

Immersive Design Primitives and Decision-Making: A Systematic Review of Mechanisms and Outcomes

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Abstract

Immersive solutions are becoming a trending technology for decision support across fields such as transportation, healthcare, and urban planning. Despite their role, the mechanism by which they affect decision-making is unclear. Our study examines the design primitives in immersive technology that are manipulated to influence decision-making and synthesizes how they operate to shape decision outcomes. We follow PRISMA guidelines to search. A total of 198 studies were included. Eight primitive families were identified, including perceptual realism, environmental structure, interactivity, temporal simulation, embodiment, social presence, multisensory integration, and other contextual manipulations. Mechanisms through which they impacted decision-making were classified into cognitive, perceptual, affective, motivational, social-influence, and behavioral-heuristic mechanisms. Perceptual realism, environmental structure, and interactivity emerged as the most frequently investigated primitives, while presence, risk perception, spatial cognition, engagement, and social influence were among the most reported mechanisms. Our results suggest that immersive technologies function as decision-shaping systems that alter how users perceive uncertainty, risks, consequences, and alternatives, highlighting the need for theory-driven research and evaluation in high-stakes decision contexts.

Keywords: immersive technology; extended reality; primitive; decision-making; human–computer interaction; virtual reality; augmented reality; mixed reality; embodiment; realism

Academic Editor: Makuochi Samuel Nkwo

Received: 4 June 2026

Revised: 26 June 2026

Accepted: 29 June 2026

Published: 29 June 2026

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1. Introduction

Making decisions under uncertainty is a fundamental human activity that affects outcomes across various fields, namely transportation, healthcare, and consumer behavior [1]. The more complex and data-rich decision environments become, the harder it becomes to make decisions [2]. Traditional decision-support systems (DSS) have heavily relied on dashboards, visual simulations, and analytics to present information and guide users [3]. However, such approaches often fall short of communicating uncertainty, spatial relationships, dynamism, and the real-world outcomes of decisions in ways that are meaningful and cognitively accessible to users. As a result, researchers resort to computational models and technologies to support human judgment and enhance decision quality [4].

Recent advances in immersive technology, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), have created new opportunities for technology-assisted decision-making [5–7]. Unlike conventional interfaces and DSS, these systems allow decision-makers to experience information through realistic interactions and environments, along with multisensory feedback [8,9]. These characteristics have positioned these tools as decision support tools and systems across different domains and for different types of decisions [8]. By enabling users to experience scenarios rather than merely observe them, immersive systems may fundamentally alter how information is perceived, interpreted, and acted upon [10,11].

Growing interest in these solutions has led to a large, but often fragmented, body of research on their actual impact on decision-making [9]. This complicates efforts to determine how immersive systems really impact decision-making outcomes. Additionally, much of this research concentrates on the technological platform (such as VR versus desktop systems) rather than on the core design features that may influence decision outcomes [5–7,9]. Thus, it remains unclear whether the effects are due to immersion in general or to specific design elements within immersive tools and experiences.

Some research suggests that immersive environments can be decomposed into manipulable design primitives that represent the building blocks through which immersive systems shape user experiences. However, research rarely examines these primitives collectively. Thus, little is known about how they impact decision-making. This gap is especially critical because immersive technologies are increasingly used in high-stakes areas where decisions impact safety, health, resource management, and public welfare. To tackle this, this systematic review consolidates the growing literature on immersive technologies and decision-making. Instead of just focusing on technological platforms or application areas, we analyze the embedded design primitives, how these primitives influence users, and the resulting decision outcomes. This approach aims to go beyond simply determining if immersive tech impacts decision-making, focusing instead on how and why these effects happen. Although numerous reviews have examined immersive technologies from perspectives such as technology adoption, user experience, education, training, healthcare applications, consumer behavior, and virtual environment design, comparatively little attention has been paid to the decision-making processes that immersive systems seek to influence. Existing reviews typically focus on application effectiveness, learning outcomes, user acceptance, engagement, or domain-specific implementation challenges.

In contrast, the present review adopts a cross-domain decision-making perspective and focuses specifically on the relationships among immersive design primitives, proposed explanatory mechanisms, and decision outcomes. Accordingly, the contribution of this review is not simply to summarize immersive technology applications, but to identify recurring design elements, synthesize the mechanisms through which they are proposed to influence decision-making, and develop an integrative framework for understanding immersive decision support across domains. This perspective complements existing reviews of immersive technology while addressing a distinct gap in the literature. The following research questions guide the review:

- RQ1. What immersive design primitives have been used to support decision-making across application domains?
- RQ2. What types of decisions have been studied in immersive environments, and in what contexts are these decisions made?
- RQ3. Through which mechanisms do immersive primitives influence decision-making outcomes?

- RQ4. What evidence exists regarding the reported relationships between immersive design primitives and decision-making outcomes, including decision quality, behavior, preferences, intentions, and performance?

By addressing these questions, this review aims to lay a foundation for a more mechanistic, theory-driven understanding of immersive decision support. Ultimately, our goal is to identify the design principles and causal pathways that can guide the development of future immersive systems to support effective, trustworthy, and human-centered decision-making.

2. Materials and Methods

We conducted a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review aimed to synthesize evidence on how immersive design primitives influence decision-making outcomes and the mechanisms by which these effects occur. The protocol is registered on OSF and can be accessed through the link <https://osf.io/85cv2>.

2.1. Search Strategy

Four electronic databases representing the biomedical, psychological, engineering, computer science, and interdisciplinary literature were systematically searched: PubMed, Web of Science, IEEE Xplore, and ProQuest CENTRAL. The search was conducted on 16 April 2026 and included studies published from database inception until the search date. The search strategy was organized around three core concepts: (1) immersive environments, (2) immersive design primitives, and (3) decision-making.

Keywords within each concept (see Appendix A) were combined using the Boolean operator “OR”, while the three concepts were combined using the operator “AND”. The search strategy was iteratively refined through preliminary searches and discussions among the authors to maximize sensitivity and specificity. All retrieved records were exported to EndNote 21 (Clarivate Analytics, Philadelphia, PA, USA) for duplicate removal and screening.

2.2. Eligibility Criteria

Studies were eligible for inclusion if they met all of the following criteria: (1) investigated immersive or semi-immersive technologies, including virtual reality (VR), augmented reality (AR), mixed reality (MR), or related immersive environments; (2) examined at least one immersive design primitive, including embodiment, interactivity, perceptual realism, temporal simulation, social presence, environmental structure, multisensory integration, or related primitive-level manipulations; (3) included a decision-making outcome, such as decision quality, choice behavior, preference formation, risk perception, risk-taking, trade-off evaluation, decision confidence, decisional conflict, or behavioral intentions; (4) examined, tested, or theoretically linked mechanisms explaining how immersive primitives influenced decision-making outcomes (e.g., cognitive, perceptual, affective, motivational, social, and behavioral mechanisms); (5) reported empirical findings through experimental studies, randomized controlled trials, quasi-experiments, mixed-methods studies, or survey-based studies with clearly defined decision outcomes; (6) were published in peer-reviewed journals or conference proceedings; and (7) were written in English.

Studies were excluded if they: (1) did not involve immersive technologies, (2) focused solely on technology development or usability without a decision-making outcome, (3) did not examine a design primitive or its influence on decision-making, (4) lacked empir-

ical data, or (5) consisted of editorials, commentaries, opinion papers, abstracts, dissertations, or non-peer-reviewed publications.

2.3. Study Selection, Data Extraction, and Coding

After duplicate removal, records underwent a two-stage screening process. First, titles and abstracts were independently screened by two reviewers against the predefined eligibility criteria. All the authors contributed to this task in a way that each record was screened or coded by two authors at a time. Studies deemed potentially relevant proceeded to full-text review. Full-text articles were independently assessed for inclusion by two reviewers. Disagreements regarding study eligibility at any stage were resolved through discussion until consensus was achieved, with additional consultation among members of the review team when necessary. The study selection process was documented using a PRISMA flow diagram reporting the numbers of records identified, screened, excluded, and included in the final review.

A standardized data extraction form was developed in Microsoft Excel to ensure consistent data collection across studies (Appendix B). Data extraction was independently performed by two reviewers using predefined coding categories. Extracted information included publication characteristics, application domain, immersive technology type, immersion level, decision-making context, decision type, immersive design primitives, operationalization and manipulation of primitives, mechanisms linking primitives to outcomes, study design, sample characteristics, and decision-making outcomes. Any discrepancies identified during data extraction were reviewed and resolved through discussion and consensus.

Particular emphasis was placed on identifying how immersive design primitives influenced decision-making processes. For each study, both the manipulated immersive primitives and their reported effects on decision-making outcomes were recorded to support pathway-based synthesis and cross-study comparison.

A coding framework was developed iteratively, drawing on prior immersive-technology literature, and refined through pilot coding of a subset of included studies. Coding of immersive design primitives and explanatory mechanisms was independently conducted by two reviewers using the predefined coding framework. Studies were permitted to receive multiple primitive and mechanism codes when multiple design features or explanatory pathways were present. Coding discrepancies were discussed and reconciled through consensus among the review team. Because coding decisions were resolved through a consensus-based review process rather than formal reliability testing, interrater agreement statistics were not calculated.

Immersive design primitives were classified into eight categories: embodiment, interactivity, perceptual realism, social presence, temporal simulation, environmental structure, multisensory integration, and other contextual manipulations. Mechanisms were classified into six categories: cognitive, perceptual, affective, motivational, social-influence, and behavioral-heuristic mechanisms. Primitive families were developed as conceptual categories intended to organize recurring immersive design features reported across the literature. These categories were not assumed to be mutually exclusive or theoretically orthogonal. Rather, they represent distinct yet potentially overlapping aspects of immersive system design that may co-occur within a single immersive experience.

