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# A SYSTEMATIC LITERATURE REVIEW ON INTERFUSION AUGMENTED REALITY MODEL (IARM) BASED ON IMMERSIVE ENVIRONMENT, ASSISTIVE TECHNOLOGY AND AFFECTIVE DESIGN PRINCIPLES FOR VISUALLY IMPAIRED INTERACTION

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**Abstract:**

Augmented Reality (AR) has emerged as a promising technology for enhancing interaction experiences quality and well-being for visually impaired (VI) users. However, existing solutions are often fragmented, focusing on isolated components such as visual enhancement, auditory navigation, or assistive functionalities without a unified integration framework. While existing systematic literature reviews (SLR) have focused on AR's impact across various domains such as education, healthcare, and entertainment, there has been limited attention to AR's applications designed for visually impaired individuals, particularly in their failure to incorporate affective design principles. This study aims to systematically review current AR-based and immersive technologies for visually impaired interaction and identify key components that contribute to effective user experience. A systematic literature review (SLR) was conducted following the PRISMA approach using three databases: Scopus, IEEE Xplore, and Web of Science. A total of 90

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records were identified, with 62 remaining after duplicate removal. Following title, abstract, and full-text screening, 24 studies were included for analysis. The findings reveal four dominant themes: assistive navigation and spatial awareness, multisensory interaction, affective and adaptive interaction, and AR-based accessibility enhancement. Despite advancements in each area, the results indicate a lack of integration across these components. Based on these findings, this study proposes a conceptual direction towards an Interfusion Augmented Reality Model (IARM), which emphasizes the integration of immersive, assistive, affective, and AR elements to enhance visually impaired interaction experiences. This study contributes to the development of unified and user-centred AR accessibility frameworks by integrating immersive, assistive, affective, and interaction-oriented design components into a single conceptual direction through the proposed Interfusion Augmented Reality Model (IARM). The framework provides a structured reference for researchers, designers, and developers in designing more holistic, adaptive, and multisensory AR interaction experiences for visually impaired users.

**Keyword:**

Augmented Reality, Assistive Technology, Affective Design Immersive Environment, Interaction Experience, Visually Impaired

## Introduction

Visual impairment significantly affects an individual's ability to interact with their surroundings, limiting mobility, accessibility, interaction quality and user well-being. Emerging technologies such as augmented reality (AR), virtual reality (VR), and mixed reality (MR) have introduced new possibilities for enhancing interaction experiences through immersive and assistive systems (Maman et al., 2025). Among these technologies, Augmented Reality (AR) has gained increasing attention due to its ability to overlay digital information onto real-world environments, enabling real-time interaction and contextual augmentation. Previous studies have demonstrated the potential of AR-based systems in supporting navigation, object recognition, and environmental awareness for visually impaired users through audio, haptic, and visual feedback mechanisms. Several studies have explored the application of AR to aid visually impaired individuals in various contexts. For instance, (Huang et al., 2019) developed a prototype software application to assist visually impaired users with sign-reading using consumer head-mounted AR devices.

AR enables interactive experiences where real-world objects are enhanced through computer-generated perceptual information. This technology has positively influenced different fields, such as industry, entertainment, medicine, tourism, and others (Garzón, 2021). Recent studies have explored various approaches, including AR-based navigation systems (Annamalai et al., 2025), spatial audio interaction (Cossovich et al., 2023) and multisensory feedback systems (Paananen et al., 2022). Over the past decade, AR technologies have evolved significantly across various application domains within the Information and Communication Technology (ICT) field. Initially associated with the technological advancement of Industrial Revolution 4.0 (IR 4.0), AR systems primarily focused on visual augmentation and digital interaction. However, the transition towards Industrial Revolution 5.0 (IR 5.0) has shifted emphasis towards human-centred interaction, inclusivity, and personalized user experiences. In this context, AR is increasingly conceptualized as a form of "Augmented Perception," where environmental information can be translated into spatial audio, haptic feedback, and multisensory interaction to support accessibility and immersive interaction experiences for visually impaired users.

While these technologies demonstrate promising outcomes, existing solutions remain fragmented. Some focus solely on visual enhancement, while others emphasize auditory or haptic feedback without integration across modalities. Furthermore, emerging research highlights the importance of adaptive and personalized interaction, particularly through conversational systems and artificial intelligence (AI) (Sherly & Velvizhy, 2024). However, such approaches are rarely integrated with AR-based assistive technologies, limiting their effectiveness in supporting holistic and user-centred interaction experiences within real-world environments. This allows users to "feel" or "hear" their environment rather than just seeing it through a screen which enables visually impaired users to perceive environmental information through non-visual sensory channels, thereby extending interaction beyond conventional screen-based visual augmentation.

Despite recent advancements, existing AR accessibility research for visually impaired users remains highly fragmented across multiple domains, including navigation assistance, visual enhancement, multisensory interaction, and adaptive conversational systems. Existing AR accessibility studies predominantly focus on isolated technical functionalities rather than integrated accessibility experiences. Most existing studies emphasize isolated functional capabilities such as obstacle detection, spatial navigation, or visual augmentation without integrating these interaction dimensions into a cohesive accessibility framework. Furthermore, current AR systems predominantly prioritize technical and functional performance while giving limited attention to affective interaction aspects such as emotional engagement, interaction comfort, personalization, and user-centred experiences. Existing reviews also tend to examine AR accessibility components independently rather than synthesizing immersive, assistive, affective, and augmented interaction perspectives into a unified conceptual direction. As a result, there remains a lack of an integrated AR accessibility framework that holistically addresses both functional and affective interaction needs for visually impaired users.

