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Technical Section

Menu user interface design for Head-mounted display Virtual Reality: A systematic literature review☆

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ABSTRACT

Head-mounted display (HMD) Virtual Reality (VR) has seen significant developments in recent years. The tech is finally being adopted by millions of consumers worldwide. System control through menu interfaces is crucial in VR for task completion. Unlike traditional two-dimensional (2D) devices, HMD-VR allows six degrees of freedom (DoF) interaction and navigation in three-dimensional (3D) and 360° virtual environments (VEs). This makes designing and placing user interface (UI) elements in VEs challenging because there is no apparent surface or boundary in VE to place UI elements like menus. Over the recent years, VR app stores have seen the introduction of numerous VR applications. However, there is a notable lack of guidance for designers and developers on designing and integrating crucial UI components, such as menus, for HMD-VR applications. This paper presents a systematic literature review of HMD-VR menu UIs. A total of 33 studies from Scopus and Web of Science databases published in English between 2012–2024 were identified using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Results describe (a) key factors that are considered when designing and evaluating menus for HMD-VR, (b) state-of-the-art on types of menu UI based on integration, and (c) study-specific design guidelines proposed on menus for HMD-VR. Furthermore, we propose synthesized, context-aware recommendations to inform future menu UI development. By bridging research insights with practical design implications, this review aims to support the creation of more usable, immersive, and goal-oriented VR interfaces.

1. Introduction

Virtual Reality (VR) is one of the emerging technologies that facilitates interaction with computer-generated experiences, which causes our brains to believe as if this computer-generated virtual environment (VE) is the real one [1]. According to Bowman and Hodges [2], in VEs, system control is one of the four universal user interactions; the others are selection, manipulation, and navigation. System controls are commands that users send to the application to complete tasks in given environments or to modify the mode of interaction and system state. The authors note that menus are one of the most common system control techniques. Jeong et al. [3] define menu as a simple term for an interface that allows the user to navigate between items and choose a specific item. A menu is a method of informing users of various alternatives and allowing them to navigate swiftly. Control components, such as menus, are identified to be the best way to make functions, modes, and data easily available [4].

Menus were first developed as part of the WIMP (windows, icons, menus, and pointer) paradigm for 2D desktop-based systems by Xerox PARC during the 1970s [5]. They were popularized by Apple Macintosh in 1984 and later incorporated into Windows GUI by Microsoft for their personal computers. Modern GUI systems in use today, like Apple's macOS, Microsoft's Windows, Linux, Android, are based on the 2D WIMP system. UIs in touchscreen devices like smartphones and tablets use WIMP elements, but due to the change in interaction techniques, they have been categorized as post-WIMP interfaces [5].

In contrast to traditional 2D devices such as personal computers or smartphones, VR allows users to explore 3D and 360° VEs that closely mimic our real world. This property of VR systems makes it challenging to design and position menu UI for effective and comfortable user interaction because, unlike 2D systems, there is no apparent surface or boundary in VE to place UI elements [4,6]. Furthermore, VR systems immerse users by surrounding them in a VE, isolating them from the real world, a phenomenon known as *immersion* [7]. Immersion exists in varying degrees from low to high, depending on how well the sensory, interaction, and continuity elements of the VR system engage the user [8,9]. Different VR systems or experiences might provide different

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levels of immersion [10]. In fully immersive devices like HMDs, the user is completely surrounded by the VE, enabling full immersion in the VE. In addition to this, users feel a sense of *presence* in the VE, a core aspect of VR [10–12]. Mel Slater notes that the degree of immersion directly influences the strength of the place illusion, a key component of presence, with greater immersion leading to a more vivid sense of reality within the VE [10]. The properties of immersion and presence in VR make it more engaging [13], enhance the state of flow [14], and set it apart from traditional 2D display devices [10,15,16]. The latest consumer-grade VR devices are also equipped with 6-DoF controllers and real-time hand-tracking capabilities, which enable realistic interaction with elements in VE [17].

The above factors have prompted researchers to explore 3D elements, components, and real-world interactions that enhance the presence in VE. One aspect of exploring these 3D elements is the design of menu UI that leverages the potential of naturalness associated with 3D environments and real-world interactions [17–21]. In this context, natural interaction refers to design approaches that mimic how we intuitively interact with objects in the physical world, such as using hand gestures, spatial positioning, and direct manipulation [22]. These menus, therefore, offer users an experience that aligns with these natural behaviors. Regardless of whether they appear in 2D or 3D, menus serve as special UI components that are primarily used to shorten the time it takes a user to discover and access an item of interest [23]. They often involve listing multiple items while optimizing screen space for other content and aid users in constructing a mental picture of the system or better comprehending it if they are adequately designed.

In VR applications, there are two menu types: (a) listing and categorization of items on VR applications to support quick and effective navigation, e.g., an application store where multiple applications are listed and selected; and (b) display of contextual actions around virtual objects for quickly changing their current system states, e.g., changing color or texture of a selected item. Depending on their complexity and domains, VR applications require extensive usage of menu interfaces as the features, functions, and contextual needs are accessed and used by menu interfaces.

Ever since the announcement of Oculus Rift in 2012, consumer-grade HMD-VR has seen growing demand, acceptance, and a significant change in the technology in recent years [24,25]. Numerous VR applications from different industries and genres have been launched on platforms like Meta Quest and SteamVR app stores [26]. Despite this recent growth and acceptance of VR applications, there is a lack of a systematic review of the scientific literature on HMD-VR menu UIs. While extensive design guidelines have been proposed for traditional 2D systems, they may not apply to 3D UIs due to HMD-VR being different in multiple aspects from such devices [17,21,27,28]. As a result, the VR designers and developers are left without a guiding overview to create and implement efficient, intuitive, and desirable menu UIs. Designers now find that user experience (UX) and UI design are crucial concerns in designing acceptable and usable VR applications [14,29–31]. However, the lack of design guidelines for HMD-VR highlighted by recent research studies [6,21,32,33] puts them at a disadvantage. Although, Hou et al. [34] and Bao et al. [35] have proposed toolkits to automatically generate VR menu UIs in the Unity game engine that may benefit designers by providing them with quick menu solutions. The use of such a toolkit does not offer insights into various factors influencing the menu UI design or best practices for integrating menus into fully immersive VEs. These aspects are important in the user-centered design process. To address these challenges, it is essential to examine the current state of VR menus and present the state-of-the-art along with key considerations for designing and implementing them in fully immersive VEs. Therefore, this paper aims to fill this gap by reviewing the progress of HMD-VR menu UIs via the following questions:

- RQ1. What are the key factors that influence the decision-making process when designing a menu UI for HMD-VR?
- RQ2. What is the state-of-the-art exploration of menu UIs for HMD-VR based on their type of integration in 3D VEs?
- RQ3. What are the design guidelines for menu UIs for HMD-VR proposed in the scientific literature?

This paper is structured as follows: Section 2 details the methods followed to identify and analyze the data for review. This includes the search strategy, record selection, inclusion/exclusion criteria, and data extraction and synthesis. Section 3 presents the results of the reviewed literature, covering (a) the key factors researchers have considered for designing menu UIs, (b) state-of-the-art on menu UI types based on their integration, and (c) study-specific design guidelines on menu UIs for HMD-VR. Section 4 offers a discussion, synthesized design recommendations, and future research directions. Section 5 describes this study's limitations. Finally, Section 6 provides the conclusions for this study and an overview of opportunity areas.

2. Method

We performed a systematic literature review to understand the state-of-the-art menu explorations in scientific research for HMD-VR and key components that require careful consideration while designing menu interfaces for HMD-VR.

2.1. Literature selection process

In this systematic literature review, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework [36] to identify relevant literature. Both Scopus and Web of Science (WoS) databases were considered to perform a keyword search. Scientific studies published in journals and conference proceedings that are indexed in these databases were selected for this review. To keep our review comprehensive, we included broad keywords such as "user interface" and "3D UI" in our search string. In the Scopus and WoS database, the advanced search function was used. The following two different search strings were input one by one:

- **Search string 1:**
  ("virtual reality" OR "VR" OR "virtual environment*") AND
  ("HMD" OR "head-mounted display" OR "head-mounted display") AND
  ("user interface*" OR "3D UI" OR "3D user interface*")
- **Search String 2:**
  ("virtual reality" OR "VR" OR "virtual environment*") AND
  ("HMD" OR "head-mounted display" OR "head mounted display") AND
  ("menu*" OR "3D menu*")

Here, the Boolean operator "OR" was used to combine search results with similar types, and the Boolean operator "AND" was used between these keyword categories to find relevant literature on menu UI designs for HMD-VR. Document source was set to "journal" and "conference" to identify peer-reviewed articles, and language was set to "English". The time frame was limited to 2012–2024, beginning with the public reveal of the Oculus Rift development kit in 2012, which marked a turning point for consumer-grade HMD-VR systems. The emergence of Oculus Rift catalyzed much of the academic research in HMD-VR interfaces, making it a logical starting point for scholarly inquiry. So prior work conducted on different types of VR devices may not apply to our context, as they may not reflect current consumer-grade VR affordances or interface expectations. The cutoff for search was set to December 2024. No industry was specified for this study.

Although commercial products and applications may incorporate innovative menu UIs, they were not included in this systematic review for three reasons: First, commercial systems rarely publish their design rationale, technical specifications, or usability data, limiting their suitability for scientific comparison. Second, this review prioritizes

Table 1
Inclusion and exclusion criteria for the selection of literature on HMD-VR menu UI design.

Inclusion criteria	Exclusion criteria
Keywords: Virtual Reality, Head Mounted Display, and Menu	Technology-driven (focus on development, demonstration or combining of different technologies to achieve the desired goal)
Timeline: 2012–2024	Solutions for CAVE/AR/MR/web/mobile
Publication type: Journal articles and conference proceedings	Studies focused on input device/methods
Language: English	Not accessible documents

scholarly contributions that articulate design decisions or present UI guidelines—criteria that commercial products typically do not fulfill. Third, commercial applications do not undergo peer review or blind review, making it difficult to assess their scientific authenticity for inclusion in an academic review. The flowchart of the review is shown in Fig. 1.

2.2. Study records and selection

To ensure the scientific quality of studies, we selected the two most prestigious databases to identify the peer-reviewed scientific literature. By using the search queries in Scopus and Web of Science databases, 996 records were discovered, and their metadata was downloaded to a computer in electronic format. From this repository, 104 articles were excluded as they were found to be duplicates. Next, the title, abstract, and keywords were screened for the remaining 892 records. In total, 855 articles did not match the inclusion and exclusion criteria (Table 1) created for this study. Out of 855, 279 studies were excluded because they were technology-centric works, two were related to cave automatic virtual environment (CAVE) system, 162 were augmented reality (AR) or mixed reality (MR) based studies, nine were on web or desktop related, 25 were smartphone or tablet VR explorations, 52 focused mainly on input methods or devices, 16 were found to be incorrect results, and 310 studies were found to focus on HMD-VR; however, they did not provide information on menu UIs and hence were excluded.

