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Virtual humans in virtual reality: a scoping review on sociability, fidelity, and expression

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Introduction: Virtual reality (VR) systems have evolved significantly over the past decade, enabling immersive experiences with enhanced realism and interactivity. This has motivated an interest in socially oriented applications. As user proxies, Virtual Humans (VHs) play essential roles in such applications. However, despite technological advancements, achieving realistic, expressive, and socially responsive VHs continues to present design and implementation challenges. In this scoping review, we present the state-of-the-art of VR VHs, examining the impact of VHs on the user experience.

Methodology: We reviewed 59 papers retrieved from five databases across three core themes: the implementation and impact of VH facial expressions, the impact of VH fidelity on the user experience, and the influence of VHs on human emotion and social engagement in VR. In addition, we categorized the methodologies of the reviewed studies, detailing the nature of participant interactions and the measurements taken to derive the results.

Results: The synthesis of the examined studies indicates that both the social context (e.g., collaborative work vs. solo tasks) and the virtual environment (realistic office vs. fantastical world) significantly influence VH design decisions, such as the appropriate level of realism and emotional expressiveness.

Discussion: Our review highlights the relation between social engagement, fidelity and expressiveness. We offer a set of guidelines for researchers and developers aimed at optimizing VH design to enhance user experience in VR.

KEYWORDS

avatars and digital agents, emotion, facial expression, perception, social VR, virtual reality, virtual human, VR

1 Introduction

The origins of virtual reality (VR) can be traced back to the 1960s (Parveau and Adda, 2020), and it has since undergone numerous changes. Early VR systems were constrained by large and immobile hardware and lacked accessibility to most potential users; however, these systems have changed significantly over the years, especially since the 2010s, with the increased availability of consumer-grade VR devices (such as Oculus, currently Meta) (Cipresso et al., 2018). Currently available VR devices include sophisticated, mobile head-mounted displays (HMDs) with multiple cameras and sensors for tracking; they possess the computing power to run their own operating systems and applications independently. Thus, more immersive and interactive experiences are enabled. As a result, VR is now widely used across many industries, including health, construction, and military.

As VR systems continue to evolve, there is an increasing focus on the social and emotional engagement of users with VR content. This has resulted in increased attention

given to virtual humans (VHs), particularly VR avatars (VHs that users can embody). Avatars are visual and emotional proxies of users (Hube et al., 2024); they act as a medium through which users interact with each other within a shared virtual world and interact with the virtual world itself. With new developments in facial tracking, these avatars have become more expressive and interactive. An avatar that is well capable of behavior realism can improve social interaction in VR Fraser et al. (2025). Social engagement in a VR context is a multidimensional measure, which constitutes popular VR concepts such as presence, behavior, personal identity, emotion, and quality of communication (QoC), and each of these factors is interconnected and even has sub-categories themselves (Oh et al., 2018; Yee and Bailenson, 2007; Garau et al., 2003). By conducting this scoping review, we aim to explore the current research on VHs and their emotional and social impacts on VR users. This takes us to our first Research Question (RQ):

RQ1. How do VHs influence the process of social interaction, and in what specific ways do they modulate the user's emotional and behavioral responses?

While emotional and social engagement describe how users respond to VHs, the characteristics of VHs also require specific attention. Specifically, their appearance, motion, and how they are presented in a VR setting require attention. These can be placed under the concept of fidelity. Fidelity is closely linked to realism; it can be described as how closely something resembles or mirrors reality Bonfert et al. (2024). Through this review, we also aim to understand how avatar fidelity influences presence, immersion, and perception. "Presence" refers to the psychological state of "being in" the virtual environment (Lee, 2004; Pan et al., 2018), while "immersion" in this context is defined as "an objective measure of the extent to which a system presents a vivid virtual environment while excluding physical reality" Makransky and Petersen (2021). Here, we investigate works that have studied VR VH graphic details, motion realism, level of embodiment, and personal resemblance. "Embodiment" is often defined as the sense of ownership and control over a virtual body (Banakou and Slater, 2017). Thus, to fully understand how VHs affect users, it is necessary to examine not only their social impact but also the design characteristics that produce these responses:

RQ2. How does the structural fidelity (visual, embodied, personalized, and physical) of VHs affect perceived realism and user experience in VR?

While RQ2 examines most aspects of VH fidelity, one specific dimension of fidelity that deserves special attention yet remains underexplored is VH facial expression, especially facial expressions of user-embodied avatars. Facial expressions are most crucial for communicating nonverbal cues and social signals (Sundaram and Webster, 2000; Oh Kruzic et al., 2020). Facial expressions convey affect, intention, and subtle interpersonal signals, making them an essential part of human-human communication, whether in real life or in VR between two avatar-embodied users. Existing research tends to focus on graphical fidelity or full-body motion, with far fewer studies systematically examining how different avatar facial expression techniques affect perceived realism in VR. The most

common methods used to implement avatar facial expression are the procedural creation of emotion-specific expressions, real-time facial tracking, or predefined animation sets. Substantial research has not been conducted on the impact of implementing avatar facial expressions and their effect on perceived realism and user experience. Here, we aim to understand the impact of implementing avatar facial expressions on the user experience and the methods used to implement them.

RQ3. As a specialized subset of structural fidelity, how are facial expressions technically incorporated into avatars (user-embodied VHs), and what role do they play in enhancing user interaction?

To provide a structural mapping of the literature, we organize our RQs in a top-down analytical framework. This begins with the examination of high-level social qualities of VH interaction and how these qualities affect user experience. We then dive into the technical design and implementation of the VH's physical qualities that allow for the social mechanisms to be effective; thus, our review moves from a human-centric mechanism to a system-centric one. These three RQs form a triad on understanding VH design because social engagement and fidelity expressions are interdependent aspects of VH-based communication. Facial expression helps with clarity in communication, fidelity commands believability, and together they dictate emotional engagement and interaction quality in VR.

While recent systematic reviews have provided rigorous taxonomies for VH visualization and rendering styles Weidner et al. (2023), our review bridges these technical descriptions with the psychological and social outcomes they elicit. We move beyond visualization to social outcomes, positioning VHs as active socio-emotional actors. We also provide a dedicated investigation into the implementation and communicative mechanics of facial expression, an area identified by Weidner et al. (2023) as a research gap, and map the objective and subjective methodological tools to measure these social effects in VR and propose design implications for socially and emotionally resonant avatars. These three research questions provide a comprehensive overview of how VHs can be designed for VR applications, particularly in social VR, by clarifying the style, expressiveness, and fidelity most appropriate for different contexts. In addition, we categorize the selected papers by interaction type and assessment methods, highlighting that there is currently no single standardized approach to VH interaction or evaluation. Although not defined as primary RQs, the customization of VHs came up as a major theme across categories. Customization has influence on multiple factors in VHs in VR, like presence, embodiment, and personal identity. This topic is therefore discussed as a cross-cutting theme, due to its organic emergence from the reviewed literature.

Overall, by mapping engagement, fidelity, facial expression, and the methodological approaches in the literature, our review acts as a guide for researchers to design future studies and for moving the field toward more consistent and comparable practices.