Mechanism coding was intended to capture explanatory constructs reported by study authors rather than to identify confirmed causal pathways. Mechanisms were coded regardless of whether they were directly tested through mediation or moderation analyses, measured as intermediate outcomes, or proposed theoretically as explanations for observed effects. Accordingly, the mechanism categories reported in this review should be interpreted as evidence of proposed explanatory processes rather than definitive causal

mechanisms. For this review, a mechanism was defined as any construct reported by study authors to explain, influence, or link an immersive design primitive to a decision-making outcome. Mechanisms were coded based on their role as explanatory constructs in the original studies and were not limited to variables formally tested in mediation analyses. This approach was adopted to capture the broader range of explanatory processes currently used within the immersive decision-making literature.

Coding was based on how authors operationalized the immersive experience and on their explanations of observed decision-making effects. Categories were treated as non-mutually exclusive. For example, a virtual evacuation study incorporating realistic smoke dynamics, interactive navigation, and virtual crowds could be simultaneously coded as perceptual realism, interactivity, and social presence. Similarly, the same study could contribute to the cognitive, affective, and social-influence mechanism categories if the reported findings included situational awareness, emotional responses, and crowd-following behavior.

When studies contained design features that did not clearly fit within the predefined primitive categories, they were classified within the “other primitives” category and documented separately. Coding decisions were guided by the operational characteristics of the intervention rather than the terminology used by the study authors.

Given the substantial methodological heterogeneity across study designs, application domains, immersive technologies, and outcome measures, a formal risk-of-bias assessment was not conducted. The primary objective of this review was to map immersive design primitives, associated mechanisms, and decision-making outcomes across the literature rather than to estimate pooled intervention effects. Consequently, findings should be interpreted as an evidence synthesis of reported relationships and proposed explanatory pathways rather than as a comparative assessment of intervention effectiveness.

3. Results

3.1. Overview of Included Studies

3.1.1. Publication-Year Trends

The 198 included studies span 2008–2026, but the evidence base is heavily weighted toward the most recent five years. Only 16 studies (8%) appeared between 2008 and 2015 [12–15], 43 (22%) between 2016 and 2020, and 139 (70%) from 2021 onward. Then, 2025 alone contributed 41 studies, 2026 a further 22 [16–18], and 2024 contributed 24 [19–21]. This acceleration mirrors the post-2020 maturation of consumer head-mounted displays and the diffusion of decision-relevant simulation paradigms across applied fields. PRISMA flowchart is summarized in Appendix C.

3.1.2. Study Domains

Domains are highly dispersed across applied fields. Fire safety and evacuation is the single largest field (19 studies) [22,23], followed by retail and marketing (17) [24], social psychology (14) [25], urban planning (14) [26], cognitive psychology (12) [27], architecture/built environment (11), pedestrian safety (10) [18], spatial cognition/navigation (9), healthcare and public health (8), transportation (7) [28], education (5), autonomous vehicles (6), moral psychology (6), food/consumer choice (5), tourism (5), sport (4), and military defense (4). Figure 1 summarizes all the fields and subfields of the included studies.

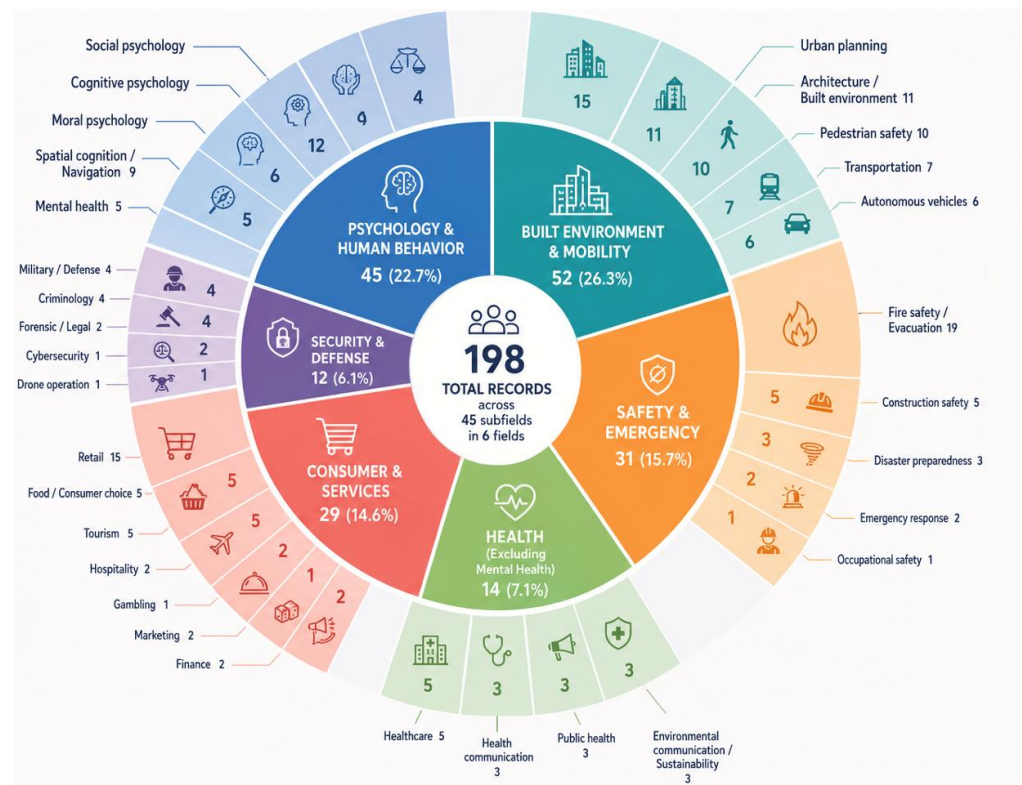


Figure 1. Domains of the included studies.

3.1.3. Technology Type

Virtual reality dominates with 167 studies (84%) [23,29], augmented reality contributes 17 (~9%) [30]; seven studies combined two or more substrates [31], and mixed reality is represented by three studies [32]. The reality–virtuality continuum is therefore unevenly covered: VR is saturated, AR is moderately represented, and MR/AV remain frontier evidence.

Most of the tools were purpose-built simulations rather than commercial applications, and their purpose tracks the decision under study. Trust-game, ultimatum, and Cyberball paradigms are used for social and economic decisions [33]; virtual stores, supermarkets, and product configurators for purchase decisions [34,35]; fire, roof, road-crossing, evacuation, and emergency simulators for safety decisions [36–39]; semi-autonomous driving and trolley-dilemma simulators for moral choices [40]; and clinical, surgical, military, and forensic simulators for specialized expert decisions [41,42].

3.1.4. Study Designs

Designs are overwhelmingly experimental, random assignment between conditions, within-subjects manipulations, factorial crossings, and discrete-choice or conjoint paradigms embedded inside immersive environments. A minority used quasi-experimental, pilot, mixed-methods, or model-based designs, especially when sampling specialized populations such as soldiers, police officers, surgeons, or people in early substance-use recovery [32,43,44]. Comparator media (2D screen, desktop VR, still images, video, or text-only) were used as controls throughout.

3.2. Immersive System Characteristics

Fully immersive head-mounted setups are the most common configuration (140 studies; 71%) [16,45]; 36 studies (18%) used semi-immersive systems [13,46]; 13 explicitly manipulated immersion level as a factor [47]; and 8 used non-immersive controls.

Interactive systems, where participants could act on the environment, control the viewpoint, or manipulate objects, dominated with a total of 135 studies (68%) [36,48]. A further 25 studies used active-locomotion designs [49], 23 were purely passive viewing [50], and 15 explicitly crossed multiple interaction modes within the same study [51]. Because most systems let users move, manipulate, or choose, interactivity and embodiment are often ambient features even when not the focal manipulation, complicating attribution of an observed effect to any one primitive.

3.3. Design Primitives Used in Immersive Decision Studies

Studies were coded for the number of primitives manipulated. In total, 17 studies manipulated only one primitive [16,36,52] at a time, and the rest (181) used co-occurrence; 38 engaged five primitives, 34 engaged 4 primitives, 30 engaged two primitives, and 28 engaged 6 primitives (See Figure 2). Because studies frequently incorporated multiple immersive features simultaneously, primitive categories were not mutually exclusive. Consequently, frequency counts reported throughout this review reflect the number of studies in which a primitive or mechanism was present rather than exclusive assignment to a single category. However, the primitive families are presented as distinct categories, and substantial conceptual and operational overlap was observed across studies. For example, highly interactive systems frequently incorporated embodied interactions, while environmental structure and perceptual realism often jointly contributed to users' perception of the virtual environment. Consequently, the primitive families should be interpreted as organizational categories rather than independent dimensions of immersive experience.