The electronic database of identified studies was reviewed independently by both authors to minimize the risk of bias and assess their eligibility for this review. Based on the inclusion and exclusion criteria, 37 studies were initially shortlisted for inclusion in this review. Next, we conducted the full-text examination of these selected studies. At this phase, the authors also reviewed if the study included at least one menu UI design for HMD-VR, whether the research objectives were clearly defined, whether the assessment of menu UI (if conducted) was well understood, and whether the study outcomes could contribute to our learning of research questions. During the full-text reading, 14 records were further removed from this review because they did not match the selection criteria, as four studies were MR/AR explorations, one was desktop-based, another was smartphone-based, two focused on input methods, one was technology-centric, two were inaccessible, and three did not present any insights on the menu UI. Finally, 23 papers are found relevant. In addition to this, we identified 12 research papers through the cross-referencing method. During the full-text reading of these additional records, two were removed because they focused on CAVE–VR and desktop systems; hence, a total of 33 papers are considered in this review to answer the research questions. Table 2 provides an overview of the shortlisted studies, the type of publication, e.g., journal (J) or conference (C), and their alignment with our RQs.

2.3. Data extraction and synthesis

We created an Excel sheet for systematically and accurately recording relevant data from the shortlisted studies according to the research objectives. For data analysis and synthesis, we adopted a thematic synthesis approach, recognized as a suitable and widely employed method in systematic reviews for the analysis and synthesis of data [37]. To fulfill our study's research objectives, we identified recurring themes among the chosen studies and conducted an in-depth analysis of the same. The common themes included immersion and presence, graphical user interface, menu's layout and position in VE, depth of hierarchy in the menu structure, and design recommendations. The results are presented in the next section. Throughout the entire review process, both authors held multiple discussions, and any differences between the authors were settled by consensus. Both authors reviewed, amended, and approved the final version of the review.

3. Results and analysis

This section presents the outcome of the systematic literature review. Each of the three research questions is answered in the following sub-sections. We start by defining the key factors identified in the literature that influence the decision-making on designing the menu UI for HMD-VR (RQ1). Then, we present the state-of-the-art exploration of types of menu UI for HMD-VR (RQ2). Finally, we present the design guidelines proposed in the literature on menu UI for HMD-VR (RQ3). The year-wise distribution of selected studies focusing on menu UIs for HMD-VR is presented in Fig. 2.

3.1. RQ1: Key factors influencing the decision-making on designing a menu UI for HMD-VR

In this review, we have carefully examined the latest research to identify the factors that are critical when designing menu UIs for HMD-VR. Our findings indicate that factors of immersion and presence, aspects of GUI, type of UI integration in VR, and hierarchical structure of a menu are key influential factors for designing a menu UI for HMD-VR. A summary of these factors is presented in Table 3. Researchers have employed a combination of these elements when designing and evaluating their menu UIs, and each factor is discussed in detail in the following sections, addressing our RQ1.

Table 4 provides an overview of studies exploring menu UIs along with key factors considered in the literature for the design of HMD-VR menus. The check mark (✓) in this table indicates the consideration of a factor in the study (for the Aspect of GUI, 2D and 3D indicate the type of graphical user interface used in the study, even if authors have not touched upon this factor in their work in detail). The asterisk symbol (∗) in the table indicates the depth of the menu hierarchy visually identified from images in the studies when the authors did not explicitly define it. The number of menu hierarchies is represented before this symbol.

3.1.1. Immersion and presence in VR

Researchers have explored different kinds of menu UI to suggest that the choice of higher or lower immersion and presence has an impact on how the menu UI is designed. Hube and Müller [43] studied immersion and presence through a data visualization concept with 'flat-emersive' and 'spatially-immersive' characteristics. According to the authors, 'flat-emersive' provides an overview of the entire dataset from a specific position, like a 2D visualization, i.e., a flow diagram with limited data sorting methods. In comparison, presenting the same dataset

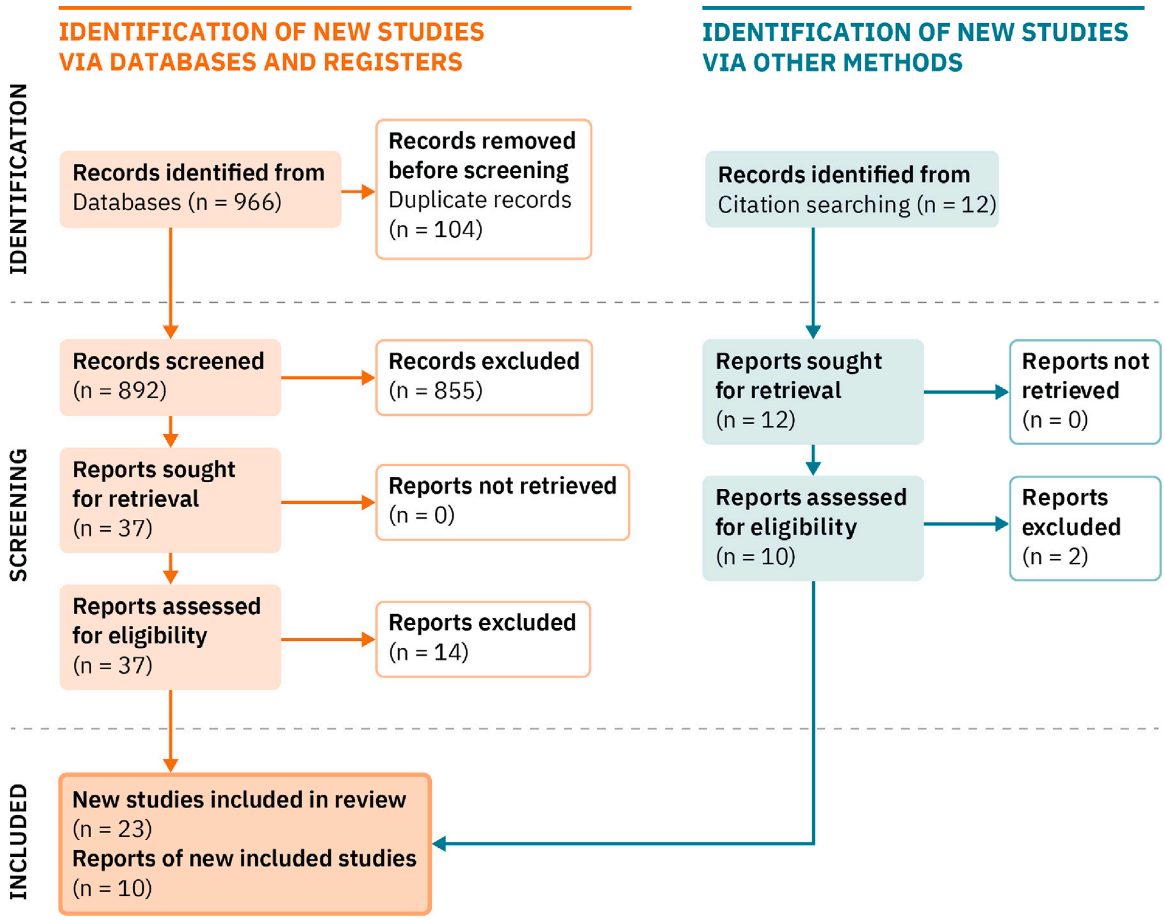

Fig. 1. Flow diagram of the literature selection process for systematic review.

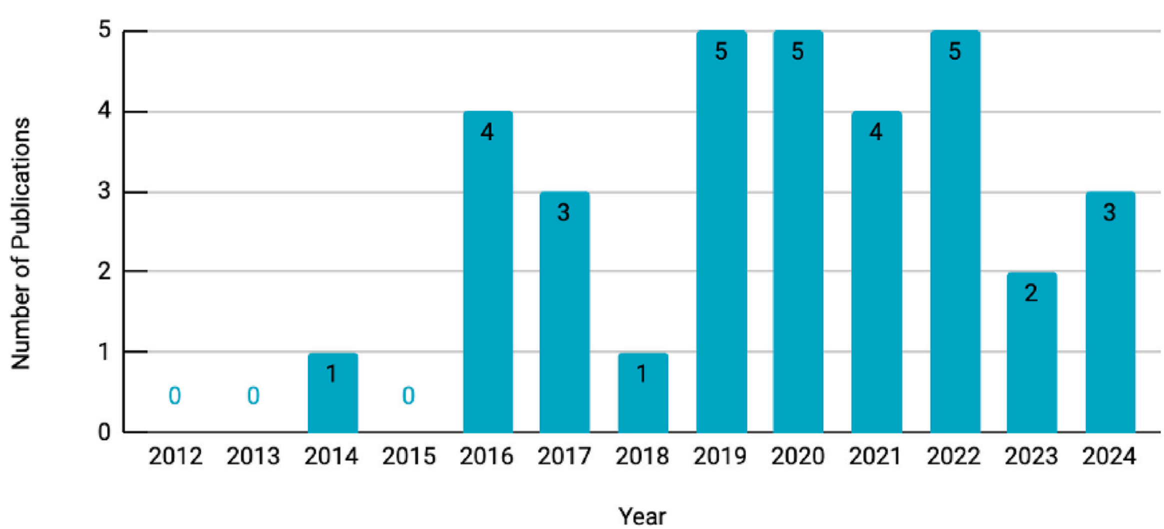

Fig. 2. Trend of publications on menu UI for HMD-VR.

in 3D and the ability to explore and identify local relationships by analyzing information from different angles and viewpoints results in a higher immersion. The 'flat-emersive' design could be applied in gaming environments requiring an overview of the game world or strategic data, such as in real-time strategy games, whereas 'spatially-immersive' design could benefit exploration-based games or educational settings, such as historical events, anatomy, or scientific processes, allowing users interactive exploration from multiple viewpoints [39,61].

Salomoni et al. [15] compared the impact of 2D and 3D menus on user's sense of presence in a VR gaming environment. They found that UI elements such as an interface window and icons, appearing as part of the world increase the immersion or user's sense of presence. Similarly, in a study, Heperrele et al. [18] assessed users' responses to the naturalness and intuitive ability of the presented menu UI concepts. The results show that 3D menus, where icons are adopted from real-world metaphors like paint buckets (Fig. 3(m)), maintained the user's

Table 2
An overview of selected studies, their type of publication (where 'J' represents a journal and 'C' indicates a conference paper), alignment with RQs, and main findings.