This study is among the first to synthesize AR accessibility research through an integrated affective-interaction perspective by combining immersive environment, assistive technology, affective design, and augmented reality components into a unified conceptual direction known as the Interfusion Augmented Reality Model (IARM). Unlike previous studies that primarily focus on isolated technical functionalities, this study emphasizes holistic and user-centred interaction experiences that integrate multisensory interaction, spatial awareness, adaptive interaction, and emotional engagement for visually impaired users. This study contributes to AR accessibility research through an integrated affective-interaction perspective by combining immersive environment, assistive technology, affective design, and augmented reality

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131

components into a unified conceptual direction known as the Interfusion Augmented Reality Model (IARM).

**Methodology**

A systematic literature review is a method for tracking down, analysing and interpreting all available research pertinent to a specific research question, topic area or phenomenon of interest. It is a process of identifying, assessing, and interpreting all available research evidence, to provide answers for a particular research question (Kitchenham, 2007) This study adopts a systematic literature review (SLR) approach guided by the PRISMA framework and follows a comprehensive search strategy to identify relevant references that contribute to understanding of AR for visual impairment to ensure a structured, transparent, and reproducible process analysis of existing research. In accordance with Kitchenham and Charters SLR guidelines, there are three primary stages includes planning review, conduction review and reporting results as illustrated in Figure 1.

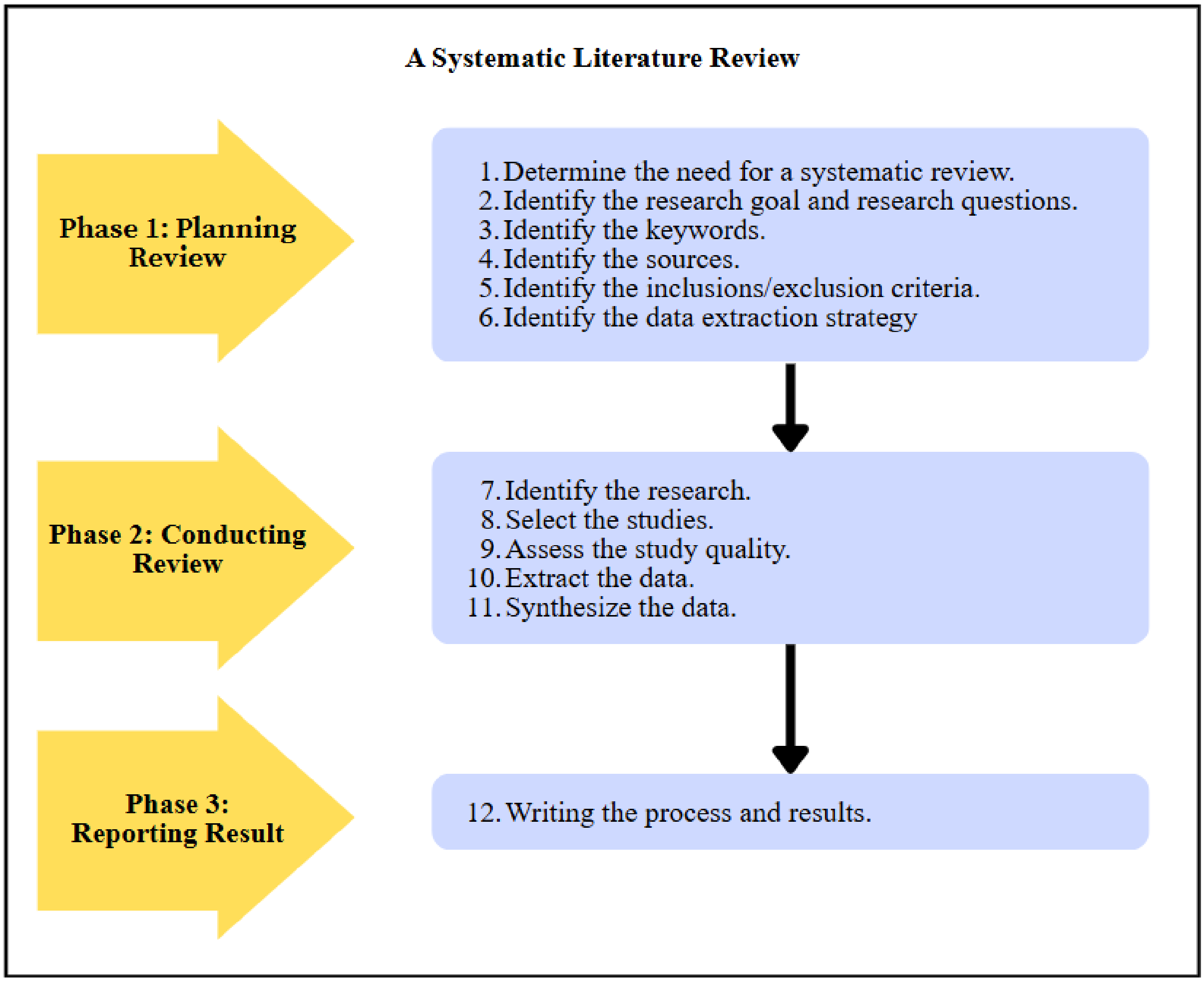


**Figure 1: Overview of SLR Phases**

***Review Planning***

The systematic literature review was conducted in three main phases: planning review, conducting the review and reporting the findings. This structured approach ensures methodological rigor and traceability from study selection to data synthesis. In this planning phase, research question, objective, keyword and resources and selection criteria are determined. The planning step comprised selecting a topic, formulating research questions, and developing a protocol for this SLR. This study research questions are formulated as the following:

RQ1: What are the existing AR models and applications developed for visually impaired interaction?
RQ2: What components, elements, and design principles are used in AR systems for visually impaired users?
RQ3: What are the limitations and research gaps in current AR approaches for visually impaired interaction?