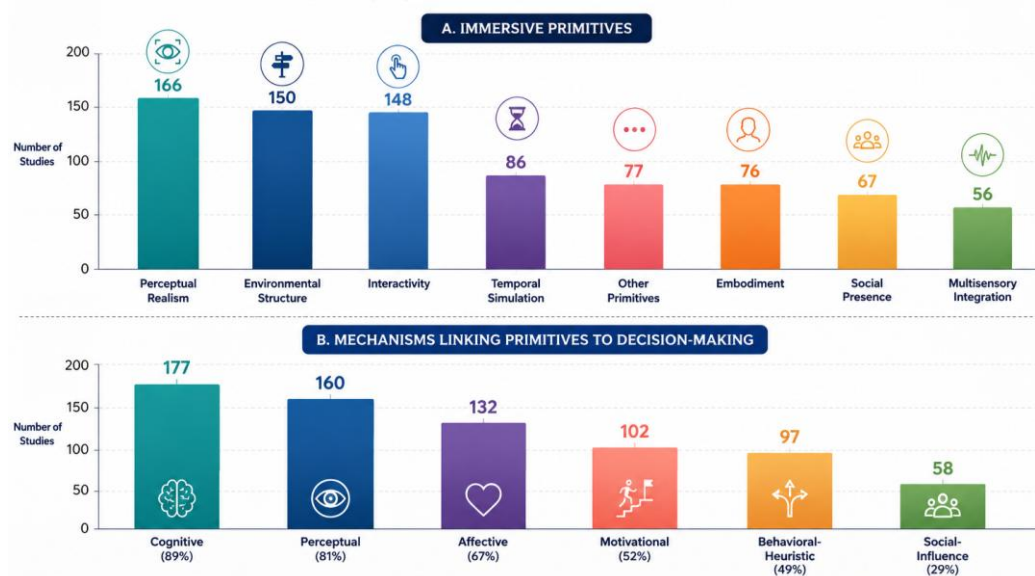


Figure 2. Primitives and mechanisms of impacting decision-making.

3.3.1. Embodiment

Embodiment, avatars, body ownership, and first-person perspective-taking were present in 76 studies. Generic self- or third-party avatars were the most common operationalization [21,53], typically presented from a first-person view via head-mounted display, and less often from a third-person observer perspective [54]. Twenty-eight studies induced body ownership via visuomotor synchrony, mirror reflections, or hand/limb tracking [33]; nine manipulated avatar gender via swaps or congruency [55]; six embodied virtual hands or arms [56]; and a small number used future self or aged-self avatars or racial-counterstereotype perspective-taking [57].

3.3.2. Interactivity

Interactivity, agency, control, and object manipulation were the second-most-common primitives (148 studies). Locomotion and route navigation (walking, joystick, walking-in-place) account for the largest cluster [52], followed by controller-based object manipulation (grab, rotate, tap) [58], user-controlled viewpoint or camera, voice or speech commands, and menu- or button-driven option selection. The primitives and their operationalizations are summarized in Table 1.

Table 1. Primitives, definitions, and operationalizations.

Primitive Family	Definition	Representative Operationalizations and Examples	Primary Mechanisms Activated	number
Embodiment	Manipulations that alter how users perceive or experience themselves within the virtual environment.	Avatars, body ownership, first-/third-person perspective, virtual hands/limbs, gender-swapped avatars, future self embodiment, aged-self embodiment.	Agency, body ownership, self-identification, empathy, perspective taking.	76
Interactivity	Manipulations that allow users to actively influence, navigate, or control elements of the virtual environment.	Navigation, locomotion, route selection, object manipulation, viewpoint control, voice commands, menu selection, user control.	Engagement, active exploration, deliberation, cognitive involvement, situational awareness.	148
Perceptual Realism	Manipulations that alter the sensory realism, fidelity, or plausibility of the virtual experience.	Visual fidelity, rendering quality, photorealism, audio fidelity, haptic feedback, stereoscopic depth, lighting variation, smoke/fire dynamics.	Presence, realism, risk perception, visual attention, emotional salience.	166
Social Presence	Manipulations involving virtual humans or social cues that create a sense of co-presence or social interaction.	Virtual humans, avatars, crowds, NPC density, peer behavior, partner behavior, facial-expression manipulation, voice assistants.	Conformity, trust, social influence, collaboration, social norms.	67
Temporal Simulation	Manipulations that alter how future, past, or evolving events are experienced.	Future self embodiment, time pressure, urgency, anticipated consequences, regret framing, dynamic hazards, repeated exposure.	Anticipation, future self-continuity, urgency, motivation, risk appraisal.	86
Environmental Structure	Manipulations of the spatial layout, geometry, and physical characteristics of the environment.	Layouts, signage, wayfinding markers, corridor geometry, exit placement, obstacle placement, road and crosswalk configurations, urban density.	Spatial cognition, mental mapping, situational awareness, navigation efficiency, cognitive load.	150
Multisensory Integration	Manipulations that engage multiple sensory channels simultaneously or congruently.	Visual–haptic combinations, visual–audio congruency, vestibular stimulation, olfactory cues, thermal cues.	Presence, attention, sensory integration, embodiment, physiological arousal.	56
Other Primitives	Manipulations that do not fit within the seven primary primitive families but influence decision-making.	Narrative framing, storytelling, economic constraints, temporal constraints, AR annotations, scale transformations, structured task constraints.	Framing effects, heuristics, motivation, anchoring, cognitive appraisal.	77

3.3.3. Perceptual Realism

Perceptual realism was the most common primitive (166 studies). Twenty-nine studies manipulated visual fidelity (rendering, texture, resolution, photorealism) [59], the largest single cluster contrasted lower-fidelity comparator media against the immersive ver-

sion: HMD versus desktop/monitor in 21 studies, VR versus 2D/non-stereo presentation in 20, VR versus text-only description in 24, VR versus 2D/360 video in 16, and VR versus still images/photographs in two, audio fidelity and ambient sound were manipulated in 14 studies, haptic fidelity (vibrotactile suits, gloves, force feedback) in nine, smoke and fire dynamics in 13 fire-safety studies, lighting, blur, brightness or color-temperature variation in 13 more, rendering style (realistic vs. stylized) in 19 [60], and stereoscopic vs. monoscopic depth in 13 [61].

3.3.4. Social Presence

Social presence was coded in 67 studies. Avatar-versus-agent framing and the presence of virtual humans accounted for the largest sub-cluster [62], facial-expression manipulation in eight studies, crowd and NPC density in 18, specific peer- or partner-behavior manipulation in 10, and voice-assistant avatars in two retail studies.

3.3.5. Temporal Simulation

Temporal simulation was coded in 86 studies, substantially more than the evidence base suggested by earlier reviews. Twenty-six studies manipulated time pressure or urgency, two used future self avatars or aged-self embodiment [44,57], nine framed anticipated consequences or regret, 19 used temporally dynamic hazards (evolving smoke, escalating threat, progressive flood), 14 used repeated exposure or test–retest paradigms, and seven measured intertemporal/delay discounting as a decision outcome.

3.3.6. Environmental Structure

Environmental structure was the most ubiquitous primitive across the corpus (150 studies). The 112-study layout-and-signage cluster is divided into four sub-themes: signage, arrows, and wayfinding markers; layout geometry and spatial configuration; density and obstacle placement; and lighting and natural elements within the layout [63,64]. Beyond layout/signage, environmental structure was further instantiated as exit, corridor, stair, or T-intersection geometry, road, street, lane, and crosswalk configurations, or greenery, built density, and urban-amenity composition. Smaller clusters used are isovist or space-syntax metrics, lighting, and color-temperature variation [65], and hazard/obstacle placement.

3.3.7. Multisensory Integration

Multisensory integration was present in 56 studies. Visual–haptic combinations are the largest sub-cluster [66], followed by visual–audio congruency manipulations, olfactory cues in two consumer studies, vestibular alterations under microgravity or balance manipulation in eight, and a thermal-channel manipulation in one.

3.3.8. Other Primitives

Seventy-seven studies coded as “other” primitive, distinct from the seven main families. Narrative framing and storytelling appeared in two [43]; economic and temporal constraints generated willingness-to-pay/time estimates in 17; and the remainder covered animation/motion cues, scale, and viewpoint-height transformations, AR annotation styles, and structured task constraints.

3.4. How Primitives Were Operationalized and Manipulated

3.4.1. Experimentally Manipulated Primitives

Almost without exception, primitives were manipulated experimentally rather than observed in a naturalistic manner. Studies used random assignment between conditions,

counterbalanced within-subjects designs, full or fractional factorials, and discrete-choice experiments embedded inside immersive environments; manipulation checks confirming that immersion, body ownership, interactivity, touch realism, or social presence differed across conditions were reported in most well-powered designs.

3.4.2. Observational or Embedded Primitives

Purely observational primitive coding was rare. Where a primitive was not the focal manipulation, it was typically embedded in the simulation as a constant or ambient feature. This applies to the embedded interactivity of locomotion in most pedestrian and evacuation studies, the embedded social presence of NPCs and crowds in evacuation studies, and the embedded environmental structure in nearly every wayfinding study.

3.4.3. Isolated vs. Bundled Primitive Manipulations

Bundling is the dominant pattern across the literature. A total of 182 of 198 studies incorporated multiple immersive design primitives simultaneously, whereas only 16 studies isolated a single primitive. This finding suggests that immersive experiences are typically constructed through combinations of interacting design features rather than through isolated manipulations. The frequent co-occurrence of primitives such as interactivity and embodiment, or environmental structure and perceptual realism, indicates that many immersive systems operate as integrated design ecosystems in which multiple primitives jointly contribute to user experience and decision-making outcomes.

3.4.4. Control/Comparator Conditions

The recurring comparator was a lower-fidelity version of the same content, 2D, desktop, screen, still-image, video, or text, used to benchmark the immersive condition. Other studies used within-condition baselines such as no-feedback, no-avatar, no-sound, no-eHMI, no-broadcast, or congruent-versus-incongruent control conditions.