Authors, Year	Article type	Summary of main findings	Related RQs
Lubos et al. [17], 2014	C	Results attribute selection errors mainly to challenges in visually perceiving objects in 3D space, impacting accurate judgment of hand position and movement in the virtual environment. Errors are most prominent along the view axis, least along the motion axis, and minimal along the orthogonal plane.	RQ1, RQ2, RQ3
Lubos et al. [38], 2016	C	Kinespheres offer a promising approach for interaction in VR by leveraging our natural body awareness and improving comfort and performance for specific tasks. Moreover, menus on wrist boundary offer both high efficiency and high comfort compared to others.	RQ1, RQ2, RQ3
Mitchell and Wilkinson [39], 2016	J	Using quick head movements towards the periphery of the user's vision to trigger spatial menus can be a successful, engaging, and repeatable interaction technique for HMD-VR.	RQ1, RQ2
Salomoni et al. [15], 2016	C	Diegetic menu UIs outperform non-diegetic menu UIs in terms of immersion, presence, usability, and motion sickness avoidance sensations.	RQ1, RQ2
Tamura et al. [40], 2016	J	The study reports that while the non-diegetic menu results in occlusion and challenges when adjusting parameters, users can effortlessly reposition the body-referenced menu anchored to virtual fingers by hand movement, ensuring an intuitive menu interaction experience.	RQ1, RQ2
Kwon et al. [1], 2017	J	The paper presents two hierarchical menu UI concepts – a wrist menu using a prism metaphor and a spatial menu using job shuttle metaphor.	RQ1, RQ2
Mendes et al. [41], 2017	C	Users preferred menu-based approach over gesture-based approach because it provided the easiest recall of options.	RQ1, RQ2
Santos et al. [42], 2017	C	In both non-diegetic and spatial menus, radial menus outperformed linear menus in task completion time. However, no statistically significant differences in error rates and usability were observed between radial and linear menus in various VR positions.	RQ1, RQ2
Hube and Müller [43], 2018	C	The paper reports that presenting the data in 3D and having the ability to view and interact with it from multiple viewpoints allows for understanding local relationships in the data and increases user's immersion.	RQ1, RQ2
Hepperle et al. [18], 2019	J	2D menu UIs excel in fast and accurate object manipulation, being easy to learn. 3D menus are recommended when perceived presence and fun are critical. Speech interfaces are ideal for ease of learning and extensive text input.	RQ1, RQ2
Park et al. [44], 2019	C	Study proposed a 2D body-referenced menu system allowing users to control the menu by performing hand postures designated for different tasks and interactions.	RQ1, RQ2
Reich et al. [45], 2019	C	Incorporating diegetic menus anchored to the user's forearm in VE for touch input can offer users an intuitive interaction experience.	RQ1, RQ2
Zielasko et al. [4], 2019	C	Both desk-aligned and mid-air menus, with or without passive haptic feedback, demonstrated positive results in task performance and subjective evaluations. However, the mid-air menu with passive haptic feedback outperformed other conditions.	RQ1, RQ2
Monteiro et al. [46], 2019	J	The study evaluates traditional panel and radial menus in VR, finding that the fixed wall placement of the menu and the traditional panel design offer better usability and user satisfaction, improving task completion and perception of actions in the virtual environment.	RQ1, RQ2
Lediaeva and LaViola [32], 2020	C	Spatial, hand, and waist menus exhibit significantly faster performance than arm menus. Moreover, the eye gaze selection technique is more error-prone than alternative methods. Users also favored the spatial menu as their preferred menu placement.	RQ1, RQ2, RQ3
Lee et al. [47], 2020	J	Radial menus are suitable for RelPoint, offering a promising alternative to conventional pointing interfaces in 3D interactions. Additionally, the study finds that the optimal radial menu design features six or fewer buttons.	RQ1, RQ2
Mundt and Mathew [48], 2020	C	Results reveal the superiority of the 2D pie menu with pick hand over hand and stick rotation selection techniques, with pick ray outperforming stick ray. Selection techniques had no impact on presence. Pick hand showed faster selections than stick rotation, and both pick hand and pick ray pie menus had lower error rates than stick and hand ray designs.	RQ1, RQ2
Pfeuffer et al. [49], 2020	C	2D grid menus paired with gaze techniques provide similar performance to pointer-based menu selection but with less physical effort.	RQ1, RQ2
Wang et al. [29], 2020	J	Fixed menus offer a superior performance over the handheld menu in terms of both speed and accuracy, with the former also leading to lower task load. Nonetheless, handheld menus minimize occlusion in VE and are recommended for highly immersive applications.	RQ1, RQ2, RQ3
Hou et al. [34], 2021	C	This paper presents a novel toolkit for automatically generating and modifying menu UIs in different layouts for VR.	RQ1, RQ2
Mußmann et al. [50], 2021	C	The study presents an overview of item selection methods in VR encompassing different 3D menu designs, VR inventory systems, and the application of inventories in adventure games.	RQ1, RQ2
Cmentowski et al. [51], 2021	C	The study explores the design of VR inventory menus by analyzing popular VR games, developing a structural taxonomy, and proposing key design implications for creating more immersive and functional item management systems in VR.	RQ1, RQ2
Sidenmark et al. [52], 2021	C	The study presents Radi-Eye, a hands-free 3D pop-up radial interface using eye gaze and head movement for input, offering fast and accurate interaction, and expanding the design space for fluid, hands-free control in VR and AR applications.	RQ1, RQ2

(*continued on next page*)

Table 2 (*continued*).

Reiter et al. [53], 2022	C	The study explores the integration of hand and eye input in hand-attached menus using the Look & Turn concept, where gaze selects items and wrist rotation navigates menus, enabling hands-free menu interaction.	RQ1, RQ2
Choi et al. [54], 2022	C	Results show that menu items placed within the "Kuiper Belt" region (25° to 45°) help minimize false inputs and improve the efficiency of visual search tasks in eye-gaze-based menu design.	RQ1, RQ2
Shi et al. [55], 2022	C	Study presents four interaction techniques (i.e., AlignPanel, AlignWidget, AlignPin, and AlignGesture) for group-based object alignment in VR. The results highlight the strengths and limitations of each technique for 3-DoF translational alignments, providing design recommendations for their use in immersive systems.	RQ1, RQ2, RQ3
Yi et al. [56], 2022	C	GazeDock is a gaze-based, non-diegetic menu selection technique for VR, designed to minimize false triggers and enhance speed by utilizing a peripheral radial menu layout, optimized for accuracy with 4–8 items.	RQ1, RQ2
Bustamante et al. [57], 2022	C	The study introduces a 2D radial menu paired with a rotation-based rapid-selection gesture using the controller angle. Preliminary observations indicate that the design is effective with 2–3 options.	RQ1, RQ2
Andersson and Hu [58], 2023	C	Results indicate that traditional top-down linear menus with motion controls provide the best user experience in VR compared to radial designs, and sitting posture results in less severe simulator sickness compared to standing.	RQ1, RQ2
Bao et al. [35], 2023	J	This paper presents a novel toolkit for automatically generating and modifying hierarchical tile menu UIs for VR.	RQ1, RQ2
Zhang et al. [59], 2024	C	Results show that the Hand Surface Menu (HSM), attached to the user's palm, reduces error rates and shortens completion time, improving VR menu interaction efficiency.	RQ1, RQ2
Pandey and Sorathia [60], 2024	C	Preliminary findings show that the proposed hand-referenced 3D hexa-ring menu UI outperforms traditional 2D radial and grid layouts in 10 and 12-item configurations.	RQ1, RQ2
Wentzel et al. [33], 2024	J	Grid menus with direct input were the fastest for single-level hierarchies, while radial menus with marking performed best in two-level hierarchies, and grid menus with ray-casting were the slowest but offered the highest usability.	RQ1, RQ2, RQ3

Table 3
Summary of key factors influencing the design of menus in HMD-VR.

Number	Key factor	Description
1	Immersion and Presence	Refers to the user's sense of being physically present in the VE. High immersion and presence enhance the feeling of realism and interaction in HMD-VR.
2	Aspects of Graphical User Interface	Focuses on the visual design of the menu UI, which can be represented as 2D or 3D elements in the VE.
3	Type of UI Integration in VR	Refers to the integration of the menu UI within the VR experience. Non-diegetic menus exist outside the VE, spatial menus are embedded within the VE, and diegetic menus are integrated as part of the VE.
4	Hierarchical Structure	Refers to the arrangement of menu items, where complex applications often require a multi-level hierarchy for organization and navigation of options within the menu.

immersive experience and were rated significantly more natural and intuitive compared to 2D menus appearing as flat menus on a wall like desktop menus (Fig. 3(e)). These types of 3D menus are highly applicable in gaming or social VR applications like virtual chatrooms and conferences, where immersive systems such as inventory management or skill trees can benefit from real-world metaphors, offering users intuitive, engaging, and immersive interactions with virtual objects [15,18,51]. Additionally, in education and training, 3D menu UIs can enhance realism by simulating real-world tasks, as seen in virtual science labs, architectural or medical simulations, improving the naturalness of interaction [62–64].

Mußmann et al. [50] explored three menu designs for VR gaming: radial, spin (ring), and grid structures. The radial menu features 2D graphics where photographs of objects are used as icons, while ring and grid menus utilize (a) 3D graphics where icons are 3D and match real-world metaphors like a lock and key, piece of terrain, utility belt, and drawer; and (b) display and interaction in the z-axis. The study found that the grid-based virtual drawer menu induced higher immersion due to having a clear layout, composition, and comprehensive item representation in addition to featuring 3D graphics and real-world metaphors of items. In addition to gaming, the grid-based virtual drawer concept can be ideal for managing and displaying objects in virtual museums or educational applications, offering quick access to a large set of objects or artifacts [51].

Mundt and Mathew [48] compared four interaction techniques (ray-casting, direct selection, hand rotation, stick rotation) with a hand-held 2D radial menu design to assess their impact on presence. The study shows that presence remained unaffected by menu style.

3.1.2. Aspect of graphical user interface in VR

The literature review suggests that the 2D and 3D aspects of GUI significantly affect the design, performance, and preference of a menu in HMD-VR. In the last 50 years, GUI has seen significant changes as the devices have evolved over the years. GUIs today can be categorized into two groups: (a) 2D interface, and (b) 3D interface.

- **2D Interface:** They are based mainly on the popular WIMP paradigm originally designed for desktop computers. They utilize flat 2-dimensional elements and desktop metaphors and can be commonly seen on devices such as desktops, smartphones, or smartwatches.
- **3D Interface:** They include 3-dimensional elements and mimic real-world interaction in VE. These properties make them appear more natural to users in HMD-VR.

To study the applicability of a 2D menu UI, Mitchell and Wilkinson [39] integrated a flat 2D linear menu system, such as menus commonly seen on desktop computers and websites, in a VR gaming application that provides users with a spatial experience. Similarly,

Table 4
An overview of menu UI explorations with consideration of key factors by authors for the design of menus.