2 Methods

To ensure a clear and thorough literature search, this scoping followed PRISMA-ScR recommendations. The scope of the study

and the eligibility requirements were created via the PCC framework: population, concept, and context. We chose to conduct a scoping review because our aim was to map the breadth of literature and methodological diversity of VH research in VR rather than to conduct a critical appraisal of the existing literature.

2.1 Eligibility criteria

The eligibility requirements were designed to be inclusive and specific to fit our three guiding research questions. Studies were included if they examined the use of VHs in virtual reality settings and their influence on user perceptions, emotional involvement, or user experience.

- **Population:** We considered studies involving human interaction with VHs; studies lacking human validation were excluded because socio-emotional factors are a significant aspect of our review. We did not place any restrictions on user demographics such as age, sex, or background. We also included studies with specialized populations (e.g., children, senior citizens) to include a diverse range of user experiences.
- **Concept:** Our focus was on the design, application, and impact of VH characteristics. We examined studies that investigated VH facial expressions, fidelity, and social engagement. Studies were included if they investigated how these characteristics affected perceived realism, emotional or social participation, or clarity of expression. The studies of interest for our review included research that contrasted the use of different types of facial expression implementation in avatars, the application of VHs in different scenarios, and the examination of VH fidelity levels.
- **Context:** We included studies that were performed in VR settings. This criterion was chosen to maintain consistent immersion and embodiment across the reviewed research.

2.2 Exclusion criteria

To maintain the focus on human-centric and VH-mediated VR interactions, we excluded studies based on the following criteria:

- **Nonhumanoid VHs:** Studies that focused exclusively on nonhuman or abstract representations (e.g., animals or geometric figures) without human-like characteristics or behaviors were excluded.
- **AI/machine learning development focus:** Papers that focused on the development of AI systems to recognize VH expressions in VR were excluded, as our focus is on the human perception of VHs.
- **Non-VR contexts:** Because of the variation in embodiment potential and visual feedback, studies concentrating on mixed reality (MR) or augmented reality (AR) systems were not included.
- **Language and duplication:** Only publications in English were included to ensure accurate interpretation. Duplicate records and papers without full-text availability were also excluded.

- **Year of Publication:** Studies published more than 6 years prior to the final search date were also excluded. The initial search covered a five-year period; however, as the review process progressed, the search was conducted a second time to ensure the literature remained current.

2.3 Databases

To ensure a wide range of searches across disciplines, we selected five major academic databases that are frequently used in VR, HCI, computing, and graphics research:

- Web of Science
- IEEE Xplore
- Scopus
- ACM Digital Library
- ProQuest

These databases were chosen to capture journal articles and conference proceedings.

2.4 Search strategy

The initial search was conducted on 15 January 2024, and was updated on 15 October 2025, to include the most recent literature. The search strategy used Boolean combinations of search terms relevant to the topic. The abstract, keywords, and title of the document were searched for the search terms.

(VR OR “Virtual Reality” OR “Immersive Virtual Environments”) AND (avatar OR “embodied agents” OR “Digital Humans” OR “Digital Characters” OR “Virtual Agents” OR “Virtual Humans”) AND (“communication” OR “behavior” OR express* OR “emotions” OR “facial expression” OR “interaction” OR “perception” OR “control” OR “Social” OR “animation” OR “tracking” OR “fidelity”).

The search was customized for each database’s syntax. All the search results were imported into Mendeley for organization, where duplicates were automatically removed before screening.

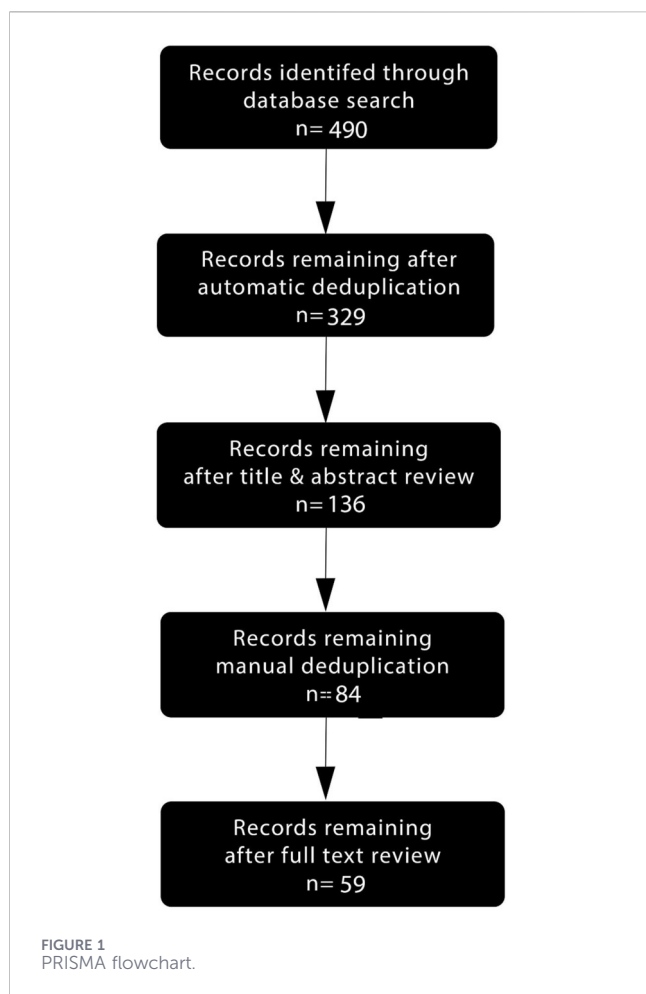
2.5 Data charting

A structured data charting Excel sheet was used to extract and organize key information from each reviewed study. The data retrieved included participant size, participant demographics, aim of the study, study design, experiment duration, equipment and software used, interaction modality, measurements taken and assessment tools, and findings. This coding process of the data was iterative.

3 Results

A total of 490 papers were found through a database search across five major academic sources. The search retrieved recent publications over the last 6 years (Figure 1).

Following de-duplication, 329 papers were retained for initial screening. These were evaluated based on title and abstract relevance, and by applying exclusion criteria, 193 papers were



removed during this stage. Automatic de-duplication did not catch all the duplicates, and 52 duplicates were further identified and manually removed during title and abstract review; the remaining 84 papers were then subjected to a full-text review.

The full-text review resulted in the selection of 59 papers. Twenty-five papers were excluded during the full-text review. These papers were excluded because they were proposing research ideas that had not yet been developed into complete studies, or they were papers that introduced algorithms or new technologies without conducting trials involving human participants. The final 59 records are categorized into three thematic categories according to their relevance to the three research questions on emotional/social engagement, VH fidelity, and facial expression.

3.1 Social and emotional impact of virtual humans

To investigate the human-centric mechanisms of social interaction (RQ1), we identified 35 studies that assessed how VHS modulate users' emotional and social engagement (see Table 1). These papers collectively emphasize that VHS are more than visual proxies; they are social entities that shape user behavior, presence, identity, emotion, and quality of communication. All papers in this section are selected because their primary research focus is on social interactions and dynamics. These papers have been

arranged into five categories according to the principal social aspect they address.

