or recall (Rec #30 [27]). Fewer apps offered more direct help. For instance, only 13.46% of apps (n=7) followed Rec #84 [19, 39] and used visual or audio cues to guide users through the AR experience. However, these cues did not actively point to off-screen content; only 2 apps (3.85%) followed Rec #86 [56, 62] and used arrows or other directional indicators to guide users toward points of interest (POIs) that were outside the FOV. Some apps also tried to help users focus on POIs; only 7.69% of apps (n=4) updated or highlighted text labels to draw attention to specific POIs and shrink the exploration space (Rec #83 [56, 58]). A small number of apps (11.54%, n=6) used pop-ups to show POI details without adding clutter to the AR view for easy navigation, as recommended by Rec #42 [56]. These results indicate that current AR apps provide minimal support for spatial orientation or navigation. Users are largely left on their own to discover off-screen content or interpret a crowded user interface, since most apps do not utilize guidance aids (like directional arrows, map views, or pop-ups) that would make exploration more intuitive.

4.5 Onboarding and User Guidance

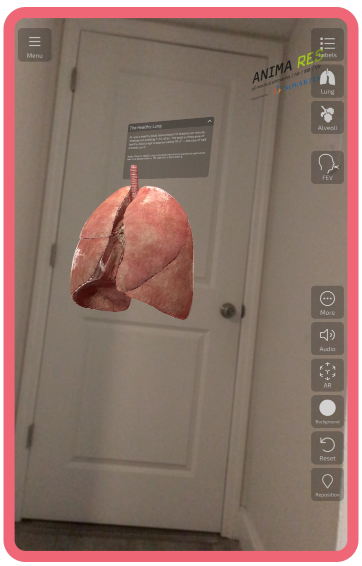
Many handheld AR experiences did not actively help users learn or proceed through tasks beyond providing basic instructions. For instance, only 38.46% of apps (n=20) included any introductory tutorial or UI elements explaining the app's purpose or controls (Rec #62 [54, 56, 58]); Figure 2b includes an example screenshot of an app (*Assemblr Studio: Easy AR Maker* [7]) that follows this design recommendation. To avoid cognitive overload, previous studies suggest gradually introducing options (Rec #54 [47]). In practice, only



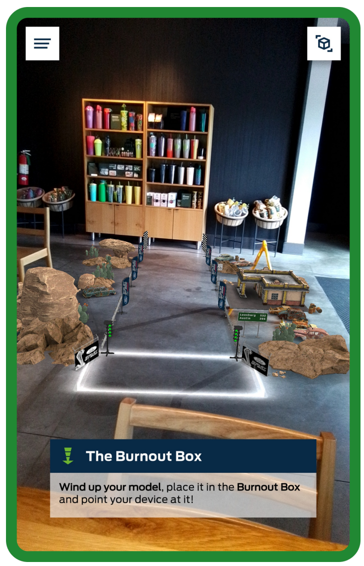
(a) *Vehicle AR Drive* [3] violating Rec #58: Ensure that presented information (e.g., text labels) does not obscure or occlude the user's focus of interest [18, 30, 62]. A static large text box is about to occlude focus from the key visual content in the AR scene (i.e., the moving car).



(b) *Assemblr Studio: Easy AR Maker* [7] following Rec #62: Include introductory tutorials or UI elements that allow users to gain further information on the application's purpose and how to use it. Dedicate time to educating users what can be done in the AR application [54, 56, 58]; the app provides a tutorial.



(c) *INSIGHT LUNG* [2] violating Rec #28: Ensure text is clear, concise, big, and easy to read, using simple descriptions, labels and appropriate fonts for readability. Use text sparingly to prevent cognitive overload [18, 19, 29, 30, 39, 48, 58, 65]. The presented text is unreadable and lacks clarity.