***Keyword and Search Strategy***

Based on the research question, keywords have been determined. Relevant studies were identified from three major academic databases: Scopus, IEEE Xplore, and Web of Science. The search strategy included keywords related to augmented reality, visually impaired users, assistive technology, and immersive interaction. The search process employed combinations of keywords related to augmented reality and visual impairment as shown in Table 1 below.

**Table 1: Search String**

| Databases | Search String |
|---|---|
| Scopus | (TITLE-ABS-KEY ( "visually impaired" OR blind OR "low vision" ) ) AND ( TITLE-ABS-KEY ( "augmented reality" OR AR OR XR OR "mixed reality" ) ) AND ( TITLE-ABS-KEY ( assistive OR accessibility OR navigation OR haptic OR audio OR multisensory OR "non-visual" ) ) AND ( TITLE-ABS-KEY ( affective OR emotion* OR engagement OR immersive OR presence OR empathy ) ) AND ( PUBYEAR > 2019 AND PUBYEAR < 2026 ) |
| Web of Science | TS=("visually impaired" OR blind OR "low vision") AND TS=("augmented reality" OR AR OR XR OR "mixed reality") AND TS=(assistive OR accessibility OR navigation OR haptic OR audio OR multisensory OR "non-visual") AND TS=(affective OR emotion* OR engagement OR immersive OR presence OR empathy) AND PY=(2020-2025) |
| IEEE Xplore | ("visually impaired" OR blind OR "low vision") AND ("augmented reality" OR AR OR XR OR "mixed reality") AND (assistive OR accessibility OR navigation OR haptic OR audio OR multisensory OR "non-visual") AND (affective |

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131

| | |
|---|---|
| | OR emotion* OR engagement OR immersive OR presence OR empathy) |

### *Inclusion and Exclusion Criteria*

The review primarily focused on the existing literature published between 2020 and 2025, 5 years to ensure the relevance to current technological developments. Three major academic databases including Scopus, Web of Science and IEEE Xplore was chosen. This study does not include secondary sources as it is aimed to provide a comprehensive, unbiased, and rigorous analysis of existing literature. Therefore, only primary sources are included to ensure the accuracy and dependability of the study.  The inclusion and exclusion standard for this SLR have two tiers which depends on the listed criteria, all papers are either included or excluded at first level and after reviewing the full text of the papers, any papers that do not appear to be relevant to the study were eliminated at the second level. Studies were selected based on the following criteria:

Inclusion Criteria:
1. Focus on AR-related applications for visually impaired users.
2. Written in English
3. Full-text accessible
4. Published between 2020 to 2025
5. Studies focusing on visually impaired users aged 18 years and above.

Exclusion Criteria:
1. Not related to AR or visually impaired interaction
2. Duplicate studies
3. Inaccessible full-text articles
4. Studies published before 2020.
5. Studies targeting children or early-age learners.

Although this review focuses on augmented reality–based interaction for visually impaired users, selected studies employing XR or mixed reality were included where the interaction mechanisms, sensory modalities, and design rationales were directly transferable to AR-based systems. XR and MR studies were selectively included not for their technological classification, but for their transferable interaction design knowledge. Only interaction mechanisms and design principles applicable to AR systems were extracted, while technology-specific implementations were excluded.

### *Study Selection Process*

The study selection process was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, rigor, and replicability of the review process. The selection procedure involved multiple stages to systematically identify, screen, and include relevant studies aligned with the objectives of this design-oriented systematic literature review. Initially, comprehensive searches were performed across the selected databases, namely Scopus, Web of Science, and the IEEE Xplore, using the predefined search strings described in Table 1 above.  All records retrieved from the databases were exported into a reference management tool to facilitate

Journal of Information System and Technology Management
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Volume 11 Issue 43 (June 2026) PP 112-131

organisation and screening. Duplicate records were identified and removed prior to the screening process. Following deduplication, a two-stage screening process was employed.

The final set of studies included in the review comprised papers that met all inclusion criteria and demonstrated relevance to the extraction of interaction components, elements, design principles, and design guidelines. The complete study selection process, including the number of 90 records identified, screened, excluded, and included at each stage, is illustrated using a PRISMA 2020 flow diagram in Figure 2. This structured selection approach ensured that the included studies offered a reliable and relevant foundation for subsequent data extraction and synthesis, supporting the development of the Interfusion Augmented Reality Model (IARM).

