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How VR Designers Manage Collisions: A Reflexive Thematic Analysis of Strategies, Trade-offs, and Design Rationales

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Abstract

Virtual Reality (VR) experiences require designers to balance immersion, safety, comfort, and spatial coherence. Within this context, collision management represents a critical challenge, as users interact simultaneously with virtual environments and physical spaces. Although the literature has extensively investigated technical solutions for collision prevention, locomotion, and boundary visualization, less attention has been given to how designers conceptualize and address collision-related problems during the design process. This study investigates how VR designers and developers perceive, communicate, and manage collisions in immersive environments, considering both virtual and real-world contexts. We conducted ten semi-structured interviews with VR professionals and analyzed the resulting corpus using Reflexive Thematic Analysis. The findings reveal that collision management is a multidimensional design problem involving safety, perceptual coherence, interaction credibility, and implementation feasibility. Participants reported a broad repertoire of strategies, including spatial and physical constraints, perceptual cues, navigation-control mechanisms, communicational approaches, and multimodal feedback. The analysis also identified situations in which designers deliberately deprioritize collision management,

treating collisions as a non-central concern due to contextual factors such as controlled environments, seated experiences, or technical limitations. Based on the literature synthesis and empirical findings, the study introduces a conceptual taxonomy of collision events in VR, distinguishing collisions occurring in virtual and real-world environments and the entities involved in each case. The results contribute an empirically grounded understanding of how practitioners reason about collision-related design decisions and provide implications for the development of tools and frameworks that support collision communication and multimodal affordances in immersive environments.

Keywords: Virtual Reality, Collision Management, Immersive Environment Design, Reflexive Thematic Analysis, Affordances

1 Introduction

Extended Reality (XR), which encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has ceased to be a resource restricted to laboratories and has become integrated into games, professional training, education, culture, and healthcare [1]. As immersive applications become more accessible and frequent, the need grows to design experiences that are simultaneously comfortable, safe, and coherent from a perceptual and motor point of view [2]. A critical point in this balance is collision management: how the system and design communicate boundaries, prevent undue crossings, reduce physical risks in the real environment, and minimize side effects such as discomfort and cybersickness [3, 4].

In VR, collisions have a hybrid nature [5]. In the virtual world, they involve passing through walls/objects, rigid blockages, movement restrictions, and feedback that can break the sense of presence and generate frustration when they seem arbitrary or inconsistent with user expectations. In the real world, collisions can represent a physical risk (impact with objects, tripping, loss of balance), especially when the user loses track of the limits of the available space [6]. Thus, collision is not just a simulated physical event; it is also a problem of boundary communication and perception-action coordination, where design decisions shape both user behavior and the safety of the experience [7].

This hybrid nature of collision in VR suggests that the problem cannot be reduced to geometry or physics simulation. Rather, it must be understood as a communicative and perceptual challenge, involving how users interpret spatial constraints and possibilities for action.

Interaction in immersive environments relies heavily on perceptual cues that guide the user on what is possible to do and what is allowed to do in a space. This discussion connects with the notion of affordances as perceived possibilities for action in the environment and with the need to design signals that make limits and restrictions interpretable without requiring excessive cognitive effort [8]. In VR, some of these signals need to compensate for the fact that the body is in the real world, while perception is mostly anchored in the virtual world, a misalignment that amplifies the importance of clear spatial orientation and boundary communication strategies [5].

However, many collision strategies are implemented as technical solutions, such as rigid colliders, total movement blocking, invisible walls, and are not always treated as a problem of experience design. This is especially sensitive because rigid interventions can induce perceptual-motor dissonances potentially related to discomfort and cybersickness, such as when the user tries to walk but the system abruptly prevents them [9]. Literature reviews indicate that factors such as sensory conflict, artificial accelerations, and movement inconsistencies contribute to symptoms of cybersickness, reinforcing the need to design constraints and feedback carefully [3, 4, 10].

VR literature and practice document a wide range of approaches to dealing with boundaries and collisions. Some act before the problem occurs (prevention), such as teleportation, visual boundaries, onboarding, and warning signals [11, 12], while others act during navigation (speed control, gradual deceleration) [13], and there are also solutions that seek to "reconcile" real and virtual space through techniques such as redirected walking, which subtly adjusts the virtual path to keep the user within a safe physical space [14–16].

Furthermore, commercial platforms often offer ready-made mechanisms for delimiting physical space, such as Guardian, which "appear" when the user approaches the configured boundary. These mechanisms, while useful, do not eliminate the need for design work. That is, they do not replace decisions about when to alert, how to guide attention, which modality to use (visual/auditory/haptic), and how to avoid disrupting the experience [17]. Research also discusses ways to integrate physical and virtual space and to make real obstacles "visible" in the scene, highlighting that the problem involves choices of representation and communication, not just geometric detection [1, 5].

Despite this, in development practice, designers often rely on what the engine or headset already offers, or resort to ad hoc, point-in-time solutions that are difficult to reuse across projects. This is even more pronounced in small teams or academic and prototypical contexts, where collision management may be deprioritized or simplified due to lack of time, lack of implementation knowledge, or assumptions about user behavior. This scenario suggests an opportunity to investigate how professionals actually reason about collisions and what strategies they report as implemented, desired, or absent, especially when faced with trade-offs between presence, comfort, safety, and scope.

Much of the knowledge disseminated about VR appears as general recommendations, heuristics, and best practices. However, collisions are strongly situated. They vary with the type of experience (seated vs. standing), context (controlled vs. open), audience (novices vs. experienced), hardware constraints, and product objectives (narrative immersion vs. instrumental task). To capture these nuances, it is particularly useful to investigate how professionals justify choices, describe limitations, and negotiate trade-offs, rather than simply measuring the prevalence of a specific technique.

Therefore, this work adopts a qualitative approach based on interviews and Reflective Thematic Analysis (RTA), which is appropriate when the objective is to produce

a structured interpretation of patterns of meaning, including justifications, rationalizations, and conditions for the applicability of solutions, without reducing rigor to statistical agreement between coders [18, 19].

This article investigates how VR application designers and developers conceive and communicate collisions and boundaries, and what strategies they report for preventing or mitigating them, considering both the virtual and real worlds. The goal is not to establish a universal ranking of "best solutions", but to map the variety of design strategies and rationales reported by professionals, producing an empirical basis to support tools, particularly in the context of the Guided User Tasks in 3D (GUsT-3D) annotation framework, aimed at inserting complementary layers of user communication into a VR environment project without requiring code rewriting [20–22].

In line with its methodology and results, the study is organized around questions such as:

- Q1. How do professionals describe and classify the problem of collisions and boundaries in VR, in the virtual and real worlds?
- Q2. What prevention, mitigation, and/or guidance strategies are reported as implemented, desired, or discarded, and under what justifications?
- Q3. What cross-cutting patterns emerge regarding modalities (visual/audio/haptic), platform dependence, and trade-offs (presence, comfort, safety, scope)?

The main contributions of this work are:

1. A thematic mapping of how professionals reason about collisions in VR, including deprioritization rationales ("collision is not a problem") and conditions for the applicability of strategies.
2. An organized inventory of collision management strategies, articulated by type (spatial/physical, perceptual, navigation/movement, communicational, and hybrid/multimodal) and modality, useful for both research and practice.
3. Implications for the GUsT-3D tool, indicating which strategies appear recurrent, which are platform-dependent, and where there are opportunities for reusable support, especially for multimodal layers associated with collisions.

The remainder of the article is organized as follows. Section 2 reviews the literature on collisions in VR, including safety, presence, cybersickness, multimodal collision communication, collision-management strategies, and introduces a conceptual taxonomy of collision events in virtual and real-world environments. Section 3 describes the method, which involved semi-structured interviews and RTA, and the analytical process. Section 4 describes the participants' profile. Section 5 presents the results, including the thematic structure and a breakdown of the themes, groups, and codes. Section 6 discusses the implications of the findings for collision management in VR, highlighting the interplay between safety, immersion, user experience, team practices, and technical feasibility. Section 7 concludes with limitations, contributions, and future opportunities.

2 Literature Review

Virtual reality (VR) environments introduce a structural tension between physical and virtual space: while the user perceives and interacts with a computationally generated world, their body remains anchored in a real physical environment [23–25]. This dissociation creates conditions in which collisions can occur both in the virtual world and in the real world , with implications for immersion, presence, and safety. In this context, collisions should not be understood only as discrete contact events, but more broadly as situations involving intersection, proximity, and, in some cases, the anticipation of impact based on movement trajectories [26–28]. Such situations are relevant because they directly affect safety, comfort, and the coherence of the user experience.

Prior work in VR and 3D interaction has examined collision-related events in the virtual world involving user-controlled avatars, other embodied agents, scene objects, and environmental limits, particularly in relation to navigation, interaction constraints, and spatial awareness [26, 29, 30]. On the one hand, studies in VR and 3D interaction have examined collisions in the virtual world, such as contact between avatars, virtual objects, and environmental boundaries, often in relation to navigation, interaction constraints, and the maintenance of perceptual coherence. On the other hand, research on safety in immersive systems has also highlighted the risks associated with the physical environment, including collisions with walls, furniture, other obstacles, and co-located users sharing the same tracked space [5, 27, 31, 32]. Taken together, these strands of literature suggest that collisions in VR are not limited to a single ontological layer, and rather, they emerge from the continuous coupling between a virtual scene and a physical setting.

Literature on VR has demonstrated that sensorimotor consistency is a central factor in the experience of presence [23, 33, 34]. When motor actions produce coherent consequences in the virtual environment, the feeling of "being there" is reinforced. Realistic virtual collisions, such as head-locking when the user reaches a virtual wall or physically plausible object interactions, can strengthen this coherence. By contrast, incongruities between bodily movement and virtual response, for example when the physical body continues moving while the avatar is abruptly blocked, may generate discomfort, disorientation, and cybersickness [35, 36].

Thus, collisions are not merely physical or geometric events, but perceptual and cognitive phenomena that emerge from the relationship between action, sensory feedback, and user expectation [8, 24]. In this sense, collision management involves decisions that articulate realism, safety, comfort, and control.

VR literature and practice document a wide range of approaches to dealing with boundaries and collisions that can be organized into three main categories:

i. pre-collision prevention strategies;
ii. control strategies during navigation;
iii. strategies for reconciling real and virtual space.

Preventive strategies act before a collision occurs, structuring the space and interaction in order to reduce the probability of impact. They prioritize anticipation and

guidance, operating at the perceptual and cognitive level to shape user behavior before impact. Among the most widespread are:

- *Teleportation*, widely adopted as an alternative to continuous joystick locomotion, reduces physical movement and potential collisions ([11, 37]);
- *Visual boundaries and boundary systems*, such as Guardian/Chaperone, which display physical boundaries in the virtual environment [38, 39]
- *Onboarding and initial instructions*, which establish expectations and navigation norms from the beginning of the experience [40];
- *Visual or audible warning signals*, which anticipate the approach of obstacles [41, 42].

Other techniques operate during movement, dynamically modulating navigation. Studies on cybersickness indicate that abrupt changes in speed or unexpected stops are relevant factors for discomfort [43]. Thus, techniques that preserve perceptual continuity tend to be preferable and fit within this set of control strategies during navigation, among which the following can be mentioned:

- *Speed control and gradual deceleration* to avoid abrupt stops that could cause discomfort.
- *Soft constraints or gradual fade-outs* to reduce sensorimotor discrepancies.
- *Multimodal feedback (visual, auditory, haptic)* to indicate imminent contact.

A third line of research seeks to reconcile physical and virtual space through perceptually subtle manipulations. The *redirected walking* technique imperceptibly adjusts the mapping between real and virtual trajectory, keeping the user within a safe physical space [44, 45]. Although promising, this approach still depends on perceptual limitations and adequate infrastructure, being more common in experimental contexts than in broad commercial applications.

In general, it is observed that the literature favors approaches that avoid collisions through spatial or perceptual reconfiguration, rather than reactive responses after the impact [25, 46].

In addition to virtual collisions, the literature emphasizes physical risks arising from the use of VR [27, 31]. Users may collide with furniture, walls, or people, especially in contexts of active movement. Boundary systems have been commercially introduced as a response to this problem, but studies show that their effectiveness depends on visual design, display frequency, and integration with the experience.

