

Evidence-Based Strategic Planning for XR: Development and Construction of the MCDA-XR Governance Framework

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Evidence-Based Strategic Planning for XR: Development and Construction of the MCDA-XR Governance Framework

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Abstract

Background: Health services increasingly face decisions about how to integrate immersive technologies into routine practice. International guidance highlights the need for structured governance in digital health, yet extended reality (XR) initiatives are often launched through isolated pilots without a clear assessment of organisational readiness or implementation risk. Although factors influencing XR adoption are well documented, healthcare organisations and system-level decision makers still lack practical, governance-oriented tools to translate these determinants into structured strategic decisions made before implementation.

Objective: To develop MCDA-XR, a strategic governance framework that translates behavioural, organisational, and technical implementation determinants into a structured decision-support process for healthcare organisations.

Methods: The study followed a sequential mixed-methods design covering the first two phases of a three-stage framework development and validation project. Phase 1 (Identification) defined strategic criteria by integrating theoretical perspectives on organisational complexity, behaviour change, technology acceptance, and immersive safety, together with a targeted review of XR implementation evidence. Phase 2 (Construction) refined the framework through participatory sessions. A multidisciplinary group of 33 stakeholders, including professionals and managers from hospital and primary care settings and postgraduate students, evaluated the proposed criteria for strategic relevance and operational clarity. This process resulted in a final ten-criterion structure and the establishment of a dual-score assessment logic. Phase 3 (Validation), planned as a subsequent step, will examine the predictive value of the framework in longitudinal clinical settings.

Results: The development process yielded a framework comprising ten operational criteria grouped into three conceptual domains (Human, Organisational, and Technical). Stakeholder ratings indicated high strategic relevance across all criteria (mean scores above 4.0 on a 5-point scale), with Safety and Comfort receiving the highest prioritisation (mean 4.6). The final instrument applies a dual-assessment approach in which each criterion is rated separately for Strategic Importance and Organisational Readiness. Mapping these dimensions enables organisations to identify priority gaps, particularly areas of high importance and low readiness, and to distinguish between manageable constraints and critical barriers requiring targeted preparatory action prior to implementation.

Conclusions: MCDA-XR addresses a key governance gap in XR implementation by providing a structured way to align adoption decisions with institutional priorities and operational constraints. Rather than relying on descriptive feasibility assessments, the framework supports explicit prioritisation and action-oriented decision making at the organisational level. MCDA-XR is positioned for Phase 3 evaluation, which will examine whether its readiness profiles anticipate implementation challenges and early sustainability outcomes in real-world clinical deployments.

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Original Manuscript

TITLE

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Keywords: Extended Reality; Digital Health Governance; Implementation Science; Multicriteria Decision Analysis; Organisational Readiness; Strategic Planning; Decision Support Systems; Health Services Administration

Introduction

Health systems are increasingly aware that emerging technologies cannot be integrated through intuition or isolated initiatives. International guidance has moved in the same direction. World Health Organization (WHO) 2019 Guidelines on Digital Interventions [1] stress that digital tools should only be introduced following structured assessment and a clear understanding of the health needs they aim to address. The Global Strategy on Digital Health 2020–2025 [2] reinforces this idea by calling for national planning processes that align digital priorities with institutional capacity and continuous evaluation. Recent European policy work on virtual worlds and health further emphasises that adoption is shaped by organisational readiness, governance arrangements, and structural barriers that extend beyond technical performance [3]. Together, these documents point to a straightforward conclusion. Sustainable digital health requires methods that help organisations define priorities, assess feasibility and prepare for implementation before technologies are deployed.

Immersive technologies complicate this picture. Extended reality (XR), which includes virtual reality (VR), augmented reality (AR) and mixed reality (MR), introduces sensory and spatial characteristics that differ from conventional digital tools, including immersive perceptual environments and embodied interaction mechanisms [4,5]. Evidence from experimental and clinical VR research shows that mechanisms such as presence and embodiment can shape attention, emotional responses and body perception in ways linked to therapeutic effect [6,7]. Variables including presence, body ownership and immersion are therefore not peripheral features of the user experience, they are part of the mechanism through which many XR interventions act. Immersive systems also alter cognitive and sensory demands. Spatial processing requirements and interface complexity can influence task performance and learning, as described in the Cognitive-Affective Model of Immersive Learning [8], while sensory conflict between visual and vestibular input can lead to cybersickness and discomfort, affecting tolerability [9]. These perceptual and cognitive characteristics fall outside the assumptions that underpin most digital health evaluation models.

Although research across clinical and educational fields reports benefits in pain and anxiety management, rehabilitation and mental-health care [4,10,11], evidence alone has not guaranteed systematic integration into healthcare services. Reviews show that routine uptake remains uncommon despite promising results [12]. These findings indicate that immersive technologies hold meaningful clinical and pedagogical value, yet translation into routine practice is constrained by organisational, professional, and governance factors that are not addressed by efficacy evidence alone. This perspective aligns with recent digital health policy work highlighting the need for governance approaches that help organisations relate implementation evidence to strategic prioritisation and readiness decisions, particularly when choices must be made about which innovations to support and when [2,3].

Within this context, the present article introduces MCDA-XR, a multicriteria decision-support framework designed to help healthcare organisations evaluate, prioritise and plan XR initiatives as part of their broader digital-health strategy, translating dispersed implementation evidence into a structured operational process for strategic decision making.

Evaluation of XR implementation: evidence, attempts, gaps

Real-world implementation evidence: a fragmented landscape

When immersive systems leave controlled settings and enter clinical practice, the frictions become visible. Spatial layout, device handling, hygiene routines and tracking stability repeatedly appear as

determinants that shape feasibility during deployment [12,13,14]. Recent reports from hospital-based XR programs add further texture, noting the need for clear protocols on headset management, staffing, patient selection and environmental safety [15]. Rehabilitation, primary care and mental health studies echo this pattern. Many show therapeutic potential, yet routine adoption remains uncommon [12,14,16]. Organisational constraints, workflow misalignment, limited training and inconsistent technical support continue to slow implementation. Work in chronic pain paints a similar picture [17].

Across settings, the pattern is similar. Many implementation problems only become visible once XR is used in routine care, which leaves teams reacting to issues that could have been anticipated earlier. This gap makes it harder to evaluate feasibility, coordinate staff and equipment or clarify how XR fits within existing care pathways. A more structured way of assessing readiness may help shift this work to the planning stage, when organisations still have room to adjust. To substantiate this landscape, Multimedia Appendix 1 provides a detailed comparative overview of the methodological, behavioural and organisational determinants reported across the primary studies reviewed.

Determinant-mapping attempts: what reviews have identified

Attempts to explain how XR becomes embedded in clinical and educational settings have expanded quickly. Kouijzer et al. (2023) [12] offer one of the most extensive syntheses and show how similar determinants recur across contexts, including clinician capability, workflow fit, organisational backing and patient acceptability. They also note substantial variation in methodological quality, which complicates comparison.

In chronic pain, Elser et al. (2024) [17] used the Theoretical Domains Framework to highlight the weight of beliefs about consequences, emotional responses and self-efficacy, yet their findings also imply that behavioural determinants alone cannot explain organisational pressures or service-level constraints. Work in education reaches similar conclusions. Lie et al. (2023) [14] describe how training structures, institutional support and professional identity shape the use of immersive tools.

Taken together, these reviews show that most relevant determinants have been identified, although they remain scattered across studies and not yet arranged into a structure that helps with planning or priority-setting.

Digital-health implementation frameworks: useful but partial

In digital health, evaluation typically relies on established implementation-science models. These frameworks illustrate how individuals, organisations and technologies interact, building on behavioural determinants described by Michie et al. (2011) [18], the organisational complexity mapped by Greenhalgh et al. (2017) [19] and the processes synthesised in Consolidated Framework for Implementation Research (CFIR) [20]. Broader overviews classify these models into determinant frameworks, process models and theories, each covering a different part of the implementation landscape [21]. More recent work stresses the importance of understanding mechanisms of action, noting that evaluation depends on clarifying how behavioural, organisational and contextual influences shape implementation outcomes [22].

These perspectives are valuable, although none was designed to address the experiential or embodied features of immersive systems. While specific guidelines such as RATE-XR [23] contribute essential descriptors for safety and reporting quality, they focus on technical transparency rather than organisational strategy. To place XR within this broader space, Table 1 summarises the implementation and behavioural frameworks most relevant to the field, detailing both their

limitations in immersive contexts and their specific conceptual contribution to the MCDA-XR framework.