3.5. Mechanisms Linking Primitives to Decision-Making

Six mechanism families were identified across the included studies: cognitive, perceptual, affective, motivational, social-influence, and behavioral-heuristic mechanisms. Cognitive and perceptual mechanisms were the most frequently reported, followed by affective and motivational mechanisms, whereas social-influence and behavioral-heuristic mechanisms were reported less frequently. The prevalence and characteristics of each mechanism family are summarized below.

3.5.1. Cognitive Mechanisms

Cognitive mechanisms were coded in 177 studies (89%), the most frequently invoked family. The construct mix is heterogeneous: cognitive load and mental effort, situational awareness, risk perception (perceived severity, susceptibility and danger), spatial cognition, mental maps, and sense of direction, attention, attentional allocation and distraction, flow, engagement and immersive engagement, uncertainty, doubt and confidence, explicit decision strategy/reasoning/deliberation, mental imagery, mental models and schemas, working memory and recall, and comprehension, ease of interpretation and understanding.

3.5.2. Affective Mechanisms

Affective mechanisms were coded in 132 studies (67%), often measured physiologically (GSR/EDR, heart rate, ECG, respiration) alongside self-report. Generic emotional state or affective response was the most common framing, fear and anxiety in 25 studies, arousal and physiological activation in 24, stress and pressure in 19, enjoyment, satisfac-

tion or hedonic affect in 16, decision comfort in 12, empathy in nine, anger or hostility in eight, awe and novelty in four, and attachment, intimacy or warmth toward virtual entities in four.

3.5.3. Perceptual Mechanisms

Perceptual mechanisms were coded in 160 studies (81%); presence is the single most common construct invoked as a link between a primitive and a decision. Presence, spatial presence and telepresence in 32 studies, immersion/focus of attention/flow in 16, perceived realism, vividness and plausibility in 15, body ownership, agency and embodiment in 14, spatial perception (depth, distance, scale, accessibility) in 17, visual attention via eye-tracking, fixations and gaze allocation in 11, situational awareness as a perceptual rather than cognitive construct in four, face recognition and identification in two, and cybersickness, simulator sickness or nausea (treated as a perceptual side-effect) in three.

3.5.4. Social-Influence Mechanisms

Social-influence mechanisms were coded in 58 studies (29%). Herding, conformity and following behavior in 15 studies, peer or neighbor effects in eight, compliance and obedience in seven, collaboration and group dynamics in seven, social presence and co-presence as a social construct in six, norms (descriptive, injunctive, authority/warden) in three, Proteus and avatar-identity effects in two, trust and credibility in two, advice-taking from AI/virtual experts in one, and counterstereotype perspective-taking as social influence in one.

3.5.5. Motivational Mechanisms

Motivational mechanisms were coded in 102 studies (52%). Generic motivation, urge or drive in 69 studies, intention as a motivational construct in 16, self-preservation and survival motivation (concentrated in safety/evacuation work) in 15, basic-need satisfaction (belonging, autonomy, control, self-esteem) in five, time pressure and urgency as a motivational driver in five, self-efficacy in two, technology acceptance and perceived usefulness in two, health behavior intention in two, user satisfaction in one, and assessment orientation/regulatory focus in one.

3.5.6. Behavioral-Heuristic Mechanisms

Behavioral-heuristic mechanisms were coded in 97 studies (49%), a much larger evidence base than in earlier-generation reviews. Herding and crowd-following heuristics in 11 studies, authority bias and automation bias in three, efficiency vs. harm-avoidance trade-off heuristics in three, anchoring on starting conditions or environmental cues in three, affect heuristics (mood-driven choice) in three, gap-acceptance and distance-based heuristics in pedestrian contexts in two, rule-following/compliance heuristics in two, status quo and inertia biases in two, the nearest-exit heuristic in one, stress-narrowed single-factor decision strategy in one, and optimism/normalcy biases in one.

3.5.7. Directly Measured vs. Inferred Mechanisms

The crucial evidentiary distinction concerns whether a proposed mechanism was formally evaluated as a mediator or moderator versus simply measured or inferred. Only 11 studies explicitly tested mediation effects using approaches such as PROCESS, structural equation modeling, or multilevel mediation analysis. Nine additional studies proposed mediators without formally estimating them, while three studies tested moderation effects. The remaining studies treated mechanisms as outcomes, predictors, correlates, or theoretical explanations. Therefore, much of the evidence summarized in this review reflects proposed explanatory processes rather than empirically verified causal pathways.

3.6. Decision-Making Outcomes Studied

Decision types are heterogeneous and frequently overlap within a single study (see Table 2). Preference and consumer choice were most common (46 studies); navigation/wayfinding (42), risk-taking (38) [36], economic and purchase decisions (34), social (22), moral (21), and perceptual judgment (20) followed; political (2) [67] and hiring (1) decisions were rare [48]. In healthcare, only three studies were for patient decision-making. Only two articles reported behavior-related decision-making (substance use behavior) [44,57], and no article reported treatment decision-making.

Continuous structures (Likert ratings, sliders, monetary allocations) appeared in 64 studies; binary choices in 54; multiple-option choices in 30; and explicit trade-off (conjoint) structures in 20; the remaining 58 studies did not explicitly report the types of decisions.

Behavioral outcomes, actual choices, exits, purchases, and response accuracy were measured in 65 studies, a notable methodological strength of this literature [68]; performance/accuracy in 31; intention in 22; self-reported preference in six; and physiological indices as decision-relevant outcomes in 10.

Table 2. Decisions made.

Cluster	Examples	Count
Navigation & Route Selection	Exit choice, evacuation routes, pedestrian crossing, maze navigation, airport navigation	42
Moral & Ethical Decisions	Trolley dilemmas, sacrifice decisions, triage, violence, helping behavior	20
Consumer & Economic Decisions	Purchases, willingness-to-pay, investments, product choice	34
Preference & Evaluation Decisions	Environmental preferences, attractiveness judgments, destination preferences	31
Clinical & Health Decisions	Diagnosis, surgery planning, treatment planning, health behaviors	12
Social & Interpersonal Decisions	Hiring, cooperation, trust, advice-taking, compliance	18
Planning & Design Decisions	Urban planning, infrastructure planning, spatial design	9
Operational & Performance Decisions	Military command, AI intervention, teleoperation, sports passing	7
Perceptual & Classification Decisions	Perpetrator identification, drone collision prediction, physics judgments	12
Behavioral Intention Decisions	Intention to visit, recommend, buy, adopt behaviors	10

3.7. Mechanistic Pathways Linking Immersive Primitives to Decision-Making Outcomes

This section treats the relationship between immersive primitives and mechanisms as a many-to-many evidence structure. Therefore, the results are not presented as a primitive-by-mechanism contingency matrix whose cells are expected to sum simultaneously to both primitive and mechanism margins. Instead, counts are reported as prevalence totals for each primitive and each mechanism family, followed by pathway-level synthesis using the extracted result statements from the final results column of the data extraction form. A summary of coded prevalence is provided. Across 198 included studies, perceptual realism, environmental structure, and interactivity were the most frequently coded primitives, while cognitive and perceptual mechanisms were the most frequently coded mechanism families. Across studies, evidence was generally stronger for recurring associations between immersive design primitives and proposed mechanism families than for any single pathway. The following sections, therefore, focus primarily on cross-study patterns, with representative examples provided to illustrate the most frequently reported relationships.

3.7.1. Cognitive Pathways

Cognitive mechanisms were coded in 177 studies, making them the most common family in the corpus. The extracted constructs included cognitive load, attention allocation, situational awareness, spatial cognition, risk perception, comprehension, mental models, confidence, recall, and explicit reasoning strategies. The strongest cognitive pathways were associated with perceptual realism, environmental structure, interactivity, and multisensory integration.

Perceptual realism -> cognitive load/attention -> decision accuracy

Changes in visual fidelity did not always improve decisions. In the Australian Rules Football simulation, the immersive 360VR condition did not significantly outperform 2D video, but visual blur significantly degraded decision accuracy from 85.33% with no blur to 73.75% with high blur ($p < 0.001$). This suggests that the cognitive pathway was not simply “more immersion produces better decisions”; rather, preserving task-relevant visual information mattered more than increasing display immersion.

Perceptual realism + multisensory integration -> situational awareness -> intervention timing

In the autonomous drone task, multimodal visual–haptic feedback yielded the highest detection accuracy and the shortest reaction delay. Median reaction delay improved from 1.61 s in the control condition to 1.12 s in the multimodal condition, with Control vs. Multimodal $p < 0.001$. Here, perceptual realism and multisensory integration appeared to support decision-making by reducing cognitive burden and improving alignment between the operator and the AI system.

Environmental structure + interactivity -> spatial cognition -> route and navigation performance

In AR navigation, interactive and spatially embedded guidance improved decision-making at complex points: response time was lower with AR than with map-based navigation (1.37 vs. 1.67 s, $p < 0.001$), and the proportion of correct responses was higher with AR (91.78% vs. 83.88%, $p = 0.003$). This pathway indicates that environmental overlays can improve decision performance by reducing the cognitive work required to translate map information into situated action.

Perceptual realism -> clinical comprehension -> diagnostic and planning decisions

In medical decision-making, immersive displays improved complex visual-spatial interpretation. For the congenital heart disease group discussions, full-immersive VR had the highest average diagnostic accuracy, and for complex cases, accuracy was 54.49% higher than conventional 2D and 146.82% higher than non-immersive VR. In spinal tumor planning, surgeons identified more anatomical structures and selected additional structures to traverse while using VR, resulting in more precise surgical approaches.