Physical safety is particularly relevant in educational, industrial, and rehabilitation applications, where users may have motor limitations or varying levels of familiarity with immersive technology. The literature indicates that risk mitigation should consider not only the system but also the context of use, i.e., the presence of mediators, controlled spaces, appropriate furniture, and other relevant characteristics. This contextual dimension reinforces the idea that collision management is a situated decision, dependent on the environment, audience, and purpose of the application [27, 31, 47, 48].

It is also important to highlight the multimodal aspect. Multimodal integration research suggests that combining visual, auditory, and haptic cues enhances perception and responsiveness [49–51]. In VR, collision communication may involve combinations of spatial audio cues, vibration feedback, visual highlighting, or textual warnings. Multimodal strategies may improve user awareness while reducing reliance on intrusive visual blocking. However, they also increase implementation complexity and may introduce cognitive load if poorly calibrated.

Although numerous technical solutions exist for locomotion, spatial orientation, and boundary visualization, the literature tends to focus on experimental evaluation of specific techniques rather than on designers' rationalities in selecting, adapting, or dismissing these strategies in real-world projects [25, 46].

There remains limited understanding of:

- How designers prioritize safety versus immersion;
- When collision management is deliberately simplified or omitted;
- How context (e.g., controlled lab settings vs. public installations) influences design decisions;
- Which strategies are perceived as technically feasible or difficult to implement;
- How multimodal combinations are conceptualized during the design process.

Addressing these gaps requires shifting the analytical focus from isolated techniques to the decision-making processes and situated rationalities of practitioners.

2.1 Toward a conceptual taxonomy of collisions in VR

The literature reviewed throughout this chapter discusses collisions from multiple perspectives, including physical safety, virtual interaction, navigation constraints, cybersickness, and spatial awareness. However, these discussions are frequently fragmented across different domains of research and application contexts. As a result, the literature lacks a unified conceptual structure capable of organizing the various collision events that may emerge during VR interaction.

To support the analysis conducted in this study, we propose a conceptual taxonomy of collisions in VR derived from the synthesis of the literature reviewed in this chapter. Rather than representing a formal ontology, the taxonomy serves as an analytical framework that organizes collision events according to the environment in which they occur and the entities involved. Conceptual taxonomies are commonly used to organize complex design spaces and establish a common vocabulary for analysis and comparison [52]. Figure 1 presents the proposed taxonomy.

At the highest level, the taxonomy distinguishes collisions occurring in the virtual world from those occurring in the real world. This distinction reflects the dual nature of VR experiences, in which users interact with a simulated environment while remaining physically situated in a real-world setting [23, 24, 53, 54].

In the virtual world, collision events may involve either the user's avatar or dynamic digital entities (objects). The user's avatar may collide with other avatars, digital objects, NPCs, or digital boundaries. In this taxonomy, digital objects represent a broad category of virtual entities. NPCs and digital boundaries are represented

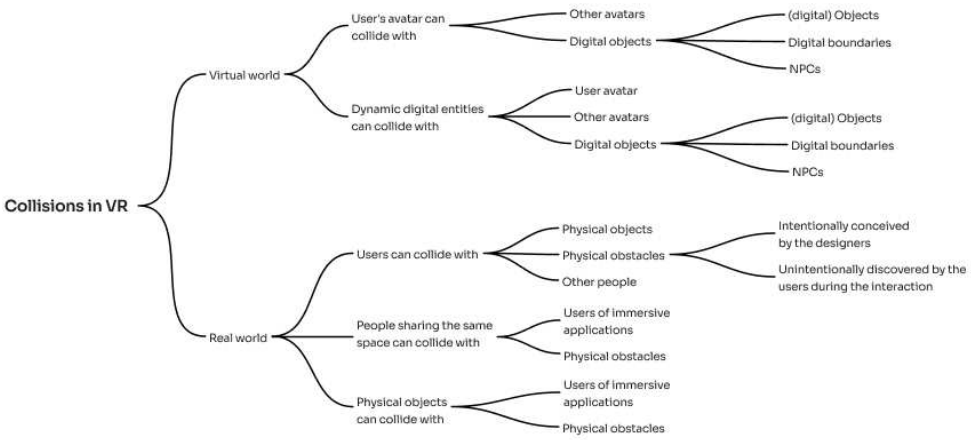


Fig. 1 Conceptual taxonomy of collisions in VR.

separately because they frequently assume distinct functional roles in interaction design and collision management, despite also being digital objects from a technical perspective [41, 55].

The taxonomy also considers situations in which dynamic digital entities initiate collision events. Such objects may collide with the user's avatar, other avatars, NPCs, digital boundaries, or other digital objects. This distinction is important because collision-management strategies may differ depending on whether the collision is initiated by the user or by an autonomous element of the environment [56, 57].

In the real world, collisions may involve users, physical objects, physical obstacles, and other people sharing the same space. Physical obstacles may be intentionally conceived by designers, such as walls, furniture, props, or installations used to delimit the interaction area, or unintentionally discovered by users during interaction. The taxonomy also includes situations in which co-located individuals collide with VR users and situations involving moving physical objects that intersect the user's trajectory [5, 27, 31, 32].

The purpose of this taxonomy is not to prescribe specific collision-management techniques, but rather to provide a conceptual lens for understanding the diversity of collision events discussed in the literature and observed in practice. By explicitly distinguishing collision domains and involved entities, the taxonomy establishes a common vocabulary that supports the interpretation of designers' accounts and the analysis presented in the following sections.

Building upon this conceptual taxonomy, the present study investigates how immersive-environment designers perceive, interpret, and manage collision situations in practice. By examining the rationales, constraints, and strategies reported by designers, the study seeks to expand the understanding of collision management beyond isolated technical solutions, providing empirical evidence that can support the design of future VR systems and approaches for collision communication.

3 Methodology

This study adopted a qualitative design based on semi-structured interviews with VR application designers and developers, aiming to identify and understand how professionals conceive, plan, and communicate collisions and boundaries in these environments and, in particular, which mitigation strategies are reported as implemented, desired, or perceived as gaps. The primary objective was to map the variety of design strategies and rationales, rather than estimating population prevalence or measuring impact, in order to support decisions on strategy support within the context of a VR annotation framework called GUsT-3D [20].

The analysis was conducted using Reflexive Thematic Analysis (RTA) [18], similar to a discursive thematic analysis [58], paying attention to how participants justify design choices, as well as the applicability of collision avoidance strategies. RTA was chosen for its suitability to studies whose central interest lies in producing a structured interpretation of meaning patterns from narratives, preserving context and nuance, rather than relying on metrics of agreement between coders as a primary criterion of rigor [19].

Although the primary focus was on interpretation and variety, descriptive practices inspired by Content Analysis [59] were employed as support at specific points, such as frequencies and co-occurrences by profile, to answer analytical questions useful in the context of Human-Computer Interaction (HCI) and VR. For example, we collected data on how many participants associated real-world collisions with physical risk, how many mentioned property damage, how many cited cybersickness, and other relevant characteristics about the respondents' profiles. These counts were used only for descriptive synthesis and exploration, not for validation of the themes.

The workflow for this research involved six main stages, which are described in Figure 2: Study planning, Interview script, Ethics Committee, Recruitment, Interviews, and Analysis of the results.

The interviews were conducted via Google Meet [60] and audio-recorded with authorization, as described in the Informed Consent Form (ICF), with the sole purpose of ensuring accuracy in transcription and analysis. Transcription was performed automatically using the Read.ai [61] tool and reviewed for corrections to the text, such as removing hesitations in speech. The transcriptions were anonymized by replacing identifiable names and references, and organized by identifiers from IE01 to IE10. After transcription, the audio files were permanently deleted. The transcribed and anonymized data were stored in a secure digital environment with access restricted to the researchers. This research was approved by the Research Ethics Committee of the Universidade Federal Fluminense under registration number CAAE 91974125.0.0000.8160.

3.1 Participants and context

Ten Brazilian individuals working in the design and/or development of VR environments participated in the study, with varying levels of experience and professional background, ranging from beginners and undergraduates to participants with academic and/or industrial experience. The sampling was based on convenience, appropriate for

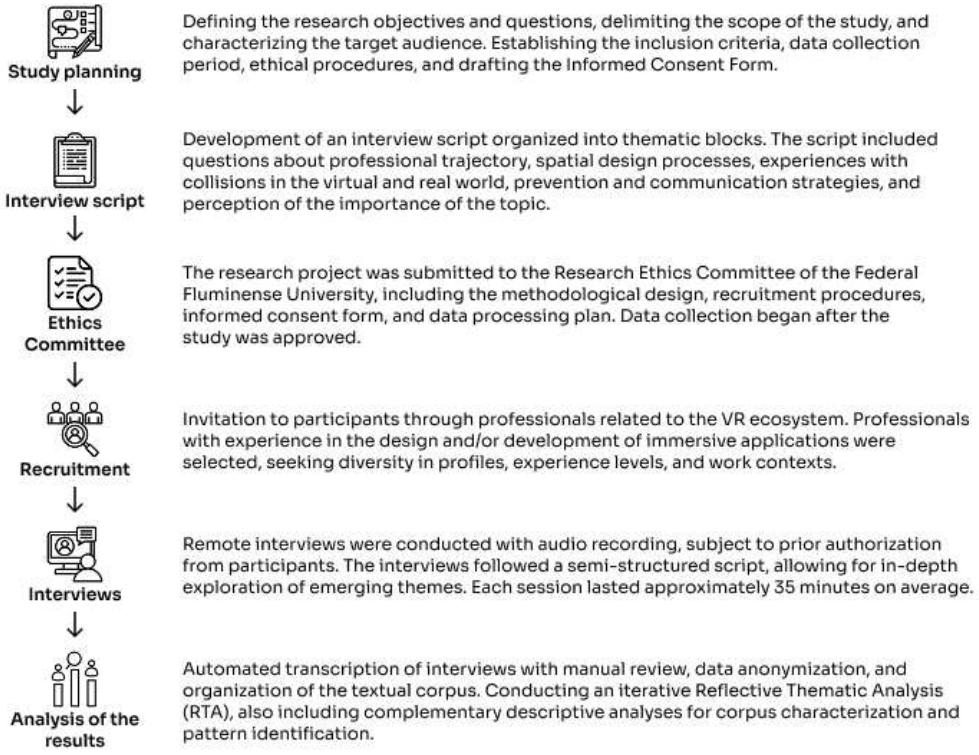


Fig. 2 High-level study pipeline, with each of the 5 stages containing a description of the tasks performed.

the exploratory objective of mapping the variety of practices and rationales in VR environment design [18, 62]. We sought to encompass diversity in experience, roles played within the team (development, game design, leadership, and other roles), and technologies used (engines and complementary tools).

For analytical characterization, experience was considered by: (i) years of experience in immersive technologies; (ii) number of projects in which the participant worked. Participants in training, such as undergraduates, were treated as beginners. Participants in postgraduate and applied research projects were considered intermediate. Participants with recurring involvement in industry projects and/or at least 5 years of experience were considered specialists. This categorization was used to contextualize interpretations, not for statistical inference. Subsection 4 describes the participants profile in detail.

3.2 Factual data

Participants were recruited through a convenience sampling strategy, drawing from individuals known to the researchers or reachable through their academic and professional networks within the VR ecosystem [18, 62]. Recruitment occurred via direct

invitation, either by telephone or through the professional social network LinkedIn. To be eligible, participants were required to (i) have direct experience in the design and/or development of immersive VR applications, (ii) have participated in at least one completed or ongoing VR project involving interactive environments, and (iii) be involved in design-related decision-making processes (e.g., interaction design, spatial design, locomotion, safety mechanisms, or user experience). The selection aimed to include professionals with diverse levels of experience, academic backgrounds, and application contexts (e.g., games, education, research prototypes), ensuring variability in design rationalities while maintaining relevance to the research questions. Although convenience sampling may introduce selection bias, this strategy was considered appropriate for accessing experienced VR professionals with specialized knowledge in immersive interaction design, a population that is not easily reachable through probabilistic sampling methods.