- Behavior: Explore how VHS shape user actions and responses (e.g., attention, interaction style) [Bailenson et al., 2001](#); [Pan et al., 2018](#)).
- Presence: Focuses on how VHS influence users' feelings of "being in" the virtual environment ([Lee, 2004](#); [Pan et al., 2018](#)).
- Identity: Investigates how VHS enable self-expression and identity construction [Bessièrè et al. \(2007\)](#); [Nowak and Fox \(2018\)](#).
- Emotion: Examines how VHS shape emotions within the user [de Melo et al. \(2012\)](#).
- Quality of Communication (QoC): Assess how VHS enable effective communication [Garau et al. \(2003\)](#).

Across all the studies, VHS were found to influence social and emotional engagement in VR users through five interconnected factors: behavior, presence, identity, emotion, and QoC. VHS shaped how users act and respond in social environments by increasing approachable and prosocial behaviors through social-resource priming [Jeong et al. \(2025\)](#), and positive self-avatar impressions [Matsui et al. \(2025\)](#), group cohesion [Buck et al. \(2023\)](#), increased attention [Gao et al. \(2022\)](#), and even improved mood [Kurzweg and Wolf \(2022\)](#). VHS also increased the feeling of presence in users merely through the use of an avatar, even without the use of full-body tracking [Hu et al. \(2025\)](#), while realistic VH animation contributed to improved presence, learning, and enjoyment [Peixoto et al. \(2021\)](#) and expressive VHS further enhanced social presence and interpersonal attraction [Wu et al. \(2021\)](#).

A recurring theme is that avatars that are customized by the user lead to an increase in achieving a positive emotional state ([Gualano et al., 2024](#); [Radiah et al., 2023](#); [Bujic et al., 2023](#)), feelings of inclusion, authenticity, self-expression, and comfort ([Buck et al., 2023](#); [Gualano et al., 2024](#); [Zhang and Juvrud, 2024](#); [Dong et al., 2024](#)), while mismatches in perceived identity shaped safety and harassment risks [Schulenberg et al. \(2024\)](#). It has also been reported that the use of customized avatars in social VR results in stronger group cohesion and participation ([Buck et al., 2023](#)), and the quality of self-representation through avatars could enhance interpersonal communication with other users. VHS also demonstrated a strong ability to evoke and regulate user emotions. It was observed that tracked and expressive avatars increased empathy and emotional resonance [Magar et al. \(2025\)](#), stylized or familiar avatars evoked nostalgia and interpersonal warmth [Yen et al. \(2025\)](#), personalized avatars produced more positive emotional states [Bujic et al. \(2023\)](#), [Radiah et al. \(2023\)](#) and self-aligned avatars reduced emotional self-discrepancy and enhanced self-related outcomes [Bujic et al. \(2025\)](#). Inclusive avatars supported positive emotional experiences among disabled users [Angerbauer et al. \(2024\)](#), and VR performances engaging with race and identity fostered deep emotional reflection [DeVeaux et al. \(2025\)](#). VHS also play an important part in clarity of communication; expressive avatars improved idea flow and collaborative communication [Osborne et al. \(2025\)](#), while uncanny appearance disrupted interaction [Zheleva et al. \(2023\)](#). The nonverbal behavior of avatars was one of the most explored topics among these studies. Nonverbal behaviors such as head nodding and arm positioning were found to be critical in the

TABLE 1 Studies addressing emotional and social impact of VHs.

Author(s)	Sample size	Social aspect	Key findings
Jeong et al. (2025)	103	Behavior	Social-resource priming led to stronger approach behaviors toward avatars, indicating motivational readiness
Matsui et al. (2025)	11	Behavior	Positive self-avatar impressions increased agreeableness and prosocial behavior during social VR interactions
Schlesener et al. (2025)	34	Behavior	Age and gender of VHs significantly influence their persuasiveness and social impact
Son and Rubo (2025)	128	Behavior	Social VR elicits natural interaction behavior and may be used to implement anonymized face-to-face interactions
Ratan et al. (2024)	132	Behavior	Avatars with cultural/organizational associations can induce stereotyped behavior, raising ethical design concerns
Buck et al. (2023)	50	Behavior	Avatar customization choices significantly impact feelings of inclusion and group dynamics in VR
Gao et al. (2022)	280	Behavior	Animated peer avatars affected participants' attention regardless of animation frequency
Kurzweg and Wolf (2022)	28	Behavior	Attentive avatars significantly improved user mood compared to passive ones
Pankotsch et al. (2024)	30	Behavior	No significant results for social pressure, encouragement, or trust
Kasapakis and Dzardanova (2022)	40	Behavior	Students using VR learning environments outperformed those using traditional platforms by 30%
Freeman and Maloney (2021)	30	Behavior	Social VR users construct self-presentations based on real-world and platform-specific traits
Joy et al. (2022)	48	Behavior	Faster responses when the object handle is aligned with the user's hand side
Hu et al. (2025)	20	Presence	Micro-phenomenological interviews revealed strong embodied presence and reflective self-awareness without tracking cues
Wang et al. (2025)	72	Presence	Visible avatars and first-person perspectives increased social presence and task performance in collaboration
Bozgeyikli (2024)	40	Presence	Bidirectional real-virtual interactions enhance presence, co-presence, and make experiences more immersive and engaging
Peixoto et al. (2021)	72	Presence	Realistic animation improved presence, learning, and enjoyment
Wu et al. (2021)	40	Presence	Highly expressive avatar control systems enhance social presence and attraction
Schulenberg et al. (2024)	223	Identity	Social VR users are more frequently harassed due to misperceptions of their identity than accurate representations
Gualano et al. (2024)	15	Identity	Social VR environments elicit more natural interaction behavior when users embody self-similar avatars
Zhang and Juvrud (2024)	101	Identity	Customized avatars enable fluidity of gender expression
Dong et al. (2024)	6206	Identity	Users highly value avatar customization, as it allows self-expression and identity formation in the virtual space
Fiedler et al. (2024)	64	Identity	Self-esteem and body shape concerns influence body perception in VR.
Radiah et al. (2023)	40	Identity	Personalized avatars elicited stronger emotional responses in valence and arousal, especially for the happy emotion
Nordin Forsberg and Kirchner (2021)	26	Identity	Improved task performance with acquaintances than with strangers
Magar et al. (2025)	99	Emotion	Role-playing with tracked VHs enhanced empathy and emotional resonance in assessment contexts
Yen et al. (2025)	48	Emotion	Familiar and stylized avatars rekindled emotional warmth and nostalgia when reconnecting dormant ties
Angerbauer et al. (2024)	26	Emotion	Study found that people with disabilities using inclusive avatars had a good overall experience in social VR.
DeVeaux et al. (2025)	52	Emotion	Avatars in a racially conscious VR performance fostered empathy and emotional reflection

(Continued)

TABLE 1 Continued

Author(s)	Sample size	Social aspect	Key findings
Bujić et al. (2025)	55	Emotion	Aligning users' avatars with their self-perception in a multi-user VR environment reduced self-discrepancies and enhanced social presence, embodiment, and self-related outcomes during collaboration
Bujić et al. (2023)	55	Emotion	Self-created avatars led to higher positive emotional states compared to default avatars
Freeling et al. (2022)	30	Emotion	Emotion influenced embodiment regardless of emotional valence
Baker et al. (2021)	16	Emotion	Avatars helped older adults increase social participation and connection
Osborne et al. (2025)	68	QoC	Playful, morphable avatars improved creativity, idea flow, and communication quality in collaborative VR meetings
Han et al. (2024)	40	QoC	Voice realism improves communication in VR more than appearance realism
Zheleva et al. (2023)	44	QoC	The eye gaze of avatars was not a significant predictor of QoC. The perceived uncanniness of avatars negatively affected QoC

flow of interactions in VR in social environments, including professional settings (Kurzweg and Wolf, 2022).