Table 1. Analytical comparison of the implementation and behavioural frameworks used to derive the MCDA-XR framework. It assesses widely used digital health and behaviour change models against the practical requirements of extended reality (XR) adoption in clinical settings. For each framework, the table summarises its core purpose and main strengths, then flags the limitations that become visible when the technology is immersive, for example, missing XR-specific descriptors for safety, tolerability, presence, or embodiment, or a level of conceptual complexity that can hinder routine use. These gaps help explain why a single-model approach was unlikely to be sufficient. The final column maps each framework's concrete contribution to MCDA-XR, clarifying whether it informs the structural, behavioural, or technical components of the final architecture.

Framework	Core Purpose	Strengths for XR Adoption Evaluation	Limitations in Real-World XR Contexts	Relevance to MCDA-XR
CFIR (Consolidated Framework for Implementation Research) [20]	Explains complexity and adoption patterns across seven domains.	Strong systemic and organisational perspective; identifies "wicked" complexity in digital health.	Broad and descriptive; limited granularity for individual behavioural mechanisms.	Structural Backbone: Serves as the primary organisational and systemic anchor for the 10 criteria.
NASSS (Non-Adoption, Abandonment, Scale-up, Spread, Sustainability) [19,24]	Models behaviour through capability, opportunity, and motivation.	Parsimonious and easy to operationalise; integrates individual and environmental factors.	Lacks specific descriptors for sensory-motor interaction or institutional governance.	Behavioural Foundation: Provides the logic for assessing clinician and patient capability and motivation.
TAM (Technology Acceptance Model) [25]	Predicts technology acceptance through usefulness and ease of use.	Validated and efficient for capturing initial user perceptions of digital tools.	Narrow cognitive focus; does not address organisational complexity or clinical safety.	Perceptual Core: Feeds into criteria regarding perceived value and ease of use.
UTAUT / UTAUT2 (Unified Theory of Acceptance and Use of Technology) [26,27]	Reporting guideline for early-phase XR clinical research.	Provides XR-specific descriptors for safety, tolerability (cybersickness), and technical fidelity.	A reporting guideline rather than an implementation framework; does not address organisational strategy.	Technical Layer: Ensures safety, ergonomic, and reporting standards are embedded in the criteria.
TDF (Theoretical Domains Framework) [28]	Diagnostic meta-framework for implementation contexts.	Comprehensive mapping of inner/outer settings and implementation processes.	High conceptual complexity (39+ constructs); difficult to translate into concise stakeholder scoring.	Secondary Insight: Informs the definitions of "Workflow" and "Resources," though not used as a primary structure.

COM-B (Capability, Opportunity, Motivation for Behaviour) [18]	Predicts behavioural intention.	Captures social influence and hedonic motivation (relevant for patient engagement).	Relies on multi-item psychometric scales; high overlap with TAM and COM-B constructs.	Represented: Perceptual determinants are captured via the simpler TAM/COM-B structures.
BCW (Behaviour Change Wheel) [18]	Synthesises behavioural determinants across 14 domains.	Enables highly granular behavioural diagnosis.	Too granular for a strategic tool; over 80 constructs make it unsuitable for rapid scoring.	Background Theory: Informs behavioural definitions but bypassed for the more parsimonious COM-B.
DOI (Diffusion of Innovations) [19]	Describes how innovations spread through social systems.	Useful for interpreting macro-level spread and scale-up pathways.	Low clinical and technical specificity; insufficient for micro-level determinant mapping.	Scale-up Context: Concepts of "relative advantage" inform the Value Proposition area of NASSS.
LHS (Learning Health Systems) [29]	Promotes data-driven learning cycles in healthcare.	Supports the need for continuous evaluation and sustainability.	High-level organisational philosophy; lacks explicit evaluative constructs.	Cycle Logic: Justifies the iterative application of MCDA-XR across different project stages.
RATE-XR Reporting guideline for early-phase XR clinical research [23]	Focused on safety, technical fidelity and methodological transparency.	Offers XR-specific descriptors for safety, cybersickness, tolerability, sensory exposure and technical detail.	Not an implementation framework, does not address organisational or behavioural determinants.	Ensures methodological, safety and reporting alignment within XR-specific criteria of MCDA-XR.

Precedents for integrative and multicriteria evaluation

A smaller body of work has begun to move beyond single-theory evaluations by explicitly linking behavioural, organisational, and technological perspectives. Within the immersive field, Chung et al. (2022) combined the Theoretical Domains Framework, COM-B, the Behaviour Change Wheel, and implementation strategy mapping to inform the implementation of virtual reality in psychiatry. This work represents one of the first structured applications of behavioural implementation frameworks to XR. Its scope, however, remains largely confined to mental health settings and centres mainly on clinician behaviour, with limited attention to organisational governance, resource allocation, or system-level decision making.

Beyond XR, recent digital health research offers relevant methodological precedents for the integrative structure proposed here. Pereira Guerreiro et al. (2025) showed that NASSS and COM-B can be applied in parallel to assess complex medical devices, suggesting that behavioural and organisational lenses can be meaningfully combined within a single evaluation process. In a complementary direction, Deason et al. (2025) demonstrated the feasibility of using multicriteria decision analysis to support virtual care selection, shifting the focus from narrative appraisal to structured and transparent scoring. Taken together, these studies point to a clear opportunity. While integrative and multicriteria approaches are already being used in broader digital health, they have not yet been translated into a unified governance framework tailored to the specific characteristics and risks of Extended Reality.

Table 2. Comparative summary of methodological precedents informing the development of the MCDA-XR framework. The table reviews recent studies that moved beyond single-theory evaluations, either by combining behavioural and organisational frameworks (for example, Chung et al., Pereira Guerreiro et al.) or by applying multicriteria decision analysis approaches to digital health decision making (Deason et al.). It identifies persisting gaps, including restriction to specific clinical domains or the absence of determinants that account for immersive and sensory features. MCDA-XR addresses these limitations by offering a unified scoring and weighting structure explicitly adapted to the operational, safety, and experiential risks associated with extended reality technologies.

Study	Scope	Methods	Strengths	Limitations	Relevance to MCDA-XR
Chung et al. (2022) [30]	XR implementation in mental health.	Integration of TDF, COM-B, BCW and ERIC.	Provides the first structured behavioural toolkit for XR.	Limited to psychiatric settings; minimal organisational or systemic modelling.	Offers behavioural precedent for multi-framework integration.
Pereira Guerreiro et al. (2025) [31]	Implementation of a non-XR medical device.	Parallel use of NASSS and COM-B.	Shows that behavioural and organisational perspectives are complementary.	Conceptual integration only; no unified scoring or weighting.	Supports the rationale for multi-level integration in MCDA-XR.
Deason et al. (2025) [32]	Technology selection in virtual care.	Application of MCDA to digital health.	Demonstrates the feasibility of structured multicriteria decision-making.	Not XR-specific; lacks behavioural and organisational determinants.	Reinforces MCDA as an appropriate analytical approach for XR adoption.

Why existing approaches remain insufficient for XR

Despite their contributions, existing frameworks fall short when applied to immersive technologies. Behavioural models such as COM-B and the TDF clarify capability, opportunity and motivation, but do not engage with the sensory, ergonomic or embodied features that shape XR use. Organisational frameworks like CFIR and NASSS describe complexity and system dynamics, yet offer little guidance on perceptual mechanisms or user experience. Usability approaches assess interaction quality but do not address institutional support or sustainability. RATE-XR provides safety and reporting descriptors rather than readiness or strategic-planning criteria.

Each model captures a relevant part of the picture. What is missing is a way to integrate behavioural, organisational, experiential, and contextual determinants into a structure that supports comparison, prioritisation, and planning. In practice, decisions about XR adoption require weighing clinical value, safety, workflow compatibility, organisational capacity, regulatory constraints, and cost. These dimensions rarely move in the same direction, and no single variable captures the trade-offs that determine whether an initiative is viable within a healthcare organisation.

The governance gap: need for an operational strategic framework

Across the literature, there is agreement that the determinants influencing XR adoption are broadly known, yet they remain dispersed across frameworks with different aims [12,14,17,30]. No current model captures behavioural, organisational and experiential determinants within a single governance

structure that can be applied explicitly to strategic portfolio management in digital health. Existing tools describe barriers, but they do not translate them into assessable criteria or link them to resource allocation, which limits their usefulness for planning.