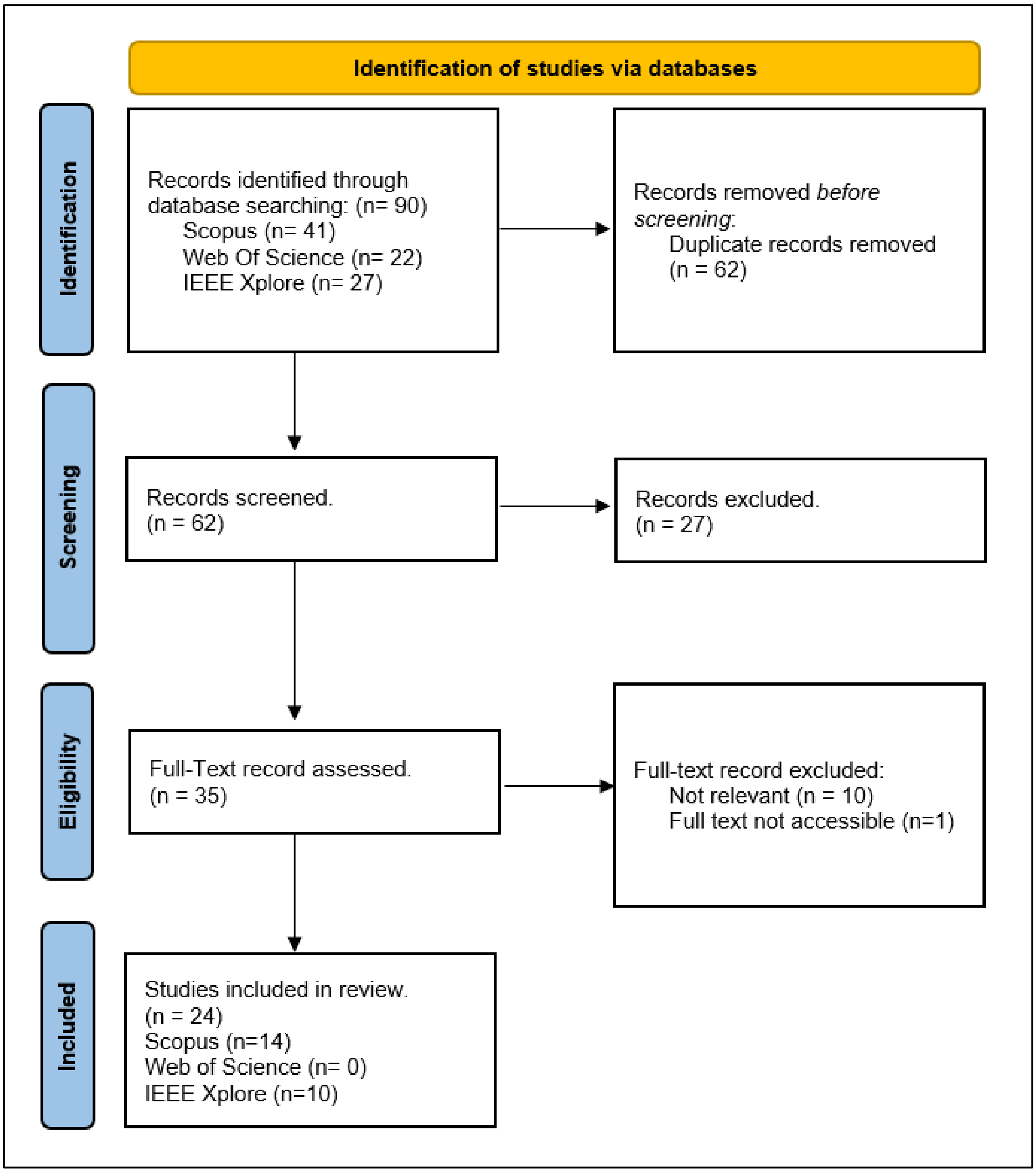


**Figure 2: PRISMA Flow Diagram of The Study Selection Process.**

Journal of Information System and Technology Management
JISTM
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Volume 11 Issue 43 (June 2026) PP 112-131
Figure 2 presents the PRISMA flow diagram of the study selection process. A total of 90 records were identified, consisting of 41 from Scopus, 27 from IEEE, and 22 from Web of Science. After removing duplicates (n = 28), 62 records remained for title and abstract screening. Following the screening process, 35 studies were selected for full-text assessment. After applying inclusion and exclusion criteria, 24 studies were included in the final analysis, comprising 14 studies from Scopus and 10 from IEEE. No studies from Web of Science met the inclusion criteria after full-text screening due to lack of relevance or inaccessible full text. Therefore, all Web of Science papers were excluded after full-text screening due to lack of relevance and inaccessible full text, ensuring only high-quality and relevant studies were included. This multi-stage filtering process ensured that only studies with direct relevance to AR-based interaction for visually impaired users and sufficient methodological quality were included in the analysis.

***Selected Studies***

Table 2 presents the summary of the 24 selected studies included in this review. The studies cover a range of AR, VR, and mixed reality applications for visually impaired interaction, spanning domains such as navigation, accessibility, education, and interaction systems.

**Table 2: Summary of Selected Studies Included in the Review**

| Paper ID | Title (Shortened) | AR Type | Application Domain | Interaction Modality | Key Contribution |
|---|---|---|---|---|---|
| P1 | Audio-First Metaverse for VI | VR/Metaverse | Social Interaction | Audio + Haptic | Non-visual immersive interaction |
| P2 | AR Navigation with IoT & RL | AR | Navigation | Audio + Haptic | Adaptive navigation system |
| P3 | Interfusion AR Concept Study | AR | Conceptual | Multimodal | Foundation of IARM |
| P4 | AR Obstacle Visibility | AR | Mobility | Visual | Object highlighting for navigation |
| P5 | MR for Color Vision Impairment | MR | Accessibility | Visual + Text | Color recognition support |
| P6 | RGB Filter in Metaverse | VR/MR | Accessibility | Visual | Color enhancement filters |
| P7 | Binaural Audio Navigation AR | AR | Navigation | Audio | Spatial audio navigation |
| P8 | Sound Design for Accessibility | XR | Cultural Experience | Audio | Immersive sound-based access |
| P9 | Acoustic Shorelining Navigation | AR | Navigation | Audio | Spatial audio path guidance |