3.7.2. Perceptual Pathways

Perceptual mechanisms were coded in 160 studies. These mechanisms captured presence, spatial presence, realism, plausibility, body ownership, agency, depth and scale perception, visual attention, gaze allocation, and perceptual alignment. Perceptual pathways were especially common when the manipulation changed display fidelity, environmental realism, avatar embodiment, or sensory channels.

Perceptual realism -> presence/realism -> preference and environmental evaluation

Perceptual realism often increased presence and changed evaluative outcomes, but the effect depended on which sensory features were manipulated. In the virtual green-space study, sound had a significant main effect on preference ($F(1.583, 60.166) = 19.856$, $p < 0.001$, partial eta-squared = 0.343), with realistic sound preferred over ambient and no-sound conditions; display alone was not significant. This suggests that realism influenced decisions most strongly when it improved the ecological coherence of the scene.

Perceptual realism -> presence -> choice blindness and detection

The choice-blindness experiment showed a counterintuitive perceptual pathway. Low immersion produced more and earlier detections than high immersion: hard concurrent detection was 38% in low immersion versus 27% in high immersion, and hard plus weak detection was 43% versus 31%. The multilevel logistic model showed a significant main effect of immersion ($Z = 2.363$, $p = 0.018$). Thus, higher realism and social/environmental richness may have increased presence but also distracted attention from the manipulated choice object.

Embodiment → body ownership → risk perception and task execution

In VR teleoperation, human-like hands increased body ownership relative to robotic hands ($M = 4.95$ vs. 4.33 ; $F(1,73) = 19.61$, $p < 0.001$), and greater body ownership increased risk perception during teleoperation. However, this pathway “backfired” in execution: stronger ownership did not straightforwardly improve high-risk task performance, suggesting that embodiment may increase perceived self-involvement while also intensifying perceived risk.

Perceptual realism → spatial scale perception → flood interpretation and evacuation judgment

Immersive storm-surge flooding improved map damage ratings and real-world height estimation compared with desktop presentation. However, participants reported that they would evacuate at higher water levels, revealing a mixed perceptual pathway: VR improved spatial understanding of flood height and damage, but this did not automatically translate into more conservative evacuation thresholds.

3.7.3. Affective Pathways

Affective mechanisms were coded in 132 studies. They included fear, anxiety, stress, arousal, emotional response, empathy, enjoyment, satisfaction, decision comfort, anger, awe, and emotional attachment. Affective pathways were most visible when immersive systems exposed participants to threat, harm, realistic hazards, embodied others, or emotionally salient social agents.

Perceptual realism + temporal simulation → fear/anxiety → preparedness and risk-related action

In the virtual flood study, participants in VR invested significantly more in flood risk reduction than the online control group. Although investments decreased after four weeks, the decrease was not significant. The extracted results state that the effects were mediated through emotions and understanding of consequences, making this one of the clearest examples of an affective–cognitive pathway from immersive exposure to preparedness behavior.

Temporal simulation → climate risk perception/anxiety → environmental intention

Repeated exposure to immersive climate content increased both climate risk perception and climate anxiety. Risk perception was higher in the repeated-exposure group than the single-exposure group ($M = 4.53$ vs. 3.18 ; $t = -6.668$, $p < 0.001$), and climate anxiety also increased ($t = -8.358$, $p < 0.001$). PROCESS results showed exposure predicted risk perception ($\beta = 0.59$, $p < 0.001$) and anxiety ($\beta = 0.65$, $p < 0.001$), while message fatigue negatively moderated these effects.

Embodiment/social presence → emotional appraisal → trust and economic decisions

Avatar facial expressions influenced trust-game investments. Mean investment was $5.63/10$ for positive expressions, but only $4.35/10$ for negative expressions; the overall Friedman test was significant ($\chi^2(3) = 15.343$, $p < 0.002$), with negative expressions producing significantly lower investment than no-expression, neutral, and positive conditions. The affective manipulation, therefore, shaped economic and social decisions through emotional appraisal of the virtual agent.

Threat realism → arousal → moral choice

In the moral-plank study, threat exposure increased arousal physiologically and by self-report. Increased arousal reduced the extent to which participants felt their decision harmed others, which in turn led to more selfish decisions. This provides an effective mediation pathway in which immersive threat changed moral decision-making by changing how harm was emotionally appraised.

3.7.4. Motivational Pathways

Motivational mechanisms were coded in 102 studies. These mechanisms included motivation, intention, self-preservation, urgency, self-efficacy, perceived usefulness, health-behavior intention, technology acceptance, and future orientation. Motivational pathways were most prominent in studies that aimed to change behavior beyond the immediate task.

Embodiment + temporal simulation → future self-continuity → delayed reward and recovery behavior

The future self VR intervention in early substance-use-disorder recovery significantly increased future self-continuity and delayed reward preference, doubled delay tolerance, and reduced craving (all p s < 0.05). At 30 days, 18 participants remained abstinent; all participants with increased future self-similarity after VR remained abstinent, whereas relapsed participants showed reduced or no increase. This pathway directly links the embodiment of a future self to motivational changes in long-term decision-making.

Embodiment + agency/control → responsibility and self-relevance → safety intention

In the alcohol-impaired-driving study, participants who customized avatars perceived them as more similar, emotionally closer, and physically more attractive. After the drunk-driving crash scenario, participants in the choice-and-control condition were more likely to change behavioral intentions positively when they identified avatars as similar and attractive, and they attributed more crash responsibility to themselves than participants observing someone else's avatar.

Perceptual realism → health-risk self-relevance → protective intention

In the embodied adverse-health-outcome study, immersive embodiment was used to increase perceived risk and healthy-behavior motivation. The extracted synthesis identifies this as a health-promotion pathway in which self-relevant risk experience was used to shift risk perception and behavioral intention rather than merely inform participants about risk.

Interactivity → perceived control/flow → consumer behavioral intention

In VR product presentations, telepresence significantly increased enjoyment ($\beta = 0.499$, $p = 0.000$), curiosity ($\beta = 0.489$, $p = 0.000$), control ($\beta = 0.194$, $p = 0.000$), and focused attention ($\beta = 0.638$, $p = 0.000$). Behavioral intention was then predicted by enjoyment, curiosity, and focused attention, suggesting that motivational engagement translated immersive product experience into behavioral intention.

3.7.5. Social-Influence Pathways

Social-influence mechanisms were coded in 58 studies. These included herding, conformity, peer effects, compliance, obedience, collaboration, group dynamics, social presence, trust, advice-taking, and avatar-identity effects. These pathways were most common in social-presence manipulations involving virtual agents, crowds, peers, wardens, or AI advisors.

Social presence → crowd following → evacuation route choice

In the built-environment evacuation model, smoke strongly decreased the probability of choosing an exit ($B_{sm} = -1.765$, $p < 0.001$), while more NPCs at an exit increased its choice probability ($B_{np} = 0.076$, $p < 0.001$). This shows that environmental danger cues

and social-presence cues operated together: participants avoided smoky exits but were also pulled toward exits chosen by virtual others.

Social presence → neighbor influence → risky evacuation decision.

In the neighbor-influence evacuation experiment, neighbors' behavior significantly influenced route choice, while smoke density significantly reduced risky decisions. Increasing the number of neighbors from one to three did not significantly change the social-influence effect, and neighbor influence was strongest when it enticed participants toward a risky route.

Social presence + authority cues → compliance → exit choice

In the metro-station evacuation experiment, both fire-warden instructions and social influence significantly affected exit choice. The fire-warden effect changed depending on perceived authority level, with the study comparing metro-staff and firefighter authority across 1048 choices from 131 participants. This pathway shows that social influence was not limited to peer following; institutional authority also shaped decisions.

Embodied AI advisor → advice-taking → ethical healthcare decisions

In the ethical-healthcare AI-advice study, humans followed AI advice from virtual agents regardless of whether the agent was trustworthy or untrustworthy. This suggests that embodied AI advisors can exert social influence on ethical decision-making even when trustworthiness cues should normatively reduce compliance.

3.7.6. Behavioral-Heuristic Pathways

Behavioral-heuristic mechanisms were coded in 97 studies. These pathways captured decision shortcuts such as herding, rule following, authority bias, anchoring, affect heuristics, distance-based heuristics, status quo tendencies, normalcy bias, and learned prevalence expectations. Unlike cognitive pathways, which emphasize deliberation and comprehension, heuristic pathways describe how immersive cues bias rapid or simplified decision rules.

Social presence → herding heuristic → rule-breaking and evacuation behavior.

In the virtual-crowd rule-breaking study, rule-breaking increased as the proportion of violators increased from 0% to 25% to 50%, except in the low-stakes crossing scenario. Eye-tracking showed that rule breakers attended more to violating characters, while rule followers focused on compliant ones. This pathway indicates that virtual crowds can provide heuristic cues for whether rule violations appear acceptable.

Environmental structure + information cues → authority heuristic → evacuation behavior

In the emergency-broadcast study, most participants who received and understood broadcasts made wayfinding decisions based on the broadcast information, even when it conflicted with prior spatial knowledge. Participants rated broadcast information as more important than spatial memory and visual cues. Information overload reduced broadcast effectiveness, showing that the authority heuristic depended on usable information volume.

Repeated exposure → learned expectation heuristic → hazard search errors.

In virtual search-and-rescue, acquired hazard expectations overrode explicit instructions. When test prevalence was lower than training prevalence, participants produced more false positives and more hazard responses, while false negatives remained consistently low. This finding shows that immersive training can create persistent heuristic expectations that bias later hazard detection.