Authors, Year	Key factors					
	Immersion and presence	Aspect of GUI (2D/3D)	Type of UI integration in VR			Hierarchical structure (*Visually evident)
			Non-diegetic	Spatial	Diegetic	
Lubos et al. [17], 2014		2D		✓		1*
Lubos et al. [38], 2016		3D		✓	✓	Unknown
Mitchell and Wilkinson [39], 2016		2D		✓		1*
Salomoni et al. [15], 2016	✓	2D, 3D	✓		✓	1*
Tamura et al. [40], 2016		2D	✓		✓	2
Kwon et al. [1], 2017	✓	2D, 3D		✓	✓	2
Mendes et al. [41], 2017		3D			✓	1*
Santos et al. [42], 2017		2D	✓	✓		1*
Hube and Müller [43], 2018	✓	2D			✓	1*
Hepperle et al. [18], 2019	✓	2D, 3D		✓	✓	1*
Park et al. [44], 2019		2D			✓	1*
Reich et al. [45], 2019		2D			✓	1*
Zielasko et al. [4], 2019	✓	2D		✓		2
Monteiro et al. [46], 2019		2D		✓		2*
Lediaeva and LaViola [32], 2020		2D, 3D		✓	✓	1*
Lee et al. [47], 2020		2D		✓		1*
Mundt and Mathew [48], 2020	✓	2D			✓	1
Pfeuffer et al. [49], 2020		2D			✓	1*
Wang et al. [29], 2020		2D, 3D		✓	✓	1*
Hou et al. [34], 2021		2D, 3D		✓		Unknown
Mußmann et al. [50], 2021	✓	2D, 3D			✓	2*
Cmentowski et al. [51], 2021	✓	2D, 3D		✓	✓	1*
Sidenmark et al. [52], 2021		2D	✓			3*
Reiter et al. [53], 2022		2D, 3D			✓	2
Choi et al. [54], 2022		2D, 3D	✓			2*
Shi et al. [55], 2022		2D, 3D				1*
Yi et al. [56], 2022		2D	✓			1*
Bustamante et al. [57], 2022		2D			✓	1*
Andersson and Hu [58], 2023		2D		✓		1*
Bao et al. [35], 2023		2D				Unknown
Zhang et al. [59], 2024		2D			✓	1*
Pandey and Sorathia [60], 2024	✓	2D, 3D			✓	1*
Wentzel et al. [33], 2024		2D			✓	2

Zielasko et al. [4] employed a standard flat 2D linear menu for a productive setup where menu interaction is required while sitting at an office desk. Andersson and Hu [58] and Monteiro et al. [46] also investigated 2D menus in a seated position, both reporting high usability and user preference. These studies demonstrate favorable usability and positive user responses to the use of 2D menus when integrated into 3D VEs.

Hepperle et al. [18] compared a 2D menu UI with a grid structure fixed on a wall with a 3D menu UI utilizing 3D virtual objects based on real-world metaphors and realistic interactions in an empirical study to determine which type of UI is ideal for immersive VEs. The results show that 2D menus are faster and easier to learn, whereas 3D menus perform poorly in task completion time, have a higher learning curve, and may feel less familiar to users in comparison to the former. It suggests that 2D menus can be a successful system control technique when adapted to 3D VEs, as recommended in LaViola et al. [65]. The study conducted by Mendes et al. [41] also indicates that users prefer a menu-based approach for object manipulation over a gesture-based approach in 3D VE, regardless of the latter being reported as more natural.

Salomoni et al. [15] compared 2D menus, i.e., flat graphics similar to desktop menus (Fig. 3(a)), against 3D menus, i.e., menus integrated as part of the world using real-world metaphors, such as smart devices, in a gaming environment and reported that the latter is more preferred by users and enhances their immersion. Shi et al. [55] highlight that, compared to 2D UIs, 3D UIs enhance the visibility of elements from various viewing angles and facilitate easier interaction within the VE. Moreover, the results from Hepperle et al. [18] on 3D menus indicate that users find them more natural, intuitive, and fun to use (Fig. 3(m)). The authors also report that 3D UI benefits in maintaining immersion, whereas 2D UI can break it. Cmentowski et al. [51] made similar observations in a study with VR game developers, where most participants agreed that flat 2D UIs tend to break immersion. In line with these findings, van Dam [5] has previously argued that we should completely move away from the WIMP paradigm and that VR should use a natural user interface, which allows users to interact with the system in the same manner they would in the real world.

These explorations suggest that 2D menus are faster and easier to learn, making them suitable for quick interactions like tool selection, media controls, character customization, inventory management, or accessing lessons and quizzes in VR learning environments [39,52,54]. In contrast, 3D menus provide a more natural experience, making them ideal for exploration and interaction-heavy scenarios, such as virtual training simulations in fields like medical training or engineering design, where users manipulate and examine complex 3D models [61,63,64].

3.1.3. *Type of menu UI integration in VR*

The latest research suggests that the method of integrating a UI in VR affects the design of a menu. In HMD-VR, the user is placed inside the VE and gets surrounded by UI elements in a 3D and 360° environment. Whereas, in other devices such as a desktop, tablet or smartphone, the user always remains outside of the interactive VE. This change in the placement of users with respect to the interface in HMD-VR requires a rethinking of the placement of UI elements such as menus [4,29,51] so that users can easily and comfortably interact with them. VR researchers have investigated several methods for integrating menu UIs in 3D VE in order to determine which kinds of menus function best and are preferred by HMD-VR users.

Studies such as [15,40,42,52] investigate flat overlaid menu solutions that, when invoked, remain locked to the device's field of view (FoV), like the UI presented in adventure, action, or racing video games on handheld devices and websites. These investigations suggest that

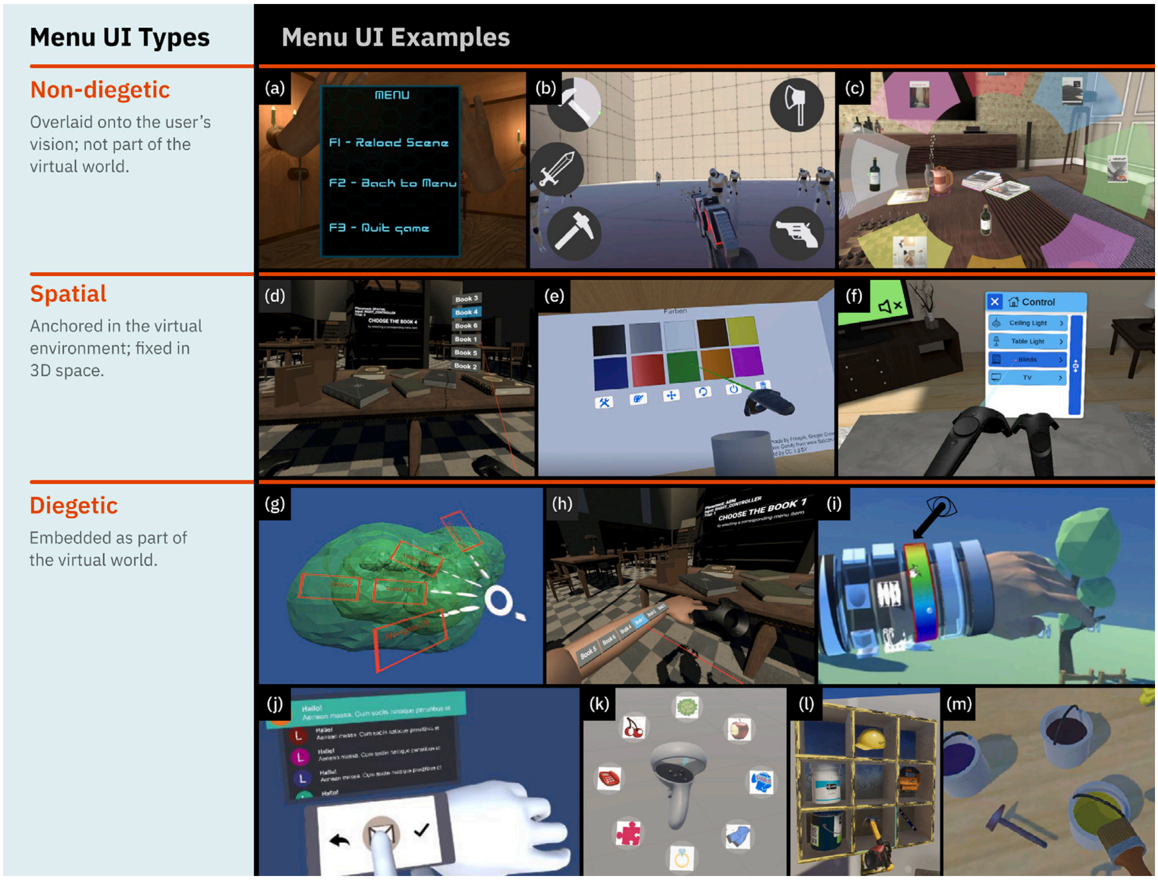

Fig. 3. A sample of non-diegetic, spatial, and diegetic menu UIs from our review. Non-diegetic menu examples: (a) 2D linear design [15]; (b) 2D radial design in the peripheral vision [54]; (c) 2D radial design [54]. Spatial menu examples: (d) 2D linear design in a fixed location [32]; (e) 2D grid design attached to a wall [18]; (f) 2D hierarchical linear design in a fixed location [46]. Diegetic menu examples: (g) 2D linear design attached to fingers [40]; (h) Body-referenced 2D linear design on the arm [32]; (i) Body-referenced 3D ring design worn around the wrist [53]; (j) Body-referenced 2D smartphone-based design on the wrist [45]; (k) Controller-referenced 2D radial design [33]; (l) 3D grid menu based on real-world metaphors [51]; (m) 3D natural design based on real-world metaphors [18].

they are quick to access and have familiarity. A study [42] reports that there is no statistically significant difference in these menus' performance compared to menus fixed on specific locations in 3D VE. However, continuous display of menus causes occlusion [28,40,56]. While studies such as [54,56] explored positioning menus in the peripheral vision to avoid occluding the central FoV, research shows that not integrating menus into the 3D space makes them appear out of place and unnatural to users [15].

To address this issue, other research studies have focused on integrating menus into 3D VEs by attaching them to walls [18,42,46], or at specified coordinates within the VE [4,17,29,51,58]. According to research [29,32], these types of menus are preferred by users since they exist within the VE and may be easily accessed by direct selection or ray-casting techniques. However, as a user moves in the VE, these menus do not account for the change in orientation. As a result, users must make extra effort to reposition themselves with menus while moving.

The third method of integrating menus in 3D VE is to display them as UI elements that appear as part of the world, similar to smart gadgets, but are not fixed on specific coordinates and can be repositioned as desired. Research works [1,15,51] investigate this approach, whereas other studies, for example [1,32,33,43,53,57,59,60], explore fixing menus on the user's body directly or to the hand-held VR controllers. A near-body or on-body location makes them easy to access due to their close proximity. In addition to maintaining the user's presence, these properties make this type of menu the most natural [15,18], desirable [15], and playful [18] in HMD-VR.

Santos et al. [42] have noted that menu UIs, based on their type of integration in VR, can be classified into three categories — non-diegetic, spatial, and diegetic.

- **Non-diegetic Menu UI:** They are overlaid with the user's vision and do not change their orientation according to the change in the user's head movement.
- **Spatial Menu UI:** They exist in the 3D space but are world-grounded, which means they remain fixed at a certain position in the VE.
- **Diegetic Menu UI:** They are integrated as part of the world. They are not world-grounded and can be positioned anywhere in the VE.

These studies suggest that non-diegetic menus are suited for fast-paced environments like gaming, productivity applications, or virtual shopping, where quick access to basic tools or settings is required, and providing high immersion is not critical [15,18,52]. Spatial menus are suitable for applications such as medical training or educational simulations, where fixed placement in the VE enables quick, low cognitive-load access to surgical tools or learning modules [32]. Diegetic menus are ideal for gaming, training simulations, and collaborative tools where high engagement, immersion, and presence are a priority [18,29]. For example, in a fantasy game, a magical book or inventory attached to a character's body may provide tools, guides, or equipment, enhancing engagement and immersion. These different menu integration methods cater to distinct needs in HMD-VR, balancing usability, immersion, and functionality based on the application requirements.