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131

| Paper ID | Title (Shortened) | AR Type | Application Domain | Interaction Modality | Key Contribution |
|---|---|---|---|---|---|
| P10 | SLAM-Based Obstacle Detection | AR | Navigation | Audio + Haptic | Real-time hazard detection |
| P11 | Conversational Audio VR | VR + AI | Interaction | Conversational | Personalized scene description |
| P12 | AR Education for VI Students | AR | Education | Visual | OCR + AR learning support |
| P13 | Mixed Reality Cane System | MR | Navigation | Audio + Haptic | Cane-based interaction system |
| P14 | Object Detection with Audio | CV/AR | Recognition | Audio + Visual | Real-time object recognition |
| P15 | Boundary Awareness in VR | VR | Safety | Audio + Haptic | Boundary detection cues |
| P16 | Drone Acoustic Interaction | XR | Interaction | Audio | Non-visual drone communication |
| P17 | Ambisonics Audio Processing | XR | Audio Processing | Audio | Spatial audio modelling |
| P18 | Reverberation Estimation | XR | Audio Processing | Audio | Sound environment analysis |
| P19 | Beamforming Audio System | XR | Audio Processing | Audio | Speech enhancement |
| P20 | MR Accessibility System | MR | Interaction | Multimodal | Mixed reality interaction |
| P21 | AR Text Recognition System | AR | Accessibility | Visual + Audio | Text-to-speech integration |
| P22 | Visual TTS Model | AI + XR | Interaction | Audio | Context-aware speech synthesis |
| P23 | AR-Based Interaction System | AR | General | Multimodal | Integrated interaction design |
| P24 | Audio Navigation Evaluation | AR | Navigation | Audio | Efficiency of audio guidance |

The analysis shows that most studies focus on specific functionalities, including navigation support, multisensory interaction, and visual enhancement, with interaction modalities primarily involving audio, haptic, and visual feedback. This diversity of approaches highlights both the richness of the field and the lack of integration across system components.

***Data Extraction and Synthesis***

Data extraction was conducted using a structured framework aligned with the research questions. Each selected study was analysed to extract data includes type of AR application, system components and features, interaction methods, design principles and identified

Journal of Information System and Technology Management JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131
limitations which the studies were then categorized into key themes. The extracted data were not analysed independently. Instead, an iterative synthesis was applied. First, extracted data were coded into comparable categories across studies and similar patterns were grouped to identify recurring concepts. The grouped patterns were then abstracted into higher -level themes through thematic synthesis. Data extraction was conducted systematically to ensure consistency and alignment with the research questions. Table 3 shows the framework of data extraction.

**Table 3: Data Extraction Framework**

| Category | Description | Related RQ | Purpose |
|---|---|---|---|
| AR Application Type | Type of AR system (navigation, learning, object detection) | RQ1 | Identify existing AR applications |
| Components | Core system modules (AR, audio, haptic, AI, SLAM) | RQ2 | Identify building blocks for IARM |
| Elements | Specific features (TTS, contrast, object detection, spatial audio) | RQ2 | Detail implementation aspects |
| Interaction Method | Mode of interaction (visual, audio, haptic, conversational) | RQ2 | Understand interaction patterns |
| Design Principles | Accessibility, usability, real-time, multisensory, adaptability | RQ2 | Extract design guidelines |
| Key Contribution | Main function/innovation of the system | RQ1 | Understand role of each study |
| Limitations | Weaknesses and gaps in system | RQ3 | Identify research gaps |

Based on the guidelines by Kitchenham and Charters, relevant data were extracted from each selected study to ensure consistency and analytical rigor. The extraction process captured key aspects of AR-based systems for visually impaired interaction, including application types, system components, interaction methods, design principles, and identified limitations. Each extracted category was explicitly mapped to the research questions. Specifically, AR application types and key contributions address RQ1, components, elements, interaction methods, and design principles address RQ2, while system limitations address RQ3.

This structured approach ensures that the analysis systematically identifies existing solutions, extracts essential design knowledge, and highlights critical research gaps in current AR systems for visually impaired users. The extracted data were further synthesised to identify recurring patterns and relationships, forming the basis for thematic analysis, and supporting the conceptual development of an integrated AR framework.

## Result and Findings

### *Overview of Included Studies*

The final dataset consists of 24 studies, covering a range of AR and immersive technologies applied to visually impaired interaction. The studies vary in application domain, interaction

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131
modality, and technological implementation, reflecting the multidisciplinary nature of the field. The diversity of approaches highlights both the richness of the field and the lack of standardization across system design.

***Thematic Synthesis***

The thematic synthesis was conducted to analyse the extracted data through recurring pattern across the selected studies by categorising and iterative coding resulting four dominant themes emerged, representing the key dimensions of AR-based interaction for visually impaired users.

***Theme 1: Assistive Navigation and Spatial Awareness***

Several studies focus on enhancing mobility and navigation for visually impaired users through AR and sensor-based technologies. These systems incorporate depth detection, spatial mapping, and obstacle recognition to improve environmental awareness. While these approaches effectively support functional navigation, they primarily emphasize task performance without considering adaptive or emotional interaction. These systems primarily emphasize functional performance, focusing on task completion rather than holistic interaction experiences.

***Theme 2: Multisensory Interaction***

Building upon navigation-focused system, multisensory approaches extend interaction beyond visual enhancement by leveraging alternative sensory channels. Multisensory interaction has been widely explored through the use of auditory and haptic feedback as alternatives to visual perception. Spatial audio, vibrotactile cues, and cane-based interaction enable users to perceive and interpret their surroundings. Although these systems demonstrate improved spatial understanding, they are often limited to specific modalities and lack integration with AR-based visual enhancements.