A multicriteria decision approach offers a way to address this gap. By allowing organisations to weigh criteria according to local priorities, such approaches support comparison between initiatives that differ in purpose, maturity, or resource demand. An organisation may prioritise safety during early piloting, focus on workflow integration during scale-up, or emphasise evidence requirements when projects compete for investment. Rather than relying on intuition, multicriteria methods make these trade-offs explicit and transparent.

To address this governance gap, the present study describes the development and formative refinement of MCDA-XR, a multicriteria governance framework designed to support feasibility assessment, readiness evaluation, and strategic prioritisation of XR initiatives within healthcare organisations.

Methods

Study design

This study follows a sequential mixed-methods design and forms part of a broader doctoral project structured around three developmental phases: identification, construction, and validation of a strategic governance framework for XR adoption in healthcare. The present article reports the methods and findings from Phases 1 and 2, which define the conceptual structure and operational logic of the MCDA-XR framework. Phase 3, focused on longitudinal validation in real-world settings, falls outside the scope of this manuscript.

Across all phases, the study adopts a pragmatic implementation perspective. Established theories of digital health governance and behaviour change were combined with empirical evidence and stakeholder input to ensure that the framework remains theoretically grounded while reflecting the operational realities of healthcare organisations. An overview of the sequential design is provided in Figure 1.

Setting and context

The study was conducted within the Doctoral Programme in Health and Psychology at the Open University of Catalonia (UOC), which provided methodological oversight. Framework development was anchored at Badalona Serveis Assistencials (BSA), an integrated healthcare organisation functioning as a living lab for applied innovation. Evidence reviewed in Phase 1 and stakeholder contributions in Phase 2 extended beyond this setting, drawing on experience from hospital and primary care services as well as academic research environments. This approach allowed the framework to be informed by diverse XR implementation contexts while remaining closely aligned with the governance and organisational constraints of routine clinical practice.

Figure 1. Sequential mixed-methods design for the development and validation of the MCDA-XR framework. The study follows three progressive stages. Phase 1 (Identification) comprises theoretical synthesis and evidence review to define core determinants relevant to XR implementation. Phase 2 (Construction) applies participatory stakeholder methods to refine these determinants into ten operational criteria and to establish the scoring logic. Phase 3 (Validation) constitutes a subsequent longitudinal phase in which the framework's predictive performance is examined in real-world

clinical settings. The present paper reports the results of Phases 1 and 2.



Phase 1: identification of strategic determinants

Phase 1 aimed to identify the behavioural, organisational and technical variables that define the strategic feasibility of XR initiatives. The work unfolded in three sequential steps that moved from theoretical framework selection to empirical evidence validation and final criterion expansion.

Step 1: strategic framework selection and synthesis

In the first step, theoretical models suitable for strategic decision making were identified through an analytical literature review (Table 1). Four frameworks were selected for their complementary coverage of system-level, behavioural, perceptual, and XR-specific considerations. Their joint use followed established precedents for integrating behavioural, organisational, and decision-analytic perspectives in digital health (Table 2). Core domains from the selected frameworks were intersected to derive an initial set of provisional evaluative dimensions.

Step 2: evidence validation via literature review:

To test the deductive structure derived in Step 1, a targeted review of XR implementation studies was conducted. The corpus of included studies is listed in Multimedia Appendix 1. Determinants were defined as explicit barriers, facilitators, or requirements related to XR implementation and were extracted exclusively from the Results and Discussion sections to preserve analytical fidelity.

This process employed a Large Language Model (LLM)-assisted workflow using GPT-5.1 to capture verbatim segments, followed by manual verification to confirm attribution accuracy and contextual

coherence. Extracted determinants were systematically mapped against the provisional evaluative dimensions to assess coverage and identify gaps. The resulting extraction matrix is presented in Multimedia Appendix 2.

Step 3: strategic gap analysis and expansion

Following empirical mapping, a thematic synthesis was performed within each evaluative dimension. Extracted determinants were examined to identify recurring patterns and higher-order themes. Themes were classified according to their frequency across studies and their potential strategic impact, with particular attention to safety-, ethical-, and regulation-related issues.

This synthesis informed the refinement and expansion of the analytical structure. Multimedia Appendix 3 documents the thematic synthesis by domain, and Multimedia Appendix 4 provides the final operational definitions and theoretical anchors used to support subsequent framework construction.

Phase 2: construction and refinement

Phase 2 examined how the validated evaluative dimensions functioned when translated into a practical decision-support instrument. The focus was on interpretability, perceived strategic relevance, and operational usability across professional profiles and care settings.

Four structured group sessions were conducted within the BSA living-lab environment and collaborating institutions. Each session followed a common format. Participants received a brief introduction to XR use in healthcare, followed by a live demonstration of immersive applications currently used in clinical and educational projects. This created a shared experiential baseline.

Participants then completed a prototype version of the MCDA-XR instrument, rating the strategic importance of each dimension using a five-point scale and providing brief qualitative comments. These comments were used to identify ambiguities, clarify terminology, and assess how criteria were interpreted across clinical, operational, and technical roles.

This phase was intentionally formative. Its objective was to refine clarity and usability rather than to establish psychometric validity. The combined dataset of quantitative ratings and qualitative feedback informed iterative adjustments to wording and structure, preparing the instrument for empirical testing in Phase 3.

Data collection and analysis

Qualitative material consisted of narrative comments generated during the construction activities and additional documentary sources from exploratory stakeholder work. These data reflected how participants interpreted each criterion and how they related it to their organisational context. Analysis followed Braun and Clarke's [46] reflexive thematic approach, combining inductive identification of emergent insights with deductive mapping informed by NASSS and COM-B. The aim in this phase was to refine conceptual wording and identify structural ambiguities that required clarification.

Quantitative data consisted solely of importance-weighting scores for the ten criteria. Descriptive statistics, including medians, means and ranges, were calculated for each participant group to summarise perceived strategic relevance. These summaries informed the iterative refinement of the instrument but were not used for inferential analysis. Hypothesis testing and validation of scoring behaviour are planned for Phase 3, where the MCDA-XR protocol will be applied in real implementation scenarios.

Ethical considerations

The study was approved by the UOC Research Ethics Committee (CE25-TE78). Participation is voluntary and all contributors provide informed consent. Information is pseudonymised before analysis and no patient-level data are included. Experiential insights from XR projects are handled in line with the approved protocol and comply with General Data Protection Regulation (GDPR) and Organic Law on Protection of Personal Data and Guarantee of Digital Rights (LOPDGDD) requirements.

Reflexive notes were maintained throughout to monitor the potential influence of the researcher's embedded role within the organisation, consistent with guidance for reflexivity in applied health research.

Results

Phase 1: Evolution of the MCDA-XR Structure

Phase 1 resulted in the transformation of an initial deductive structure into a governance framework composed of ten operational criteria. This evolution reflects how theoretical assumptions were reshaped when tested against empirical evidence from XR implementation studies.

The evolution of the framework clarified how different theoretical perspectives held up under empirical testing. NASSS primarily structured system- and organisation-level considerations, while COM-B and TAM informed criteria related to adoption, usability, and behavioural feasibility. RATE-XR contributed safeguards linked to safety, transparency, and technical integrity. Empirical mapping confirmed the relevance of these contributions, but also showed that governance, evidence legitimacy, and regulatory alignment could not remain implicit within organisational domains and required explicit representation as independent criteria.

From seven provisional criteria to a ten-criterion structure

The initial synthesis produced seven provisional criteria addressing relevance, safety and comfort, usability, workflow integration, resources and cost, training requirements, and patient acceptability. Together, these criteria captured core condition, technology, organisational, and adopter-related considerations relevant to XR adoption.

When empirical determinants from the literature were mapped onto this structure, clear limitations became apparent. A substantial proportion of extracted determinants could not be meaningfully accommodated within the original criteria without stretching their scope. In particular, issues related to evidence quality, institutional commitment, and regulatory or ethical compliance repeatedly emerged as distinct considerations rather than secondary aspects of organisational readiness.

To resolve these structural mismatches, the framework was expanded to include three additional criteria: Evidence and credibility, Institutional support, and Legal and ethical alignment. Their inclusion marked a shift from an implicitly organisational interpretation of system-level factors to an explicit recognition of governance, legitimacy, and accountability as independent strategic determinants. The resulting ten-criterion structure provided a more faithful representation of the empirical landscape observed across XR implementation studies. The final allocation of determinants to criteria is documented in the extraction matrix (Multimedia Appendix 2).

Thematic refinement and operational definition

Following the establishment of the ten-criterion structure, determinants within each domain were examined to identify recurring patterns and higher-order themes. Themes were classified as Major when supported by three or more independent studies and as Critical when directly related to safety, ethical, or regulatory requirements, regardless of frequency.