3.1.4. Hierarchical menu structure

With the increasing demand for VR applications from multiple domains, such as virtual stores, museums, healthcare, education, and entertainment, developers need to support a complex listing of items on their applications. Menus in traditional desktop environments support multiple levels of submenus. These submenu panels provide quick and easy access to categorized items and are referred to as hierarchical menus. So far, limited empirical research has been conducted on studying hierarchical menu designs in HMD-VR.

Hierarchical menus in VR become essential when the number of available options exceeds a manageable limit, typically around 6 to 8 items, as too many visible choices can clutter the interface and disrupt immersion [29]. To address this in a data visualization VR application, Tamura et al. [40] designed a finger-anchored hierarchical menu for data visualization, where sub-panels open in the direction of the selected finger (Fig. 3(g)). This design can be particularly useful in VR gaming, virtual stores, or virtual training simulations where quick access to complex, multi-level inventories or tools is required. Kwon et al. [1] proposed two hierarchical menu concepts for home applications. One uses a wristband-triggered linear holographic menu anchored to the wrist, and the other employs a 'jog-shuttle' metaphor, where users rotate a virtual dial to reveal radial sub-menus anchored to the parent item. While no usability tests were conducted, the wristband menu may suit medical simulations, providing quick access to tools, while the jog-shuttle concept could benefit technical or industrial training, where users can quickly rotate through different task options or controls with minimal distraction.

Zielasko et al. [4] compared a desk-aligned hierarchical menu with a mid-air version for seated office work in VR, using flat linear panels similar to traditional WIMP menus. Findings indicate that both menus provided similar performance. Mußmann et al. [50] proposed a ring menu and grid layout based virtual drawer for hierarchical inventory management in VR games. Although this study also lacks a usability evaluation, the authors emphasize the grid menu's clear layout for comprehensively representing multiple items. Such layouts may suit action-based applications like combat games, strategy games, or tool selection in virtual workshops, allowing quick access and organization of inventory items during gameplay.

Reiter et al. [53] proposed a 2-level wrist-based ring menu inspired by the 'bangle' metaphor, using gaze and pinch gestures for interaction (Fig. 3(i)). The sub-menu then extends outward as a ring worn around the wrist. While an informal evaluation of the design indicated mixed usability feedback, participants appreciated its simple hierarchical structure and uniform appearance. These qualities make it suitable for interactive VR training simulations or exploration-based games where users need quick, intuitive access to tools or data while remaining immersed in the environment [50]. Bao et al. [35] developed a toolkit for automatically generating 2D tile-based hierarchical menu UIs in various layouts. The study aimed to assist rapid VR prototyping, rather than evaluating the usability of the generated menus.

Wentzel et al. [33] assessed 2D hierarchical radial (Fig. 3(k)) and grid menus in 8- and 24-item configurations with 18 participants using three interaction techniques (ray-casting, marking, direct touch). To accommodate 24 items, the 2D radial menu was extended into 3D with a spherical layout, while the grid menu remained 2D. Results showed grid menus with direct input were fastest in single-level menus, while radial menus with marking performed the best in two-level hierarchies. Grid menus with ray-casting were the slowest but rated highest in usability. Monteiro et al. [46] compared linear and radial menus with 2-level hierarchies in spatial (example Fig. 3(f)) and hand-referenced positions using 51 participants using ray-casting for linear and controller-based touchpad for radial menus. Although spatial linear menus were preferred, differing interaction techniques within VEs may limit the validity of this comparison [29,32,48]. Nevertheless, these studies indicate that the linear and grid layouts suit virtual design tools for selecting components, while radial menus can support immersive modeling for quick access to a limited set of options.

Choi et al. [54] compared two 2-level hierarchical radial menu designs attached to the HMD. One placed in the central FoV was effective for visual searches, while the other, positioned in the periphery (Fig. 3(b)), avoided occlusion and suited longer tasks. Results suggest that central and peripheral menu placements suit VR tasks like architectural design and medical simulations that demand accuracy and longer use without occlusion. Sidenmark et al. [52] evaluated 3-level radial menus with concentric rings using gaze input with 12 participants. Results show that larger ring sizes increased selection time and workload, with the medium size preferred for its speed and ease of use. Participants favored horizontal or vertical selection directions, making the medium-sized ring ideal for virtual home and world-building scenarios.

Overall, **RQ1** studied key factors influencing the decision-making of designing a menu UI for HMD-VR. We found that UI elements using real-world metaphors, appearing in 3D, and enabling movement and interaction in the z-axis enhance immersion and presence. 2D menus are easier to adopt and faster for task completion, while 3D menus have a higher learning curve but offer a natural and intuitive experience. Three prominent UI integration approaches emerge, i.e., non-diegetic, spatial, and diegetic. Among these, diegetic menus are considered the most natural and desirable. Complex applications benefit from hierarchical menu structures, though a majority of studies lack comprehensive statistical evaluations across different scenarios and usage positions for such menus. Formal usability testing of hierarchical designs, however, shows that radial and grid menus, when paired with suitable interaction techniques and optimal layouts, improve usability by speeding up task completion, increasing accuracy, and reducing visual clutter, particularly when placed in peripheral zones.

3.2. RQ2: State-of-the-art exploration of menu UI types for HMD-VR based on integration categories

This review covers a variety of menu explorations designed for HMD-VR. These explorations have been categorized in the following sections based on different types of menu UI integration in VR, namely non-diegetic, spatial, and diegetic. Many VR researchers have defined their work based on this categorization. This addresses our RQ2. An overview of details on the type of menu UI explorations based on their integration in VR and their corresponding authors is provided in Table 4.

3.2.1. Non-diegetic menus

Non-diegetic menus (see Fig. 3(a) and (b)) are overlaid in the user's FoV and do not change their position or orientation in response to the user's head movement (e.g., the player's health bar in a desktop game). In a VR data visualization application, Tamura et al. [40] compared a non-diegetic 2D menu with five menu items (three vertical and two horizontal panels forming a plus (+) layout) and a diegetic hand-referenced menu (Fig. 3(g)). The non-diegetic menu was displayed at the center of FoV to provide users with quick menu access. The diegetic version uses a linear menu layout attached to each of the user's fingers. The authors employed the direct selection technique and found that the non-diegetic version occluded the user's FoV all the time and hindered data exploration, making it less preferred.

Salomoni et al. [15] evaluated non-diegetic menus with a flat linear structure (Fig. 3(a)) and diegetic menus integrated using real-world metaphors of smart devices in a VR gaming context. The study with 10 participants revealed that the non-diegetic menus, which were similar to desktop menus, disrupted their immersion and felt unnatural. Whereas the diegetic menus increased the feeling of presence and were found to be more user-friendly.

Santos et al. [42] evaluated non-diegetic and spatial menu designs in linear and radial layouts in a comparative study with 8 participants. This study aimed to understand the effect of menu layout and size on its performance. The results showed that radial menus perform faster in both non-diegetic and spatial versions, though usability and error rates were similar across types. Yi et al. [56] introduced a flat radial menu design that is automatically triggered in the user's peripheral vision using the GazeDock technique. It outperformed other gaze-based methods (i.e., Dwelling and Pursuit) in terms of speed, and was easy to use and learn. However, the authors emphasized that the radial menu design performs optimally with 5–8 options.

3.2.2. Spatial menus

Spatial menus are fixed in a particular position and at specific coordinates in the 3D environment (i.e., placed on a wall) as illustrated in Fig. 3(d) and (e). Mitchell and Wilkinson [39] studied peripheral menu positions using gaze interaction in a tower defense game with 23 participants. The 2D linear menus were fixed to tower locations in the 3D VE and kept hidden until users fixated upon the towers. Once activated, these menus appeared in the peripheral zone and were found to be easy to use and good for hiding complexity despite occasional accidental activation due to gaze interaction.

Zielasko et al. [4] examined the role of physical desks in menu interaction within productivity-focused VR settings. They compared desk-aligned 2D linear menus to mid-air counterparts with 33 participants. Both showed similar performance, but users preferred desk-aligned menus for their passive-haptic feedback, though some found them less enjoyable and felt less confident using them. Andersson and Hu [58] evaluated 2D spatial menus in seated and standing positions and found no significant difference in interaction, though seated users reported reduced simulator sickness. The study also found that traditional top-down linear menus with motion controls provided better usability compared to radial menus, although the authors noted the performance may have been influenced by joystick sensitivity and button inconsistency. Santos et al. [42] examined the effect of menu layout (linear and radial) and size (number of items and space occupied) on their efficiency with 8 participants using the ray-casting method. They placed 2D spatial menus in linear and radial layouts with four, eight, and twelve elements on the walls of the VE. Results indicate that radial menus perform significantly faster, but layout and size did not substantially impact overall usability.

Lee et al. [47] introduced the Relative Pointing Interface (RelPoint), a 3D gesture-based system, to evaluate spatial radial menus with 20 participants. The menu was designed based on human pointing behavior in 3D space. Results show that radial menus with four to six buttons, symmetrically distributed in space, provide the best performance. Kwon et al. [1] developed spatial and diegetic menu UIs inspired by the 'jog shuttle' and 'prism' metaphors, respectively. The spatial menu is mid-air, while the diegetic menu is anchored to the user's wrist using a virtual wristband. Both menus allow spatial interaction with the direct selection method. The menus support a hierarchical structure and offer a new perspective on the traditional 2D WIMP design, but the authors did not evaluate their concepts in their study.

Lediaeva and LaViola [32] compared body-referenced menus (Fig. 3(h)) to spatially placed ones (Fig. 3(d)) with 24 participants and found spatial menus to be faster and preferred. Wang et al. [29] compared fixed menus in radial and matrix layouts with hand-held menus and found that fixed menus perform better in both speed and accuracy; however, users found them to cause occlusion in the VE.

3.2.3. Diegetic menus

Diegetic menus are presented as part of the virtual world, e.g., interactive objects or smart devices, so they must be carefully designed to match the environment (see Fig. 3(i), (j), (l), and (m)). Salomoni et al. [15] designed two diegetic menus for a VR gaming application using a linear layout, integrated into a digital tablet and a smartwatch. In a field trial study with 10 participants, the authors found that diegetic menu UIs enhanced immersion and the sense of presence. Participants also reported that the menus felt natural and did not clutter the VE due to their seamless integration. Similarly, Hepperle et al. [18] studied diegetic menus with 30 participants and found them to be the most natural and intuitive, supporting sustained immersion in the VE.

Cmentowski et al. [51] explored two diegetic menus for inventory systems in VR games. Although these designs were not empirically evaluated, they were informed by qualitative insights from interviews with VR game developers. The designs featured a floating, grid-based virtual drawer (Fig. 3(l)) and a magnetic table, both having 3D items inspired by real-world metaphors. van Dam [5] previously noted that integrating interfaces as surfaces or elements of the VE can reduce the interface clutter caused by traditional WIMP systems. Mitchell and Wilkinson [39] also supported this claim.