The invitation presented the general objectives of the study, focusing on design and development decisions related to collisions in VR. After expressing interest, the ICF was sent to the participants, and signatures were collected before the interviews. Subsequently, the interviews were conducted remotely via videoconference. This flow was adopted to reduce friction in participation and ensure that consent was obtained beforehand, maintaining a record of the agreement in a channel accessible to the participant.

The interviews were semi-structured and conducted during the first quarter of 2026. Each interview lasted approximately 35 minutes on average. After transcription, each interview resulted in an average of 2,065 words, forming a textual corpus that served as the basis for the thematic analysis. As the primary objective was to map the diversity of design rationales and practices, these data are reported as a characterization of the corpus and the density of accounts rather than as a basis for quantitative inference.

The interviews were conducted individually via videoconference and aimed to elicit narratives regarding professional profile and trajectory, development processes, work organization, testing practices, experiences with collisions (both in virtual and real-world contexts), and strategies used or desired for collision prevention and user guidance. The interview guide was structured into thematic blocks, allowing for in-depth probing questions according to the context introduced by each participant. It is noteworthy that the scope of the semi-structured interview was discussed iteratively among the researchers and validated in a pilot interview with a VR designer and developer researcher who did not participate in the discussions, with the scope being finally adjusted based on his feedback. It is also worth noting that, despite the existence of well-established thematic blocks in the interview script, the themes were defined and revised after the interviews, throughout the analysis process. To guide the structure of the interview, the collision taxonomy presented in Figure 1 was also used. Table 1 presents the thematic structure of the semi-structured interview guide.

3.3 Analysis process

The unit of recording adopted for coding was the sentence or micro-paragraph, typically 1 to 3 sentences. This choice balances two requirements: (i) preserving sufficient

Table 1 Thematic structure of the semi-structured interview. In the table, each thematic block is described in relation to its objectives and dimensions explored, and the questions that guided the interviews in each block are presented.

Thematic Block	**Objective**	**Explored Dimensions**	**Guiding Questions**
Professional profile and trajectory	To characterize the participant's educational background, professional experience, and contextual engagement with immersive technologies.	Age range; gender; academic background; professional role; years of experience in XR; project types; platforms and tools; role in projects; individual vs. team-based workflow.	– Please describe your educational background and your trajectory in XR. – How many years of experience do you have with VR/AR/MR? – What types of projects have you worked on? – What responsibilities did you have in those projects? – Do you typically work individually or in teams? – Which tools and platforms have you used?
Spatial design and navigation process	To investigate how designers structure virtual environments, organize objects and interactions, and plan user navigation.	Spatial organization strategies; use of pre-built assets; early-stage planning (e.g., sketches); project scheduling; team decision-making; user orientation strategies; delimitation of navigable areas.	– How do you typically initiate the development of an immersive environment? – How do you design the virtual space and position objects/interactions? – What strategies do you use to guide users? – How does the user know where they can or cannot go?
Collisions in the virtual environment	To understand how designers perceive, interpret, and address collisions within virtual environments.	Types of virtual collisions observed; user perception; potential benefits and drawbacks; prevention strategies; visual, auditory, and haptic feedback; impact on immersion; cybersickness.	– Have you observed virtual collisions? Could you provide examples? – How do you address virtual collisions in your projects? – What are the potential advantages and drawbacks of such collisions? – Which techniques would you use to prevent or communicate them?
Collisions in the physical environment	To investigate how designers consider physical risks associated with VR use and the strategies adopted to mitigate them.	Unintentional collisions with objects/people; loss of balance; cognitive disorientation; preventive strategies (e.g., seated use, monitoring); systems such as Guardian; auditory and visual boundary cues.	– Have you observed real-world collisions during immersive experiences? – How do you address this risk in your projects? – What techniques would you employ to prevent physical collisions?
Evaluation of the importance of collision design	To assess the importance attributed to collision communication and to the support provided by development tools.	Likert scale (0–5); importance of communicating virtual and physical collisions; boundary communication; multimodal feedback; need for dedicated tools; reusable libraries; engine-level support.	– How important is it to inform users about virtual collisions? – How important is it to communicate physical boundaries? – Is visual, auditory, and/or haptic feedback important? – Is there a need for specific tools or libraries to support collision design?
Closing	To allow participants to provide additional reflections and to authorize follow-up contact if needed.	Additional comments; availability for a second round.	– Is there anything you would like to add? – May I contact you again if necessary?

context to interpret design rationales and trade-offs and (ii) maintaining adequate granularity to identify co-occurrences and relationships between codes.

In exceptional cases, when a relevant idea depended on a longer passage to be completed, longer passages were noted. These occurrences were recorded as exceptions, using an identifier in the style "Exception RU-##", where "##" is the incremental number of the exception, accompanied by a comment justifying why the passage exceeded the standard unit. This procedure increases consistency and comparability between interviews.

The analysis followed an iterative refinement procedure, articulating familiarization, coding, and thematic consolidation in multiple rounds, until the interpretative set stabilized, that is, operational saturation at the level of codes and groups. The following list describes each step, and Figure 3 illustrates the iterative procedure of the iterative procedure.

- Step 1 - Familiarization and initial memos: Full reading of transcripts and production of analytical memos, focusing on: (i) descriptions of collisions and risks, (ii) reported strategies for prevention/mitigation/guidance, (iii) justifications and trade-offs (presence vs. safety; comfort vs. control), and (iv) indications of gaps (what the participant would like to have, but did not implement).
- Step 2 - Mixed initial coding, guided and emergent: The initial coding was influenced by two sources: (a) the thematic blocks of the interview structure, which naturally directed some of the responses towards expected themes, and (b) codes that emerged from the content, mainly in the category of collision avoidance strategies. Codes were created to capture actions, decisions, roles, resources used (e.g., reference sources), and rationales.
- Step 3 - Code Review and Refinement: Codes were reviewed to remove redundancies, merge equivalent labels, split overly broad codes, and rename terms to maximize semantic clarity. At this stage, groups began to form that organize codes by conceptual affinity.
- Step 4 - Formation and adjustment of themes: From the second round onwards, themes were consolidated as interpretive structures that organize groups and codes. In some cases, theme and category coincided due to their proximity to the script's structure. Even so, themes were defined by their explanatory role (what they allow to be understood) and not just by their correspondence to the script.
- Step 5 - Reflective review of themes and thematic map: A review of internal coherence (compatible codes within the theme) and external distinction (clear boundaries between themes) was carried out, with adjustments to the hierarchy between codes, groups, and themes. The product of this step includes: (i) a final structure of themes, groups, and codes and (ii) a thematic map that represents relationships between components. The relationship between themes, groups, and codes is explained in detail in Subsection 5.2.
- Step 6 - Analytical syntheses and matrices for design implications: For the central theme of collision avoidance strategies, a synthesis was constructed using a scheme that relates each strategy to two dimensions: (i) type of environment in which it operates (virtual world, real world, or both) and (ii) perception modality (visual,

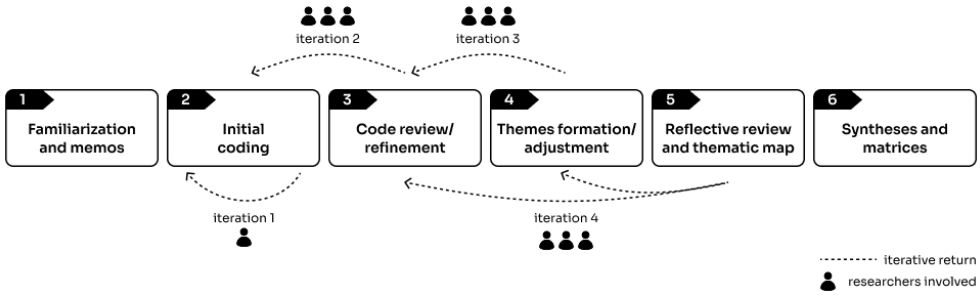


Fig. 3 Stages of the thematic analysis process.

auditory, haptic). This matrix, together with the thematic map, supported the discussion on which strategies are candidates for development in the context of GUsT-3D. Subsection 5.3.2 presents the classification scheme for each of the strategies.

The analysis was conducted collaboratively, with regular discussions between the principal investigator and supervising researchers, acting as "critical friends." The objective of these discussions was to strengthen interpretative coherence, question boundaries between codes and themes, and refine the final structure (codes, groups, and thematic map). This process did not seek to "validate" codes through statistical agreement, but to promote reflexivity, explicit assumptions, and narrative consistency.

To support rigor and transparency, an audit trail was maintained with: successive versions of the code set, records of renaming/merging/splitting decisions, analytical memos, and snapshots of visual artifacts, such as mind maps.

4 Participant profile

The participants in this study are ten immersive environment designers, designated IE01 to IE10, selected based on their practical experience in developing virtual reality applications. The group exhibits intentional heterogeneity, encompassing different levels of experience, academic backgrounds, professional roles, and work contexts, which allowed for capturing a wide variety of perspectives on the design and management of collisions in immersive environments.

In terms of demographics, the participants are distributed across age ranges from 18 to 44 years old, with 7 men and 3 women. Regarding academic background, the group is predominantly interdisciplinary, including participants with degrees in Computer Science, Internet Systems, Game Development, Mathematics, Physics, Design, and Communication, as well as participants enrolled in undergraduate, master's, and doctoral programs. This diversity reflects the multifaceted nature of immersive environment development, which frequently involves the integration of technical, creative, and scientific knowledge.

Regarding experience with immersive technologies, participants were classified into three profiles:

i. **beginners**, with up to three years of experience, often linked to academic projects, internships, or research grants;
ii. **intermediate level**, with three to five years of experience, working in both academic and applied contexts;
iii. **experienced professionals** with over five years of experience, involved in projects of greater technical complexity, including commercially distributed applications, industrial training, and multi-user platforms.

This classification considered not only the declared experience time, but also the quantity and diversity of projects developed, as well as the degree of autonomy reported by the participants.

The roles assumed by the interviewees in the projects varied significantly. Some participants (4/10) reported working in a multifunctional way, accumulating responsibilities such as development, interaction design, coordination, and decision-making. Others (6/10) described more specialized work contexts, with a clear division of roles between programmers, game designers, UX/UI designers, audio designers, 3D artists, and researchers. Participants who play mediating roles were also identified, such as game designers or researchers who act as a bridge between technical teams and domain experts (e.g., professors, healthcare professionals, or researchers from other fields).

Regarding work methods, participants reported experiences in both individual development and in teams of varying sizes, ranging from small groups of 2 to 3 people to larger multidisciplinary teams, often associated with funded projects or research institutions. In several cases, especially in academic and cultural contexts, participants highlighted the need to adapt design solutions to controlled environments, such as museums, laboratories, or exhibition spaces, which directly influences decisions related to navigation, interaction, and collision management.

Table 2 summarizes the profile of the ten participants by mapping their experience with immersive technologies in relation to their primary work context. In the table, filled squares indicate category membership, including gender, age range, predominant role in the development process, application domain, tools used, years of VR experience, context of developed environments, and level of experience. One field also shows the number of VR projects in which the developer has participated. The distribution of marks highlights the heterogeneity of educational backgrounds, experience levels, and professional contexts represented in the dataset.

Overall, participants' profiles indicate a practice-oriented group that, despite differing levels of specialization, shares an emphasis on experimentation, adaptation to tool constraints, and attention to target users. This profile contributed to grounding the collision-related accounts in concrete situations of development, testing, and user observation, providing a rich basis for the thematic analysis reported in the subsequent sections.

Participant	Nº. [1]	Gender		Age range			Roles			Application domains					Tools/ Software			VR experience			Developed projects			Level of experience		
		Male	Female	18–24	25–34	35–44	Developer	Multifunctional	Mediator	Games	Education	Health	Culture	Research	Unity	Unreal	Blender	<3 years	3–5 years	>5 years	Academic	Commercial	Industry	Beginner	Intermediate	Advanced
IE01	3	■		■			■			■	■	■		■	■			■			■			■		
IE02	3	■			■		■			■	■				■			■				■			■	
IE03	9	■			■		■			■	■		■	■	■			■	■			■	■			■
IE04	1	■		■			■			■		■	■		■		■	■			■			■		
IE05	1	■					■	■		■	■	■			■		■				■			■		
IE06	2	■			■		■			■	■				■		■			■			■			■
IE07	3		■			■		■		■	■			■	■					■		■				■
IE08	5		■			■		■		■	■	■			■	■				■			■			■
IE09	3	■			■			■	■	■	■	■			■			■			■			■		
IE10	4		■	■				■			■		■		■		■		■						■	

Table 2 Profile of the interviewed participants.

