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Regulatory orchestration in immersive retail innovation systems: A capability-based framework for AI and XR governance☆

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ABSTRACT

Immersive retail technologies, including AI-driven personalisation, augmented and virtual reality, biometric and affective analytics, spatial computing, and metaverse environments, are transforming consumer experiences and retail innovation systems. However, they also pose systemic governance challenges related to data protection, algorithmic bias, behavioural manipulation, surveillance, platform concentration, and consumer vulnerability. Existing studies typically portray regulators as external rule-setters, compliance authorities, or providers of regulatory instruments, overlooking the organisational capabilities by which they influence innovation system dynamics. This conceptual paper develops a capability-based framework of regulatory orchestration in immersive retail innovation systems by integrating innovation systems theory, regulatory science, dynamic capabilities, and orchestration research. It identifies five regulatory orchestrator capabilities: sensing and sensemaking, experimentation and adaptation, co-creation and boundary spanning, orchestration and coordination, and reflexive learning and meta-regulation. These capabilities are enacted through regulatory sandboxes, audits, impact assessments, standards, codes of conduct, post-market monitoring, and cross-agency coordination. By linking these capabilities to knowledge development, entrepreneurial experimentation, legitimation, market formation, coordination, directionality, and reflexivity, the framework explains how regulators can reduce uncertainty, address knowledge and power asymmetries, and guide AI and XR retail innovation towards responsible and socially aligned outcomes. It therefore conceptualises regulators as active participants in innovation systems.

1. Introduction

Immersive retail, encompassing artificial intelligence (AI)-driven personalisation, augmented and virtual reality (AR/VR) interfaces, metaverse environments, spatial computing, and biometric analytics, is emerging as a frontier domain of digital innovation. These technologies are transforming how consumers search, evaluate, and experience products by creating increasingly personalised, interactive, and multisensory retail journeys (Kim and Choo, 2023; Chylinski et al., 2020; Gleim et al., 2025; Alexander et al., 2025). Yet immersive retail is not simply a new technological application in retailing. It is a complex innovation ecosystem in which platform providers, retailers, technology developers, data brokers, standards bodies, research institutions, consumers, and public authorities jointly shape the development, diffusion, and governance of innovation (Albishri et al., 2026; Caboni and Pizzichini, 2023). This ecosystemic character makes immersive retail a particularly relevant context for reconsidering regulators as active participants in innovation systems, rather than merely as external evaluators of safety, quality, and compliance.

The increasing complexity of immersive retail ecosystems raises an important theoretical question. Existing research has extensively examined how regulation constrains, enables, or oversees technological

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innovation, but less attention has been devoted to how regulators themselves develop the organisational capabilities required to manage innovation under technological uncertainty. This gap is especially relevant in AI-enabled and immersive environments, where effective governance relies not only on formal authority but also on regulators' ability to coordinate diverse actors, integrate dispersed knowledge, facilitate experimentation, and adapt governance strategies as technologies evolve. This paper therefore investigates *how regulators develop and utilize organisational capabilities to coordinate innovation within AI- and XR-driven immersive retail ecosystems.*

Immersive retail provides a particularly suitable context for addressing this question because it combines multiple sources of technological, organisational, and institutional complexity. AI-driven personalisation increasingly relies on large-scale data analytics that may reproduce algorithmic bias, discriminatory pricing, and opaque decision-making processes (Barocas and Selbst, 2016). At the same time, biometric and affective computing systems capable of tracking facial expressions, physiological responses, bodily movements, and emotional states raise important concerns regarding surveillance, privacy, autonomy, and the commodification of intimate consumer data (McStay, 2020; Menges, 2025). These challenges are reinforced by ecosystem-wide power asymmetries, whereby a limited number of dominant digital platforms increasingly control critical data infrastructures, standards, interfaces, and access to innovation ecosystems (EU, 2022; EU, 2024). Together, these dynamics generate governance challenges that extend beyond conventional consumer protection or market regulation and require continuous coordination across technological, organisational, legal, and societal domains.