This synthesis informed the refinement of the scope and wording of each criterion, ensuring conceptual clarity and practical interpretability. Multimedia Appendix 3 presents the thematic structure by criterion, while Multimedia Appendix 4 provides the final operational definitions and example indicators that guided the framework construction activities in Phase 2.

The MCDA-XR framework and governance matrix

Phase 1 concluded with the definition of the MCDA-XR framework, comprising ten operational criteria intended to guide strategic decision making on XR adoption in healthcare.

The resulting structure is formalised as a governance matrix that brings behavioural, organisational, and technical considerations into a single analytical space. Rather than treating these dimensions as parallel or sequential factors, the matrix reflects how they interact when XR initiatives are assessed, prioritised, and implemented in real-world settings.

This synthesis does not seek to replace existing models. Its purpose is to translate their combined insights into a pragmatic diagnostic tool that makes misalignments visible, particularly those between technological readiness, workforce capability, and organisational or policy constraints. Figure 2 illustrates the structure and logic of the MCDA-XR governance matrix.

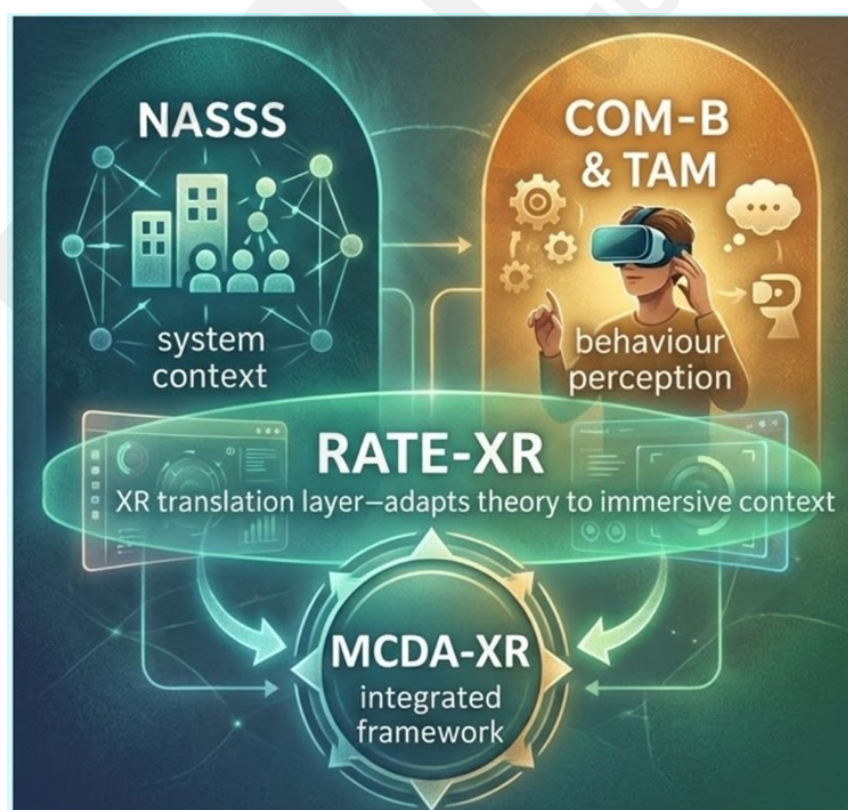


Figure 2. Conceptual integration of theoretical perspectives within the MCDA-XR governance matrix. NASSS (Non-Adoption, Abandonment, Scale-up, Spread, Sustainability) provides the

system-level structure for analysing XR implementation. COM-B (Capability, Opportunity, Motivation–Behaviour) and TAM (Technology Acceptance Model) contribute behavioural and adoption-related considerations. RATE-XR operationalises safety, transparency, and technical integrity specific to immersive technologies. The converging arrows illustrate how these perspectives interact within the governance matrix to support strategic decision making on XR adoption in healthcare.

The ten strategic criteria

The ten MCDA-XR criteria fall into three broad layers of implementation. One layer concerns people, their capability to use XR and the conditions that make its use realistic in daily care. Another relates to organisational structures, workflows and resource constraints. A third concerns the technology, its safety, usability and alignment with sector standards such as RATE-XR.

These layers are not treated as isolated components. They help identify where tensions or enablers usually appear as teams move from conceptual ideas to operational deployment.

Table 3 summarises the ten criteria and shows how each one aligns with the NASSS, COM-B, TAM and RATE-XR constructs. The table also provides the guiding questions that form the basis of the decision-support instrument.

Table 3. Operational derivation and theoretical mapping of the ten MCDA-XR criteria.

The table shows how theoretical constructs are translated into operational governance criteria. Each criterion is mapped to its corresponding domains within NASSS (system level context), COM-B (behavioural mechanisms), TAM (perceptual acceptance), and RATE-XR (immersive safety and technical standards). The final column reports the Guiding Question refined during stakeholder sessions, which functions as the qualitative anchor for the 1 to 5 strategic importance rating.

NASSS Area (structural anchor)	MCDA-XR 10 Criterion	Cross-Framework Basis (COM-B / TAM / RATE-XR)	MCDA-XR Guiding Question (rated 1–5)
1. Condition	1. Relevance	Capability (COM-B), perceived usefulness (TAM), clinical indication descriptor (RATE-XR)	Does the XR intervention address real clinical needs and patient goals?
	2. Evidence and credibility	Reflective motivation (COM-B), perceived usefulness (TAM), evidence transparency (RATE-XR)	Is its use supported by scientific evidence and recognised clinical legitimacy?
2. Technology	3. Safety and comfort	Physical capability and automatic motivation (COM-B), sensory and ergonomic descriptors (RATE-XR)	Is the XR experience safe, tolerable, and comfortable for patients?
	4. Usability	Physical capability (COM-B), perceived ease of use (TAM), usability and interaction fidelity (RATE-XR)	Is the system intuitive, reliable, and manageable for clinicians and patients?
3. Value proposition & workflow	5. Integration in workflow	Physical and social opportunity (COM-B), perceived usefulness (TAM), workflow compatibility (RATE-XR)	Does XR fit realistically within available time, routines, and workspace?
	6. Resources and cost	Opportunity (COM-B), perceived usefulness (TAM), operational requirements (RATE-XR)	Are the required resources, staffing demands, and maintenance needs feasible?
4. Adopters (patients & professionals)	7. Training requirement	Capability (COM-B), perceived ease of use (TAM), supervision and training descriptors (RATE-XR)	Can required training be achieved with current time, skills, and support?

	8. Patient acceptability	Motivation (COM-B), usefulness (TAM), user experience descriptors (RATE-XR)	Do patients trust, enjoy, and accept XR as part of their care?
5. Organisation	9. Institutional support	Social opportunity (COM-B), motivational alignment (COM-B), organisational readiness (RATE-XR)	Does the institution provide the support needed for meaningful and sustained use?
6. Wider system	10. Legal and ethical alignment	Opportunity (system constraints) (COM-B), compliance descriptors (RATE-XR)	Does the intervention meet ethical, regulatory, and data-protection requirements?

To support traceability, the empirical themes that informed these operational definitions are presented in Multimedia Appendix 3, and the detailed conceptual–empirical mappings grounding each criterion in the NASSS, COM-B, TAM and RATE-XR constructs are provided in Multimedia Appendix 4. Together, these materials document the analytic steps that link the thematic synthesis to the final structure summarised in Table 3.

Stakeholder importance ratings in phase 2

A total of 33 participants contributed importance-weighting data. Most were female (28, 84.8%), and ages ranged from early adulthood to the late 60s, with 12 participants (36.4%) in the 18–29 group, 6 (18.2%) aged 30–39, 6 (18.2%) aged 40–49, 5 (15.2%) aged 50–59 and 4 (12.1%) aged 60–69. The sample included 21 practising health professionals (63.6%) from primary care, intermediate care, mental health and neurorehabilitation services, alongside 12 postgraduate psychologists (36.4%) enrolled in a Master's program in Psychogerontology. Detailed characteristics, including specific institutional origins (hospital, primary care, and university settings) and professional roles for all participants, are provided in Multimedia Appendix 5. Prior exposure to XR was limited: 16 participants (48.5%) reported no previous experience, 13 (39.4%) recreational-only use and 4 (12.1%) involvement in a clinical pilot.