Priming cues → automatic response heuristic → navigation choice

In the mixed-reality subliminal priming study, prime-compatible responses were more frequent than non-primed responses (53.8% vs. 48.4%), and free-choice responses were approximately 7% more frequent than expected in the prime-compatible direction

(chi-square(1, $N = 1289$) = 6.119, $p < 0.05$). Visibility tests indicated that the primes were genuinely subliminal. This demonstrates that subtle environmental cues can bias rapid decisions even without conscious awareness.

Cross-pathway synthesis

The evidence suggests that immersive primitives affected decision-making primarily by changing how users perceived, interpreted, felt, and simplified decision environments (See Table 3). Perceptual realism and environmental structure most often shaped cognitive and perceptual pathways, especially in navigation, safety, clinical, and spatial tasks. Embodiment and social presence more often shaped affective, motivational, and social-influence pathways, particularly in moral, health-behavior, trust, and compliance decisions. Temporal simulation was most influential when the decision depended on urgency, evolving hazards, anticipated consequences, or future-oriented self-regulation. Multisensory integration was most useful when it improved alignment between environmental states and user perception, but it could also increase errors when feedback was aversive or distracting.

Table 3. Mechanistic pathway evidence map.

Mechanism Family	Primitive Pathway	Mechanism Construct	Observed Impact from Extracted Results	Example Paper
Cognitive	Perceptual realism	Task-relevant visual information/cognitive load	Blur reduced AFL decision accuracy from 85.33% to 73.75%; display modality itself was not significant.	[16]
Cognitive	Perceptual realism + multisensory integration	Situational awareness/AI alignment	Multimodal feedback produced highest accuracy and reduced median reaction delay from 1.61 s to 1.12 s.	[68]
Perceptual	Embodiment	Body ownership	Human-like hands increased body ownership and greater body ownership increased risk perception, but effects could backfire in high-risk teleoperation.	[69]
Affective	Temporal simulation + perceptual realism	Emotions and consequence understanding	VR flood exposure increased flood-risk-reduction investment; effects were mediated through emotions and understanding of consequences.	[70]
Motivational	Future self embodiment + temporal simulation	Future self-continuity	VR increased future self-continuity, delayed reward preference, delay tolerance, and reduced craving.	[57]
Social-influence	Social presence	Crowd following/authority	NPCs increased exit-choice probability; fire warden instructions and neighbor behavior also shaped evacuation decisions.	[71]
Behavioral-heuristic	Social presence/environmental cues	Herding and priming heuristics	Rule-breaking increased with proportion of violators; subliminal primes biased free choices by approximately 7% beyond expected levels.	[72]

4. Discussion

This review synthesized evidence from 198 studies examining how immersive design primitives influence decision-making through cognitive, perceptual, affective, motivational, social-influence, and behavioral-heuristic mechanisms. Several important findings emerge. First, immersive decision-making research is characterized by substantial mechanistic heterogeneity, with studies invoking a wide range of cognitive, emotional, perceptual, and social constructs to explain observed effects. Second, the literature is dominated by low- and moderate-consequence decision tasks, while relatively few studies examine decisions with significant real-world implications. Third, immersive technologies appear to influence decision-making not simply by providing additional information, but by changing how uncertainty, consequences, and alternatives are perceived and experienced.

Finally, the effects of immersive systems are rarely attributable to a single design primitive, as most studies manipulate multiple primitives simultaneously (see Figure 3).

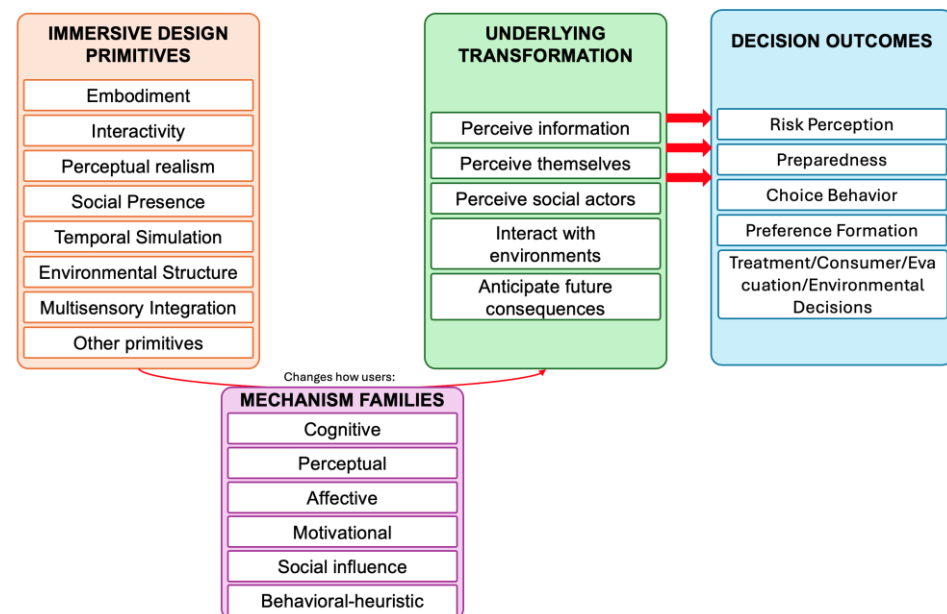


Figure 3. Conceptual framework of the study.

4.1. Immersive Decision-Making Research Remains Mechanistically Fragmented

The most striking finding of this review is the diversity of mechanisms proposed to explain immersive decision-making effects. Cognitive mechanisms were identified in 89% of studies, perceptual mechanisms in 81%, affective mechanisms in 67%, motivational mechanisms in 52%, behavioral-heuristic mechanisms in 49%, and social-influence mechanisms in 29%. However, within these broad categories, researchers employed dozens of distinct constructs, including cognitive load, situational awareness, risk perception, confidence, presence, realism, empathy, fear, conformity, trust, future self-continuity, and heuristic processing.

This finding aligns with prior immersive technology literature, which has repeatedly noted the absence of a unified explanatory framework linking immersive experiences to behavioral outcomes. Previous reviews have emphasized constructs such as presence, embodiment, and immersion as central explanatory mechanisms, yet often treat them as independent constructs rather than components of a broader decision-making process [73,74]. Our findings suggest that many of these constructs may represent overlapping pathways through which immersive systems shape information processing and behavior.

From an HCI perspective, this fragmentation presents both a challenge and an opportunity. The challenge is that it limits the accumulation of knowledge and makes it difficult to compare findings across studies. Two studies may report similar behavioral outcomes while invoking entirely different mechanisms. The opportunity, however, is the emergence of a richer understanding of immersive experiences as multifaceted interventions that simultaneously affect cognition, perception, emotion, and social processes. Future research should move beyond descriptive accounts of mechanisms and adopt more rigorous causal modeling approaches, including mediation and moderation analyses, to determine whether the proposed mechanisms identified throughout the literature genuinely explain observed decision-making effects. While many studies invoke constructs such as presence, embodiment, risk perception, empathy, or trust as explanatory mechanisms, relatively few formally test these relationships. Consequently, the present review should be interpreted as identifying recurring patterns of proposed explanatory processes

rather than establishing definitive causal pathways. Notably, only eleven studies in the corpus formally tested mediation pathways, highlighting a major methodological gap. This finding may be among the most significant methodological observations from the review. Although the immersive decision-making literature frequently invokes constructs such as presence, body ownership, realism, trust, empathy, situational awareness, and risk perception as mechanisms explaining observed outcomes, only 11 of 198 studies (5.6%) formally evaluated mediation effects. This suggests that much of the existing literature remains focused on identifying associations between immersive experiences and decision outcomes rather than empirically testing the causal processes through which these effects occur. As a result, many proposed mechanisms currently function more as explanatory narratives than as validated causal accounts. Researchers often discuss potential pathways after observing significant effects without prospectively designing studies to evaluate whether the proposed mechanism actually mediates the relationship between immersive design features and decision-making outcomes. This distinction is important because interventions can influence the same outcome through multiple competing processes, and conclusions regarding mechanisms cannot be established solely through post hoc interpretation. The field would benefit from a stronger emphasis on theory-driven mechanism testing. Future studies should explicitly formulate mechanistic hypotheses during study design, collect appropriate intermediate measures, and employ mediation, moderation, longitudinal, or experimental-causal approaches to evaluate proposed pathways. Advancing from descriptive mechanism claims to empirically validated causal explanations represents an important next step in the development of immersive decision-making research.

Practically, this finding suggests that designers of immersive decision-support systems should avoid focusing exclusively on technological characteristics such as display type or immersion level. Instead, designers should explicitly consider which psychological mechanisms they seek to influence and select immersive primitives accordingly. It is important to note that the term “mechanism” is used broadly throughout this review to refer to explanatory constructs reported by study authors. The purpose of the review was to identify and synthesize the range of mechanisms proposed within the literature rather than to establish which mechanisms have been conclusively validated through formal causal modeling. Consequently, the identified mechanism families should be interpreted as recurring explanatory frameworks used within immersive decision-making research.

4.2. Immersive Technologies Primarily Reshape How Uncertainty Is Experienced

A second major finding is that immersive technologies rarely improve decision-making by simply providing more information. Instead, immersive primitives appeared to influence how uncertainty, consequences, risks, and alternatives were perceived and interpreted. Perceptual realism frequently altered risk perception, confidence, realism, and perceived severity. Environmental structure influenced spatial cognition and situational awareness. Embodiment increased self-relevance, empathy, and ownership. Temporal simulation changed anticipation and future-oriented reasoning. Social presence influenced conformity, trust, and compliance. Collectively, these findings suggest that immersive systems function less as information-delivery technologies and more as uncertainty-shaping technologies.