[1] Number of VR projects in which the interviewee participated during development.

5 Results

This section presents the results of a RTA conducted based on ten semi-structured interviews with immersive environment designers. The analysis aimed to understand how these professionals perceive, communicate, and manage collisions in VR experiences, considering both the virtual and real worlds.

The results are organized into eight main themes, derived from the coding and thematic refinement process, as presented previously. In addition to the qualitative description of the themes and codes, this section also includes quantitative data characterizing the corpus, used in a complementary way to reinforce the robustness and consistency of the findings.

5.1 Characterization of the analyzed corpus

The analyzed corpus consists of the text of ten interviews conducted with participants who present varied profiles, as already described in the Subsection 4. The interviews lasted approximately 35 minutes each, were rich in description, and strongly anchored in practical development experiences. Figure 4 presents an overview of the analyzed corpus.

These data indicate a dense and consistent corpus, suitable for in-depth thematic analysis, allowing the identification of recurring patterns, variations in practices, and conceptual divergences among participants, which enriched the analysis.

5.2 Thematic distribution of codes

The thematic analysis involved 8 themes: *Development Team*; *Tools Used*; *Collection of References*; *Collisions in the Real World*; *Collisions in the Virtual World*; *Collision Management*; *Modalities*; *Technical Problems*. The distribution of the 78 codes found involved grouping them into groups and/or themes. Figure 5 shows the grouping of the codes into themes and/or groups.

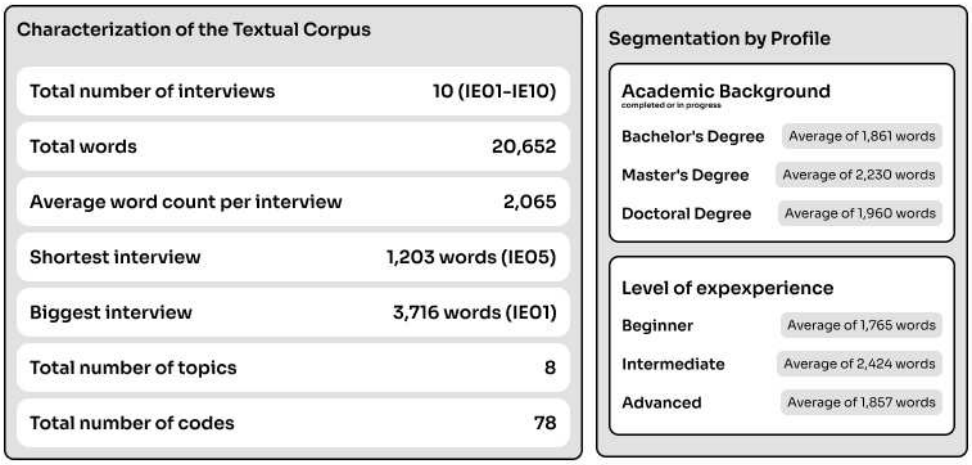


Fig. 4 Information about the textual corpus used in the thematic analysis.

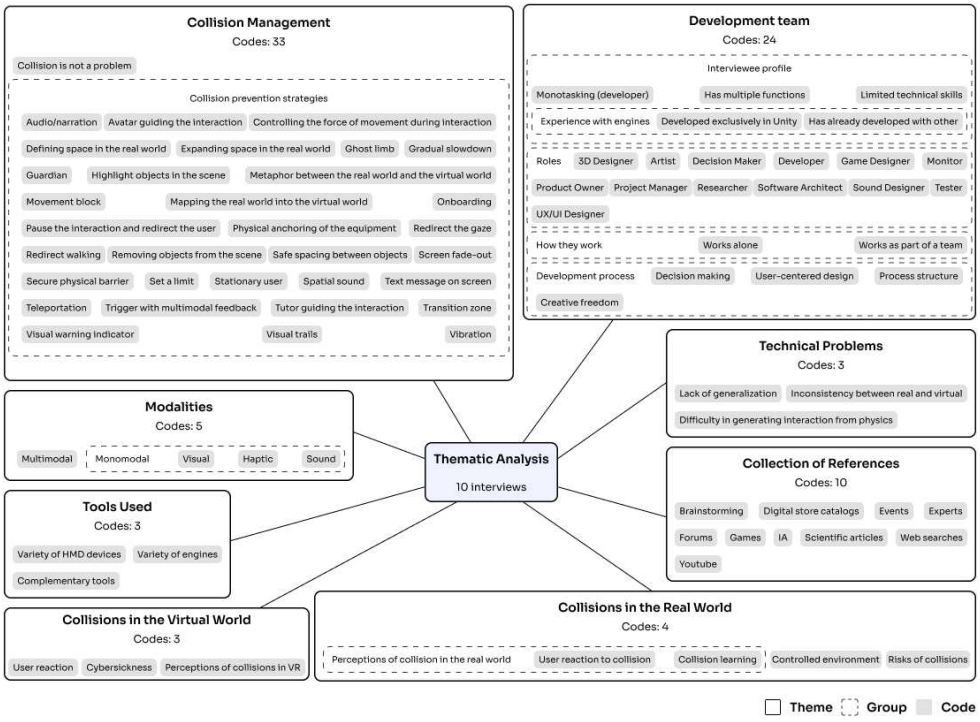


Fig. 5 Thematic structure involving themes, groups, and codes.

Collision Management accounted for 44% of all coded recording units, indicating that collision-related concerns occupy a central role in immersive environment design. However, this concentration was not uniformly distributed across participants.

More experienced and hybrid-profile participants, those combining development and project management roles, such as IE06, contributed a wider range of strategies, including multimodal feedback, spatial remapping, gradual deceleration, environmental soft constraints, and onboarding mechanisms, described in detail in subsection 5.3.2. Conceptually oriented participants, such as IE03, emphasized the perceptual consequences of collision inconsistencies (e.g., cybersickness and breaks in presence), while UX-focused participants, such as IE07, highlighted iterative user testing and adaptive spatial design.

In contrast, less experienced developers, such as IE01, tended to rely primarily on controlled environments, stationary user setups, and built-in boundary systems (e.g., Guardian/Chaperone) as their main preventive strategies.

This distribution suggests that collision management is not merely a technical constraint but a multidimensional design challenge involving safety, perceptual coherence, user experience, and environmental structuring. The variation in contributions across profiles also indicates that professional experience and role configuration influence the sophistication and diversity of collision mitigation strategies.

5.3 Collision Management

The *Collision Management* theme concentrates the largest number of codes identified in the analysis and represents the practical core of the participants' reports. Unlike more descriptive themes (such as *Modalities* or *Collection of References*), this theme was predominantly made up of prescriptive and explanatory passages, in which designers detailed design decisions, justified technical choices, or reflected on implementation alternatives.

The codes for this theme emerged from three main types of statements in the corpus:

i. explicit descriptions of strategies already implemented (*"we set a limit"*, *"we use the Guardian"*);
ii. hypothetical or conditional statements (*"if I had to prevent... I would use..."*);
iii. design rationalizations, in which participants justified the absence or simplification of collision mechanisms.

Figure 6 shows the structure of the Collision Management theme, with strategies classified by environment type and modality, and ordered by the number of occurrences in the corpus.

5.3.1 The code "collision is not a problem"

A specific code within this theme was used to describe situations in which designers explicitly understood that "collision is not a problem" within the scope of the project. Six annotations with this code were made, distributed among participants

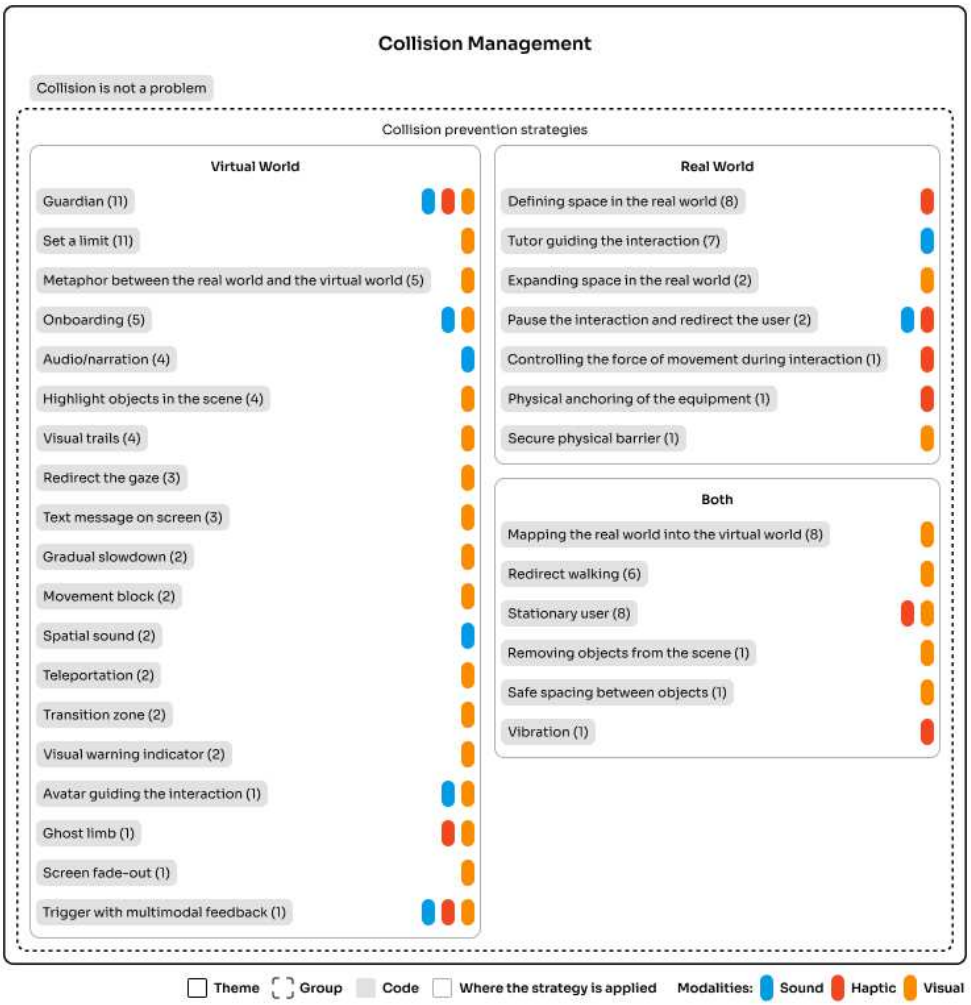


Fig. 6 Mind map of the structure of the topic "Collision Management".

with different levels of experience and contexts of activity. This code was identified when participants explicitly minimized the need for collision management, justified the absence of blocking or prevention mechanisms, or associated collisions with an irrelevant risk given the adopted design.

The analysis of these excerpts reveals that the code does not correspond to a lack of awareness about collisions, but to situated decisions of deprioritization. Three main design rationales were identified. In the following, each rationale is accompanied by representative statements from the interviewees.

1. **Technical limitation or lack of mastery of implementation.** This rationale appears when the participant recognizes that approaches exist to prevent/mitigate collisions, but explicitly states that they do not have the practical experience to implement them in the project. For example, IE01 describes that the Quest headset offers possible paths (e.g., detecting obstacles and pausing/reorienting), but states that they do not know how to implement the solution: *"I find virtual collisions somewhat difficult to deal with. They easily cause problems..."*.
2. **Structural risk reduction via experience design.** Here, the "non-centrality" of collisions is attributed to the way the experience was designed, reducing the probability of physical displacement or the need for rigid barriers. IE09, for example, reports games where the user remains seated as a way to keep the participant "on the axis" of the experience: *"These games that we play sitting down... we don't worry about collisions..."*. Similarly, IE03 reports a case where not inserting solid walls was an option because the scenario itself signals a "self-explanatory" limit (e.g., cliff), dispensing with barriers: *"Super Wheels doesn't have any solid walls in the game... So, I don't need to put in a collision to prevent the person from passing"*.
3. **Controlled usage contexts as sufficient mitigators.** In this rationale, deprioritization is anchored in the fact that the experience occurs in supervised environments (laboratories, museums, exhibitions, hospitals), with measured space, support staff, and removal of physical obstacles. IE09 describes this framework by stating that, because they operate in controlled scenarios, they didn't need to "stop and think" about inserting additional barriers: *"We end up worrying little about that, because our games... are developed for controlled environments... are being played... monitored by people."*. IE02 also describes that, when the game does not offer structural limitations, mitigation comes from human mediation and the delimitation of space on the floor: *"what we had to do was have the monitors... prevent the person from walking around... We always put a marking on the floor to delimit the space"*.