Participants rated all ten MCDA-XR criteria on a 1–5 scale, where 1 reflected the lowest strategic importance and 5 the highest. The resulting means fell between 4.03 and 4.61, which already gives a sense of how consistently all the criteria were regarded as relevant for XR adoption (Figure 3). Safety and comfort reached the highest score (mean 4.61) and showed the narrowest variability (SD 0.56), a pattern that aligns with its role as a non-negotiable condition for safe clinical deployment.

The picture was more heterogeneous for Institutional support (SD 1.06) and Legal and ethical alignment (SD 0.97). Differences of this magnitude appear to stem from the organisational diversity of the participating services, rather than from any ambiguity in how the criteria were defined. These distributions suggest a shared understanding of relevance, yet they also highlight how local structures, resources and governance maturity continue to shape how risks and priorities are interpreted in practice.

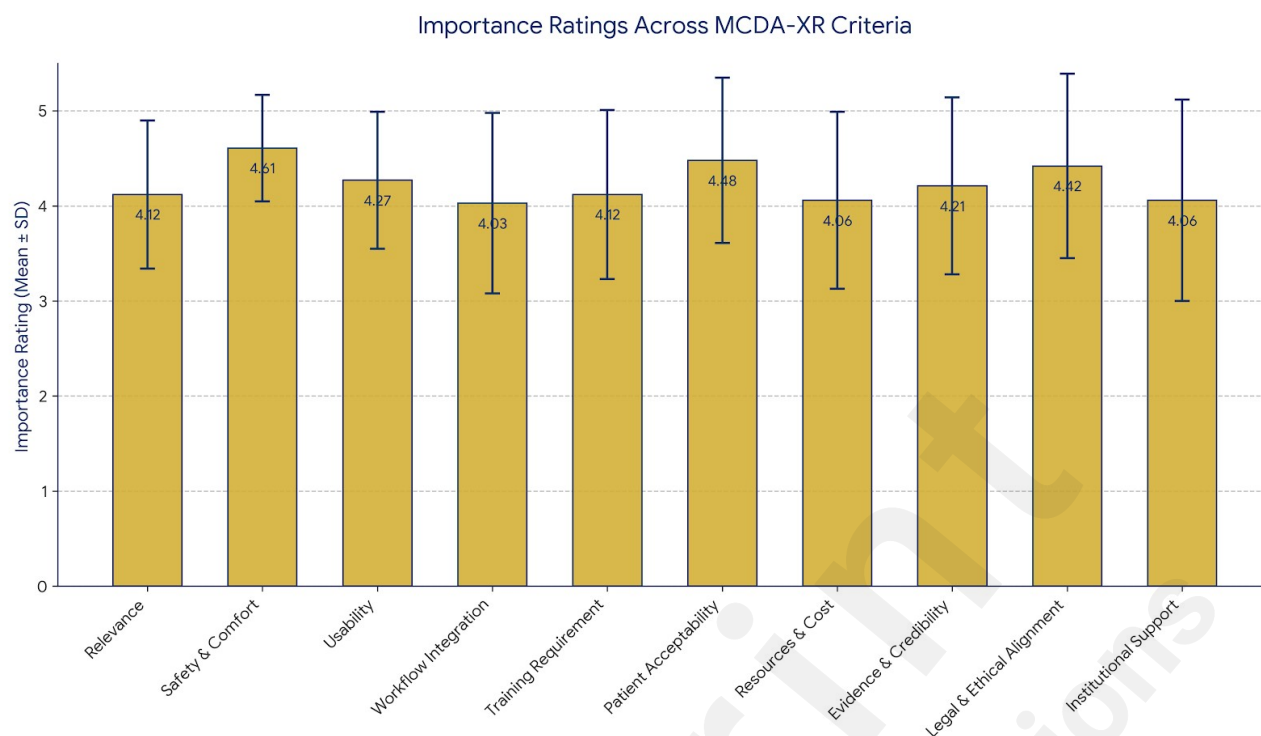


Figure 3. Mean strategic importance ratings for the ten MCDA-XR criteria, grouped by implementation domain. Ratings were provided by 33 stakeholders (clinicians, managers, and operational staff) on a 5-point scale (1=lowest importance, 5=highest importance). Error bars represent standard deviations. High mean scores (>4.0) across all domains indicate broad consensus on the strategic relevance of the selected criteria.

Open-text comments were brief and generally positive, noting perceived clinical usefulness, patient engagement and comfort. Remarks concerning workload and the need for protected time aligned with the existing criteria of workflow integration, institutional support and resources and cost. No participant identified determinants outside the ten predefined domains, and informal discussion during the sessions suggested that the set was viewed as complete.

These patterns supported retention of the ten-criterion structure and indicated that stakeholders viewed the framework as aligned with their strategic concerns, supporting its readiness for structured validation in Phase 3.

From criteria to decision support: operationalisation of MCDA-XR

Following the refinement of the ten criteria and their prioritisation by stakeholders in Phase 2, the MCDA-XR framework was formalised as a decision-support tool designed for strategic use. The final instrument operationalises the framework through a dual-score structure that distinguishes between institutional priorities and current implementation conditions.

For each of the ten criteria, stakeholders first rate strategic importance on a five-point scale (1–5). This step captures how critical each dimension is within the local organisational context, independently of any specific XR solution. Importance ratings reflect institutional values, service objectives, and strategic goals, making explicit which considerations carry the greatest weight in adoption decisions.

Stakeholders then assess organisational readiness for each criterion on a three-point scale (1–3), indicating the extent to which current conditions, resources, and capabilities are in place to support

implementation. Readiness scores reflect practical feasibility, including workflow compatibility, staff capacity, governance arrangements, and technical preparedness.

Rather than collapsing these dimensions into a single aggregate score, MCDA-XR relies on their joint interpretation at the criterion level. Comparing importance and readiness allows priority gaps to be identified in a structured and transparent manner. Criteria rated as highly important but associated with low readiness signal domains where preparatory action is likely required before implementation or scale-up, such as targeted training, workflow adaptation, clarification of governance responsibilities, or allocation of additional resources. In contrast, lower readiness in criteria assigned limited strategic importance may represent constraints that are acceptable or manageable in the short term.

This importance–readiness alignment transforms the framework from a descriptive checklist into an actionable diagnostic tool. It supports informed discussion among multidisciplinary stakeholders by making trade-offs explicit and by distinguishing between critical barriers and manageable risks under current organisational conditions. The logic of this cross-score interpretation and its translation into prioritised gaps are illustrated in Figure 4.

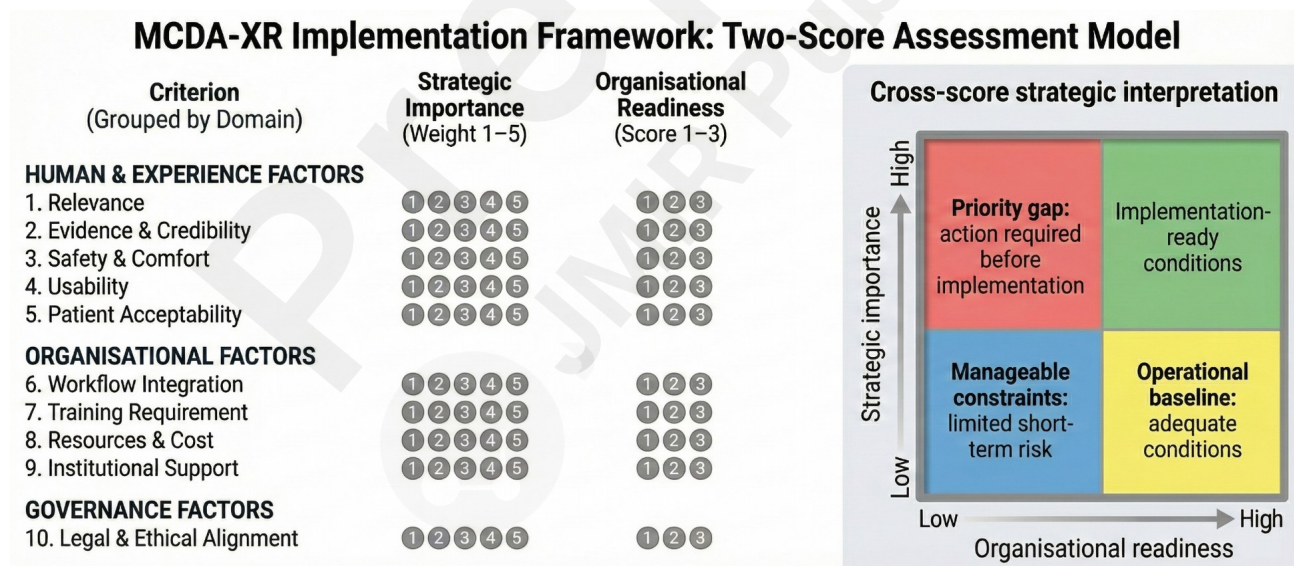


Figure 4. Conceptual illustration of the MCDA-XR application. The left panel shows the evaluation scorecard where stakeholders rate the ten criteria on strategic importance (1–5) and organisational readiness (1–3). The right panel shows the cross-score interpretation matrix, where these two dimensions are plotted to identify priority gaps (high importance/low readiness) versus implementation-ready conditions, avoiding the use of a single aggregated score.