Recent regulatory developments illustrate that regulators are increasingly assuming a more proactive role within these evolving ecosystems. The European Union's Artificial Intelligence Act introduces a comprehensive risk-based framework governing AI applications, including strict requirements for biometric and emotional AI systems (EU, 2024). Similarly, the Digital Services Act and updated consumer protection legislation strengthen platform accountability and address manipulative online commercial practices (EU, 2022; EU, 2019/2161). Beyond formal legislation, regulators are increasingly adopting experimental governance instruments such as regulatory sandboxes, testbeds, impact assessments, audits, standards, codes of conduct, and adaptive regulatory frameworks that facilitate innovation while managing uncertainty in rapidly evolving technological environments (OECD, 2020; OECD, 2023). These developments reflect a broader transition from predominantly ex post compliance towards more anticipatory, collaborative, and adaptive approaches to regulation. Through these mechanisms, regulators increasingly contribute to the generation of regulatory knowledge, the coordination of experimentation, and the development of governance arrangements alongside firms, technology developers, consumers, civil society organisations, and other ecosystem participants. However, these instruments do not operate effectively on their own. Their capacity to shape innovation depends on the organisational capabilities through which regulators interpret emerging technologies, mobilise expertise, coordinate actors, and learn from experimental interventions.

Despite these developments, the theoretical foundations for understanding this evolving regulatory role remain fragmented. Although adjacent perspectives—including responsible innovation, anticipatory governance, experimental governance, mission-oriented innovation policy, platform governance, and regulatory intermediation—have substantially advanced understanding of digital governance, they primarily explain governance principles, institutional arrangements, policy objectives, or ecosystem coordination mechanisms rather than the organisational capabilities through which regulators intentionally shape innovation-system dynamics. Likewise, innovation systems theory recognises institutions as essential components of innovation ecosystems but generally conceptualises regulators as enabling conditions rather than as active organisational actors shaping innovation-system evolution (Hekkert et al., 2007; Bergek et al., 2008; Edler and Fagerberg, 2017). Regulatory science has significantly advanced understanding of regulatory instruments, risk assessment, evaluation standards, and adaptive governance (Janssen and van der Voort, 2016; Boakye et al., 2022), yet has devoted comparatively less attention to the organisational capabilities through which regulators deploy these instruments in complex innovation environments. Dynamic capabilities theory explains how organisations purposefully sense, seize, and reconfigure resources in rapidly changing environments (Teece et al., 1997; Teece, 2007), but its application has remained largely confined to private organisations, with comparatively limited attention devoted to regulatory agencies. Consequently, no single theoretical perspective adequately explains how regulators develop and deploy the organisational capabilities required to coordinate actors, integrate distributed knowledge, facilitate experimentation, and continuously adapt governance within emerging innovation ecosystems.

To address this limitation, we develop a capability-based conceptual framework that integrates innovation systems theory, regulatory science, dynamic capabilities, and orchestration research. Innovation systems theory explains how innovation emerges through interactions among heterogeneous actors; regulatory science explains the instruments and evaluative practices through which public authorities assess and steer technological change; dynamic capabilities theory provides an organisational lens for understanding adaptation under uncertainty; and orchestration research explains how autonomous actors may be coordinated across ecosystems without relying solely on hierarchy. Bringing these perspectives together allows us to conceptualise regulators as organisational actors whose capabilities enable them to sense technological change, coordinate heterogeneous stakeholders, facilitate experimentation, and continuously adapt governance arrangements. In doing so, the framework shifts analytical attention from what regulators regulate, and which instruments they use, to how regulators develop the organisational capacities required to shape innovation-system evolution.

Specifically, the framework identifies five interrelated regulatory orchestrator capabilities: sensing and sensemaking, experimental and adaptive capability, co-creation and boundary spanning, orchestration and coordination, and reflexive learning and meta-regulation. It conceptualises how these capabilities are operationalised through regulatory instruments, including regulatory sandboxes, impact assessments, audits, codes of conduct, standards, and cross-agency coordination mechanisms. The framework further explains how these capabilities shape key innovation-system functions, including legitimation, entrepreneurial experimentation, knowledge diffusion, coordination, directionality, and reflexivity, thereby enabling regulators to support responsible innovation while mitigating ecosystem-level risks. The primary contribution of the paper is therefore conceptual integration and theory extension. It develops a capability-based account of regulatory orchestration that links organisational regulatory capacity to innovation-system functions.