This observation extends prior work in HCI and decision-support systems. Traditional decision-support tools seek to improve decisions through better information presentation, visualization, and analytics. In contrast, immersive technologies appear capable of transforming abstract information into experiential representations [75]. Rather than merely informing users about a flood, a medical condition, or a future consequence, immersive systems allow users to experience those possibilities directly. This distinction

may explain why several studies reported improved risk perception, preparedness, or future-oriented behavior despite presenting information that was already available through conventional media [70].

Importantly, the review also demonstrates that increased realism does not necessarily improve decision quality. Several studies found that highly realistic environments increased distraction, emotional arousal, or perceived risk without producing objectively better decisions. This finding is consistent with cognitive load theory and previous research suggesting that realism and fidelity do not always translate into improved performance [76]. The evidence synthesized in this review suggests that the relationship between realism and decision-making outcomes depends on alignment with task requirements.

For practitioners, this suggests that immersive decision-support systems should be designed to facilitate understanding of uncertainty rather than simply maximize immersion. In high-stakes domains such as healthcare, emergency management, and public policy, the goal should be to help users understand uncertainty and consequences rather than to create the most realistic possible experience.

4.3. The Evidence Base Is Dominated by Low- and Moderate-Consequence Decisions

Despite increasing interest in immersive technologies as tools to support complex decision-making, most studies have examined relatively constrained decision tasks. Navigation and route selection, consumer choices, environmental preferences, evacuation decisions, social dilemmas, and economic games accounted for much of the evidence base. In contrast, relatively few studies investigated decisions with substantial real-world consequences, such as clinical diagnosis, treatment planning, surgical decision-making, public policy decisions, or long-term health behavior change.

This finding mirrors broader trends in immersive technology research, where experimental control often comes at the expense of ecological validity. Consumer, navigation, and laboratory-based moral decision tasks are easier to operationalize, manipulate, and measure than decisions involving uncertainty, competing objectives, long-term consequences, or organizational constraints [77]. However, these simplified tasks may not accurately reflect how immersive technologies function in real-world decision environments.

The limited representation of healthcare decision-making is particularly noteworthy. Although immersive technologies are frequently promoted as tools for patient education, clinical training, and treatment planning, only a small number of studies examined actual patient or provider decisions [8]. Similarly, few studies investigated long-term behavioral outcomes beyond immediate task performance.

This gap has important implications for future HCI research. As immersive technologies mature, there is a need to evaluate their role in supporting consequential decisions where uncertainty, ambiguity, and competing stakeholder interests are central. Such work will be critical for understanding whether the mechanisms identified in laboratory studies generalize to real-world settings.

An important consideration when interpreting the findings of this review is the substantial diversity of decision contexts represented across the literature. Although recurring immersive design primitives and mechanism families were observed across domains, the nature of the decisions being studied varied considerably. Consumer-choice, tourism, and environmental-preference decisions generally involve relatively low personal risk and limited consequences, whereas healthcare, emergency evacuation, military operations, and transportation decisions often involve substantial uncertainty, time pressure, safety implications, and potentially irreversible outcomes.

These differences have important implications for interpretation. Mechanisms such as presence, realism, engagement, embodiment, or social influence may operate differently depending on the stakes of the decision and the consequences of errors. For example, increased realism may improve understanding and preparedness in emergency-management contexts while simultaneously introducing distraction or emotional overload in other settings. Similarly, social-presence manipulations that successfully influence consumer preferences may not produce equivalent effects in clinical, operational, or public-safety decision environments.

The evidence synthesized in this review, therefore, should not be interpreted as demonstrating universally transferable effects of immersive design primitives. Rather, the findings identify recurring patterns of association that appear across multiple domains while highlighting the need for domain-specific validation. Future research should explicitly examine whether mechanisms observed in low-consequence laboratory tasks generalize to high-consequence real-world decision environments where accountability, expertise, uncertainty, and long-term consequences are more pronounced.

4.4. Primitive Interactions May Matter More than Individual Primitives

Another important finding concerns how immersive experiences are constructed. Although studies often focused on a specific primitive, such as embodiment or realism, most immersive environments simultaneously incorporated multiple primitives. Only a small minority of studies isolated a single primitive, while the vast majority manipulated several primitives concurrently.

This finding suggests that immersive experiences should be understood as integrated systems rather than collections of independent features. Users do not experience realism, embodiment, interactivity, or social presence in isolation; instead, these characteristics jointly shape how information is processed and acted upon [78]. Consequently, many reported effects may emerge from interactions among primitives rather than from any individual design element.

This observation aligns with recent calls within HCI to move beyond technology-centric evaluations and toward systems-level models of immersive interaction. Rather than asking whether realism improves decision-making or whether embodiment increases empathy, future research should investigate how combinations of primitives jointly influence cognitive, affective, and social mechanisms.

From a practical perspective, this finding highlights the importance of holistic design. Designers should consider how primitives reinforce or interfere with one another. For example, increasing realism may enhance presence but simultaneously increase distraction. Similarly, embodiment may increase empathy while also increasing perceived risk or emotional burden. Understanding these interactions will be essential for designing effective immersive decision-support systems.

Importantly, the primitive families proposed in this review should not be interpreted as fully independent theoretical constructs. The high prevalence of bundled manipulations suggests that immersive experiences are inherently multidimensional. Consequently, the taxonomy is best understood as an organizational framework for describing recurring design features rather than a definitive model of orthogonal immersive components. Future research should investigate whether specific combinations of primitives consistently emerge across domains and whether particular configurations yield distinct decision-making effects.

4.5. Toward a Human-Centered Science of Immersive Decision-Making

Taken together, the findings suggest that immersive technologies should not be viewed solely as visualization tools or communication media. Rather, they represent a

distinct class of human-centered decision technologies capable of altering how users perceive uncertainty, consequences, risks, social influences, and future outcomes.

The review supports a conceptual shift from studying immersive technologies as hardware platforms to studying immersive primitives as design interventions. By focusing on the mechanisms by which these primitives influence cognition, perception, emotion, and behavior, researchers can move beyond simple comparisons between VR and non-VR systems and begin to develop predictive theories of immersive decision-making [79].

Ultimately, the most important contribution of immersive technologies may not be their ability to present information differently, but their ability to change how information is mentally represented. Understanding these representational transformations will be essential for developing the next generation of immersive decision-support systems and for establishing a more rigorous science of immersive decision-making. The maturation of immersive decision-making research will depend not only on demonstrating whether immersive technologies influence decisions, but also on rigorously establishing the causal processes through which these effects emerge.

The frequency distributions reported throughout this review should be interpreted as descriptive characteristics of the identified evidence base rather than normative benchmarks. For example, the high prevalence of cognitive and perceptual mechanisms reflects the dominant research interests in immersive decision-making studies but does not imply that these mechanisms are inherently more important than less-studied constructs. Similarly, the predominance of VR reflects the current composition of the literature and the historical development of immersive technologies rather than a comparative evaluation of alternative platforms.

4.6. Limitations

This study has some limitations that should be noted. First, the literature has substantial heterogeneity in immersive technologies, design primitives, decision tasks, outcome measures, and reported mechanisms. This variability limited direct comparisons across studies and precluded quantitative synthesis. While the taxonomy developed in this review provides a structured framework for organizing the evidence, differences in terminology and operationalization remain a challenge for cumulative knowledge building.

5. Conclusions

Our results suggest that immersive technologies may function as decision-shaping systems that alter how users perceive uncertainty, risks, consequences, and alternatives. However, the mechanisms identified throughout the literature should be interpreted as recurring patterns of evidence and proposed explanatory processes rather than universally established causal pathways. Additional theory-driven studies employing formal mediation and moderation analyses are needed to validate these proposed mechanisms and strengthen causal understanding of immersive decision-making. Importantly, the transferability of these findings across domains remains uncertain, as decision contexts differ substantially in their stakes, complexity, and validity requirements. Future research should evaluate immersive decision-support systems within domain-specific contexts before generalizing proposed mechanisms across application areas.

Author Contributions: Conceptualization, S.E.; methodology, S.E.; validation, S.E.; formal analysis, S.E., S.B., A.T. and D.H.; data curation, S.E.; writing—original draft preparation, S.E.; writing—review and editing, S.E.; visualization, S.E.; supervision, S.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: This study is based exclusively on published literature and did not involve the collection of original participant-level data. A study-level extraction and coding dataset was generated during the review process and used to support the analyses presented in this manuscript. Due to its size, the dataset is not included in the manuscript but is available from the corresponding author upon reasonable request.

Conflicts of Interest: Authors Achraf Tounsi is employed in ROADIE, Atlanta, GA 30305, USA. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A. Keywords Used in the Search and Search Strings

Table A1. Keywords Used in the Search and Search Strings.