Discussion

Addressing the strategic gap in digital health governance

This work responds to a persistent gap in how extended reality is governed and planned within healthcare organisations. Across rehabilitation, mental health and primary care, recent reviews consistently identify determinants such as workflow fit, clinician capability, sensory tolerability and organisational support as central to successful XR implementation [12,14,16,17]. Although these factors are well characterised, they are typically reported as descriptive findings and only rarely operationalised into tools that can support prospective planning. As a consequence, healthcare services often lack a structured means to assess feasibility before committing staff time, infrastructure or financial resources.

MCDA-XR addresses this gap by translating established behavioural, organisational and technical determinants into a ten-criterion structure intended for strategic appraisal. The framework does not introduce new constructs. Instead, it reorganises existing evidence into an operational format that can be used during early planning and decision-making stages. This orientation is consistent with international guidance calling for more structured and evidence-informed approaches to the assessment and planning of digital health interventions [1,3]. This perspective also resonates with the European Commission's 2025 report on virtual worlds, which highlights substantial fragmentation in how safety, governance and broader institutional considerations are currently examined, and notes the lack of cumulative, integrative approaches capable of informing policy and implementation decisions in immersive systems [47]. From this perspective, MCDA-XR functions less as a conceptual contribution and more as a governance instrument, intended to support decision making at the transition between exploratory pilots and formal implementation planning.

Positioning MCDA-XR within the state of the art

The multicriteria structure of MCDA-XR differentiates it from existing approaches by explicitly linking implementation determinants to strategic decision making. By separating strategic importance from organisational readiness, the framework requires organisations to articulate priorities in advance, whether related to safety, workflow integration, regulatory alignment or resource feasibility. This distinction enables comparison across heterogeneous XR initiatives without collapsing decisions into a single aggregate score, a common limitation of existing appraisal approaches.

This design responds to limitations repeatedly identified in prior work, where evaluation tools tend to focus on a single layer of adoption. Behavioural analyses such as Chung et al. (2022) [30] provide insight into individual mechanisms but offer limited guidance for organisational planning. Usability-focused studies document technical fragmentation while rarely connecting findings to governance or resource allocation decisions [13]. Broader syntheses identify recurring barriers across settings but remain largely descriptive, without translating these findings into methods for prospective prioritisation [12,14,17].

Findings from Phase 2 reinforce the need for an integrative approach of this kind. The consistently high prioritisation and low variability observed for safety and comfort suggest that stakeholders view XR as an embodied clinical intervention, for which immersive safety constitutes a non-negotiable condition of legitimacy. In contrast, the greater variability observed for institutional support and legal and ethical alignment indicates that governance-related risks are interpreted through the lens of local organisational maturity, rather than uniform technical standards.

Taken together, these patterns support the use of a multicriteria framework that distinguishes between universally required safety conditions and context-dependent governance risks. MCDA-XR extends earlier integrative efforts by operationalising behavioural and organisational perspectives within an explicit multicriteria decision logic, moving beyond parallel model use toward structured decision support [31]. In doing so, it shifts XR evaluation from retrospective explanation toward prospective planning, in line with current calls for more structured digital health governance.

Strengths and limitations

A central strength of MCDA-XR lies in its dual grounding. The framework is anchored in established implementation and behavioural theory, while being iteratively refined within a living-lab environment embedded in a real healthcare organisation. This setting exposed the framework to competing clinical priorities, resource constraints, and governance requirements that are often underrepresented in conceptual or purely theoretical work. As a result, the criteria and their operational definitions are shaped by conditions encountered during actual planning and decision making, rather than by idealised assumptions about technology adoption.

A second strength is the participatory construction process. By engaging professionals from clinical, operational, and managerial roles, the framework integrates multiple institutional perspectives. The consistency observed in importance ratings across domains, together with the absence of additional determinants proposed by participants, suggests that the ten-criterion structure captures a coherent and sufficiently comprehensive representation of key XR implementation considerations. This convergence lends support to the framework's face validity within the studied context.

Several limitations should also be acknowledged. First, this study focuses on framework development and formative validation. While participants confirmed the relevance and interpretability of the criteria, the readiness scoring component has not yet been tested for predictive validity. In addition, a substantial proportion of stakeholders reported limited prior exposure to XR. Importance ratings may therefore partly reflect an anticipatory view of implementation, rather than insights grounded in sustained clinical deployment. At this stage, MCDA-XR is best understood as a diagnostic instrument to identify potential misalignments between proposed XR initiatives and organisational capacity, rather than as a tool to predict implementation success.

Second, the framework remains sensitive to technological and regulatory evolution. Ongoing changes in XR hardware, software platforms, and regulatory interpretations may require periodic revision of technical descriptors. This reinforces the need to treat readiness assessment as an iterative process, embedded within routine governance, rather than as a one-off evaluation.

These limitations will be addressed in Phase 3, which will examine whether organisational readiness profiles generated by MCDA-XR anticipate real-world implementation challenges during roll-out and early scaling in longitudinal clinical settings.

Strategic implications for research and practice

For researchers, MCDA-XR provides a structured way to characterise implementation contexts using a shared analytical language. By organising behavioural, organisational, and technical determinants within a single decision framework, it facilitates comparison across studies and supports cumulative knowledge development beyond isolated case reports.

For healthcare organisations, the framework has immediate practical relevance. MCDA-XR enables teams to assess initiatives against explicit criteria, make trade-offs visible, and identify areas where

additional preparation or institutional support may be needed before scaling. Rather than replacing professional judgement, it offers a transparent structure to support collective decision making and align adoption choices with organisational priorities.

More broadly, MCDA-XR contributes to a shift away from ad hoc decision making toward more deliberate strategic planning in digital health. By explicitly linking adoption decisions to organisational readiness and governance considerations, the framework supports a more sustainable and defensible approach to innovation, particularly in resource-constrained healthcare settings.

Conclusion

Extended reality introduces forms of interaction, sensory engagement, and organisational demand that are not adequately addressed by conventional digital health planning approaches. Although the determinants influencing XR adoption are increasingly well characterised, healthcare organisations still lack practical, governance-oriented tools to support structured decision making before implementation. This study responds to that gap through the development of MCDA-XR, a framework intended to support ex-ante strategic planning for XR adoption in healthcare settings.

By explicitly distinguishing between strategic importance and organisational readiness across a shared set of empirically grounded criteria, MCDA-XR enables decision makers to identify priority gaps, assess feasibility, and surface governance challenges before committing institutional resources. In this way, the framework shifts evaluation away from descriptive feasibility assessments toward a more transparent and action-oriented planning process, grounded in organisational capacity and strategic intent.

The work presented here establishes the conceptual architecture and operational logic of MCDA-XR. The next phase of research will examine whether the readiness profiles generated by the framework anticipate implementation challenges and early sustainability outcomes during real-world clinical deployment. If supported, MCDA-XR could contribute to more deliberate, accountable, and sustainable approaches to digital health governance, particularly within resource-constrained healthcare systems.

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ChatGPT (GPT-5, OpenAI, 2025) and Gemini (Flash 1.5, Google, 2025) were used to support language refinement, editorial polishing, literature synthesis, extraction and organisation of implementation determinants during Phase 1, reference formatting, and the drafting of figures for illustrative purposes. These tools were used under the direct supervision of the authors and did not perform data collection, statistical analysis, interpretation of results, or decision making. All AI-assisted outputs were critically reviewed, edited, and approved by the authors to ensure accuracy, coherence, and fidelity to the study data, methods, and theoretical frameworks.

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Authors' contributions

JFC conceptualised the study, conducted data collection, and led the construction sessions. MAR and PBK provided methodological oversight and contributed to the theoretical framing and methodological refinement. All authors contributed to manuscript drafting, critical revision, and approved the final version.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of interest

None declared.