We also observed that most of the studies used university-aged participants, as the mean age of all the studies except three was in the age range of 18–29 years (Gao et al., 2022; Baker et al., 2021; Magar et al., 2025). Among all the studies, only one Baker et al. (2021) was conducted over a longer period of time. Most studies have been short-term and laboratory-based, with limited ecological validity.

Overall, VHS with emotional expressiveness and social responsiveness play an important role in creating emotionally rich virtual experiences. VHS affect social and emotional engagement of users in VR by shaping how users act, how present they feel with others, how they express their identity, how emotionally involved they are with their virtual partners, and how effectively they communicate. Additionally, VHS are capable of eliciting a various range of emotions in users, emotions such as nostalgia, emotional warmth, empathy, and improved mood. Collectively, these findings suggest that future research should treat VHS as active socio-emotional agents rather than passive graphical assets and that design choices in expressiveness, identity cues, and customization directly influence the quality of interaction and user wellbeing.

3.2 Virtual human fidelity

To address the system-centric structural baseline (RQ2), we found 17 studies that investigated how different levels of fidelity establish perceived realism (see Table 2). These studies are categorized into four fidelity types. Even though fidelity can affect social engagement, the papers selected for this section primarily focus on fidelity comparison rather than the social aspects. Fidelity can be described as the degree of exactness to which something is reproduced. Usually, when discussing VH fidelity, the focus tends to be on visual fidelity (how real a VH looks), but the same concept can also be applied to other aspects of the avatar, which is explained by the categorization below.

- **Embodiment:** Compares the different embodiment conditions of both user-embodied avatars and partners' avatars (e.g., hand vs. no hand, full body vs. torso only) Kilteni et al. (2012).

- **Visual Style:** Compares the visual style of avatars (e.g., photorealistic vs. cartoonish) McDonnell et al. (2012).
- **Personalization:** Flexibility in designing avatar-to-user likeness (e.g., generic avatar vs. avatar that looks like the user) Yee and Bailenson (2007).
- **Physicality:** Comparison of the physiological properties of avatars (sweating avatar vs. non-sweating avatar) Slater and Sanchez-Vives (2016).

The studies discussed here largely focused on the influence of avatar fidelity on user experience in VR environments. The common theme across these studies from all categories except visual style is that high-fidelity avatars are almost always preferred owing to their ability to create realistic VR experiences.

From the studies reviewed, it was clear that fidelity has a strong influence on user experience. Higher embodiment fidelity enhanced users' presence and engagement with the VR environment. Full-body avatars increased long-term engagement and improved learning outcomes Schnitzer et al. (2025), fully embodied avatars improved copresence, balance, and task involvement compared to low-level embodiment and no avatar conditions. Visual fidelity of VHS directly impacts perceived realism and social credibility. Photorealistic avatars improved confidence in judgments Etienne et al. (2023), they were perceived as more realistic and visually appealing Zibrek et al. (2019), and they increased users' self-esteem and attractiveness perception when embodying ideal-weight avatars Holderrith et al. (2025). The context also matters in VH design; it was found that during social simulations, subtle differences in VH render style affected users' visual attention patterns. Stylized visualizations were preferred when users were not directly interacting with VHS, but medium to high-fidelity visualizations were preferred when users were actively interacting with VHS Volonte et al. (2019). This suggests that optimal visual fidelity depends on the context and purpose and must be carefully matched with the goals of the VR application. For example, sweaty avatars increase realism during workout scenarios (Grace et al., 2025), whereas photorealistic avatars improve presence in social scenarios (Zibrek et al., 2019). In another workout scenario (Baneriski et al., 2025), participants guided by avatar trainers were significantly more motivated than those trained by humans or their

TABLE 2 Studies addressing VH fidelity.

Author(s)	Sample size	Fidelity type	Key findings
Schnitzer et al. (2025)	32	Embodiment	Animated full-body avatars enhanced long-term vocabulary retention, comprehension, and engagement
Wagmann et al. (2025)	31	Embodiment	Proprioceptive motion feedback improved the perceived naturalness of avatar movement
Resch et al. (2024)	24	Embodiment	Avatars improved balance and engagement compared to no-avatar conditions
Chang et al. (2022)	10	Embodiment	Gestural Agent enhanced copresence and reduced workload compared to the Voice-only Agent
Unruh et al. (2021)	121	Embodiment	An avatar leads to a faster perceived passage of time
Li et al. (2024)	24	Embodiment	Participants perceived full-body avatars as socially engaged
Boban et al. (2025)	20	Visual Style	Users' perceived ideal body proportions align closely with their real-world morphology
Holderrieth et al. (2025)	16	Visual Style	Embodying photorealistic, ideal-weight avatars increased short-term self-esteem and perceived attractiveness
Kim et al. (2025)	20	Visual Style	Stylized and IK avatars enhanced body ownership and agency
Etienne et al. (2023)	125	Visual Style	Photorealistic avatars increase participants' confidence in their judgments
Zibrek et al. (2019)	622	Visual Style	Photorealism alters interpretation of character intent, increases sense of presence, and is perceived as more visually appealing
Volonte et al. (2019)	78	Visual Style	Visual attention varies depending on the rendering style of the VH in interpersonal simulations
Salagean et al. (2023)	20	Visual Style, Personalization	Higher levels of photorealism and personalization can enhance embodiment and self-identification in virtual environments
Kocur et al. (2025)	24	Personalization	Customized avatars led to greater exertion and engagement
Kocur et al. (2020)	32	Personalization	Avatars' appearance to both the user and the others must be considered when designing for cognitively demanding tasks
Banerski et al. (2025)	108	Physicality	VR avatars improved affective attitude and motivation toward exertion
Grace et al. (2025)	17	Physicality	Physiological effort and perceived exertion increased with sweaty avatars during high-intensity cycling

flat-screen counterparts. Another notable finding was that time perception in a virtual environment is influenced by the embodiment of an avatar; the passage of time was perceived to be faster when the participants were embodying an avatar as opposed to the absence of an avatar (Unruh et al., 2021).

High-fidelity avatars improve VR experiences in general. Avatars with high visual realism and detail (photorealistic avatars), embodiment (full-body tracking), and visualization all lead to stronger presence, immersion, and perceived realism within VR. However, these methods are context sensitive as well. Only one study (Schnitzer et al., 2025) conducted longitudinal tests as part of their research; they found that increased immersion prevents loss of knowledge and fully embodied VR experiences help with memory retention.