This framework contributes to ongoing debates in innovation systems, regulatory science, and dynamic capabilities in several ways. First, it extends innovation systems theory by conceptualising regulators as active orchestrators of innovation-system functions rather than as external institutional constraints. Second, it advances regulatory science by shifting analytical attention from regulatory instruments towards the organisational capabilities that enable regulators to deploy those instruments effectively. Third, it extends dynamic capabilities theory beyond private firms by demonstrating its explanatory value for understanding adaptive regulatory action within complex socio-technical systems. Fourth, it contributes to orchestration and platform governance research by clarifying how public regulators can coordinate fragmented innovation ecosystems without relying exclusively on hierarchical authority. Unlike responsible innovation, anticipatory governance, mission-oriented policy, or platform governance, which mainly explain normative principles, institutional arrangements, or governance

objectives, the proposed framework explains the organisational capabilities through which regulators orchestrate innovation systems.

The paper is organised as follows. Section 2 reviews the literature on innovation systems, immersive retail technologies, regulatory science, dynamic capabilities, and regulatory orchestration. Section 3 develops the conceptual framework of regulatory orchestrator capabilities in immersive retail innovation systems. Section 4 discusses the integrated framework and clarifies how regulatory capabilities, instruments, innovation-system functions, and responsible innovation outcomes are connected. Section 5 presents the theoretical and practical implications of the framework. Finally, section 6 concludes the paper and outlines a future research agenda.

2. Literature review

This section develops the theoretical foundations for conceptualising regulators as orchestrators within immersive retail innovation systems. The review does not treat innovation systems theory, regulatory science, dynamic capabilities, and orchestration as parallel literatures. Instead, it specifies how each tradition explains a different level of the phenomenon. Innovation systems theory explains the systemic functions through which innovation emerges; regulatory science explains the institutional and decision-making mechanisms through which public authorities evaluate and steer technological change; dynamic capabilities theory explains the organisational capacities required for purposeful adaptation under uncertainty; and orchestration research explains how heterogeneous actors are coordinated across ecosystems without relying solely on hierarchical authority. Bringing these perspectives together makes it possible to explain not only what regulatory instruments are available, but how regulators develop and deploy the organisational capabilities through which those instruments influence innovation-system evolution.

The review is organised into six parts. Section 2.1 revisits innovation systems theory and identifies the under-theorised role of regulators as intentional system actors. Section 2.2 explains why immersive retail constitutes a distinctive AI/XR innovation context rather than a generic instance of platform governance. Section 2.3 shifts from regulatory instruments to regulatory capabilities and connects the argument to regulatory science as a form of decision science. Section 2.4 explains why dynamic capabilities provide the missing organisational lens for understanding regulatory adaptation. Section 2.5 positions regulatory orchestration in relation to adjacent concepts, including regulatory intermediaries, mission-oriented governance, responsible innovation, experimental governance, anticipatory regulation, and platform governance. Section 2.6 integrates these arguments into the capability-based theoretical synthesis that informs the framework developed in the following section.

2.1. Innovation systems and the under-theorised role of regulators

Innovation systems theory has become a central perspective for explaining how technological innovation emerges through interactions among heterogeneous actors embedded in institutional environments (Freeman, 1987; Lundvall, 1992; Edquist, 1997). Rather than treating innovation as an isolated firm-level process, this perspective conceptualises innovation as a collective and interactive phenomenon shaped by knowledge flows, complementary resources, institutional arrangements, and learning relationships among firms, universities, intermediaries, policymakers, users, and civil society actors (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; Bergek et al., 2008). Innovation therefore depends not only on technological capabilities within individual organisations, but also on the quality of system-level interactions that enable experimentation, knowledge diffusion, legitimation, market formation, resource mobilisation, and directionality.