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Abbreviations

AR: Augmented Reality

COM-B: Capability, Opportunity, Motivation – Behaviour

MCDA: Multicriteria Decision Analysis

MR: Mixed Reality

NASSS: Non-Adoption, Abandonment, Scale-up, Spread, Sustainability

TAM: Technology Acceptance Model

VR: Virtual Reality

XR: Extended Reality

Multimedia Appendix 1. Comparative Overview of XR Implementation Studies and Their Reported Implementation Determinants

This file compiles the primary studies included in the comparative overview and summarises the implementation determinants described in each publication. It provides a consolidated view of the real-world barriers, facilitators, and requirements documented across XR health research. The table serves as the empirical foundation for subsequent determinant extraction and synthesis.



Multimedia Appendix 2. Verbatim Determinant Extraction Matrix With MCDA-XR Classification

This matrix presents the verbatim implementation determinants extracted from each study, restricted to the sections where authors report their own findings or analysis. Determinants are classified as barriers, facilitators, or requirements and mapped to one of the ten MCDA-XR criteria. The file provides the methodological audit trail linking individual study findings to the thematic synthesis and the construction of the MCDA-XR criteria.

Multimedia Appendix 3. Empirical Support for the Ten MCDA-XR Criteria: Thematic Determinant Synthesis

Master themes were derived by clustering related determinants across studies. Frequency counts reflect the number of unique studies contributing to each theme, with repeated mentions within the same study counted once. Themes were classified as Major ($N \geq 3$), Critical (safety or ethical relevance regardless of frequency), or Minor (infrequent or methodological and not retained for weighting).

The full verbatim determinants underlying this synthesis are provided in Multimedia Appendix 2.

Multimedia Appendix 4. Theoretical–Empirical Framework Alignment Underlying the Ten MCDA-XR Criteria

This table outlines the conceptual foundations of the MCDA-XR tool. Each of the ten criteria is linked to the structural domains of NASSS, the behavioural mechanisms of COM-B, the perceptual constructs of TAM, and the XR-specific descriptors of RATE-XR. The table clarifies how these frameworks jointly inform the conceptual meaning of each criterion and shows how they translate into practical evaluative questions for healthcare settings.

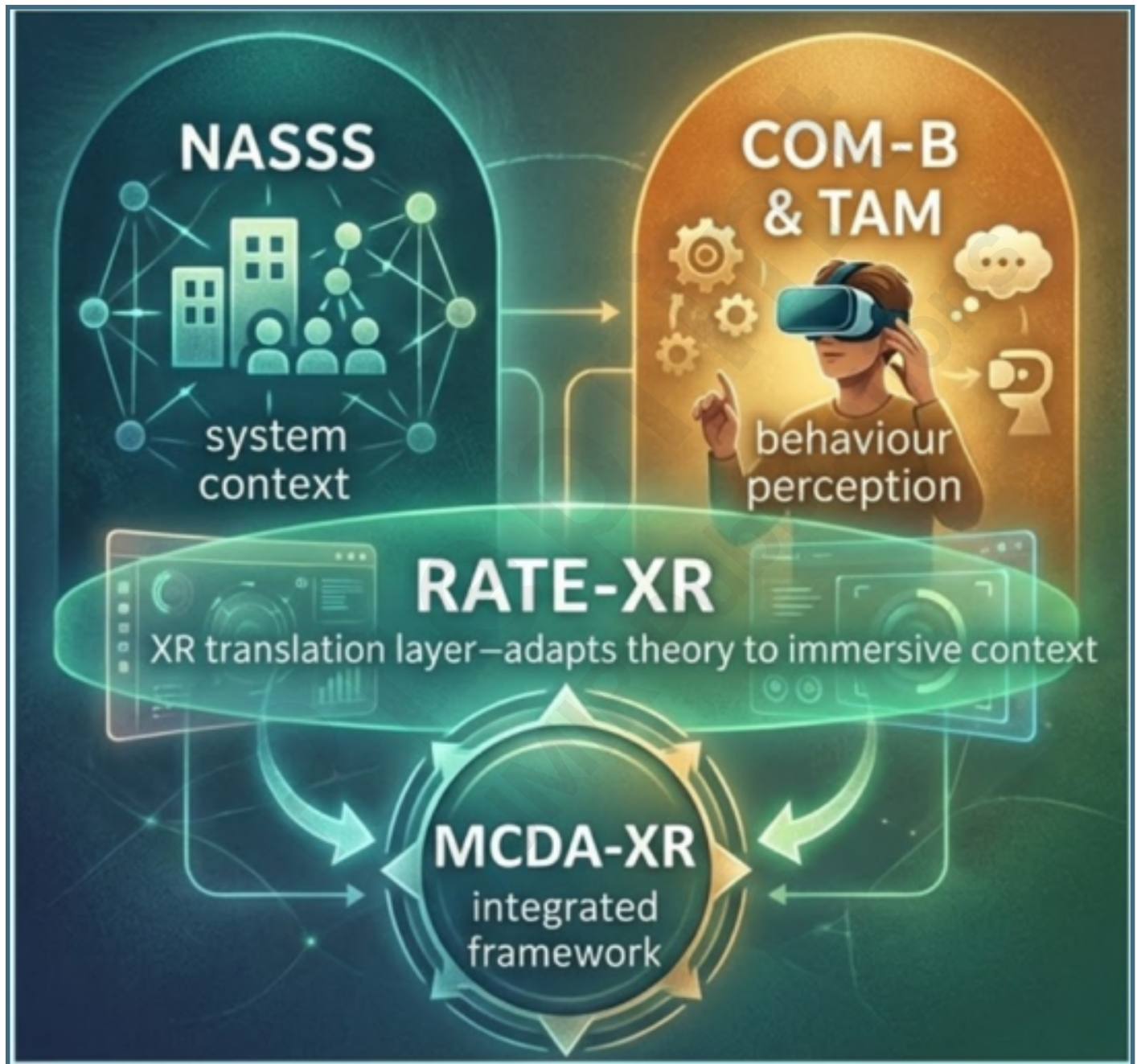
Supplementary Files

Figures

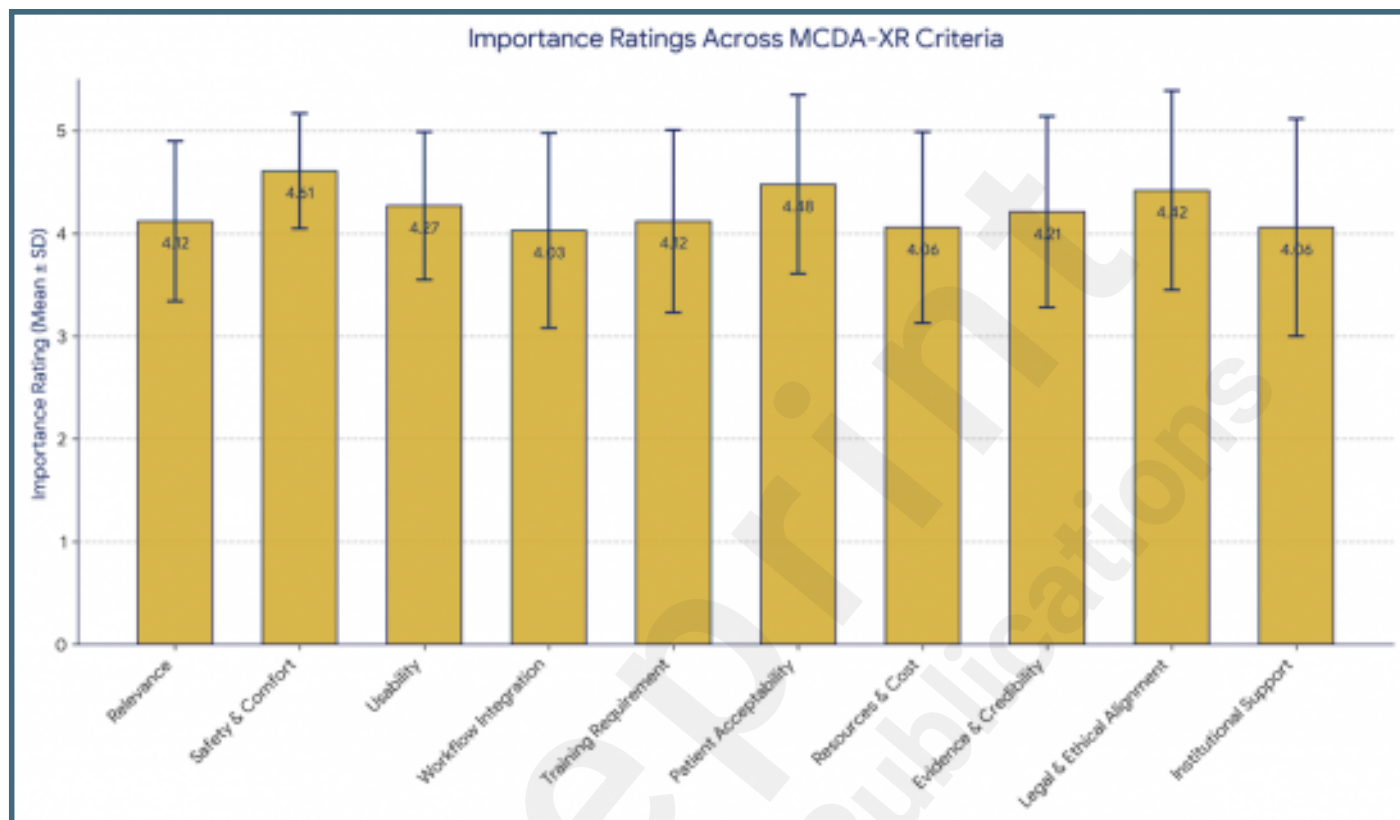
Sequential mixed-methods design for the development and validation of the MCDA-XR framework. The study follows three progressive stages. Phase 1 (Identification) comprises theoretical synthesis and evidence review to define core determinants relevant to XR implementation. Phase 2 (Construction) applies participatory stakeholder methods to refine these determinants into ten operational criteria and to establish the scoring logic. Phase 3 (Validation) constitutes a subsequent longitudinal phase in which the framework's predictive performance is examined in real-world clinical settings. The present paper reports the results of Phases 1 and 2.