(d) *LEGO TECHNIC AR* [9] following Rec #37: Utilize salient visual elements and indicators (colors, shapes, icons) to direct users' attention to relevant AR elements, especially in complex and clutter environments. Prioritize distinct visual elements over text for critical information [18, 65].

(e) *Peak Finder AR* [1] violating Rec #48: Label menus similarly and store features under the same menu topics so users know what to expect [31]. The app's menu structure lacks usability, making it harder for users to predict where to find specific features.

Figure 2: Example screenshots illustrating both implementation and non-implementation of selected AR design recommendations (Rec # as listed in Table 1 and Supplementary Material). Images outlined in red (subfigures a, c, e) indicate a violation of the corresponding recommendation, while green outlines (subfigures b, d) indicate alignment.

28.85% (n=15) apps introduced options progressively. For apps that did include help menus, only 34.62% (n=18) followed best practices, such as dividing help into manageable steps or sections for straightforward navigation (Rec #74 [18, 38, 42, 58]). Relatively few apps guided users in real time. For example, only 25% of apps (n=13) offered real-time corrective feedback to help prevent repeated errors by the users (Rec #69 [54, 55, 62]).

4.6 Physical Safety and Data Privacy

Prior studies have emphasized the importance of designing AR interactions to be physically accessible and safe, recommending that actions be easy to perform, not require excessive coordination, and adapt to the user's physical capabilities (Rec #26 [18, 27]). However, none of the apps in our dataset followed this recommendation. All 52 apps (100%) failed to implement features that ensure physical accessibility, such as reduced physical strain or accommodation for varying physical abilities. We also observed a complete lack of support for another critical area: user privacy. Not a single app in our dataset implemented features to address user privacy concerns or data transparency (Rec #61 [43]). Despite AR applications often accessing camera, location, and other sensitive data, none of the 52 apps provided privacy-enhancing options as recommended. This complete lack of adoption highlights a significant gap in how user privacy is addressed within current AR practices.

5 Discussion

To contextualize our findings within existing literature and inform future work, we focus our discussion on three areas: (a) examining the disconnect between evidence-based AR design recommendations and their implementation in current handheld AR applications, (b) highlighting areas in which AR design guidance remains limited or underdeveloped, and (c) discussing the subjectivity and context-specific nature of existing AR design recommendations.

5.1 The Research-Practice Gap in Handheld AR

Our analysis shows that while commercial handheld AR apps reliably incorporate fundamental usability principles (e.g., maintaining text clarity, using familiar iconography, conventional UI placement, etc.), they consistently fail to leverage AR's distinctive affordances: context-awareness, multimodal interaction, and spatial navigation aids. This disconnect is not unique to AR; similar gaps have been identified in domains such as children's touchscreen apps [59] and mHealth handheld app notifications [63]. Within AR, this gap severely limits the potential of the technology. Azuma defines AR systems as those that combine real and virtual elements, are interactive in real time, and are registered in 3D space [15]. However, many of the apps we reviewed did not fully engage these spatial and interactive properties. In our analysis of real-world AR apps, we found many apps result in experiences that demonstrate conventional 2D interfaces superficially overlaid on the physical world, rather than fully leveraging AR's interactive and spatial potential. Prior work advises integrating the real environment beyond simple object placement, encouraging designers to leverage real-world spatial features and activities as part of the AR experience [62].

Apps in our analysis mostly failed to leverage users' current context. For instance, Rec #1 suggests to tailor and filter content to location, viewing angle, activity, environment, and user preferences [27, 43], and only had 15.38% adoption (n=8). Furthermore, Rec #6 emphasized to offer context-adaptive interaction options such as pause, enlarge, switch between direct and far interaction, and accommodate outdoor or weather conditions [19, 30, 48], and only had 13.46% adoption (n=7). The lack of utilization of user context and context-adaptive interaction in current handheld AR apps suggests that AR developers are not taking full advantage of the platform's capacity to tailor content for users' needs.