Our findings further point out that fidelity is not a one-size-fits-all solution: different contexts require different levels of realism. For instance, stylized avatars may be more effective in education or entertainment scenarios, where clarity and accessibility matter, whereas photorealism is more impactful in social collaboration or professional training, where trust and presence are critical. This highlights the need for adaptive design that considers when realism supports engagement and when stylization avoids distraction or uncanniness. User preference for personalization demonstrates that fidelity is not only visual but also psychological, tied to self-worth and identity. Future research should focus on developing flexible

fidelity frameworks that adapt to user goals, contexts, and cultural expectations, making avatar design more inclusive and effective. Overall, in most VR experiences we can enhance user experience by the use of VHs whose appearance and behavior are more consistent with real-world expectations. This in turn improves perceived realism or naturalness and makes users more present and immersed.

3.3 Virtual human facial expression

Similar to fidelity, facial expressions can also influence social aspects in a VR environment and can also be classified based on fidelity, but it is a crucial aspect of VH that is underexplored Weidner et al. (2023) and needs to be investigated more. The studies included in this section primarily focus on embodied avatars and their facial expressions. We examined the technical communicative mechanisms (RQ3) through 7 studies that isolate the implementation and impact of avatar facial expressions that implemented facial expressions on VR avatars and investigated their impact. While there were other papers that proposed methods for implementing expressions in VHs in VR, these papers were excluded due to the absence of a formal validation study using human participants and therefore did not meet our inclusion criteria. These studies that helped answer RQ3 have been categorized into three sections on the basis of the method of facial expression implementation:

TABLE 3 Summary of studies addressing facial expression and animation in avatars in VR.

Author(s)	Sample size	Expression implementation method	Key findings
Wei et al. (2024)	122	Tracked	Positive facial expressions significantly reduced visual attention on avatars when faces were static
Tarnec et al. (2023)	29	Tracked	Social presence is higher with facial expressions and more gaze time
Fraser et al. (2022)	61	Tracked	Animation realism and interaction quality benefits from higher levels of face and body expressiveness
Kullmann et al. (2023)	44	Synthesized, tracked	Static faces were less natural than animated faces
Schott et al. (2025)	40	Synthesized, animated	Users could tolerate up to 8° gaze deviation before detecting redirection. Helps in redirecting gaze without breaking perceived eye contact
Baloup et al. (2021)	31	Synthesized, animated	Menu-based techniques showed greater preferences
Yi et al. (2023)	45	Animated	Eyebrows are more expressive than eyelids

- Tracked: Studies that used face tracking or other sensors to map user facial expressions onto avatars [Li et al. \(2015\)](#).
- Synthesized: Coded/programmed expression based on inflections in voice [Cassell et al. \(2001\)](#).
- Animated: Facial expressions were implemented through animation systems such as blend trees ([Lewis et al. 2014](#); [Kshirsagar 2002](#)).

This section maps studies that explicitly looked into the impact and implementation of facial expression in embodied human avatars ([Table 3](#)). From the seven studies identified for this section, facial expressions were incorporated using the three methods mentioned above. It was observed that tracked facial expressions elicited more gaze and higher social presence [Tarnec et al. \(2023\)](#), when higher levels of facial expressiveness were achieved through tracked expressions and then combined with body expressiveness, it strengthened perceived realism in users [Fraser et al. \(2022\)](#). However, tracking shifted user attention in unexpected ways; tracking has reliability issues (latency, jitter), which limited user preference. Synthesized expressions provided stable, controllable cues such as programmed eye movement; hence, they were preferred over static ones [Kullmann et al. \(2023\)](#), and procedural gaze manipulation was found to be convincing up to an 8° deviation [Schott et al. \(2025\)](#). Animated methods were useful in highlighting which facial regions matter the most for emotional clarity, with eyebrow movement found to be more important than eyelid motions [Yi et al. \(2023\)](#) and while implementing animation, menu-based methods were found to be reliable and precise for controlling facial animation [Baloup et al. \(2021\)](#).

Overall, it's clear from these papers that there is no one ideal method that fully solves the implementation of avatar facial expressions. Tracked expressions show the most potential for realism, but still some improvements need to be made. Currently the best way to achieve realistic facial expressions would be to use hybrid systems that combine some procedural cues with selective tracking. There is a clear need for more research on facial expression systems for embodied VHs in VR, especially those that integrate real-time tracking with adaptive animation. When compared with other body parts, VH's face can generate a larger uncanny valley (the feeling of eeriness evoked by slightly imperfect human-like

characters [Stein and Ohler \(2017\)](#)) effect [Makransky and Petersen \(2021\)](#). So when implemented with caution to reduce uncanny valley effects, dynamic facial animation significantly enhances avatar realism and plausibility, increasing the effectiveness of social interaction and emotional expression. Future work should explore adaptive expression systems that combine automated expressions with partial tracking, ensuring both scalability and believability. By treating facial animation as a core component of socio-emotional communication rather than a cosmetic detail, avatars can better support trust, empathy, and authenticity in VR interactions.

3.4 Methodological characteristics

To understand how current research of VH in VR is conducted, we examined the methodological characteristics of the included studies in terms of physiological/biometric measurements, self-reported measurements, and interaction paradigms. The biometric data measured were as follows:

- Eye gaze: The user's direction and the target's gaze.
- Heart rate: User's heartbeat per minute.
- Electrodermal activity: Measuring changes in the ability of the skin to conduct electricity
- Volume of oxygen (VoX): Indicates how much oxygen the body uses during physical activity.
- Skin temperature: Monitors peripheral temperature.
- Electroencephalography (EEG): Brain activity was recorded through sensors placed on the scalp.

[Table 4](#) includes studies that incorporated physiological data collection as part of their evaluation methods. These physiological indicators offer objective evidence and valuable insight into users' cognitive load, arousal levels, attentional focus, embodiment, and stress response, all of which are critical in evaluating the nuanced effects of VH interactions in immersive environments. For example, gaze metrics were used for measuring attention allocation and QoC, while heart rate and skin conductance were used to measure arousal, exertion, and emotional engagement. There are 11 studies that utilized physiological measurements for their research; out of

TABLE 4 Studies that measure physiological data.

Author (year)	Physiological measurement	To assess
Wei et al. (2024), Radiah et al. (2023), Tarnec et al. (2023), Zheleva et al. (2023), Volonte et al. (2019)	Eye Gaze	Visual attention, Perceived Quality of Communication
Salagean et al. (2023)	Electrodermal Activity	Embodiment
Banerski et al. (2025)	Heart rate	Physical exertion
Grace et al. (2025)	Heart rate, Volume of Oxygen	Physical exertion, <i>Proteus</i> effect
Kocur et al. (2025)	Heart rate	Physical exertion, <i>Proteus</i> effect
Kocur et al. (2020)	Skin temperature	Thermal sensation
Chang et al. (2022)	EEG	Cognitive Load