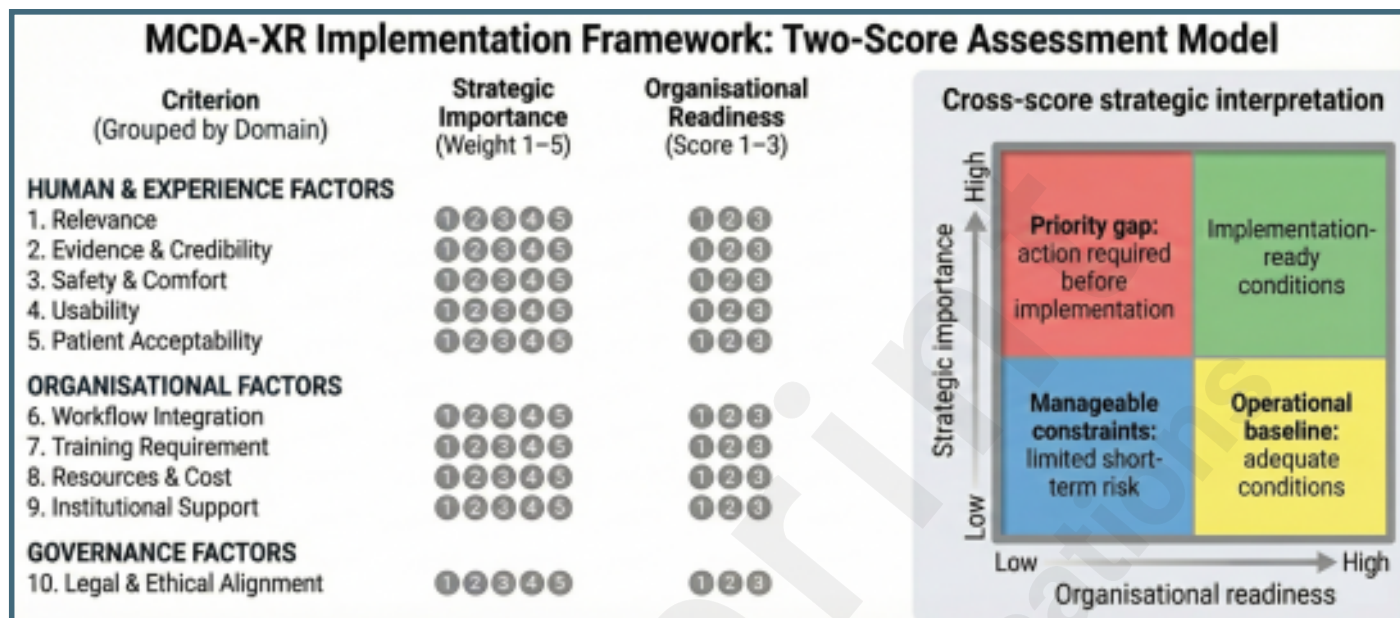
Conceptual integration of theoretical perspectives within the MCDA-XR governance matrix. NASSS (Non-Adoption, Abandonment, Scale-up, Spread, Sustainability) provides the system-level structure for analysing XR implementation. COM-B (Capability, Opportunity, Motivation–Behaviour) and TAM (Technology Acceptance Model) contribute behavioural and adoption-related considerations. RATE-XR operationalises safety, transparency, and technical integrity specific to immersive technologies. The converging arrows illustrate how these perspectives interact within the governance matrix to support strategic decision making on XR adoption in healthcare.



Mean strategic importance ratings for the ten MCDA-XR criteria, grouped by implementation domain. Ratings were provided by 33 stakeholders (clinicians, managers, and operational staff) on a 5-point scale (1=lowest importance, 5=highest importance). Error bars represent standard deviations. High mean scores (>4.0) across all domains indicate broad consensus on the strategic relevance of the selected criteria.



Conceptual illustration of the MCDA-XR application. The left panel shows the evaluation scorecard where stakeholders rate the ten criteria on strategic importance (1–5) and organisational readiness (1–3). The right panel shows the cross-score interpretation matrix, where these two dimensions are plotted to identify priority gaps (high importance/low readiness) versus implementation-ready conditions, avoiding the use of a single aggregated score.



Multimedia Appendixes

Comparative Overview of XR Implementation Studies and Their Reported Implementation Determinants This file compiles the primary studies included in the comparative overview and summarises the implementation determinants described in each publication. It provides a consolidated view of the real-world barriers, facilitators, and requirements documented across XR health research. The table serves as the empirical foundation for subsequent determinant extraction and synthesis.

URL: <http://asset.jmir.pub/assets/3cc47fa4e216ed7b03505acec563e16d.pdf>

Verbatim Determinant Extraction Matrix With MCDA-XR Classification This matrix presents the verbatim implementation determinants extracted from each study, restricted to the sections where authors report their own findings or analysis. Determinants are classified as barriers, facilitators, or requirements and mapped to one of the ten MCDA-XR criteria. The file provides the methodological audit trail linking individual study findings to the thematic synthesis and the construction of the MCDA-XR criteria.

URL: <http://asset.jmir.pub/assets/8ed9c397478091e293e44c2eeb17bc8.pdf>

Empirical Support for the Ten MCDA-XR Criteria: Thematic Determinant Synthesis Master themes were derived by clustering related determinants across studies. Frequency counts reflect the number of unique studies contributing to each theme, with repeated mentions within the same study counted once. Themes were classified as Major ($N \geq 3$), Critical (safety or ethical relevance regardless of frequency), or Minor (infrequent or methodological and not retained for weighting). The full verbatim determinants underlying this synthesis are provided in Supplementary Material 2.

URL: <http://asset.jmir.pub/assets/b3dd38bcd9dcd6b6ec6456792975da68.pdf>

Theoretical–Empirical Framework Alignment Underlying the Ten MCDA-XR Criteria This table outlines the conceptual foundations of the MCDA-XR tool. Each of the ten criteria is linked to the structural domains of NASSS, the behavioural mechanisms of COM-B, the perceptual constructs of TAM, and the XR-specific descriptors of RATE-XR. The table clarifies how these frameworks jointly inform the conceptual meaning of each criterion and shows how they translate into practical evaluative questions for healthcare settings.

URL: <http://asset.jmir.pub/assets/ce58a19c509be8768f5b617be00a28f3.pdf>

Participant Demographics and Professional Roles (Phase 2 Construction) This table details the composition of the 33 stakeholders who participated in the construction and refinement sessions. Participants were drawn from four distinct groups representing hospital care, primary care, and academic research.

URL: <http://asset.jmir.pub/assets/484875d6f54faa73da3ea45466e046cd.pdf>

TOC/Feature image for homepages

A multidisciplinary healthcare team meeting in a clinical setting, where one clinician uses an extended reality headset to visualise and interact with digital clinical information during a strategic discussion. The scene illustrates the integration of immersive technologies into organisational decision making, highlighting collaborative planning, governance considerations, and the evaluation of XR adoption in healthcare environments.