The functional approach to innovation systems is particularly relevant for the present paper because it shifts analytical attention from system structures to the processes through which innovation systems evolve (Hekkert et al., 2007; Bergek et al., 2008). Functions such as entrepreneurial experimentation, knowledge development, knowledge diffusion, market formation, legitimation, resource mobilisation, and guidance of the search explain how technological fields emerge, stabilise, and scale over time. Subsequent work has further shown that these functions are shaped by public and private actors whose activities interact across multiple institutional levels (Bergek, 2015; Edler and Fagerberg, 2017). This functional perspective provides a useful foundation for studying immersive retail because AI, XR, biometric analytics, spatial computing, and platform infrastructures develop through interdependent activities rather than linear technology-push processes.

Despite this systemic orientation, the role of regulators remains comparatively under-theorised. Regulation is usually treated as an institutional condition that constrains or enables innovation through standards, compliance requirements, market rules, or policy incentives (Blind, 2012; Blind et al., 2017; Edler and Fagerberg, 2017). Such work has generated valuable insights into how regulation affects innovation incentives and market outcomes, but it often treats regulators as external rule-setters rather than as organisations that actively learn, interpret, coordinate, and adapt. As a result, innovation systems theory explains where regulation matters in the system, but says less about how regulators develop the capabilities required to shape system functions intentionally.

Recent research in regulatory science and innovation begins to challenge this passive view. Regulatory agencies influence market access, category legitimacy, public perception, and non-market selection processes for novel products (Polidoro Jr., 2013). They can reduce uncertainty in the 'valley of death' between invention and commercialisation, act as innovation enablers (Roca, 2024), and, in some contexts, operate as catalytic actors whose review practices directly support the commercial transition of innovations while preserving public-interest safeguards (Boakye et al., 2026). These studies are important because they move beyond the idea that regulators merely impose costs or delays; they show that regulatory action can shape legitimacy, expectations, and the direction of technological development.

However, this emerging literature also exposes a theoretical gap. If regulators can influence innovation-system functions, then their contribution cannot be explained solely by the existence of laws, standards, or review procedures. It also depends on their capacity to sense emerging developments, interpret uncertain evidence, convene distributed expertise, design experimental governance arrangements, and adjust regulatory responses over time. These are organisational capabilities. Innovation systems theory therefore provides the system-level foundation for the argument, but must be complemented by perspectives that explain regulatory decision-making, capability development, and ecosystem coordination. Immersive retail makes this need especially visible because it combines technological convergence, consumer vulnerability, platform power, and rapidly evolving data practices.

2.2. Immersive retail as an AI/XR innovation system

Immersive retail represents more than the digitalisation of retail channels. It is an emerging AI/XR innovation system in which artificial intelligence, augmented and virtual reality, metaverse environments, spatial computing, biometric sensing, affective analytics, and platform infrastructures converge to create persistent, interactive, and highly personalised consumer experiences (Xi and Hamari, 2021; Caboni and Pizzichini, 2022, 2023; Kim and Choo, 2023; Gleim et al., 2025; Alexander et al., 2025). These technologies transform how consumers search for information, evaluate products, interact with brands, and move between physical and virtual retail spaces (Cao, 2021). Innovation in this domain is therefore not produced by retailers alone, but by a wider ecosystem of platform providers, technology developers, data brokers, payment providers, standards organisations, research institutions, advertisers, consumer groups, and public authorities.

The innovation-system character of immersive retail is reinforced by platform and ecosystem dynamics. Digital platforms organise access to data, interfaces, complements, standards, and user communities, thereby shaping the incentives and opportunities of retailers and technology suppliers (Gawer, 2014; Jacobides et al., 2018; Nooren et al., 2018). In immersive environments, these dynamics become more consequential because control over spatial interfaces, identity systems, biometric data streams, content moderation, payment infrastructures, and interoperability standards can influence both market formation and consumer agency. Platform governance research has shown how platforms exercise private ordering through rules, algorithms, data access, and moderation practices (Gillespie, 2018; Gorwa, 2019; van Dijck et al., 2018). Yet immersive retail also involves embodied and affective consumer interaction, making the governance challenge broader than conventional platform regulation (Cao, 2021).