Keyword Group	Keywords Used
Immersive Environments	"virtual reality" OR VR OR "augmented reality" OR "mixed reality" OR immersive OR "virtual environment" OR "3D environment" OR "computer-generated environment"
Primitives' taxonomy	embodiment OR "body ownership" OR avatar OR "self-presence" OR "first-person" OR "third-person" OR perspective OR POV OR interactiv OR agency OR control OR navigation OR realism OR fidelity OR immersion OR "temporal simulation" OR "future self" OR "future projection" OR emotion OR empathy OR affect OR "context" OR scenario OR framing OR "social presence" OR "virtual agent" OR "risk visualization" OR "uncertainty visualization" OR primitive
Decision-making	Decision OR "decision making" OR "choice behavior" OR choice OR "decision task" OR "decision under uncertainty" OR uncertainty OR "risk perception" OR "risk taking" OR preference OR "preference formation" OR tradeoff OR "value-based decision" OR "decision confidence" OR "decisional conflict" OR "choice accuracy"

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OR "3D environment"[Title/Abstract]
OR "computer-generated environment"[Title/Abstract])
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OR perspective[Title/Abstract]
OR POV[Title/Abstract]
OR interactiv*[Title/Abstract]
OR agency[Title/Abstract])

OR control[Title/Abstract]
 OR navigation[Title/Abstract]
 OR realism[Title/Abstract]
 OR fidelity[Title/Abstract]
 OR immersion[Title/Abstract]
 OR “temporal simulation”[Title/Abstract]
 OR “future self”[Title/Abstract]
 OR “future projection”[Title/Abstract]
 OR emotion*[Title/Abstract]
 OR empath*[Title/Abstract]
 OR affect*[Title/Abstract]
 OR context[Title/Abstract]
 OR scenario*[Title/Abstract]
 OR framing[Title/Abstract]
 OR “social presence”[Title/Abstract]
 OR “virtual agent”[Title/Abstract]
 OR “risk visualization”[Title/Abstract]
 OR “uncertainty visualization”[Title/Abstract]
 OR primitive*[Title/Abstract])
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 OR uncertainty[Title/Abstract]
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 OR “risk taking”[Title/Abstract]
 OR preference*[Title/Abstract]
 OR “preference formation”[Title/Abstract]
 OR tradeoff*[Title/Abstract]
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 OR “decision confidence”[Title/Abstract]
 OR “decisional conflict”[Title/Abstract]
 OR “choice accuracy”[Title/Abstract]))

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 OR VR
 OR “augmented reality”
 OR “mixed reality”
 OR immersive
 OR “virtual environment”
 OR “3D environment”
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OR "body ownership"
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 AND
 (decision*
 OR "decision making"
 OR "choice behavior"
 OR choice
 OR "decision task"
 OR "decision under uncertainty"
 OR uncertainty
 OR "risk perception"
 OR "risk taking"
 OR preference*
 OR "preference formation"
 OR tradeoff*
 OR "value-based decision"
 OR "decision confidence"
 OR "decisional conflict"
 OR "choice accuracy"))
 IEEE XPLORE
 (
 (
 "virtual reality"
 OR VR
 OR "augmented reality"

OR "mixed reality"
OR immersive
OR "virtual environment"
OR "3D environment"
OR "computer-generated environment"
)
AND
(
embodiment
OR "body ownership"
OR avatar*
OR "self-presence"
OR "first-person"
OR "third-person"
OR perspective
OR POV
OR interactiv*
OR agency
OR control
OR navigation
OR realism
OR fidelity
OR immersion
OR "temporal simulation"
OR "future self"
OR "future projection"
OR emotion*
OR empath*
OR affect*
OR context
OR scenario*
OR framing
OR "social presence"
OR "virtual agent"
OR "risk visualization"
OR "uncertainty visualization"
OR primitive*
)
AND
(
decision*
OR "decision making"
OR "choice behavior"
OR choice
OR "decision task"
OR "decision under uncertainty"
OR uncertainty
OR "risk perception"
OR "risk taking"
OR preference*
OR "preference formation"

OR tradeoff*
OR "value-based decision"
OR "decision confidence"
OR "decisional conflict"
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ABSTRACT(
(
"virtual reality"
OR VR
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AND
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 OR “risk taking”
 OR preference*
 OR “preference formation”
 OR tradeoff*
 OR “value-based decision”
 OR “decision confidence”
 OR “decisional conflict”
 OR “choice accuracy”
)))

Appendix B. Data Extraction Form

Table A2. Data Extraction form.

General	Title
	Year
	Journal
	Study design
	Field/domain (healthcare, retail, etc)
Immersive system	Technology type (ar, vr, etc)
	immersion level (Fully, semi, etc)
	interaction type (passive, active, interactive)
	Tool brief description
Design primitives	Embodiment primitives? (yes/no)
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	Interactivity primitives? (yes/no)
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	Perceptual realism?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	Social presence?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	temporal simulation?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	environmental structure?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)

	Describe
	Multisensory integration?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	Other?
	How was it operationalized
	How was it manipulated? (experimental via control, observational, etc)
	Describe
	Cognitive?
	What was it?
	How was it measured?
	What's its role?
	Describe
	Affective?
	What was it?
	How was it measured?
	What's its role?
	Describe
	Perceptual?
	What was it?
	How was it measured?
	What's its role?
	Describe
Mechanism	Social Influence?
	What was it?
	How was it measured?
	What's its role?
	Describe
	Motivational?
	What was it?
	How was it measured?
	What's its role?
	Describe
	Behavioral heuristics?
	What was it?
	How was it measured?
	What's its role?
	Describe
	Decision to be made (describe)
Decision-Making Outcomes	Decision type (risk-taking, preference, moral decision, economic decision (purchase) social decision (trust))
	Decision structure (binary, multiple options, trade-off, continuous)
	Outcome measurement (behavioral as in actual choice made, intention, self-reported preference, performance or accuracy, etc)
	Impact of primitive manipulation on decision-making outcomes (results with findings, exact numbers and all)
Results	

Appendix C. PRISMA Flowchart

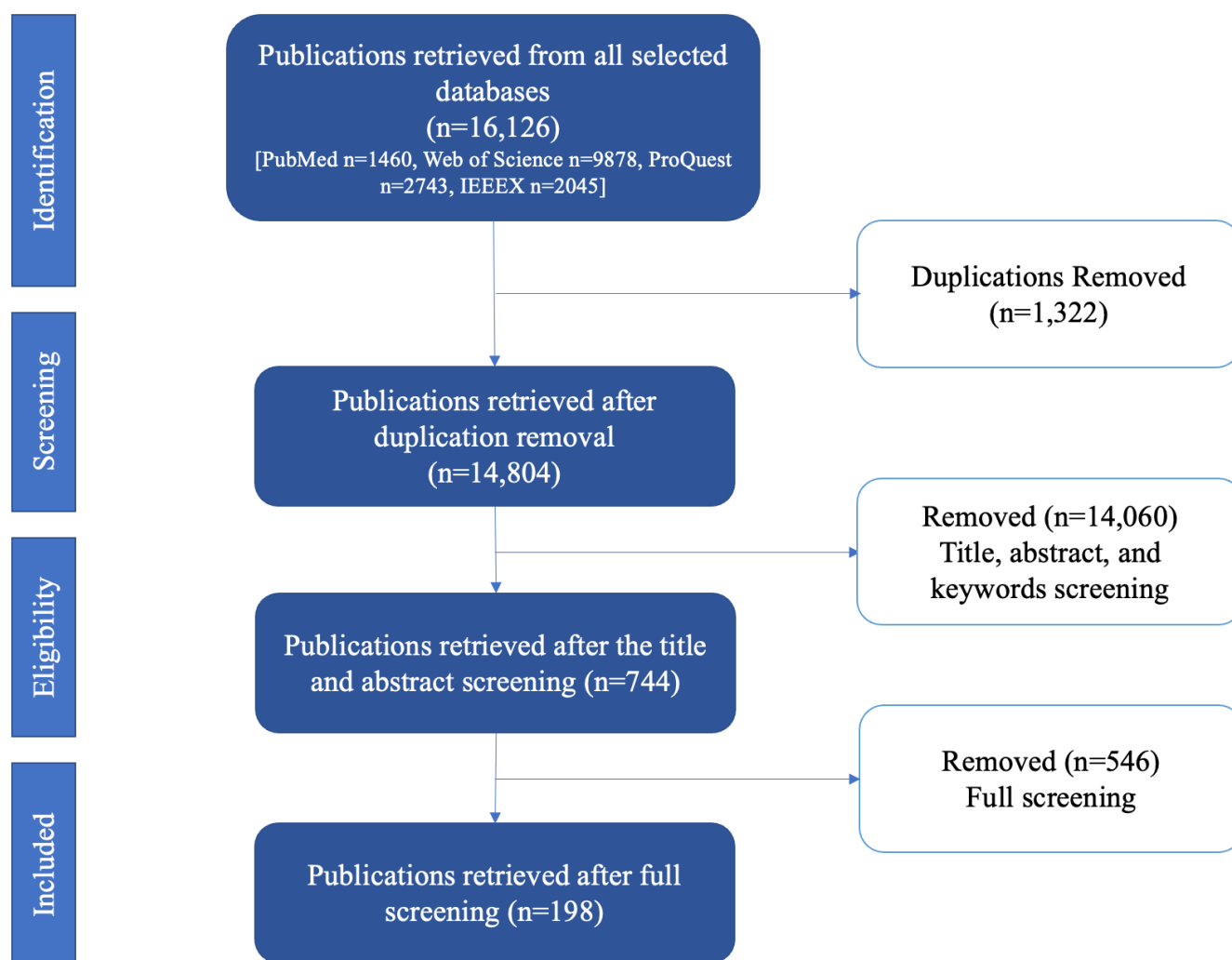


Figure A1. The database search identified 16,126 records. After removal of 1322 duplicate records, 14,804 publications remained for title and abstract screening. A total of 14,060 records were excluded during this stage, leaving 744 articles for full-text review. Following full-text assessment, 546 articles were excluded based on the predefined eligibility criteria. The final review included 198 studies.

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