Furthermore, an important complementary pattern emerged: allowing passage appears as a decision to reduce friction and avoid rigid interruptions, preventing sensorimotor dissonance associated with the risk of cybersickness, especially in open spaces and tasks with a well-defined focus. IE01 describes that, in open areas, it tends to "change the user's focus", but acknowledges that there is no total blockage if the user insists: *"if he pushes the limits, there's nothing that will stop him from continuing... he'll keep leaving the scene, no problem"*.

In general, the code *collision is not a problem* reveals that collision management is not conceived as a universal requirement in VR design, but as a variable dependent on the context, the target audience, the application environment, and the technical maturity of the project. The presence of this code within the theme indicates that, in addition to the multiple prevention and communication strategies identified, there are also scenarios in which the dominant design option is to minimize or frame the problem structurally.

5.3.2 Collision prevention strategies

In addition to the deprioritization code, 32 distinct codes were identified, grouped under "Collision Prevention Strategies." These codes emerged primarily from reports of concrete implementation (*"we use highlighting"*, *"we put on a fade"*), descriptions of recurring practices (*"I always ask for a two-by-two area"*), or responses to hypothetical questions about prevention (*"I would bet more on sound and haptics"*).

It is important to highlight that many participants did not use formal technical terminology. In several cases, the code was constructed from the researcher's interpretation of operational descriptions. For example, IE02 describes the logic of delimiting physical space (including extra margin for arm reach) and even reducing virtual space relative to real space to decrease the chance of physical collision, which underlies codes such as delimiting space in the real world and setting a limit: *"this game here needs a space of two meters by two meters, at least... it has to have, in addition to the space that the game demands, an extra space for prevention..."* and *"if you leave the space in VR a little smaller than the space you are delimiting for the game... it reduces the chance of the person going there and hitting that real wall"*.

The reported strategies range from spatial and physical solutions to perceptual, communicational, and multimodal approaches, reflecting the diversity of contexts, technical limitations, and user profiles involved in the projects.

Table 3 presents the types of strategies and their descriptions. Table 4 presents the codes for the *Collision Prevention Strategies* group from the *Collision Management* theme classified by strategy type, highlighting the trends in the solutions adopted by the designers. Some strategies were associated with more than one category (for example, *stationary user* appears in 3 categories). The total number of strategies is 32.

Table 3 Grouping of collision-management strategies by strategy type.

Strategy type	**Description**
Spatial/physical strategies	Interventions that act on the organization or configuration of the physical space by modifying boundaries, layout, barriers, or spatial relations to reduce collision risks. These strategies involve structural control of the environment or spatial restriction of the user.
Perceptual strategies	Strategies that operate by modulating the user's perception, using sensory cues to guide, warn, constrain, or redirect potentially risky behaviors.
Navigation/movement strategies	Strategies that directly regulate or reconfigure locomotion, movement dynamics, or interaction mechanics.
Communicational strategies	Strategies that rely on explicit mediation through language, instruction, or the presence of a human or virtual agent, providing direct communication about risks, boundaries, or expected behaviors.
Hybrid/multimodal strategies	Strategies that combine two or more perceptual channels or simultaneously integrate spatial, perceptual, and communicational aspects, forming integrated solutions for prevention or user guidance.

Strategy	Spatial / Physical	Perceptual	Navigation / Movement	Communi-cational	Hybrid / Multimodal
Audio/narration		■		■	
Avatar guiding the interaction		■		■	■
Controlling the force of movement during interaction			■		
Defining space in the real world	■				
Expand space in the real world	■				
Ghost limb		■			■
Gradual slowdown		■	■		
Guardian		■			■
Highlight objects in the scene		■			
Mapping the real world into the virtual world	■				
Metaphor between the real world and the virtual world		■			
Movement block		■	■		
Onboarding		■		■	■
Pause the interaction and redirect the user		■	■		■
Physical anchoring of the equipment	■				
Redirect the gaze		■			
Redirected walking			■		■
Removing objects from the scene	■				
Safe spacing between objects	■				
Screen fade-out		■			
Secure physical barrier	■				
Set a limit		■	■		
Spatial sound		■			
Stationary user	■		■		■
Teleportation		■	■		
Text message on screen		■		■	
Transition zone	■	■			
Trigger with multimodal feedback		■			■
Tutor guiding the interaction				■	
Vibration		■			■
Visual trails		■			
Visual warning indication		■		■	

Table 4 Classification of collision-management strategies according to strategy type. Gray cells indicate category membership.

The qualitative analysis indicates three cross-cutting patterns:

1. **The predominance of strategies based on mediation and operational control**, where the design depends on monitoring and simple repositioning/reorientation resources. IE08 describes this procedure as a recurring practice in exhibitions: *"If it's near an object in the real world, the Quest 3... fades the experience... and gives a warning for it to return to the safe area."*.
2. **Strategies described as dependent on HMD ecosystem resources**, such as environment detection and pause/reorientation interventions. IE01 describes, in Quest, the possibility of identifying obstacles and interrupting the experience for the user to avoid/remove the object, then resuming: *"it can track the environment... you can pause the game, ask the person to avoid the object... pause*

the game, rotate their physical body, and the game will return as if nothing had happened".

3. **Multimodal/haptic strategies** that connect directly to vibration codes and other sensory cues. IE02 comments on examples observed in third parties, such as vibration when "entering" a wall or loss of vision when traversing geometry as a mechanism to induce retreat: *"there are things I've seen people do that involve vibration... if your hand is touching the wall... vibrating at a frequency that is bothersome..."* and *"when you stick your head in, you lose vision inside... instinctively the player pulls their head back out".*

The strategies reported range from spatial and physical solutions to perceptual, communicational, and multimodal approaches, reflecting the diversity of contexts, technical limitations, and user profiles involved in the projects.

5.4 Development Team

The *Development Team* theme was structured from four analytical groups derived from coding: (i) *Interviewee Profile*, (ii) *Roles*, (iii) *How They Work*, and (iv) *Development Process*. Each group brings together specific codes that describe characteristics of professional performance, work organization, and design rationales associated with the development of VR applications. Below, we detail each group, explaining the codes that compose it and the patterns observed in the corpus.

5.4.1 Job profile and technical experience

The *Interviewee Profile* group comprises tree main codes and one group, respectively: *Limited Technical Skills*, *Monotasking (Developer)*, *Multiple Roles*, and *Experience with Engines*. These codes allowed us to characterize the degree of specialization, technical autonomy, and diversity of roles of the participants. In terms of profile, 9/10 participants were coded as multifunctional, reporting an accumulation of responsibilities (IE01, IE02, IE03, IE04, IE05, IE06, IE07, IE08, IE10). This pattern appears in both academic and applied contexts, where the participant describes the need to take on multiple roles: *"It's complicated, I do a little bit of everything"* (IE05) and *"Since the project is small, my role is manager, designer, programmer, you know? It's a lot of little things like that. I do a little bit of everything"* (IE06). In projects conducted with a strong focus on individual skills, multifunctionality appears as the complete execution of the product: *"I did everything"* (IE10).

Technical limitations were also mentioned. 4/10 participants verbalized limited technical skills in at least one dimension of development (IE01, IE06, IE07, IE09), frequently indicating dependence on third parties, ready-made solutions, or prioritization of feasible deliverables. In one case, the limitation appears as a practical difficulty in implementation even when the participant recognizes the existence of the technique: *"I know that these techniques exist, there is a way to do this. I just don't know how to implement it, because I've never tried"* (IE01). In the other three, the limitation is associated with specific experience with VR or the level of the team: *"I myself don't have that much experience with VR"* and *"It's a small and amateur team"* (IE06).

There are also cases where the delimitation is made explicit by the division of functions: *"Same functions. I don't talk about the programming part, for example, that wasn't me"* (IE07) and *"I also end up tinkering a little bit with Unity, but I'm not a programmer"* (IE09).

Regarding the core development tools, everyone reported using Unity, often as the exclusive base: *"Basically I only worked with Unity"* (IE01) and *"Actually, to develop VR I only used Unity"* (IE03). Some of the interviewees (5/10) also mentioned complementary tools (for example, Blender and Sketchfab) and, in one case (IE08), other engines/platforms in specific projects. *"All the projects were for Quest glasses and I did them in Unity..."* (IE02).

5.4.2 Professional roles and specialization

The *Roles* group comprises 13 codes associated with the functions performed in the development cycle, including Developer, Game Designer, UX/UI Designer, Product Owner, Decision Maker, among others. The most recurrent role was that of developer (9/10), cited by IE01, IE02, IE03, IE04, IE05, IE06, IE07, IE08, and IE10. In more direct accounts, this framing appears explicitly: *"I am more of a developer. Starting with the scripting, coding part"* (IE04). Roles associated with design also appeared frequently. In two cases, the interviewee primarily positions themselves as a game designer: *"I am a game designer"* (IE05) and *"In this project I am a game designer"* (IE09).

Coordination and mediation roles were also identified, in which the participant acts as a bridge between stakeholder objectives and technical feasibility. IE09 explicitly describes this intermediary role: *"One of my roles, as a game designer, is to be the bridge between the team and the teachers"* (IE09). In other contexts, coordination blends with development and team guidance: *"I also, out of necessity, end up getting involved in development as well"* (IE06).

The data suggest two recurring arrangements: (i) small teams in which the same participant concentrates on technical and design roles; and (ii) more segmented arrangements, in which there is a clearer division between roles (e.g., dedicated UX/UI, parallel audio/art, etc.). This second arrangement is explicitly described in IE08: *"there was one person dedicated only to UX, there was one person for programming, one person for audio, so it was more separated"* (IE08).

5.4.3 How they work: individual vs. team

The *How They Work* group was composed of two central codes: *Works alone* and *Works as part of a team*, allowing for the identification of organizational and coordination patterns. In the coded corpus, 10/10 mentioned teamwork in some context (IE01–IE10), and 5/10 also reported solo work in at least one project (IE01, IE02, IE03, IE06, IE08). This overlap indicates that the same professional may move between organizational modes depending on the type of project (academic, institutional, commercial, extension, etc.). IE01, for example, explicitly states the exception of solo work in the final thesis: *"Except for my final thesis, which was actually just me"* (IE01). IE02 points to a more solo pattern in certain periods: *"I worked more solo in general"* (IE02). IE03 also summarizes this mode: *"It's more solo"* (IE03).

In team contexts, descriptions of coordination through meetings, collective discussion, and validation by external instances emerge. IE04 describes a decision-making and documentation workflow with coordination tools: *"we just sit down, the three of us... and discuss what the best decision will be"* and *"we write it down... usually in Notion, and follow through. And we coordinate through GitHub"* (IE04). IE02, on the other hand, describes governance with monitoring and escalation for decision-making: *"we had a meeting once a week and we also had a master's student who looked after us"* (IE02). In contrast, individual work appears as more direct and focused execution, as in the case of IE08: *"In some projects I went alone"* (IE08).

5.4.4 Development and decision-making process

The *Development Process* group brings together four codes: User-Centered Design, Structured Process, Creative Freedom, and Decision Making, articulating methodological and decision-making aspects reported by the participants. 10/10 participants were coded into the process structure, suggesting that all describe some sequence of steps (planning, prototyping, testing, refinement, etc.). Formalization through documents and steps appears in accounts such as that of IE02: *"Normally we would create a Game Design Document (GDD)"* (IE02). IE04 also describes starting with a GDD, validation, and subsequent division of tasks: *"we had a meeting to write a GDD, which is where everything begins"* and *"then we started dividing tasks"* (IE04).