***Theme 3: Affective and Adaptive Interaction***

In contrast to functional and sensory-driven approaches, this theme introduces user-centered and experience-driven interaction. Emerging studies introduce affective and adaptive interaction through conversational systems and artificial intelligence. These approaches allow personalized and context-aware interaction, enhancing user engagement and experience. However, such systems are rarely integrated with navigation or AR-based assistive technologies, resulting in isolated implementations.

***Theme 4: AR-Based Accessibility Enhancement***

While effective for low-vision users, these approaches remain largely visual-centric and do not leverage the full potential of multimodal interaction. AR-based solutions primarily focus on enhancing visual accessibility, including object highlighting, text enlargement, and contrast adjustment. These techniques improve readability and perception for low-vision users. However, most implementations rely solely on visual augmentation and do not incorporate multisensory or affective elements. Although each theme demonstrates significant advancements, the analysis reveals that these approaches are largely developed in isolation. Navigation systems focus on spatial awareness, multisensory systems emphasize alternative

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 11 Issue 43 (June 2026) PP 112-131
perception, adaptive systems introduce personalization, and AR enhancement targets visual clarity.

However, there is minimal integration across these dimensions. This fragmentation indicates that current AR systems do not provide a holistic interaction experience. Instead, they address specific problems independently, resulting in limited scalability and reduced real-world applicability. Furthermore, affective, and adaptive interaction remains underexplored in combination with AR-based assistive systems, highlighting a critical gap in current research. The synthesis of findings across the reviewed studies revealed recurring interaction dimensions involving spatial awareness, multisensory augmentation, adaptive interaction, and accessibility enhancement. Although these dimensions contribute significantly to visually impaired interaction support, they are predominantly implemented as isolated functionalities rather than interconnected accessibility experiences. This recurring fragmentation highlights the need for a more unified conceptual direction capable of integrating these dimensions into a cohesive and user-centred interaction framework.

The findings from the thematic synthesis provide a clear foundation for the development of the Interfusion Augmented Reality Model (IARM). The identified themes correspond to key interaction dimensions, including spatial awareness, sensory augmentation, adaptive interaction, and visual enhancement. These dimensions are not independent but interconnected. Therefore, the proposed IARM aims to integrate these components into a unified framework, addressing the fragmentation observed in existing systems. Building upon this synthesis, the identified themes not only highlight the current landscape of AR-based interaction for visually impaired users but also provide a structured basis for addressing the research questions. While the themes describe the key dimensions and patterns observed across the studies, further interpretation is required to systematically analyse these findings in relation to the research objectives. Therefore, the following section synthesises the thematic results to provide focused answers to RQ1, RQ2, and RQ3

***RQ1: What are the existing AR models and applications developed for visually impaired interaction?***

***Existing AR Applications for Visually Impaired Interaction***

The reviewed studies show that AR applications for visually impaired interaction are concentrated in a limited number of functional domains, rather than representing a broad, mature, and unified ecosystem. Across the selected studies, the most common application areas were navigation and obstacle avoidance, visual enhancement for low-vision users, educational accessibility, multisensory environmental exploration, and conversational or adaptive scene description. This suggests that AR research for visually impaired users is still strongly driven by task-specific problem solving rather than by a comprehensive interaction framework. Table 4 shows the AR application categories for visually impaired interaction.

**Table 4: Categories of AR Applications for Visually Impaired Interaction**

| Application Domain | Purpose | Paper ID | Key Contribution |
|---|---|---|---|
| Navigation & obstacle avoidance | Enhance mobility and safety | P2,P6,P9,P11,P12, P16,P18,P21,P22,P23 | Real-time spatial awareness and guidance |

| | | | |
|---|---|---|---|
| Visual enhancement | Improve perception for low vision | P1,P3,P4,P12,P17, P20 | Context-aware visual augmentation |
| Educational Accessibility | Support reading and learning | P20,P3 | Information access through AR |
| Multisensory Interaction | Enable non-visual perception | P5,P7,P8,P13,P14, P15,P18,P21,P22,P 23 | Audi-haptic interaction |
| Adaptive/Conversatio nal system | Provide personalised interaction | P10, P19 | AI-driven user centered experience |

A major category of application is navigation support. In this area, AR is used to improve environmental awareness, route following, and obstacle detection. For example, a mobile AR system based on SLAM and depth estimation was developed to identify obstacles and cliffs in real time using commodity mobile devices, while providing audio and haptic warnings to support safer mobility. Similarly, the acoustic shore lining study evaluated how spatial-audio cues can guide blind and low-vision users through path-following tasks, showing that spatial auditory cues can support faster and smoother navigation than conventional spoken instructions. These studies indicate that AR is not limited to visual overlay alone but can also act as a framework for spatially aware assistive interaction.

A second major category is visual enhancement for low-vision users. In these studies, AR is used to increase the salience of important environmental or textual information. The low-vision mobility study demonstrated that AR-based obstacle highlighting significantly reduced walking time and path length while improving confidence and safety during real-world obstacle-course navigation. The study is particularly important because it shows that AR can support low-vision users not by replacing perception, but by selectively enhancing it in context. This aligns with a functional, user-centered view of AR as an augmentation layer rather than a purely immersive display.

A third category is educational and reading accessibility. AR has also been used to support visually impaired students in classroom environments by capturing board content, extracting text, and re-rendering it in readable forms through digital augmentation. This type of application extends AR beyond mobility into learning support, showing that visually impaired interaction is not limited to orientation and navigation but also includes information access, academic participation, and environmental comprehension.