Effective AR experiences rely on combining visual, auditory, and haptic feedback and cues [42]. However, our analysis indicates that most apps did not provide clear or consistent feedback to help users understand whether their actions were aligned with the intended outcome. For instance, only 25.0% of apps (n=13) offered real-time corrective feedback (Rec #69 [19, 48, 56]), and just 11.54% (n=6) included clear visual or auditory feedback or cues to reinforce user interactions (Rec #70 [19, 48, 56]). Additionally, we found that our analyzed apps were missing support for multimodal interaction as recommended by Rec #13 [25, 56]; only 30.77% of the apps (n=16) went beyond basic touchscreen interaction by supporting additional modalities such as speech or gesture input. These results highlight that current designs fall short in providing multimodal interaction techniques and relevant feedback in AR, leaving users unsupported when interacting within the complex AR environment.

AR introduces novel interaction paradigms that are not intuitive to all users [40], since they require physical and cognitive engagement beyond traditional touchscreen interactions [25]. However, we observed that many apps did not provide support or help users understand how to interact with the AR interface. For instance, only 38.46% of the apps (n=20) included introductory tutorials or UI elements to guide first-time use (Rec #62 [54, 56, 58]). This finding does not align with prior work that emphasizes the importance of onboarding and user support in AR systems [54, 61]. Vi et al. [61] stressed the importance of explicit visual and audio cues to guide users, while Radu and Schneider [54] emphasized the need for upfront education and onboarding, yet we found such guidance is often missing from real-world AR apps.

5.2 Underexplored Areas

Alongside gaps in design practice, our findings point to areas within the academic literature that remain underexplored. We recommend that future research prioritize the development of actionable design recommendations in underrepresented areas: accessibility, collaborative AR, and safety and privacy. Our findings highlight that these areas are not adequately addressed in both the academic literature and current development practices. In the following subsections, we examine each area in more depth.

Accessibility. We found that accessibility is not only underrepresented in the literature but also largely ignored in practice. In our literature search, we identified only two design recommendations related to accessibility; one (Rec #26 [18, 27]) emphasized physical accessibility and safety, while the other (Rec #27 [18]) was only applicable for assembly contexts and thus excluded from our handheld AR evaluation. Our findings showed that none of the evaluated apps incorporated features designed for users with visual, auditory, or motor impairments (Rec #26 [18, 27]). Although our literature review only surfaced two accessibility-related design recommendations, prior work has demonstrated both the feasibility and importance of accessible AR experiences. For example, Herskovitz et al. [35] developed and evaluated accessible interaction patterns for blind users. Dudley et al. [26] highlighted how multimodal feedback and inclusive interface design can improve AR usability. The lack of accessibility implementation in our investigation suggests that accessibility considerations are not being incorporated into current handheld AR development, despite growing research interest in inclusive AR interaction design [26, 35].

Collaborative AR. Although interest in collaborative AR experiences is growing [49, 53, 66], we found only two design guidelines explicitly focused on collaborative AR interactions. While some recent studies explore co-located immersive experiences in AR and VR contexts [21, 32], they tend to focus on system-level evaluation rather than producing actionable design recommendations for collaboration. As collaboration becomes a key use case for AR, more clear and applicable design recommendations are needed [49].

Safety and Privacy. In our evaluation, none of the 52 apps implemented features that reduced physical strain or accounted for users with different physical capabilities (Rec #26 [18, 27]). Similarly, none of the apps addressed privacy concerns, such as access to the camera, location, or environmental data, or provided any privacy-enhancing options or transparent data practices (Rec #61 [43]). As AR increasingly integrates into our daily lives, the absence of actionable privacy safeguards represents both an ethical and practical shortcoming that future work must address.