Diegetic menus have primarily been explored in two contexts, i.e., body and object. Menus that appear relative to the user's body are referred to as body-referenced, while those that appear attached to or associated with virtual objects are called object-referenced.

Body-referenced Menus: These menus provide an intuitive frame of reference and enable eyes-off interaction, but can lead to fatigue when placed on areas like the head, shoulder, elbow, and arm—except for the wrist or hands [32]. Lubos et al. [38] studied joint-centered menus with 20 participants and found wrist-centered menus to be the most comfortable and viable solution for long-term usage. Wrist placement helps reduce selection errors by bringing the menu closer to the user's FoV. In contrast, elbow or arm placement may cause fatigue without physical support (e.g., a desk or armrest).

Tamura et al. [40] and Hube and Müller [43] investigated flat 2D body-referenced menus for data visualization. Tamura et al. found that the fingertips-based menu (Fig. 3(g)), operated by the dominant hand with direct selection, was rated natural and easy to use. Hube and Müller anchored the menu to the user's palm, finding it potentially useful, though it was not formally evaluated. Zhang et al. [59] investigated a Hand Surface Menu (HSM) in a study with 20 participants, using both sides of the hand for menu interactions and tactile feedback. Compared to hand-attached floating and hand-held menu designs, users reported higher levels of naturalness and comfort with the HSM.

Mendes et al. [41] conducted a comparative study with 24 participants to evaluate a hand-referenced ring menu with 3D icons against a gesture-based system for 3D object manipulation. They found that users preferred the diegetic menu solution for its ease of recall and clearer representation of available actions. Kwon et al. [1] explored a wrist-centric hierarchical menu using a 'prism' metaphor, where flat 2D semi-transparent panels were projected around the wrist upon activation via a virtual wristband. While promising in concept, the study was exploratory and did not assess performance or usability. Park et al. [44] designed a hand-referenced menu system (HandPoseMenu), operated with various hand gestures. The menu appears as a 2D flat vertical panel attached to the user's palm, but lacks an empirical evaluation. Reich et al. [45] studied a touchpad attached to the user's arm for menu operation with 20 participants (Fig. 3(j)). The design was found intuitive due to smartphone familiarity. However, some users found arm-scrolling unnatural, with horizontal swiping preferred over vertical, possibly due to the limited surface area.

Lediaeva and LaViola [32] evaluated body-referenced menus with 24 participants and found that hand- and wrist-based menus outperformed arm menus (Fig. 3(h) in speed. However, the authors reported technical and design issues during the arm menu evaluation, which indicates that a further investigation is needed. Monteiro et al. [46] and Wang et al. [29] compared hand-held and fixed menus in separate studies with 51 and 23 participants, respectively. Monteiro et al. employed 2D linear (Fig. 3(f)) and radial menus, while Wang et al. used 3D icons in a 4×4 grid structure with a semi-transparent background. Both studies found that hand-held menus, though more mobile, performed worse than fixed menus in speed and accuracy. Wang et al. further noted that the hand-held menus do not occlude the 3D scene and may be better suited for highly immersive VR applications.

Reiter et al. [53] explored a wrist-based hierarchical ring menu using a 'bangle' metaphor (Fig. 3(i)). The 3D menu wraps around the wrist like a bracelet and presents 2D icons. The authors conducted an informal evaluation with seven participants and found mixed usability feedback, where half found it easy to use, while others struggled with the desig. Pandey and Sorathia [60] conducted a pilot study with five participants to compare a honeycomb-based menu with traditional grid and radial designs in 10- and 12-item configurations. Preliminary results indicate that participants favored the diegetic wristband-based 3D Hexa-ring menu over traditional 2D WIMP-based designs.

Mundt and Mathew [48] tested 2D radial menus with eight divisions around the VR controller with 24 participants. The findings suggest that menu style (radial menu with different selection techniques) did not affect the user's presence. Wentzel et al. [33] compared 2D radial and grid menus positioned around VR controllers and at fixed locations in 8- and 24-item configurations, with 18 participants using three interaction techniques (ray-casting, marking, and direct touch). Similarly, Pfeuffer et al. [49] examined a 2D grid menu placed on the non-dominant hand with 17 participants using direct selection, pointer, and gaze. Both studies concluded that 2D grid menus with direct selection offered faster performance in single-level hierarchies.

Object-referenced Menus: These menus are contextual in nature. They provide quick interactions that a user can perform with respect to individual virtual objects, such that users can manipulate their orientation or cause a change to their system state (i.e., color change, purchase an item, or remove it from the environment). Although several commercial VR applications have implemented object-referenced or contextual menus, studying commercial applications is out of the scope of this review. This literature review reveals a recent focus in scholarly studies on exploring the design of contextual menus in immersive VEs. Mendes et al. [41] evaluated a menu UI for Boolean operations in a Constructive Solid Geometry (CSG) application, while Shi et al. [55] compared 2D and 3D menu UIs for object alignment tasks in VEs. Both studies designed menus that provide quick actions for manipulating virtual objects, with the menus placed around the hands or near the user's body. Though contextual, these menus were body-referenced due to their close proximity to the user's hands.

Choi et al. [54] compared head-gaze (HG) and Kuiper Belt (KB) radial menus fixed to the HMD for contextual tasks. The KB method supported up to eight contextual options for home and gaming scenarios, with items placed in the user's peripheral vision and selected via eye gaze (Fig. 3(b)). Results showed that the KB method avoided blocking central vision and was better suited for prolonged tasks, though it was less effective for precise inputs like eye typing or zooming. In contrast, HG supported visual search but occluded the FoV and forced unnatural gaze behavior to prevent false selections. Similarly, Sidenmark et al. [52] studied a 2D gaze-activated pop-up radial menu with 12 participants. The menu was positioned mid-air in the central viewing zone, independent of the 3D VE. The design used concentric rings to organize hierarchical options based on the selected object. Results showed that participants preferred medium-sized rings, as larger rings increased selection time and workload, while small and extra-large ones reduced precision.

Bustamante et al. [57] proposed a ring menu for data visualization and weapon selection, using input via button press, controller rotation, and hand movement. Preliminary findings suggest that the rotation-based menu could be a promising alternative for tool selection, adjusting continuous and discrete options, and modifying visualization settings. However, the authors note that limiting the menu to 2–3 options would improve usability. Except for these studies, our search query did not yield any additional research on this topic. Research on object-referenced menus for HMD-VR has been limited between 2012 and 2024, although interest in this area has been increasing in recent years.

Overall, **RQ2** addressed the state-of-the-art exploration of types of menu UI based on integration categories for HMD-VR. We found that non-diegetic menus, despite being familiar, are generally less preferred due to challenges of occlusion, feeling unnatural, and disrupting user immersion. Spatial menus are faster and more accurate to use than other types of menus, and users prefer using them. However, they may cause occlusion if poorly designed and cannot be repositioned by users as they prefer since their appearance is predefined and controlled by the VR application. Diegetic menus are the most natural and intuitive to use, and they help to maintain the user's sense of presence in VE. They also cause the least amount of occlusion when placed on the user's body. Object-referenced menus have received limited attention during this period, unlike other types of menus, but they benefit the user by offering quick contextual menu options in complex VR applications.

3.3. RQ3: Design guidelines on menu UIs for HMD-VR

To provide an answer to our RQ3, in this systematic review, we found six studies that provided design guidelines related to menus for HMD-VR. These recommendations are discussed in this section, with a summary of the key guidelines provided in Table 5.

Wang et al. [29] compared spatial menus against hand-held menus with three interaction techniques, i.e., hand pointing with button press (Hand-BP), head pointing with button press (Head-BP), and head pointing with dwell (Head-DW). The authors presented multiple design guidelines. They recommend spatial menus with Hand-BP for applications with a low task load and when the primary goal is an efficient and effective selection of options. For situations requiring hands-free interaction, the authors also recommend these menus combined with Head-DW because it does not require the use of any additional device for selection. However, they suggest that Head-DW is suitable for tasks requiring slow-paced selection, and the head movement should be limited to reduce VR sickness. Additionally, the authors recommend spatial menus with Head-BP because it reduces the Heisenberg effect of spatial interaction. For highly immersive applications, the authors recommend using handheld menus with Head-BP. Lastly, they recommend handheld menus combined with Head-DW are suitable for menus with fewer options.

Lubos et al. [17] analyzed the direct selection of spherical menu items in a spatial environment. They presented design guidelines that (a) the position of UI elements, such as menus, should be near the eyes when a higher accuracy in 3D selection activities is required rather than in the lower areas, which may be more comfortable; and (b) to improve touch selections of spherical menu targets, such as points, expanding the selection space by employing an ellipsoid cursor that encompasses the 95% confidence region for touch selections is recommended for an accurate selection.

Lubos et al. [38] focused on body-referenced menus and explored joint-centered menu placement for spatial interaction. They concluded that (a) the use of wrist joints for UI positioning is highly recommended; (b) it is not recommended to place menus at long or short tested distances, e.g., the tip of the hand when the arm is fully stretched; and (c) it is not advisable to place menus on the elbow and shoulder joints.

Lediaeva and LaViola [32] compared spatial and body-referenced menus in linear and radial layouts with three selection techniques, i.e., ray-casting with a controller device, head, and eye gaze. The authors presented design guidelines that recommend the use of spatial graphical menus in any layout with ray-casting due to their faster performance and higher user preference. For body-referenced menus, the authors recommend an optimal configuration involving hand menus (positioned near the wrist or palm) in a radial layout combined with ray-casting. Furthermore, they suggest that arm menus in any layout paired with an eye gaze selection method offer a more natural and physically simpler interaction. However, the interaction length for arm menus should be reduced to prevent arm fatigue, particularly when the arm needs to be kept up. Additionally, the authors propose the use of waist menus in a linear layout with ray-casting, but they are less

Table 5
Design guidelines for menu UIs in HMD-VR based on their type of integration, layout, task requirement, and interaction techniques.