Furthermore, 8/10 mentioned creative freedom (IE01, IE03, IE04, IE05, IE06, IE07, IE08, IE10), frequently associated with adapting ideas and external references to the project's limitations. In some cases, this logic appears as incremental construction (*"I always try to do it in concentric circles. From the very basic, then I progress little by little."* IE05) and, in others, as an explicit strategy of prototyping and gradual improvement: *"let's do this, let's make a base, then we can improve anything"* (IE06).

Regarding decision-making, 7/10 were coded as decision-making (IE02, IE03, IE04, IE05, IE06, IE07, IE10). In two cases, decision-making appears as a negotiation between technical feasibility, project objectives, and validation from people "above" in the chain (supervisors, coordinators, stakeholders). IE01 explicitly describes this external validation mechanism: "at the end of the day she has to approve what we are designing or not" (IE01). IE06 also indicates stakeholder-mediated decision-making and constraints: *"the whole process starts with a discussion with our stakeholders, to find out what they need"* (IE06).

Finally, 6/10 participants mentioned practices associated with user-centered design (IE01, IE04, IE06, IE07, IE08, IE09), including testing, behavioral observation, and adjustments based on user feedback. This element appears directly in IE03: *"it's no use just doing it, you have to test it with people to see if they will follow what you expect"* (IE03), and in IE07 when reporting user evaluations as part of the work: *"I helped... in the assembly part, from the beginning, of the design and the tests we did"* (IE07).

5.5 Tools Used

The *Tools Used* theme consolidates participants' mentions of the technical ecosystem mobilized in the development of VR experiences. The theme's structure was organized around three main codes: Variety of HMD Devices, Variety of Engines, and Variety of Complementary Tools. Together, these codes describe (i) which devices are used to test and run immersive experiences, (ii) which engines and platforms support the implementation, and (iii) which parallel tools enable the production, organization, and coordination of the work.

In the coded corpus, 8 out of 10 participants were associated with the code variety of HMD devices, indicating contact with different headsets and usage contexts. In three cases, the diversity of devices appears as part of the learning and adaptation process to specific hardware ecosystems. IE01, for example, makes this dimension explicit when mentioning the work with the Quest: *"Of course, we learn how to use the VR headset itself, which is full of very specific settings, the Quest, but in terms of the engine to do the experiments, I did everything in Unity."* (IE01).

IE04 describes the initial contact with MetaQuest 2 through introductory applications: *"Then we got together, it was my first real contact, I played some more basic games, that introductory one from MetaQuest 2, which I think it had."* (IE04).

IE08 describes the use of mobile solutions associated with headsets coupled to smartphones: *"There was a lot of craze where you could take your glasses, especially Samsung ones, and put them inside the case and use the VR application there."* (IE08).

The code variety of engines was identified in 9/10 participants, suggesting that, although there is a predominance of a central engine, participants recognize and/or use alternatives in specific projects. Unity appears as the recurring (and sometimes exclusive) basis for development, but there are occasional mentions of other engines and platforms. IE08 summarizes this pattern by saying: *"Unity. There was Unreal, but it was for a few projects."* (IE08). Platforms that operate as a publishing/integration environment for experiences also appear, as described by IE10: *"Unity and Spatial, which is the platform that unites everything."* (IE10). In interpretative terms, these reports suggest an ecosystem centered on Unity, with variations conditioned by project demands, team history, and resource availability.

The variety of complementary tools mentioned by 9 out of 10 participants highlighted the presence of auxiliary tools for both production (modeling, SDKs) and development coordination and documentation. IE09 describes a typical distributed collaboration setup, combining documentation, communication, and versioning: *"In our case, we use Notion. And besides Notion, we use Discord for online meetings. And text tools, right? Like Google Docs to share texts. Miro comes in sometimes to make a flowchart. (...) We share projects on GitHub."* (IE09).

From a more operational perspective, IE06 reports the adoption of tools as a contingency for last-minute adjustments: *"And I downloaded Blender here, in case of an emergency, if I needed to modify something."* (IE06). There are also mentions of kits and components specific to the VR ecosystem: *"I think we are using the Meta XR SDK now, and then we got to work with two others..."* (IE04).

In summary, the topic highlights that VR development practices depend on a set of "satellite" tools that support incremental production and work organization, combining engine resources, SDKs, and coordination platforms.

5.6 Collection of References

The *Collection of References* theme encompasses the ways in which participants describe obtaining repertoire for design decisions, interaction mechanics, spatial organization, and communication strategies in VR. Unlike themes focused on rationalizations about collisions, this theme is predominantly descriptive and quantitative, as it groups reference sources mentioned in the corpus. Ten codes associated with reference gathering routes were identified, with heterogeneous distribution among participants.

In the coded set, the most frequent category was references via games (7/10), followed by more sporadic occurrences on YouTube (2/10), experts (2/10), digital store catalogs (2/10), and scientific articles (2/10). The other routes occurred in 1/10 participants each: participation in events, research on web search engines, forums, brainstorming, and AI.

The predominance of games as a source of reference suggests that, for a significant portion of the participants, the repertoire is built through observation and appropriation of mechanics already tested in existing products. IE02 explicitly describes this process as a translation from reference to conceptualization: *"For example, the photography game we made, the idea, when we conceptualized it, was based on a Pokémon game, which is also VR... our ideas, in general, came from a repertoire of games..."* (IE02).

Similarly, IE03 highlights the practice of using games as a basis (even when not played directly), emphasizing accessibility criteria: *"But a lot of the reference I have also comes from playing... There's one called Arca's Path... it's an example I use a lot, actually, in all the projects I do."* (IE03).

Although less frequent, academic references appear as an explicit route in research and postgraduate contexts. IE07 reports: *"Since I immediately joined to provide support for a master's research project, academic references came right away."* (IE07). IE03 reinforces this pattern in projects with a strong university component: *"Since most of the projects are also academic, I look for articles a lot."* (IE03).

In the corpus, YouTube appears as a route to follow trends and observe practical examples: *"I think on YouTube. On YouTube I'll see what's trending in VR at the moment..."* (IE05).

Forums are mentioned as a source of technical solutions and practical research: *"I usually look in forums."* (IE06). The use of AI appears in a punctual and instrumental way: *"for this one from Fiocruz, we looked on ChatGPT."* (IE01).

In summary, the theme indicates that the collection of references in VR combines experiential repertoire (games), academic routes (articles), and pragmatic sources (video, forums, and AI), with a strong asymmetry in distribution: games function as the main vector of inspiration, while formal and technical sources appear associated with specific project contexts.

5.7 Collisions in the real world

The theme *Collisions in the Real World* brings together accounts in which participants describe physical risks and situations of involuntary contact with people, objects, and obstacles during the use of VR, as well as practical conditions adopted to reduce this risk. The thematic structure of this set is organized into two complementary blocks: (i) conditions of use and environmental control, which frame when and why the risk is perceived as more manageable; and (ii) perceptions and effects of collision, including immediate reactions, situational learning, and changes in user behavior after incidents.

In the coded corpus, 5 out of 10 participants were associated with the controlled environment code (IE01, IE02, IE08, IE09, IE10). In these reports, space control (measurement, supervision, spaced furniture, seated user) appears as a way to reduce the probability of physical collisions and, in some cases, as justification for not prioritizing additional mechanisms beyond what is already offered by the headset and the application context. IE01 describes this framework directly: *"But, since they were all used in controlled scenarios, I guaranteed that the person would be able to move around the entire area without bumping into anything. So, in my undergraduate thesis tests, for example, the space was measured, so the person couldn't bump into anything. If they followed the instructions correctly in the virtual space, they wouldn't bump into any walls or anything. And there were no objects in the way."* (IE01).

Similarly, IE10 reports a mitigation strategy based on posture and close monitoring: *"I put the visiting staff in the chair. Even though everyone was around to monitor the person, the chair was isolated in the middle of the museum, with nothing nearby so there was no risk."* (IE10).

The *Risks of collisions* code occurred in 9/10 participants (IE01, IE02, IE03, IE04, IE05, IE06, IE07, IE09, IE10), suggesting that the physical dimension of collision is widely recognized, even when the environment is controlled. Reports range from minor impacts and scares to situations with the potential to harm third parties and equipment. IE01 exemplifies the unexpected occurrence of physical contact during immersion: *"I've been punched by a child because of this."* (IE01).

IE06 describes a typical incident associated with the momentary loss of spatial reference to the real world during immersion: *"But I forgot I was in a virtual environment, I was in a very deep immersion, and I hit my colleague in the head with the controller."* (IE06).

Taken together, these excerpts reinforce the idea that risk is not merely theoretical: it emerges from common actions (reaching, throwing, sudden movements) and tends to be intensified in contexts of public demonstration, testing, or laboratory settings, where the circulation of people and objects around the user can change rapidly.

Collision learning was identified in 4 out of 10 participants (IE04, IE05, IE06, IE10). In this code, collisions and near-collisions function as events that reconfigure how the user (or the developer themselves during testing) moves and explores the environment, often with greater caution and self-restraint in their gestures. IE05 summarizes this effect as a bodily change in the mode of interaction: *"I become much more cautious, you know, like, I move my hand much more slowly, I start walking a little slower, always testing, as if I were blind."* (IE05).

In another direction, IE10 describes learning associated with physiological effects and safety orientation: *"I think that, besides the desperation to understand what is happening, the loss of balance was the first thing."* (IE10).

The *User reaction to collision* code occurred in 9/10 participants (IE01, IE02, IE03, IE04, IE05, IE06, IE07, IE08, IE10). The reactions described include fright, task interruption, momentary confusion, and loss of presence, with variation between experienced and novice users. IE04 explains the typical disorientation of less familiar users: *"But when I did this at the beginning, or when I pass VR to a friend of mine who isn't so used to it, you can see that the person kind of stops for a while, confused, like you're trying to understand what happened."* (IE04).

IE07 describes the reaction as a mix of bodily alertness and playful interpretation of the incident, especially in experiences with physical equipment: *"But, like, fright. But it's a kind of mix of fright with fun, I think. Because, like in our case, with the bicycle, several times people almost fell off the bicycle, for real."* (IE07).

In summary, the reports indicate that collisions in the real world are treated as an eminently situated problem, whose perceived severity varies according to (i) the degree of environmental control, (ii) posture and task type (sitting vs. standing; throwing and reaching), and (iii) the presence of mediation (monitor, team, spatial constraint). Even in controlled scenarios, however, collisions and near-collisions persist as plausible and relevant events, with immediate effects on presence, continuity of interaction, and perception of safety.

5.8 Collisions in the virtual world

The theme *Collisions in the Virtual World* brings together accounts in which participants describe collisions as simulated events (between avatar and environment/objects) and discuss their implications for immersion, realism, sensorimotor coherence, and comfort. The theme's structure is organized into three core areas: (i) perceptions of the role of collisions (when they are desirable and when they are problematic), (ii) cybersickness and dissonance as a risk associated with certain forms of blocking/interruption, and (iii) user reaction in situations of inconsistency, bugs, or poorly communicated collisions.

The code *Perceptions of collisions in VR* occurred in 8/10 participants (IE01, IE02, IE03, IE04, IE05, IE06, IE08, IE10). In general, the discourse positions collisions as a mechanism capable of amplifying presence and consequence when well implemented, especially in object-to-object interactions and manual actions, but also as a source of friction when it generates inconsistency between the real movement and the virtual response. IE03 formulates a practical rule about physical consistency as a credibility requirement: *"There's one that, for me, is law. Whenever the two virtual objects interact, they have to collide. So it's that example of the guy picking up the box and hitting the other one. For me, that has to happen. So it was something, for example, in Space Stones, that I do. You pick up the stone, throw it at the computer, and the computer falls off the table. Also, one thing I got wrong in the game is that you don't do the same with the little robot that's in the back. The little robot that passes by, you hit it and it doesn't fall. It's something I see as a mistake. It's because it greatly increases the user's immersion if they see that their action has consequences*

in the virtual world. The fact that they threw the stone at the virtual computer and the computer fell greatly increases immersion." (IE03).