5.3 Subjectivity and Context Dependence

While many AR design recommendations aim to improve usability (see Supplementary Material), their level of specificity often poses challenges for practical implementation. Some recommendations are vague and rely on the designer's interpretations. For example, Rec #28 [18, 19, 29, 30, 39, 48, 58, 65] advises designers to *use text sparingly to prevent cognitive overload* and prefer *structural diagrams over lengthy text.* However, it does not clearly explain how much text is too much or how to adjust for different users' needs. Similarly, Rec #53 [27, 43, 54, 65] recommends avoiding *visual clutter,* but the threshold for clutter is highly subjective and depends on screen size, content density, and use case.

On the other hand, some recommendations are context-specific and may not generalize to broader AR use cases. For instance, Rec #73 [21] encourages designers to support physical contact in co-located AR experiences, such as *playfully bumping and pushing each other* to enhance social connection. This recommendation was developed in the context of playful AR games among friends and family in which physical interaction is both expected and welcome. However, it does not generalize to many other AR use cases, such as education, healthcare, or professional settings, in which physical proximity or touch may be inappropriate or constrained. Additionally, Rec #76 [19] focuses on medical AR game scenarios and advises designers to *use free hand tracking* and *posture-activated controls* to prevent unintended triggers and accommodate patient mobility. While this is relevant for rehabilitation-focused applications, it may not apply to broader medical AR use cases that involve different tasks, users, or other constraints. Such design recommendations illustrate how context-specific guidelines may not translate across different AR use cases. While context-specific guidelines are valuable, designers and developers need to consider whether or not such recommendations align with their app's context and use case.

Furthermore, some recommendations may not apply universally. For instance, we noticed that many apps lacked guidance aids to help users find off-screen content; only 2 apps (3.85%) followed Rec #86 [56, 62] and used guidance aids. While this may seem like a shortcoming, it could be a deliberate and informed design choice in apps that prioritize open-ended exploration. Designers must evaluate whether specific guidelines fit their app's goals and context. As Krauß et al. [44] highlighted, research-based recommendations tend to be more abstract than those used in industry, which may complicate direct translation between contexts. We encourage researchers to synthesize more specific and actionable design recommendations; for example, determining the specific amount of on-screen AR content which may raise or lower cognitive workload.

6 Limitations and Future Work

Our study has several limitations. We only analyzed 52 free handheld AR apps from the Google Play Store, although this is similar to previous studies [57, 59, 63]. We focused on Android apps and excluded iOS apps to avoid platform-specific differences (SDKs and store policies). For example, ARKit features that rely on LiDAR run only on certain devices [13], so the same app may behave differently across devices; those differences come from hardware, not design. It is possible that some paid apps may offer different or more advanced design features that were not represented in our analysis. Another limitation is that while we grounded our analysis in published design recommendations, our literature review may have missed some relevant work. We also did not evaluate guidelines that were hardware-specific, such as those requiring adaptation based on device performance and hardware capabilities as these were not directly observable during app usage. In addition, the apps in our dataset did not cover all AR domains mentioned across our 96 design recommendations. For instance, we did not analyze any apps involving assembly tasks, co-located social interaction, or guided instruction. Future work could explore whether context-specific guidelines are being applied in these areas. Furthermore, we focused specifically on handheld AR for our evaluation. HMDs present different affordances and interaction constraints that were outside our scope. Future work could extend this analysis to HMD-based AR to examine whether similar gaps between research and practice exist across platforms.

7 Conclusion

We carried out a two-phase investigation to examine the gap between academic AR design recommendations and current handheld AR practice. First, we synthesized 96 evidence-based design recommendations from existing literature. Then, we analyzed 52 commercial handheld AR apps to assess the extent to which these guidelines are implemented in real-world apps. Our findings reveal that while current apps mostly follow basic usability principles such as following traditional UI conventions, they often neglect AR-specific practices such as improved spatial affordances, context awareness, and multimodal interaction. We also found limited coverage and implementation of recommendations in areas such as accessibility, privacy, and collaboration. This work contributes a structured synthesis of AR design recommendations and offers empirical evidence of where practice aligns or diverges from research.

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