Application context	Input method	Menu type	Menu layout	Design guidelines for HMD-VR menu UIs	Study, Year
Rapid interaction tasks, Gaming	Direct touch	Spatial	Radial	- Place radial menu elements near the eyes and use ellipsoid cursors for improved selection accuracy.	Lubos et al. [17], 2014
Rapid interaction tasks, Gaming	Ray-casting	Spatial	Radial	- Use marking-based radial menus with ray-casting for fast-paced item selection and gestural learning. - Use marking-based radial menus in hierarchical tasks as they outperform grid menus.	Wentzel et al. [33], 2024
Rapid interaction tasks, Gaming	Ray-casting	Spatial	Linear, Radial	- Spatial menus in linear and radial layouts with ray-casting are fast and preferred.	Lediaeva and LaViola [32], 2020
Rapid interaction tasks, Gaming	Ray-casting	Body-referenced	Radial	- Body-referenced menus near the wrist in radial layouts with ray-casting are best.	Lediaeva and LaViola [32], 2020
Educational and training	Direct touch, Ray-casting	Spatial	Grid	- Use grid menus with direct input for larger, single-level menus. - Use grid menus with ray-casting for accessibility and minimizing movement.	Wentzel et al. [33], 2024
Educational and training	Gaze, Ray-casting	Body-referenced	Linear	- Arm menus with eye gaze are ideal for natural interaction. - Use waist-mounted linear menus with ray-casting for intuitive tool access in short-duration training tasks.	Lediaeva and LaViola [32], 2020
Productivity and collaborative	Hand pointing with button press, Head pointing with dwell	Spatial	Grid	- Spatial menus with hand pointing with button press are ideal for low task load and efficient selection. - Head pointing with dwell is suitable for hands-free interaction, but only for slow-paced tasks to reduce VR sickness.	Wang et al. [29], 2020
Productivity and collaborative, Gaming	Head pointing with button press, Head pointing with dwell	Body-referenced	Grid	- Use hand-held menus combined with head pointing with button press for highly immersive applications. - Use hand-held menus combined with head pointing with dwell for menus requiring fewer options.	Wang et al. [29], 2020
High-precision tasks, Design and prototyping	Direct touch	Body-referenced	Grid	- AlignPanel (2D grid menu) is suitable for 3-DoF translational alignments, but not for 6-DoF tasks. - AlignWidget and AlignPin (3D menus presenting realistic visualization) are better for 6-DoF tasks, with AlignPin being more practical due to its higher usability.	Shi et al. [55], 2022
Design and prototyping, Gaming	Direct touch, Gaze	Body-referenced	Varied	- Place menus near the wrist for optimal performance. - Avoid placing menus at extreme distances (e.g., fully extended arm). - Arm menus should use eye gaze for natural interaction, reducing interaction length to prevent fatigue. - Waist menus should be in a linear layout but are less suited for long-term use.	Lubos et al. [38], 2016

preferred for prolonged use. Lastly, the authors recommend the position of system messages in close proximity to waist menus.

Wentzel et al. [33] compared hierarchical radial and grid menus, positioned around VR controllers and at fixed locations in 8- and 24-item configurations. They proposed design guidelines emphasizing that the choice of menu type should depend on the application context. For fast-paced applications, radial menus based on marking are best for speed and gestural learning, while grid menus with direct input are more suitable for larger, single-level menus. Additionally, grid menus with ray-casting minimize movement, making them ideal for accessible designs, particularly for users with limited mobility. For high usability and accuracy, ray-casting grid menus excel in single-level hierarchies with low error rates. In hierarchical menus with fewer items per level, marking-based radial menus offer better performance and speed, with less complexity than grid menus.

Shi et al. [55] compared 2D and 3D menu UIs for object alignment tasks in VEs. The authors recommend that 'AlignPanel', a 2D grid menu, is suitable for 3-DoF translational alignments but not for 6-DoF tasks due to its less intuitive 2D representation of complex 3D relationships. In contrast, 'AlignWidget' and 'AlignPin', both 3D menu UIs providing realistic representation in 3D VE, are effective for 6-DoF alignment tasks, with 'AlignPin' being more practical due to its higher usability. These guidelines, based on group-based object alignment in VR, can be applied in applications such as VR world-building games and collaborative productivity tools where efficient group alignment is essential.

Overall, **RQ3** addresses the design guidelines and presents recommendations on menu design and interaction techniques. The recommendations include the use of spatial menus with Hand-BP and ray-casting for higher efficiency and faster performance, near-eye positioning of UI elements, and an increase in the selection area of spherical targets for 3D selection accuracy. For user comfort, wrist and waist positioning of body-referenced menus are encouraged, along with radial layouts and eye-gaze selection methods for arm-based tasks. Radial menus with ray-casting are recommended for hand interactions, while 3D menus, offering a realistic representation of complex tasks like object alignment, are ideal for applications requiring high accuracy and 6-DoF tasks. Additionally, hierarchical grid and radial menus can be effectively used for organizing large data sets or inventory systems, with ray-casting enhancing accessibility and usability in complex applications.

4. Discussion and future research directions

4.1. Key factors influencing menu design (RQ1)

The **RQ1** addresses key factors that are considered when designing and evaluating menus for HMD-VR. It was accomplished by the systematic analysis of the literature. This review found that VR researchers exploring menu UI for HMD-VR have considered a combination of four factors such as immersion or presence, aspect of GUI, type of UI integration in VR, and hierarchical structure of a menu while designing and developing their concepts. By presenting these elements, we aim to guide VR designers and researchers in developing more informed and contextually appropriate menu interfaces.

Despite the attention given to these factors, our review reveals a significant gap in the consideration of a user-centered design approach in current research. Specifically, user persona, individual characteristics, and contextual factors remain underrepresented. Established HCI literature affirms that usability and effectiveness are substantially enhanced when design is grounded in a user-centered approach [66,67]. This oversight limits the generalizability and inclusivity of current menu UI solutions. Future research should actively incorporate user diversity into both the design and evaluation of VR menus. This includes addressing situational accessibility challenges, such as designing for seated or standing users, those with motor impairments, or users operating in constrained physical spaces. The research can take into account various elements such as age, physical and cognitive abilities, technology literacy, and prior VR experience as they impact the overall performance and acceptability of VR applications [68–72].

Another important yet underexplored factor is long-term user engagement. With modern consumer-grade HMD-VR devices increasingly supporting extended periods of continuous use, applications in domains such as education, prototyping, gaming, commerce, and social networking often involve frequent and repetitive menu interactions. However, most existing studies primarily focus on short-term usability and performance metrics, overlooking how menu designs impact user engagement, comfort, and satisfaction over time. Hence, researchers can explore the longitudinal effects of menu usage on user engagement and retention in VR applications. This includes assessing how menu structure, placement, input methods, and visual integration influence cognitive load, physical fatigue, and overall satisfaction during prolonged use. Understanding these dynamics is essential for developing menu systems that not only perform well in short trials but also support sustained immersion, efficiency, and user well-being in real-world VR applications.

4.2. Diversity of menu UI integration types (RQ2)

4.2.1. Dominance of WIMP paradigms and need for scalable and user-centric designs

Our review under **RQ2** reveals that most existing HMD-VR menu UIs remain heavily rooted in WIMP paradigms. Despite the 3D capabilities of immersive environments, these menus often mimic 2D desktop-like structures, utilizing layouts such as linear, radial, and grid layouts [34]. Research shows that non-diegetic menus with linear and radial designs perform similarly to spatial menus with equivalent layouts [42]. However, this approach introduces usability challenges. For instance, non-diegetic menus that remain constantly visible can cause occlusion and disrupt visual continuity in VEs [40]. In contrast, spatial menus, often explored as flat 2D surfaces within the VE, tend to offer improved comfort and faster task completion times compared to diegetic menus [32]. These advantages are echoed in comparisons with handheld menus, where spatial grid menus were preferred by users [29].

Nevertheless, diegetic menus are consistently favored for their perceived realism and immersive quality [15,18]. Moreover, between the common layout types, radial menus outperform linear ones in speed, particularly when used in 4- or 6-item configurations [32,47]. Yet, a critical limitation in current literature is the lack of research on how many items different menu structures can effectively support. Most studies focus on interfaces with 6 to 8 options, even though many real-world applications (e.g., color pickers, object selectors, or gaming inventories) demand interaction with 10, 12, or more items.

This limited focus on small-scale menus leaves a research gap around scalable UI design in VR. As VR applications increasingly demand richer interaction sets, there is a pressing need to explore efficient and usable menu designs for higher option counts. Future studies should systematically evaluate how different layouts, such as linear, grid, radial, or ring, perform with expanded item sets and varying interaction methods and provide recommendations. While radial menus demonstrate speed advantages, user preferences across applications and individual differences remain underexplored. Some users may prefer linear or grid layouts for their familiarity or spatial clarity. Therefore, researchers can investigate which menu designs are most favored, accepted, and efficient for particular applications and user groups.

4.2.2. Reassessing 2D vs. 3D menu interfaces

Although 2D menu UIs have been shown to be effective and widely adopted in HMD-VR applications [4,39,46,58,65], they are frequently criticized for feeling unnatural or out of place in immersive environments, thus breaking presence [4,15,18]. In contrast, 3D diegetic menus enhance realism and user presence but often suffer from poorer performance and higher learning curves due to their unfamiliarity [15,18]. This indicates that, although users prefer a natural user interface with realistic interactions, it may not always be the desired approach, especially when primary user goals are quick and effective task completion with fewer errors in VR [2,41,55]. This opens up an opportunity for researchers to explore and investigate a hybrid method that combines the strengths of both 2D and 3D UI. 2D interfaces are familiar to most users, which can help reduce the learning curve and improve usability. On the other hand, 3D interfaces can provide a more natural and immersive experience, increasing the users' sense of presence and immersion. Researchers can focus on designing and evaluating hybrid menu systems by combining these strengths, potentially offering users the best of both worlds regarding immersion, presence, and task performance, as seen in a pilot study [60]. Designing and evaluating such hybrid menu paradigms could yield new directions that balance speed, presence, and intuitiveness.

4.2.3. Underexplored potential of body-referenced menus

Another promising avenue lies in body-referenced menu UIs, which position menus relative to the user's body (e.g., wrists, hands, waist). Research indicates that such placements enhance efficiency, accuracy, and comfort during long-term use [32,38]. Wrist-mounted menus provide selection accuracy within the user's visual field [38], whereas hands and waist placements enable more relaxed, "eyes-off" interactions [32]. However, few studies have rigorously evaluated these body-referenced approaches, and most limit themselves to linear or radial layouts. VR researchers have the opportunity to explore the use of wrist and hand placement for long-term usage of body-referenced menus. Further, additional evidence-based research is needed that explores the use of different body locations to define which position is suitable for which use case, as a limited amount of research is conducted in exploring different body parts for body-referenced menu UI [1,41,43,44,49].

Given that training, productivity, gaming, have different objectives, designing and evaluating different body-referenced menus based on the VR application domains is required. This could also include designing menus in different layouts and not limiting the exploration to linear or radial structures. Further studies can also address the technical and design-related challenges faced by Lediaeva and LaViola [32] while evaluating arm menus. Re-evaluating their effectiveness and efficiency will increase our understanding of arm menus.

4.2.4. Missed opportunities in object-referenced and contextual menus

Object-referenced menus, which appear near or on the objects being interacted with, offer the potential for intuitive, context-specific interactions without the need to navigate nested structures. While object-referenced menus have potential benefits, there is limited scientific research on their design and effectiveness for HMD-VR. Although some studies have explored object-referenced menus, in practice they are implemented as body- or head-referenced interfaces, failing to leverage the affordances of object-specific placement [41,55]. Similarly, other contextual menus evaluated in the literature are fixed to the HMD or located outside the VE [52,54], limiting their effectiveness within immersive VEs [4,18]. Future research should critically examine how object-referenced UIs affect interaction flow, cognitive demand, and physical effort, particularly in applications involving tool use, assembly, or learning. Properly designed object-referenced menus could significantly reduce task-switching overhead and improve immersion and task efficiency during prolonged or complex interactions.