The risks associated with immersive retail are therefore systemic rather than merely additive. AI-driven personalisation and dynamic pricing may reproduce bias, discrimination, and opaque decision-making (Barocas and Selbst, 2016; Mittelstadt et al., 2016; Yeung, 2018). Immersive interfaces can intensify behavioural manipulation because spatial presence, haptic feedback, emotional engagement, and real-time adaptation make persuasive design harder for consumers to detect or resist (Susser et al., 2019). Biometric and affective computing systems expand the scope of data collection by tracking faces, eye movements, physiological responses, emotions, gait, and other bodily signals, raising concerns about surveillance, autonomy, consent, and the commodification of intimate data (Lewinski et al., 2016; De Keyser et al., 2021; Garaus et al., 2021; McStay, 2020; Menges, 2025). Security and trustworthiness concerns are also heightened by adversarial attacks, spatial-data vulnerabilities, and robustness failures in real-time immersive systems (Dwivedi et al., 2023; Lowry et al., 2025).

These risks differ from those found in ordinary e-commerce because immersive retail combines AI personalisation with spatial presence, sensory salience, biometric inference, and platform control within consumer decision environments. It therefore requires a governance framework that accounts for convergence across data protection, consumer law, competition policy, product safety, advertising regulation, children's rights, accessibility, and AI governance. Regulators cannot rely only on ex post enforcement or isolated risk assessment. They must build technical understanding of evolving systems, coordinate across domains, and create settings in which firms, experts, and publics can surface risks before they become embedded in dominant designs. Immersive retail therefore provides an analytically demanding context for examining regulators as orchestrators of innovation-system functions.

2.3. From regulatory instruments to regulatory capabilities

Regulatory science offers the institutional basis for understanding how public authorities assess, legitimize, and guide technological innovation. In the realm of emerging technologies, it transcends the mere application of fixed rules to stable entities. Instead, it involves decision-making under conditions of uncertainty, establishing evaluative standards, interpreting incomplete evidence, and balancing innovation with safety, fairness, accountability, and public trust. This understanding connects directly with Jasanoff's (1995) view of regulatory science as decision science, where procedural choices, evidentiary standards, and institutional judgments influence societal perceptions of acceptable risk.

Within innovation-oriented regulation, regulatory agencies are increasingly understood as active participants in innovation landscapes rather than neutral filters positioned at the end of a development pipeline. Regulatory review decisions affect the speed, delay, legitimacy, and market survival of new products (Boakye et al., 2022). Regulatory categories and certifications influence how novel products are interpreted by markets and institutional audiences (Polidoro Jr., 2013). Regulators can also mitigate uncertainty for innovators during the transition from technological promise to commercial adoption and can act as innovation enablers when they provide guidance, interpretive clarity, and credible pathways to market (Roca, 2024).

The catalytic regulatory framework proposed by Boakye et al. (2026) further extends this view by conceptualising regulatory agencies as actors that may accelerate innovation through review practices, collaboration, and market-transition support.

Digital and AI governance literatures have expanded the regulatory toolbox through risk-based regulation, algorithmic audits, impact assessments, transparency duties, certification schemes, standards, codes of conduct, post-market monitoring, regulatory sandboxes, testbeds, and adaptive regulatory frameworks (Zetzsche et al., 2017; Ranchordás, 2021; OECD, 2020; OECD, 2023; Kaminski, 2021; Laine et al., 2024; Selbst, 2021; Yordanova and Bertels, 2023; Novelli et al., 2026). Empirical work on regulatory sandboxes is particularly important because it shows that instruments operate through social interaction and knowledge exchange, not only through formal authorisation (Lee and Seo, 2022). Alaassar et al. (2020) show that regulator-regulatee interactions within sandboxes can increase innovators' legitimacy, regulatory knowledge, and risk-management capabilities, while also improving regulators' understanding of technological constraints, emerging risks, and innovators' support needs. In this sense, sandboxes are not merely legal exemptions or testing venues; they are interactional infrastructures through which regulators and innovators co-produce knowledge. This insight is highly relevant for immersive retail because regulators cannot fully understand AI/XR risks by observing final products alone. They require structured proximity to development processes, technical experiments, user-experience designs, and data-governance practices.