those 11, 10 of them combined physiological data with self-reported questionnaires. The use of physiological measurements in these studies reflects an emerging trend toward multimodal evaluation frameworks, where a subjective measure such as the user perspective is backed by behavioral data, an objective measure. The integration of subjective and objective measures is widely used in domains such as psychology and human-computer interaction. For example (Cacioppo and Tassinari, 1990; Hellhammer and Schubert, 2012), showed how physiological measures combined with subjective measures can improve the validity of the assessment of a person's emotional state, such as in stress studies. Similarly (Nielsen and Landauer, 1993), the usability evaluation model emphasizes combining behavioral data with user feedback to evaluate system effectiveness. Similarly, Kiefer et al. (2023) found that using subjective visibility ratings with objective discrimination performance gives a more coherent and valid analysis of visual awareness. Eye-gaze measures were paired with subjective assessments of attention and communication quality (Wei et al., 2024; Tarnec et al., 2023; Volonte et al., 2019; Radiah et al., 2023). Electrodermal activity and skin temperature were used alongside embodiment, realism, or thermal-sensation questionnaires to capture users' internal states during avatar interaction (Salagean et al., 2023; Kocur et al., 2020). Studies examining physical exertion or Proteus-effect (tendency for users in virtual environments to adapt their behavior to the characteristics of their respective avatars Praetorius and Görlich (2020)) outcomes combined heart rate and VoX measurements with perceived exertion, self-identity, or motivation scales (Banerski et al., 2025; Grace et al., 2025; Kocur et al., 2025). EEG-based workload assessments were similarly supported by cognitive-load questionnaires (Chang et al., 2022). This two-pronged approach of combining physiological and self-assessed measurements strengthens the validity of the results, particularly in areas central to our review, such as presence, embodiment, expressiveness, and socio-emotional engagement.

In addition to physiological data, assessment tools across the reviewed studies varied significantly, reflecting the interdisciplinary nature of VR research. The most used self-report questionnaires (Table 5), include validated tools such as the Slater–Usuh–Steed (SUS) Presence Questionnaire Slater et al. (1994), the Igroup Presence Questionnaire (IPQ) Vasconcelos-Raposo et al. (2016), and the Simulator Sickness Questionnaire (SSQ). Kennedy et al.

(1993) Most studies relied exclusively on questionnaires. A few studies have used task-based metrics (e.g., performance time or accuracy percentage), whereas others have relied on qualitative interviews or custom thematic evaluations. This diversity in tool selection highlights both the richness and the fragmentation of current VR VH research methodologies. We also discuss the variability between studies in Table 6 in terms of how users engage with VHs, ranging from passive observations to rich, multimodal interactions. Through this methodological analysis, we hope to identify the best practices in VH-based VR experimental design. We classified the studies according to the types of interaction paradigms. The interactions of participants are categorized into three categories.

- No Interaction: Purely observational from the user's perspective.
- Single Modal: Interaction using one mode (e.g., voice only, touch only).
- Multi Modal: Interaction using multiple modes.

This classification provides insight into how immersive and socially rich the study environments were, as well as how much influence participants had on shaping the interaction.

Nine studies did not feature any interaction from the side of the participants but instead involved passive observation or evaluation of VH behavior. In these cases, VHs engaged in scripted actions or displayed predefined expressions. These studies aimed at measuring perception, plausibility, or emotional interpretation without the interception of the participant.

Single modal interaction was employed by 16 studies; as the name suggests, they involve only one mode of interaction, such as a non-verbal gesture or simple controller-based response. While the remaining 34 studies allowed for multimodal interaction, where participants could engage through combinations of speech, gesture, gaze, and spatial movement. The latter category reflects more naturalistic and ecologically valid experiences, closely resembling real-world human interactions, and is used in research of socio-emotional engagement of VHs.

In addition, Table 6 distinguishes whether interaction occurred with another avatar (controlled by the experimenter or another participant) or a non-embodied VH. This categorization is

TABLE 5 Questionnaires used across studies.

Author, year	To assess	Questionnaire(s)
Angerbauer et al. (2024), Grace et al. (2025), Kocur et al. (2025), Schlesener et al. (2025), Resch et al. (2024), Chang et al. (2022), Gao et al. (2022), Kocur et al. (2020)	Cognitive load	NASA task load index/raw/extended, ratings of perceived exertion, subjective mental effort, utrecht work engagement scale
Schlesener et al. (2025), Son and Rubo (2025), Fiedler et al. (2024), Tarnec et al. (2023), Kullmann et al. (2023), Freeling et al. (2022), Peixoto et al. (2021)	Cyber sickness	Cyber sickness symptoms, simulator sickness, VR Sickness
Angerbauer et al. (2024), DeVeaux et al. (2025), Grace et al. (2025), Kim et al. (2025), Magar et al. (2025), Kocur et al. (2025), Son and Rubo (2025), Fiedler et al. (2024), Radiah et al. (2023), Freeling et al. (2022), Unruh et al. (2021), Joy et al. (2022), Kocur et al. (2020), Wagmann et al. (2025)	Embodiment	16-item scale by Peck and Gonzalez-Franco (2021), 3 item scale by Seashore et al. (1982), 5-statement post-experience, adapted ducheneaut scale (2009), avatar appearance, avatar embodiment, body ownership, body responsiveness, body sensation, customized inventory on subjective time, self, and space, embodiment, perceived illusion scale, realism, self, and other scale, virtual embodiment, extended virtual embodiment, perceived self-embodiment
Angerbauer et al. (2024), Banerski et al. (2025), Magar et al. (2025), Bujic et al. (2023), Radiah et al. (2023), Yi et al. (2023), Freeling et al. (2022), Kurzweg and Wolf (2022), Zibrek et al. (2019)	Emotion	5-item lebender scale, circumplex affect model battery, emotional response scales, empathy type evaluation, mood/wellbeing scale, positive and negative activation visual analogue scale, self-assessment manikin, uncanny valley effect scales
Peixoto et al. (2021)	Language	CEFR english test
Bujic et al. (2025), DeVeaux et al. (2025), Holderrieth et al. (2025) Fiedler et al. (2024), Wei et al. (2024), Buck et al. (2023), Bujic et al. (2023), Radiah et al. (2023)	Personality	14-item self-appraisal scale (Napper et al., 2009), big five inventory-10, paranoid thoughts scale (Freeman et al., 2021), rosenberg self-esteem scale, schwartz value survey, self-focus linguistic (Wegner and Giuliano, 1980), ten-item personality inventory
Banerski et al. (2025), Grace et al. (2025), Kocur et al. (2025), Volonte et al. (2019)	Physiological	Edinburgh handedness inventory, fitzpatrick scale, perceived exertion scale, SPF
Angerbauer et al. (2024), DeVeaux et al. (2025), Banerski et al. (2025), Grace et al. (2025), Kim et al. (2025), Kocur et al. (2025), Schlesener et al. (2025), Schott et al. (2025), Son and Rubo (2025), Baloup et al. (2021), Chang et al. (2022), Etienne et al. (2023), Fraser et al. (2022), Freeling et al. (2022), Gao et al. (2022), Bozgeyikli (2024), Fiedler et al. (2024), Resch et al. (2024), Wei et al. (2024), Kullmann et al. (2023), Radiah et al. (2023), Salagean et al. (2023), Tarnec et al. (2023), Yi et al. (2023), Baker et al. (2021), Li et al. (2024), Peixoto et al. (2021), Wu et al. (2021), Unruh et al. (2021), Joy et al. (2022), Kocur et al. (2020), Zibrek et al. (2019)	Presence	Almere model, behavior naturalness scale, co-presence, igroup presence, items from Herrera et al. (2018), MEC spatial presence questionnaire, networked minds inventory, PQ, self-reported copresence, social presence/co-presence scale, social presence, slater-usoh-steel, telepresence index, Witmer & Singer presence
Angerbauer et al. (2024), Bujic et al. (2025), Son and Rubo (2025), Buck et al. (2023), Kurzweg and Wolf (2022), Wu et al. (2021)	Social	16 items by Jansen et al. (2014) 8-item scale by Matos et al. (2015), interpersonal attraction, quality of interaction, work group identification measure
Baloup et al. (2021), Etienne et al. (2023), Peixoto et al. (2021), Wagmann et al. (2025)	UX	AttrakDiff, system usability scale, quality of experience, user experience

important because the social presence and emotional engagement elicited by avatars from their users may differ depending on whether users believe that they are interacting with a real person or a simulated agent. This classification of interaction reveals different levels of immersion and social complexities present in VR environments.