IE01 describes the same logic of realism as a gain in presence when collisions are believable: *"Several of the virtual collisions will increase immersion if they are well implemented. If they are realistic, they will greatly increase the immersion of the game, which is very important for virtual reality. So, both immersion and presence will be growing. For example, the one you showed of the guy hitting his head, that's sensational. That wall too, very cool, that you can't cross. That gives a very high level of immersion. Even if you're not feeling the physical aspect, the virtual one brings a lot of that feeling."* (IE01).

The *Cybersickness* code was identified in 6/10 participants (IE01, IE03, IE04, IE05, IE06, IE10). In this block, discomfort is mainly associated with abrupt stops, unexpected blockages, and discrepancies between the real body (which continues moving) and the virtual body (which is interrupted). IE03 summarizes this trade-off when discussing hard collisions: *"While not being able to walk through walls is great, in the sense of bringing realism to the game, the moment you're walking and you accidentally hit your head on something you didn't expect and you stop walking, it creates a lot of cybersickness."* (IE03).

IE04 complements this by situating the problem in joystick-mediated movement and individual tolerance to motion sickness: *"I, at least, have a lower tolerance for motion sickness. Even though I work with it, if I play for a long time, I still feel very nauseous. So, for example, when the game requires joystick movement, I can't play for very long. Because I'm moving very fast, I'm on the edge of the game, but my body isn't moving. That makes me feel kind of strange."* (IE04).

Taken together, these accounts reinforce that virtual collisions are not evaluated solely on realism, but also on their perceptual predictability, the type of navigation, and how the system communicates (or does not communicate) the obstacle before the collision.

The *User reaction* code to the virtual collision appeared in 2/10 participants (IE05, IE08). Although less frequent, this core describes situations where the collision (or its effect) is perceived as inconsistent and triggers reactions of bewilderment, falling, or loss of reference. IE05 exemplifies an extreme case associated with a bug and bodily disorientation: *"I always stick with the example of one time, I think it was one of the first VR games I played, that had some bug and I spun out of the environment very quickly and I fell in real life because I went into shock. I simply lost my balance. I think this collision can generate a bit of that."* (IE05). IE08 describes the problem as a failure to read the obstacle, producing uncertainty about the cause of the blockage: *"then you don't know why it's colliding."* (IE08). In short, the theme indicates that collisions in the virtual world are treated as a design feature with clear gains for immersion and...

5.9 Modalities

The *Modalities* theme synthesizes how participants describe the sensory channels mobilized to guide, communicate limits, and sustain interaction in VR. Like *Collection of References*, this theme is predominantly descriptive/quantifying in nature, as

it records the occurrence of modalities cited in the corpus, rather than focusing on a large set of rationalizations.

In the coded corpus, visual occurred in 10/10 participants, multimodal in 6/10, auditory in 4/10, and haptic/tactile in 3/10. This pattern suggests a predominance of the visual channel as the minimum basis for communication, with multimodality appearing as a relevant, but not universal, strategy.

The visual modality appears both as a readability resource (what is interactive) and as a mechanism for communicating state, risk, and limits. IE03 describes an example of visual feedback for collision involving a real hand and a virtual hand: *"when I touch it, the virtual hand stays still, but it creates a second hand to show where your real hand is... it shows that there was a collision, but it doesn't remove the real movement either."* (IE03). IE08 also emphasizes the importance of making explicit what can be manipulated and of using UI elements in the visual field: *"making explicit what can be interacted with... also putting UI messages... as messages on the screen itself..."* (IE08).

Multimodality emerges as a solution to reduce ambiguities and increase accessibility in critical situations, generally combining visual signaling with auditory warnings and, to a lesser extent, haptic feedback. IE08 explicitly describes a typical combination: *"Auditory warnings and visual warnings, mainly... putting a warning on the screen, or even an auditory warning..."* (IE08).

IE06 discusses multimodality as a practical requirement in the face of limitations of a single channel, explicitly stating accessibility concerns: *"And speaking is always a problem because of deafness... So, I wouldn't go for sound alone."* (IE06).

The sound channel appears associated with spatial orientation and attention capture. IE07 describes sound orientation as part of a design that sought to guide the user: *"the idea was also to guide by sound... it would also have this part of other senses... to guide."* (IE07).

Haptics/tactile emerges as an alternative to signal contact and limits when the device supports vibration, as described by IE02: *"There are things I've seen people do that involve vibration... if your hand is touching the wall... going into the wall and vibrating..."* (IE02). IE02 also mentions a tactile dimension in the real world as a physical reference strategy: *"A viable solution would be to have an object there in real life..."* (IE02).

In summary, the theme indicates a practical hierarchy of modalities: visual as a base (universal in the corpus), multimodality as reinforcement in critical situations, and sound/haptics as complements that depend on context, accessibility, and hardware support.

5.10 Technical Problems

The *Technical Problems* theme includes reports in which participants describe implementation limitations, stability difficulties, and challenges to consistency between real movement and virtual behavior. The theme's structure consisted of three codes: Difficulty generating interaction from physics, Lack of generalization (need for specific configurations), and Inconsistency between the real and the virtual. Unlike more frequent themes, this set appears with less distribution in the corpus, but it contributes

to contextualizing why certain strategies can be avoided, simplified, or delegated to platform solutions. The code *Difficulty in generating interaction from physics* was identified in 1/10 of participants (IE01), but with a detailed excerpt describing the practical complexity of collisions between objects and manual interactions: *"I find virtual collisions kind of difficult to deal with. They easily cause problems... especially those object-to-object collisions... when it involves the person's real hand, it often causes problems..."* (IE01). This report reinforces the perception that physically coherent interactions are desirable, but often costly and fragile in terms of implementation. The code *Lack of generalization* also occurred in 1/10 of participants (IE01), where the designer say about need for specific configurations, pointing to a dependence on particular hardware/ecosystem configurations: *"I really had to learn how to use the Quest glasses, because it has specific configurations that Meta puts on."* (IE01). The excerpt suggests development friction associated with the coupling between solutions and platforms, which can impact reuse and portability.

The code *Inconsistency between real and virtual* appeared in 3/10 participants (IE01, IE02, IE07), describing the perceptual effect of divergence between physical action and virtual response. IE02 explains the strangeness resulting from a bodily blockage in the virtual world when the real body moves: *"His physical head moved, right? Why isn't his virtual head moving? So this can also cause problems even for the experience of the person who is not synchronized with the virtual world."* (IE02).

Taken together, these accounts connect technical difficulties to impacts experienced by the user, reinforcing that implementation problems and perceived inconsistency are not just "bugs", but elements that shape design decisions and strategy choices.

6 Discussion

This chapter discusses how immersive environment designers understand, communicate, and manage collisions in VR, interpreting the eight themes in light of the research goal and the empirical patterns found in the interviews. The discussion highlights collisions as a multidimensional design challenge that goes beyond technical implementation, involving safety, perceptual coherence, experiential quality, workflow constraints, and the organizational context in which VR experiences are produced.

6.1 Collision management as the practical center of VR design work

A central finding is the prominence of the *Collision Management* theme, which concentrated the largest proportion of coded recording units (44%). This concentration indicates that, from the designers' standpoint, collision-related concerns function as a practical "core problem" around which many design decisions are organized. Importantly, this does not suggest that collisions are always treated as a single isolated issue. Instead, the way participants speak about collision management reveals an integrated design space involving navigation choices, spatial structuring, onboarding, feedback modalities, risk mitigation, and platform constraints.

The distribution of strategies across participants also suggests that collision management operates as a proxy for broader VR design maturity. Experienced and

hybrid-profile participants, those combining development responsibilities with coordination or decision-making, reported a wider repertoire of strategies (e.g., gradual deceleration, environmental "soft constraints," multimodal warnings, spatial remapping, onboarding mechanisms). In contrast, less experienced developers tended to rely on controlled contexts, stationary setups, and headset boundary systems as primary measures. This pattern supports an interpretation that collision management becomes more sophisticated as designers accumulate not only technical skills, but also exposure to user testing, deployment contexts, and iterative refinement cycles.

6.2 Why "collision is not a problem" is still a collision-management decision

One of the most analytically relevant contributions of the results is the identification of the code *collision is not a problem*. Rather than representing a denial of collision risks, this code reflects *situated deprioritization* where designers explicitly frame collisions as non-central due to constraints and contextual assumptions. The three rationales identified, technical limitation, structural risk reduction through experience design, and reliance on controlled usage contexts, reveal a key point: choosing not to implement collision mechanisms is not an absence of design, but a design strategy anchored in feasibility and context.

This finding has two implications. First, it reinforces that collision management is not a universal checklist item; it is a variable that designers negotiate based on application domain, target audience, deployment setting, and available team capability. Second, it suggests that "collision is not a problem" can be understood as an implicit risk model where the design intentionally shifts collision prevention to other layers (human monitoring, room configuration, seated posture, boundary systems). In practice, these alternatives often work, especially in museums, labs, and supervised settings. However, as the results also show, physical collision risk remains widespread (9/10 participants), indicating that even "controlled" configurations do not eliminate incidents. Therefore, deprioritization strategies should be interpreted as trade-offs that reduce certain risks while potentially increasing dependence on supervision and environmental predictability.

6.3 Real-world collisions: safety as an operational and social problem

The theme *Collisions in the Real World* makes explicit that physical collisions are recognized as plausible events across most participants and contexts. Designers' accounts indicate that the risk is closely tied to common interaction behaviors (reaching, sudden gestures, throwing), and is intensified in public demonstrations and shared spaces where bystanders, furniture, and equipment may shift around the user.

Notably, designers frequently mitigate these risks through operational control rather than purely in-world mechanics: measuring the space, clearing obstacles, isolating a chair, monitoring users, and marking the floor. This indicates that collision management is partially external to the virtual environment and often becomes a sociotechnical arrangement involving staff, environment preparation, and user instruction.

The "learning" effect reported by some participants further suggests that collision events reshape user behavior, producing more cautious movements and heightened bodily awareness. This supports the interpretation that collisions are not only disruptive incidents but also moments that recalibrate how users perceive safety and act in immersive environments.

6.4 Virtual-world collisions: immersion gains vs. sensorimotor risks

In the theme *Collisions in the Virtual World*, participants described collisions as simultaneously beneficial and risky. On one side, collisions are treated as a credibility mechanism when object-to-object interactions follow expected physical logic, users perceive consequence and realism, increasing immersion and presence. This is especially clear in accounts emphasizing that "virtual objects must collide" to maintain the integrity of interaction.

On the other side, designers consistently described cybersickness as a risk linked to certain collision implementations, particularly abrupt stops and unexpected blockages that conflict with the user's bodily motion and expectations. This tension suggests that designers are not simply deciding whether to include collisions, but *how* to implement them in a way that balances realism with comfort. In practice, the findings imply that collision design operates as a perceptual negotiation: "hard realism" may strengthen presence in some interactions, while "soft or communicative constraints" may better preserve comfort and continuity, especially during locomotion.

An additional nuance is that user reaction to virtual collisions appeared less frequently in the corpus than reactions to physical collisions. A plausible interpretation is that designers more readily observe and remember physical incidents due to their immediate safety consequences, while virtual collision discomfort may be underreported unless it escalates to obvious events (e.g., severe disorientation caused by bugs). This reinforces the importance of iterative testing and observation, particularly for virtual collision mechanics that can produce subtle discomfort before producing overt reactions.

6.5 Strategy types as a design space: from spatial control to multimodal guidance

The classification of collision prevention strategies into spatial/physical, perceptual, navigation/movement, communicational, and hybrid/multimodal types provides a useful interpretive lens for the corpus. Across these categories, three cross-cutting patterns stand out.

First, many solutions are grounded in mediation and operational control, showing that collision prevention often depends on procedures and supervision rather than sophisticated in-world systems. Second, designers frequently depend on HMD ecosystem resources (e.g., boundary systems, fading and warnings), which indicates that collision management is partly "platform-mediated." This dependence can accelerate implementation and reduce complexity, but it can also constrain portability and

standardization across devices and contexts, aligning with the reported lack of generalization and platform-specific configurations. Third, multimodal strategies appear as an "upgrade path" when designers seek to reduce ambiguity and increase reliability: combining visual cues with auditory warnings and, when available, haptics.