4.2.5. Hierarchical menus: Limited depth in evaluation

Many complex VR applications, such as design tools, educational platforms, or games, require multi-level hierarchical menus. Despite this, only a handful of studies have proposed or evaluated hierarchical menu structures. For instance, a study [40] proposed a finger-anchored hierarchical menu, allowing for direct selection, while others [1,53] conceptualized designs based on wristband, bangle, and jog-shuttle metaphors. However, all of these studies lack robust empirical validations. Research that does assess hierarchical interactions, such as [4,33,46,50], shows that grid layouts support faster access in flat structures, while marking-based radial menus perform better in two-level hierarchies. Studies also suggest that radial menus centered in the user's field of view are more effective for quick visual searches, while peripheral positioning is better suited for prolonged tasks [52,54]. Moreover, medium-sized, 3-level radial menus were preferred for speed and ease of use in virtual home and world-building scenarios [52].

Overall, the lack of statistical evaluation of hierarchical menu structures in HMD-VR interfaces is a significant issue, as half of the eight studies reviewed did not assess the designs. Hence, there is a need to build experiments and conduct studies to establish potentially effective hierarchical menu structures for HMD-VR. One of the directions can be exploring different types of body-referenced menu designs because previous studies have suggested several advantages to this method, such as a real-world frame of reference, continued access to menus while moving, and high efficiency and comfort for long-term usage. Hence, body-referenced menus can be further evaluated to identify whether they can be a positive direction for supporting different numbers of submenus when the complexity is high. These evaluations will help identify the strengths and weaknesses of different types of menus, guiding the VR designers and developers in using appropriate menu systems depending on the application.

4.3. Design guidelines for menu UIs in HMD-VR (RQ3)

The **RQ3** addressed the design guidelines on menu UIs for HMD-VR proposed in scientific literature. During this review, we found six papers that have incorporated design guidelines on graphical menus. The proposed guidelines on spatial and body-referenced menus broadly focus on their structure, method of integration in VE, and which interaction techniques are beneficial to combine them with. However, in comparison to the available UI design guidelines for 2D devices, such as desktops or smartphones, HMD-VR still lacks detailed UI guidelines for individual components, e.g., menus, buttons, or search functions, tailored to specific use cases including training, productivity, commerce, or gaming scenarios. Given that VR showcases immense potential in architecture, interactive training, and applications that transcend the physical spaces, there is an opportunity to design, experiment, and present guidelines for application and context-centric menus beyond the spaces they have been proposed for. Having detailed design guidelines for a range of use cases will not only expedite the VR development process but also ensure that even novice designers or developers deliver optimal user experiences in their VR applications. Table 6 presents an overview of the future research directions for the design and evaluation of HMD-VR menu UIs.

4.4. Application-specific considerations from menu designs and interaction methods

Building on the thematic patterns observed in our review, the following synthesis connects menu structures, interaction techniques, and usability outcomes, and highlights how particular design choices may support specific goals such as speed, precision, immersion, or long-term usability. These insights emphasize the value of context-aware menu UI design and offer practical guidance for VR designers and developers aiming to make informed, purpose-driven decisions across diverse VR usage scenarios:

Gaming Contexts: Gaming scenarios typically demand fast interactions, low cognitive load, and minimal disruption to immersion. Studies on radial menus, particularly those employed with marking-based selection, have shown their superior performance in supporting quick item selection and fluid task execution [32,33]. When coupled with ray-casting or gesture-based input, these menus support rapid navigation through flat or hierarchical structures. Additionally, wrist-mounted body-referenced menus have been found effective for enabling "eyes-off" interaction, maintaining immersion while minimizing physical fatigue [32]. These features can prove advantageous in combat-oriented or strategy games requiring real-time decisions and minimal interface distraction.

Educational and Training Contexts: Applications such as virtual training modules or educational simulations may benefit from menu systems that enhance engagement, presence, realism, and ease of use. Diegetic menus, modeled on real-world objects like wristwatches, control panels, or medical kits, can effectively simulate authentic contexts and support intuitive learning [15,18,29,41,51]. When paired with direct input, ray-casting, or gaze-based interaction, such menus facilitate natural object manipulation and tool usage in exploratory or instructional scenarios [15,18,40,41,45,55]. Additionally, spatially placing menus within the user's reachable workspace improves usability and comfort during prolonged learning tasks [29,33].

Productivity and Collaborative Contexts: VR applications designed for productivity, collaboration, or virtual office work prioritize consistency, ease of access, and minimal cognitive load to support an effective workflow. In such cases, non-diegetic or spatial menus, often using linear or grid layouts, with input methods like direct touch, employed with ray-casting, or head-pointing with button press, have been proven useful [4,29,32,33,42]. These approaches allow for quick access to tools. However, these menus should be thoughtfully placed to avoid occlusion or fatigue during extended sessions, as overuse of always-visible interfaces can negatively affect visual comfort.

Medical and Scientific Contexts: For tasks involving precise interaction, such as virtual surgery simulations or scientific data visualization, menu systems must enable accurate selection, low error rates, and minimal interaction time. Research suggests that spatial grid or radial menus in single- or two-level hierarchical structures serve these needs well, particularly when combined with gaze-based or direct input techniques [33,52,55]. Central menu placement of radial designs within the field of view facilitates visual search, while peripheral positioning helps avoid occlusion during prolonged interactions [54].

Table 6
An overview of future research directions for menu UI design in HMD-VR applications.

Number	Future research directions
1	Investigate user-centered design approaches, considering diverse user groups (age, physical/cognitive abilities) and context of use.
2	Explore long-term user engagement and retention in VR applications with frequent menu usage, focusing on sustained interest and satisfaction.
3	Design and evaluate hybrid menu systems combining 2D and 3D UI elements to balance usability, immersion, and task performance.
4	Explore the use of wrist and hand placement for long-term use of body-referenced menus in VR, considering different body locations and use cases.
5	Address technical and design-related challenges in body-referenced menus, particularly with arm menus, to enhance their effectiveness and efficiency.
6	Explore body-referenced menus' suitability for supporting a high number of submenus in complex applications, evaluating them across different VR domains.
7	Investigate the effectiveness of object-referenced menus that are integrated within the VE for faster task completion and reduced fatigue during long-term interactions.
8	Conduct empirical studies to evaluate hierarchical menu structures in VR, focusing on the number of submenus supported and their efficiency.
9	Develop detailed, context-specific design guidelines for VR menus to support various applications, including training, productivity, commerce, and gaming.

Design and Prototyping Contexts: In 3D modeling, UI prototyping, and architectural walkthroughs, designers often need quick access to numerous tools while maintaining spatial awareness. Grid menus are suited for presenting many options simultaneously in a clear structure, while radial menus show improved usability in hierarchical depth [4,46,50,52]. These are typically paired with controller-based input or direct touch, allowing precise interaction without disrupting immersion. Wrist-anchored and mid-air menus have also been explored for efficient tool switching, inventory access, and object manipulation [32,50,51,60]. By keeping essential controls within easy reach, they may maintain workflow continuity during complex design tasks.

4.4.1. Synthesized design guidelines for HMD-VR menu UIs

Drawing on key results from our analysis, we propose the following actionable guidelines:

1. Match the choice of GUI dimension (2D or 3D) with the intended user experience and task goals—whether speed, immersion, precision, or ease of use (cf. Section 4.2.2).
2. Apply 2D menus for rapid task completion in goal-oriented tasks (cf. Section 3.1.2).
3. Use 3D menus with real-world metaphors to enhance immersion and presence (cf. Section 3.1.2).
4. Integrate spatial or non-diegetic menus in consistent positions to maintain usability (cf. Section 3.1.3).
5. Avoid use of non-diegetic menus in content-rich environments; they are better suited for brief tasks or low-complexity applications (cf. Section 4.2.1).
6. Adopt diegetic menu integration for high immersion scenarios (cf. Section 3.1.3).
7. Use wrist-referenced or peripheral placement for hierarchical menus to reduce interface clutter and support prolonged interaction (cf. Sections 3.1.4 and 3.2.3).
8. Use radial layouts for menu depth and grid layouts for breadth, i.e., providing simultaneous visual access to many items (cf. Section 3.1.4).
9. Limit menu options per level to improve usability; use up to six options for radial menus (cf. Section 4.2.1).

By incorporating these synthesized guidelines into their applications, VR researchers and developers can create more effective, intuitive, and contextually relevant menu interfaces that support both user goals and application-specific requirements in HMD-VR environments.

5. Limitations of the study

This research study presents some limitations that need to be considered. Firstly, the review's scope is confined to journal articles and conference proceedings published between 2012 and 2024 that are indexed in Scopus and Web of Science databases, and written in English. As a result, sources such as thesis reports, book chapters, blogs, websites, and commercial applications have not been included in this review.

Second, although commercial products often introduce innovative menu UI solutions, they were not included in this review. This exclusion stems from the limited availability of detailed documentation on their design rationales, usability evaluations, and technical specifications—elements necessary for consistent evaluation across studies. Nonetheless, we acknowledge that not all academic publications included in this review provide empirical validation of their proposed interfaces, and we have noted this as a constraint when drawing insights and suggesting recommendations for future work.

Third, the focus of this review is not on examining interaction techniques. However, it should be noted that interaction behavior could potentially influence the design of menu UIs for HMD-VR. Lastly, while other technologies such as CAVE-VR, AR, MR, desktop/web, and mobile applications do have relevant menu UIs, they have not been considered in this review due to their departure from the central focus on HMD-VR. Future research may choose to expand on this scope to incorporate commercial systems, interaction techniques, or alternative VR platforms. Such an approach may yield a more inclusive picture of current menu UI practices and challenges.

6. Conclusion

In this paper, we presented a systematic review of menu UIs for HMD-VR published between 2012 and 2024. Results have been categorized into three broad categories: (a) key factors which are considered when designing and evaluating menus, (b) state-of-the-art on types of menu UIs for HMD-VR, and (c) design guidelines proposed on graphical menus for HMD-VR. Our findings indicate that when 2D menus of any layout similar to desktop systems are integrated into 3D VE, they perform faster but feel unnatural and can break the user's immersive experience. 3D menus, on the other hand, feel natural and maintain the user's immersive experience, but perform poorly on task completion time and have a higher learning curve. Researchers have also explored various positions for menus in the VE and found that placement on the user's virtual body, especially on wrist and hand location, serves several advantages in VR, such as close proximity for interaction, the ability to reposition the menu in case of occlusion, and increased immersion. Few research studies have proposed guidelines for designing and implementing spatial and diegetic menus for HMD-VR.

With this review paper, we present design recommendations along with multiple opportunity areas where designers and researchers can design, experiment, and propose new scientific knowledge in HMD-VR menu design. Overall, there is scope for further research on the design and evaluation of body-referenced, object-referenced, and hybrid menus in single or multiple levels of hierarchy. Researchers can also investigate the number of menu items effectively supported by different menu layouts other than radial, and which menu structures are preferred by different user groups for particular application contexts. Finally, researchers can also provide detailed menu UI guidelines for spatial and diegetic menus in different contexts beyond the spaces for which they have been designed. This will benefit VR designers and developers in creating intuitive and user-friendly immersive experiences.

CRediT authorship contribution statement

Rishabh Pandey: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Keyur Sorathia:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Data availability

The data used to identify the relevant literature and support the findings of this study are included in the article.

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