4 Design guidelines

After exploring the literature to answer our guiding RQs, we recommend the following compilation of design guidelines for an effective VH-based communication system for VR.

4.1 Social & emotional guidelines

- Enable personalization: Provide avatar customization options whenever possible, as these enhance comfort, authenticity, inclusion, and positive emotional states.

- Prosocial priming: Use “social-resource priming” aka assign roles to VHs to facilitate different approach behavior towards VHs.
- Identity risks: Ensure that identity representation is accurate to reduce the risk of harassment that could stem from misrepresentations or misinterpretations.
- Empathy: Use tracked and expressive VHs to increase empathy during interactions.

4.2 Structural fidelity & realism guidelines

- Photorealism: Use photorealistic VHs for tasks requiring high trust or presence and stylized VHs where clarity and accessibility are priorities.
- Full-body: Use full-body tracking and full-body VHs for long-term engagement, copresence, and memory retention.
- Context: Align physical properties of VHs with scenarios to increase perceived naturalism; for example, “sweaty” avatars increase realism specifically in high-intensity workout settings.

TABLE 6 Types of interaction in the studies.

Author (year)	Interaction by participant	Interaction by another Avatar/VH
Unruh et al. (2021)	No interaction	None
Han et al. (2024), Wei et al. (2024), Etienne et al. (2023), Kullmann et al. (2023), Yi et al. (2023), Gao et al. (2022), Kurzweg and Wolf (2022), Zibrek et al. (2019)	No interaction	VH
Boban et al. (2025), Holderrrieth et al. (2025), Hu et al. (2025), Kocur et al. (2025), Wagmann et al. (2025), Fiedler et al. (2024), Salagean et al. (2023), Radiah et al. (2023), Freeling et al. (2022)	Single modal	None
Jeong et al. (2025), Schlesener et al. (2025), Bozgeyikli (2024), Pankotsch et al. (2024)	Single modal	VH
Banerski et al. (2025), Fraser et al. (2022), Kocur et al. (2020)	Single modal	Avatar
Grace et al. (2025), Joy et al. (2022)	Multi modal	None
Bujic et al. (2025), DeVeaux et al. (2025), Kim et al. (2025), Osborne et al. (2025), Schnitzer et al. (2025), Schott et al. (2025), Son and Rubo (2025), Wang et al. (2025), Yen et al. (2025), Angerbauer et al. (2024), Dong et al. (2024), Gualano et al. (2024), Li et al. (2024), Schulenberg et al. (2024), Resch et al. (2024), Zhang and Juvrud (2024), Buck et al. (2023), Bujic et al. (2023), Tarnec et al. (2023), Zheleva et al. (2023), Kasapakis and Dzardanova (2022), Baker et al. (2021), Baloup et al. (2021), Nordin Forsberg and Kirchner (2021), Wu et al. (2021), Freeman and Maloney (2021)	Multi modal	Avatar
Magar et al. (2025), Matsui et al. (2025), Ratan et al.(2024), Chang et al. (2022), Peixoto et al. (2021), Volonte et al. (2019)	Multi modal	VH

4.3 Facial expression guidelines

- Upper face: Prioritize the upper face during design, as eyebrows and eye gaze are critical regions for emotional clarity.
- Hybrid systems: Use hybrid systems to combine procedural cues with selective real-time tracking to balance realism and technical stability.
- Dynamic nonverbal behavior: Focus on nonverbal cues like head nodding and arm positioning of VH to maintain the natural flow of communication.
- Eye gaze: Programmed eye movements that stay within 8° deviation provide stable eye contact and increased perceived naturalness.

4.4 Methodological guidelines

- Multimodal Evaluation: Adopt multimodal evaluation techniques that combine subjective self-reported questionnaires with objective physiological data to strengthen the validity of study results.
- Utilize validated scales for specific outcomes, such as NASA-TLX for cognitive load or VEQ for embodiment, to improve cross-study comparability.

5 Discussion

A systematic review that was conducted by Weidner et al. (2023) is closely related to our scoping review. Our scoping review and their systematic review both address the visualization and representation of VHs, yet they differ fundamentally in scope, methodology, and analytical focus. While both reviews have a shared interest in rendering style, fidelity, and embodiment, our review offers three

primary contributions that extend the current literature. The first difference between our review and Weidner et al. is that they have explicitly identified facial animation as a primary gap that needs to be investigated more; we address this through RQ3. Second of all, they organize findings by task domains (e.g., physical activity, hand interaction) to provide design guidelines; our review organizes findings by social mechanisms (e.g., behavior, identity, empathy). This allows us to investigate social interactions in a way that technical taxonomies do not prioritize. So our scoping review focuses on how a VH design can influence human experience. Finally, we also catalogued the methodological characteristics of reviewed papers across multiple dimensions, like interaction and measurement tools used; this provides an extensive mapping of evaluation frameworks in VH-based research in VR. By pairing objective physiological markers with subjective questionnaires, we offer a functional roadmap for researchers to validate the social effectiveness of their designs. Despite these differences, both papers intersect at several key findings, such as the importance of avatar realism on presence and the context-dependent nature of appropriate avatar design.

Our scoping review analyzed 59 studies to examine VH designs, specifically facial animation, fidelity, and emotional expression. We were able to understand how VHs affect user experiences in VR environments. Our review was guided by three RQs focused on avatar facial expression, avatar fidelity, and VH influence on users' emotions. It is important to note that some studies within each section or assigned to each RQ may also address some aspects of another RQ; however, they are included in their respective sections due to their primary research focus.

Thirty-five papers included in this review helped us answer RQ1. These papers emphasized that VHs play a central role in shaping emotional and social experiences in VR. VHs influence how users feel, behave, and connect with their environment and other users.