Another important category is multisensory and embodied exploration. In these studies, users interact with virtual or mixed environments through audio and haptic feedback rather than visual reliance. For instance, the mixed reality cane system used mobile AR tracking and virtual interaction to allow visually impaired users to explore virtual spaces using audio and vibrotactile cues. This expands the definition of AR-related interaction by showing that the "augmentation" may occur through non-visual sensory channels rather than through graphical overlays alone.

Finally, there is an emerging category of adaptive and conversational systems. The personalized conversational audio description system for blind and low-vision users illustrates a shift from static accessibility support to dynamic, user-driven interaction. The system captures a head-

pose-aligned scene snapshot, processes spoken questions, and generates AI-based spoken responses tailored to user preferences and interaction history, creating a more personalized and affective interaction experiences. This is especially relevant because it introduces adaptive and emotional dimensions that are largely absent from more conventional assistive AR systems.
Taken together, the evidence suggests that current AR applications for visually impaired users can be grouped into several functional domains, but these domains remain largely disconnected. Most applications are designed to solve one problem at a time, such as navigation, reading, obstacle detection, or description generation. This fragmentation becomes the first major foundation for the need for IARM.

***RQ2: What components, elements, and design principles are used in AR systems for visually impaired users?***

***Components, Elements and Design Principles***

The analysis of the selected studies reveals a recurring set of core components, interaction elements, and design principles that underpin AR systems for visually impaired users. These layers collectively define how such systems are designed and implemented. The components, element and design principles are as represented in the following Table 5.

**Table 5: Components, Elements and Design Principles.**

| Level | Description | Paper ID |
| --- | --- | --- |
| **Components** | AR core, spatial understanding (SLAM), audio, haptic, AI/adaptive systems | P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24 |
| **Elements** | Obstacle detection, object recognition, spatial audio, vibrotactile feedback, OCR, text-to-speech (TTS), contrast enhancement, conversational interaction | P2, P6, P9, P11, P12, P13, P14, P16, P17, P18, P19, P20, P21, P22, P23, P24 |
| **Design Principles** | Accessibility, real-time interaction, multisensory integration, user-centered design, adaptability | P1, P3, P4, P5, P7, P8, P10, P13, P14, P15, P19, P20, P21 |

At the component level, AR system typically consists of spatial understanding components, assistive components, audio components, haptic components and adaptive or AI components. These components demonstrate the AR systems for VI users are inherently multimodal even when not explicitly designed as integrated systems. At the implementation level, system incorporate specific elements such as obstacle detection and classification, depth-map generation, and spatial segmentation, spatialised audio cues, voice input and conversational interfaces, text-to-speech streaming, visual highlighting and contrast enhancement, OC4-based text extraction and user preference modelling. These elements represent the operational mechanism through which system components are realised.

Across the reviewed studies, several design principles emerge consistently such as accessibility and usability which are fundamental to ensure that system are easy to use, practical and aligned with user needs (Koulouris et al., 2025) Real-time responsiveness design principles are also critical as most systems rely on continuous environmental feedback and immediate interaction

Journal of Information System and Technology Management
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loops (Dang & Lee, 2025; Koulouris et al., 2025) Multisensory interaction principles is widely adopted combining audio, haptic, and visual cues to enhance perception and interaction (Zhang et al., 2020; Zhu et al., 2025) In addition, the user-centered design principles is emphasized in systems that incorporate personalisation and adaptive interaction particularly in AI-driven approaches (Dang & Lee, 2025).

***RQ3: What are the limitations and research gaps in current AR approaches for visually impaired interaction?***

### *Limitations and Research Gaps*

Despite significant advancements, several critical limitations are consistently observed across the reviewed studies. The most prominent issue is the fragmentation of system design. Most studies focus on isolated functionalities, such as navigation, visual enhancement, or conversational interaction, without integrating these components into a cohesive system (Gregg et al., 2022; Janapati et al., 2024). For example, navigation systems based on SLAM provide strong spatial awareness but lack adaptive or affective interaction capabilities (Koulouris et al., 2025) while conversational systems provide personalization but are not integrated with real-world AR navigation (Dang & Lee, 2025) These limitations and research gaps are as illustrated in Table 6 below.

**Table 6: Identified Limitations and Research Gaps**

| Limitation | Description | Paper ID |
|---|---|---|
| Fragmentation | Systems focus on single function | (Paper I20; Paper I11) |
| Lack of personalization | Limited adaptive interaction | (Paper I11) |
| Hardware constraints | Dependence on device setup | (Paper I20) |
| Weak multisensory integration | Limited robustness of audio/haptic | (Paper I24) |
| Limited validation | Controlled testing environments | Multiple studies |

Another key limitation is the lack of personalization and affective interaction. While adaptive systems are emerging, most AR applications remain task-oriented and do not consider emotional engagement, user preferences, or interaction experiences. (Gregg et al., 2022; Koulouris et al., 2025) Hardware and usability constraints also present challenges. Some systems require specific device positioning, wearable technologies, or controlled environments, which may limit real-world applicability (Koulouris et al., 2025)

Additionally, multisensory integration remains incomplete. While many systems incorporate audio or haptic feedback, these modalities are not always fully integrated or optimized. For instance, spatial-audio rendering in AR environments may not yet match real-world auditory perception (Nguyen et al., 2023) Finally, limited real-user validation is observed in some

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studies, where systems are tested under controlled conditions or with non-target participants, reducing ecological validity(Guarese et al., 2023).