Taken together, these patterns suggest that collision management strategies are layered by combining environmental setup, platform-level protections, and in-world cues. In this sense, collision management can be conceptualized as a *stack* of mitigations rather than a single mechanism. The prominence of hybrid solutions also aligns with accessibility concerns raised by participants (e.g., not relying on sound alone), indicating that robustness in collision communication is often achieved through redundancy across modalities.

6.6 Team structure, roles, and experience shape collision solutions

The *Development Team* theme shows that some participants (4/10) operate as multifunctional professionals and that team structures vary from solo development to segmented multidisciplinary arrangements. This context matters because collision management strategies appear tied to who is making decisions, who has implementation autonomy, and how testing feedback is incorporated.

Participants with hybrid roles and decision-making responsibility reported richer and more diverse solution sets, suggesting that collision management benefits from a systems view that includes deployment constraints, user behavior, and iteration cycles. Conversely, participants who explicitly reported limited technical skills described knowing that certain approaches exist but not implementing them due to lack of mastery. This highlights a practical gap between awareness and execution, and suggests that collision management may be a locus where teams with limited VR-specific technical depth tend to externalize responsibility to platform tools, controlled environments, or simplified experience designs.

The prominence of user-centered practices (reported by 6/10) also connects with collision management. Designers who described iterative testing and observation tended to frame collisions as something to be refined based on real user behavior rather than solely planned in abstraction. This reinforces the interpretation that collision mitigation strategies are often discovered empirically, especially in contexts where novice users behave unpredictably or do not follow assumed "safe" interaction patterns.

6.7 Tools and reference gathering: reuse, repertoire, and constraints

The themes *Tools Used* and *Reference Gathering* help explain why certain collision strategies dominate in practice. A Unity-centered ecosystem shapes the technical feasibility of collision implementations and the ease of prototyping. Meanwhile, the predominance of games as a reference source suggests that designers build their collision repertoire through experiential benchmarking: observing how existing VR products communicate boundaries, guide locomotion, and handle interaction consequences.

In contrast, scientific articles and experts appeared as less frequent reference routes, more associated with academic project contexts. This asymmetry suggests that collision management knowledge may circulate primarily through practice-based channels, implying that many collision design decisions are grounded in "what works" patterns borrowed from existing products rather than formalized guidelines. This observation is consistent with participants' descriptions of non-formal terminology and the need for researcher interpretation when coding operational descriptions. In analytical terms, collision management emerges as a craft domain where tacit knowledge, platform affordances, and iterative experimentation play central roles.

6.8 Technical problems as constraints that shape design trade-offs

The *Technical Problems* theme, although less frequent, provides critical context: even when designers value physically coherent collisions, implementation can be fragile, costly, and difficult to generalize. Difficulty generating interaction from physics and inconsistency between real and virtual movement are not merely engineering inconveniences; they directly affect user experience, immersion, and comfort. This reinforces the broader tension identified in the results when collision realism is desirable, but it can also amplify discomfort if implemented as abrupt blocking or if it produces mismatches between real and virtual behavior.

As a result, many designers (7/10) appear to adopt strategies that reduce the need for complex physics-based collision systems (e.g., stationary users, simplified interactions, reliance on platform boundary systems). From a design perspective, this indicates that collision management is shaped by feasibility boundaries when teams choose solutions that are robust under time, skill, and hardware constraints, even if those solutions sacrifice certain aspects of realism.

6.9 Synthesis: collisions as a multidimensional design problem

Overall, the results support framing collision management as a multidimensional challenge with at least four interdependent dimensions: (i) *safety in the real world* (risk mitigation through space control and supervision), (ii) *perceptual coherence and comfort* (avoiding dissonance and cybersickness), (iii) *interaction credibility* (ensuring consequences and realism in virtual object interactions), and (iv) *development feasibility* (technical constraints, team skill, platform dependencies). Designers' strategies can be interpreted as attempts to optimize across these dimensions under different constraints.

This synthesis also clarifies why collision management dominates the corpus: it is the intersection point where VR's embodied nature, spatial constraints, and user experience risks converge. The variation across participant profiles further suggests that collision management knowledge grows through exposure to deployment realities, user testing, and iterative refinement, rather than being fully determined by tool availability alone.

7 Conclusions, limitations and future work

This study investigated how designers and developers of immersive environments conceptualize, communicate, and manage collisions in virtual reality (VR) applications. Through ten semi-structured interviews analyzed using Reflexive Thematic Analysis, the research aimed to understand how collision-related design decisions emerge in practice, considering both the virtual environment and the physical context in which VR experiences take place. Rather than focusing on the technical evaluation of specific collision-handling techniques, the study sought to capture the variety of design rationalities, strategies, and constraints that shape how practitioners address collision-related challenges in real development scenarios.

The results indicate that collision management occupies a central role in the design of immersive environments, emerging as a recurring concern that intersects with multiple aspects of VR development. Designers' accounts reveal that collisions are rarely treated as isolated technical events; instead, they are embedded in broader considerations related to spatial organization, navigation design, user safety, sensory communication, and platform capabilities. The thematic analysis showed that designers rely on a wide repertoire of strategies to anticipate, communicate, or mitigate collisions, ranging from spatial and physical configurations to perceptual cues, navigation constraints, communicational mechanisms, and multimodal feedback. These strategies often operate in combination, forming layered solutions that integrate environmental preparation, platform-level safeguards, and in-experience guidance mechanisms.

An important finding concerns the identification of a design rationale captured by the code "collision is not a problem." Rather than indicating a lack of awareness about collision risks, this pattern reflects situated design decisions in which collision management is deprioritized due to contextual conditions such as controlled environments, seated experiences, or the perceived feasibility of implementation. In such cases, designers rely on alternative mitigation layers, including supervision, environmental preparation, or behavioral assumptions about the user. This observation highlights that collision management in VR is not universally treated as a mandatory design feature but instead emerges as a context-dependent decision shaped by technical constraints, development resources, and the intended use scenario of the application.

The findings also reveal a tension between realism and comfort in the design of virtual collisions. On one hand, designers frequently associate physically coherent interactions with increased immersion and presence, especially when virtual objects respond to user actions in expected ways. On the other hand, abrupt blocking or inconsistent responses between the real body and the virtual avatar were repeatedly associated with discomfort and cybersickness. This tension suggests that collision design involves balancing perceptual credibility with sensorimotor comfort, often leading designers to adopt softer or communicative constraints rather than rigid physical blocking mechanisms. In practice, designers appear to treat collision handling as a perceptual and experiential problem as much as a technical one.

Another relevant aspect concerns the influence of professional experience and team organization on collision-management strategies. Participants with hybrid roles, combining development responsibilities with design coordination or decision-making,

tended to describe more diverse and sophisticated solution sets. Conversely, participants with limited technical expertise often acknowledged the existence of certain techniques but reported difficulties implementing them in practice. These observations suggest that collision management knowledge is not only dependent on available tools but also on accumulated project experience, exposure to user testing, and familiarity with VR-specific interaction challenges.

The study also highlights how development ecosystems shape collision design practices. The predominance of Unity as the primary development engine, combined with the widespread use of platform-level boundary systems provided by head-mounted displays, indicates that designers frequently rely on existing platform affordances to mitigate collision risks. At the same time, the analysis of reference-gathering practices revealed that designers often draw inspiration from existing VR games and products rather than from formal design guidelines or scientific literature. This suggests that much of the knowledge surrounding collision management circulates through experiential and practice-based channels, reinforcing the importance of empirical studies that document how practitioners actually reason about these problems.

Taken together, the results support the interpretation that collision management in VR is a multidimensional design problem that involves the interplay of safety, perceptual coherence, interaction credibility, and implementation feasibility. Designers' decisions reflect attempts to balance these dimensions within the constraints of available tools, team expertise, and deployment contexts. By revealing how practitioners conceptualize and operationalize collision-related strategies, this study contributes an empirically grounded perspective on a topic that is often discussed primarily from a technical or experimental standpoint.

The findings also have implications for the development of design-support tools and frameworks for immersive environments. The diversity of strategies identified in the interviews suggests that flexible and modular approaches may better reflect real design practice than single prescriptive solutions. In particular, approaches that allow designers to experiment with multimodal cues, spatial constraints, onboarding mechanisms, and perceptual feedback layers may help bridge the gap between conceptual design intentions and technical implementation. In this sense, the empirical insights presented in this study inform ongoing efforts to develop annotation-based frameworks for immersive environments, such as the proposed GUsT-3D framework[20], which aims to support the integration of additional communication layers and affordances without requiring extensive modifications to existing application code.

Despite these contributions, this study has several limitations. First, the sample size was intentionally small and exploratory, involving ten participants with heterogeneous profiles. While this diversity allowed capturing a wide range of perspectives, the findings should not be interpreted as statistically representative of the broader VR development community. Second, most participants (8/10) were connected to academic or research-oriented contexts, which may influence the types of projects described and the relative emphasis on experimentation or prototyping. Third, the study relied on self-reported experiences rather than direct observation of development practices or user testing sessions. Future research could complement these

findings through observational studies, design ethnographies, or controlled evaluations of collision-management strategies in real VR applications.

Beyond these methodological considerations, some analytical and scope-related limitations should also be acknowledged. The findings reflect designers' interpretations, rationales, and accounts of their practices rather than direct observations of design activities or analyses of implemented artifacts. Consequently, the study captures how participants conceptualize and justify collision-management decisions, which may not always correspond to how such strategies are ultimately implemented in production environments. Furthermore, although participants frequently discussed the effects of collisions on immersion, presence, comfort, and cybersickness, these assessments were derived from designers' perspectives rather than from empirical evaluations involving end users. The participant pool was also predominantly composed of professionals working in academic, research, or prototype-oriented contexts, where controlled environments and supervised deployments are common. As a result, some identified rationales, particularly those related to the deprioritization of collision management, may not fully reflect the realities of large-scale commercial VR applications. Finally, because all participants were recruited from the Brazilian XR ecosystem, the findings may be influenced by local professional practices, resource availability, and development cultures, limiting broader cultural or industrial generalizations.

Future work may also expand the empirical scope of this research by involving designers from additional industry sectors and geographical contexts, as well as by exploring how collision-management decisions evolve across different stages of the development lifecycle. Another promising direction involves the implementation and evaluation of tool-based support for collision-related design strategies, particularly those involving multimodal feedback and adaptive spatial constraints. Building on the findings reported in this study, future investigations may explore how designers create and configure collision-related affordances using tools such as GUsT-3D, enabling the addition of visual and auditory collision cues without modifying the original application code. Furthermore, controlled studies with end users could evaluate the effectiveness of these designer-created affordances in communicating collision risks, improving spatial awareness, reducing unintended collisions, and supporting comfort and presence in immersive environments. Such investigations may provide valuable insights into how collision communication can be systematically incorporated into existing VR applications and how tool-supported affordance design can contribute to safer and more effective immersive experiences.

In summary, this study contributes to a deeper understanding of how VR designers conceptualize and address collisions as part of immersive experience design. By revealing the strategies, rationalities, and constraints that shape these decisions in practice, the research highlights the importance of treating collision management not merely as a technical constraint but as a central design problem in immersive environments.

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Ethics approval and consent to participate: This study was approved by the Research Ethics Committee of the Universidade Federal Fluminense (UFF) under registration number CAAE 91974125.0.0000.8160. All participants voluntarily agreed to participate in the study and provided informed consent prior to the interviews. Participants were informed about the objectives of the research, the procedures involved, the voluntary nature of their participation, and their right to withdraw at any time without penalty. All interview data were anonymized, stored in a secure digital environment with restricted access, and handled in accordance with applicable ethical guidelines and regulations.

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Materials availability: No additional materials are associated with this study.

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Author contribution: VV, DT, and MW contributed to the conceptualization and methodology of the study, including the design of the research protocol and the development of the semi-structured interview guide. VV and DT were responsible for the ethics approval procedures. VV, DT, and MW participated in participant recruitment. VV conducted the interviews and performed the initial data preparation, familiarization process, and development of preliminary analytical memos. VV, DT, and MW collaboratively carried out the coding process, code refinement, theme development, thematic map construction, data synthesis, and interpretation of the findings. VV prepared the original draft of the manuscript. DT and MW contributed to the review and editing of the manuscript and supervised the research process. All authors read and approved the final manuscript.

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