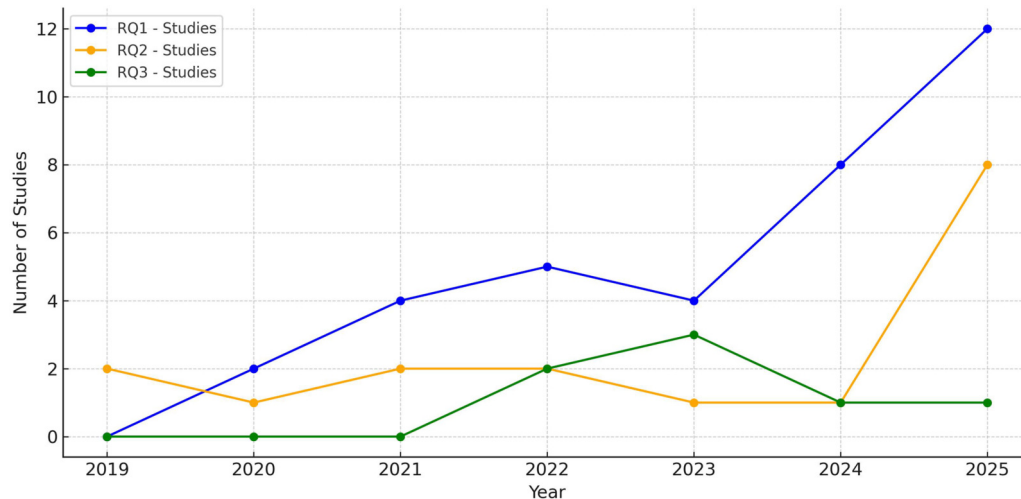


FIGURE 2
Number of studies identified for each research question from 2019 to 2025.

Personalized and customized avatars are strongly associated with the comfort and projection of identities; hence, they are more preferred than are generalized or random avatars. VHS with richer nonverbal behaviors (e.g., eye gaze, head nod) supported more natural interaction patterns. Research shows that subtle behavioral cues can influence attention, rapport, and pro-social tendencies, suggesting that a VH's emotional expression and social signalling are core factors influencing social experiences in VR.

Seventeen studies reported on the impact of VH fidelity in VR environments, particularly in terms of visual style and realism. Having a high embodiment or fully bodied VH improved the sense of presence and engagement of the users. Photorealistic or stylistically coherent avatars improved perceived realism, self-evaluation, and trust, while mismatches between avatar style and context occasionally amplified cognitive effort. Personalization also played an important role; by aligning an avatar's appearance to that of the user, researchers were able to enhance embodiment and emotional investment in users. Fidelity plays a key role in social VR environments by dictating the realism and coherency of a VR system.

Seven studies focused on facial animation techniques for avatars. The compilation of the findings of these studies revealed that upper facial cues such as eyebrow movements and eye gaze are important in the effective communication of emotions; facial cues thus contribute strongly to plausibility. Focusing more on the implementation of face tracking in avatars; tracking, while effective, could disrupt immersion if the tracking is not smooth and technically sound. This has led to a preference for using animated or synthesized expressions, revealing a trade-off between expressiveness and technical robustness. The literature clearly shows that expressive faces enhance the clarity of communication and emotional resonance. These findings highlight that avatars are not simply digital assets but key social and emotional agents that can shape the quality of realism, engagement, and interaction in VR.

The findings of our review clearly indicate an interdependence between the three core RQs. This underscores that sociability, fidelity, and facial expression are mutually reinforcing factors in a VH. The literature that we reviewed for our first RQ indicates that emotionally

expressive and socially responsive avatars significantly enhance social presence, empathy, and the overall quality of interaction (Tarnec et al., 2023; Magar et al., 2025; Yen et al., 2025; Kurzweg and Wolf, 2022). This directly connects to RQ2, which examined the impact of VH fidelity on user experience. We also found that high-fidelity VHS not only improve presence and immersion but also improve social and emotional cues displayed by the VHS, which in turn affects the quality of social and emotional engagement (Holderrieth et al., 2025; Salagean et al., 2023). These studies indicate that context-appropriate high-fidelity VHS with plausible facial expressions result in the most socially and emotionally engaging VR experiences (Buck et al., 2023; Radiah et al., 2023; Bujic et al., 2023).

A central theme that emerged while reviewing the studies was that of customization/personalization. There is a growing focus on VH personalization, especially in relation to user identity, as a means of enhancing emotional engagement and inclusion. Studies consistently reported greater user satisfaction and group interaction when avatars were customized to reflect user traits or preferences. Our review shows that VH design in VR is best implemented as an interaction of fidelity, expressiveness, and socio-emotional engagement, rather than as separate dimensions. High fidelity may improve presence and trust, but it could also feel unnatural or bland if it does not allow for emotional expression. Expressive VHS can also make social presence stronger, but the extent to which they do this depends on how realistic they are and how well they fit in with the identity cues in their design. In turn, social and emotional engagement gives meaning to fidelity and expression by letting users judge VHS not only by how they look or move, but also by how well they support inclusion, empathy, and real interaction. This interdependence indicates that the future of VH design is in adaptive systems capable of dynamically balancing realism, expressiveness, and contextual relevance. This can be achieved by using extremely customizable avatars for various applications, including healthcare, education, and workplace collaboration. We recommend a design that combines technological feasibility and behavioral believability by treating VHS as active socio-emotional agents instead of just as visual representations. This will lead to more realistic virtual experiences.

Another trend we observed is the growing body of literature that focuses on avatars for social VR over the years (Figure 2). There was a growth in the literature from 2019 to 2022, after which the number of studies decreased in 2023, possibly due to the global pandemic and the restrictions associated with it. Since then, the number of papers has increased in 2024, and up till the final search in October 2025, the overall number of papers is much greater than that in previous years by a large margin. Studies on VH social behavior and fidelity show increased focus and priority in research towards broader social dimensions of the usage of VHs.

5.1 Gaps in literature

Despite substantial progress in VR VH research, several gaps in the reviewed literature were identified. There was a lack of demographic diversity among the participant samples. There is minimal representation of older adults, children, and neurodiverse individuals.

There is also little data on the background and culture of the participants. This limits the generalizability of the studies. The long-term effects of avatar use, especially with respect to identity construction, emotional adaptation, or behavioral change, remain largely unexplored.

The facial expression aspect of avatars in social environments is quite underexplored, despite being one of the most crucial aspects of human communication.

5.2 Limitations

While our review collected evidence on VH social impact, fidelity, and expressiveness in VR, there are several limitations to our approach. The exclusion of AR and MR-based VHs makes it impossible to encompass VHs in all immersive environments. Publications that did not involve experiments using human participants were excluded; this resulted in the omission of papers that introduced new algorithms and techniques that were not validated by human subjects. We included only English-language publications, which may exclude relevant findings in other languages.

5.3 Future

Future research should pay more attention to complex emotions while studying the emotional impact of VHs and should also implement longitudinal or repeated-exposure designs to examine how trust, identification, and plausibility evolve. Utilize ecologically valid settings, such as virtual classrooms, remote meetings, or training simulations where users interact with VHs repeatedly. Examine long-term plausibility and whether facial expressions remain effective or begin to feel repetitive. Studies should also consider expanding their participant pool to include more diverse participants, including older adults, neurodiverse individuals, and users from different cultural backgrounds. For example, seniors could be recruited in cognitive load studies, adolescents or teenagers could be included to understand identity formation while using avatars, and cross-cultural samples could reveal how VHs' behavior and social cues are interpreted over different cultures. By addressing these areas, future research can support the development of avatar systems that are inclusive, emotionally

intelligent, and contextually responsive. Thus, the potential of VR as a transformative human experience can be fully realized.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JK: Conceptualization, Data curation, Formal Analysis, Methodology, Visualization, Writing – original draft, Writing – review and editing. ML: Methodology, Supervision, Validation, Writing – review and editing. CE: Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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