***Implication for conceptual Interfusion AR Model Development***

The findings from RQ1–RQ3 collectively highlight that current AR systems for visually impaired interaction provide valuable but partial solutions. Each system contributes to a specific aspect of interaction, such as spatial awareness, sensory augmentation, or adaptive interaction, but fails to integrate these aspects into a unified experience. This fragmentation suggests the need for an integrated framework that combines sensory augmentation such audio, haptic and visual, spatial understanding such as environmental mapping and perception, interaction integration such as real-time feedback and user-system interaction and adaptive user experience which emphasize personalisation and affective interaction. These SLR findings are mapped toward the interfusion AR model needs illustrated in the Table 7 below.

**Table 7: Identified Limitations and Research Gaps**

| SLR Finding | Implication |
|---|---|
| AR systems are task-specific | Need unified framework |
| Multisensory elements exist | Need integration across modalities |
| Adaptive systems are isolated | Need affective integration |
| Design principles are fragmented | Need structured model |

The systematic synthesis of these findings demonstrates that while individual components of visually impaired interaction are well explored, their integration remains underdeveloped. This directly motivates the need for a comprehensive framework that unifies these components into a cohesive interaction model.

**Discussion**

The findings indicate that existing research in AR and immersive technologies for visually impaired interaction is highly fragmented. While significant progress has been made in individual domains such as navigation, multisensory feedback, and adaptive interaction, these components are often developed independently. This fragmentation highlights the need for a unified framework that integrates multiple interaction dimensions. A holistic approach that combines assistive, immersive, affective, and augmented reality components is essential to enhance interaction accessibility, user engagement, and interaction effectiveness. Based on the identified gaps, this study proposes a conceptual direction towards an Interfusion Augmented Reality Model (IARM) as illustrated in Figure3 below.

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JISTM
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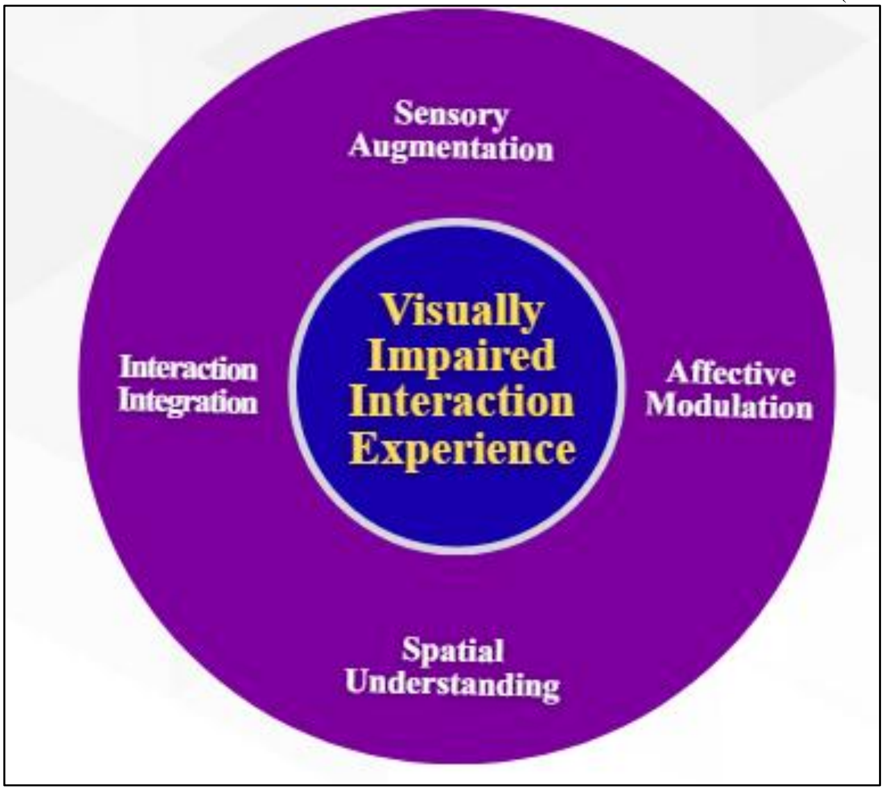


**Figure 3: Conceptual of Interfusion Augmented Reality (IARM) Model for Visually Impaired Interaction Experience**

The model emphasizes the integration of multiple components, including sensory augmentation, spatial understanding, interaction mechanisms, and adaptive user experience. Unlike existing systems that focus on isolated functionalities, the concept of interfusion highlights the continuous interaction between these components to create a cohesive and user-centered experience. This model serves as a foundational framework for future research and development in assistive AR systems for visually impaired users. The proposed IARM framework is conceptually grounded in affective design principles, user-centred design perspectives, and immersive interaction theory. From an affective design perspective, emotional engagement, interaction comfort, and personalized accessibility experiences are considered essential in enhancing interaction quality for visually impaired users. In parallel, user-centred design emphasizes the importance of aligning interaction systems with users' sensory, cognitive, and accessibility requirements rather than focusing solely on technical functionality. Furthermore, immersive interaction theory supports the integration of multisensory feedback, spatial interaction, and environmental engagement to create more meaningful and accessible AR interaction experiences. These theoretical perspectives collectively strengthen the conceptual foundation of the proposed IARM framework.

## Conclusion

This study systematically reviewed AR and immersive technologies for visually impaired interaction and identified key themes and gaps in existing research. The findings reveal a lack of integration across assistive, immersive, affective, and AR components. To address this limitation, this paper proposes a conceptual direction towards an Interfusion Augmented Reality Model (IARM), which aims to unify these components into a comprehensive interaction framework. Future work will focus on developing and validating the model to enhance accessibility and user experience for visually impaired individuals.

| | |
|---|---|
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