Nevertheless, the availability of instruments does not itself explain effective regulation. Sandboxes can suffer from opacity, unequal access, weak public participation, capture risks, and limited scalability (Ranchordás, 2021; Johnson, 2023; Yaksan, 2024). Audits and impact assessments may become procedural tick-box exercises if regulators lack the expertise and authority to interpret, challenge, and enforce them (Ananny and Crawford, 2018; Selbst, 2021). Co-regulation can mobilise industry expertise but may reproduce power asymmetries when accountability mechanisms are weak (Marsden, 2011; Saurwein et al., 2015). These limitations point to the distinction at the centre of this paper: regulatory instruments are formal mechanisms of intervention, whereas regulatory capabilities are organisational capacities that determine how those mechanisms are selected, combined, interpreted, monitored, and adapted under uncertainty.

This distinction clarifies why two agencies with similar legal powers may achieve different governance outcomes. One regulator may operate a sandbox as a narrow compliance exemption, while another may use it as a structured learning system that connects firms, technical experts, consumer representatives, and other agencies. One authority may require algorithmic audits without meaningful follow-up, while another may combine audits with technical review, post-market surveillance, public reporting, and enforcement. Regulatory performance therefore depends not only on the instrument portfolio, but also on capabilities for sensing, sensemaking, experimentation, stakeholder coordination, reflexive evaluation, and resistance to capture (Carpenter and Moss, 2013).

2.4. Dynamic capabilities and public regulatory organisations

Dynamic capabilities theory provides the organisational lens needed to explain how regulators adapt under uncertainty. Originally developed to understand how firms sustain advantage in rapidly changing environments, dynamic capabilities refer to the capacities through which organisations integrate, build, and reconfigure internal and external resources in response to environmental change (Teece et al., 1997; Teece, 2007). Teece (2007) conceptualises this process through sensing

opportunities and threats, seizing opportunities through organisational response, and transforming or reconfiguring resources and routines over time. Later work emphasises the relevance of dynamic capabilities in contexts marked by technological discontinuity, distributed knowledge, ecosystem interdependence, and business-model change (Teece, 2018). Recent knowledge-based interpretations further show that dynamic capabilities help organisations generate, integrate, and reconfigure knowledge across boundaries when managing paradoxical tensions such as experimentation and control (Pascucci et al., 2024).

Although the theory originated in strategic management, its basic logic is not limited to private firms. Public organisations also face changing environments, distributed expertise, resource constraints, stakeholder pressures, and the need to adapt routines without abandoning legitimacy or accountability (Piening, 2013; Meijer, 2015; Glyptis et al., 2020). The translation of dynamic capabilities into regulatory contexts therefore requires a change in purpose rather than a change in theoretical logic. Regulators do not develop dynamic capabilities to secure competitive advantage. They develop them to achieve public objectives such as safety, fairness, consumer protection, innovation quality, legitimacy, accountability, and societal alignment under conditions of technological uncertainty.

In regulatory organisations, sensing involves identifying emerging technologies, business models, risks, social expectations, and regulatory blind spots through horizon scanning, expert networks, platform monitoring, stakeholder consultation, complaint analysis, and sandbox participation (Marchant, 2011; Johnson, 2023; Ahern, 2025). Seizing involves designing appropriate regulatory responses, such as adaptive guidance, sandbox protocols, tailored authorisations, enhanced scrutiny for high-risk practices, cross-agency task forces, or new standards (Ranchordás, 2021; Gleiss et al., 2023; Novelli et al., 2026). Transforming involves learning from regulatory interventions, revising rules, reorganising internal expertise, and institutionalising feedback loops through ex post reviews, post-market surveillance, and recursive rule-making (Rangoni and Zeitlin, 2021; Yang et al., 2024).

The relevance of dynamic capabilities for regulatory science is reinforced by recent empirical evidence. Cerchione et al. (2026), in their study of Industry 5.0 technologies and the nexus between SMEs and regulators, show that regulatory actors shape organisational adoption by establishing conditions of stability, directionality, legitimacy, and capability formation. Their findings are important because they link regulation, institutional signals, and dynamic capabilities in a context where firms must translate regulatory expectations into everyday routines, human skills, and technological governance. For immersive retail, a similar logic applies: regulators influence not only compliance decisions, but also how retailers and platforms interpret responsible AI/XR adoption, organise data practices, develop technical expertise, and build consumer-protection safeguards.

However, dynamic capabilities theory alone is insufficient for explaining regulatory orchestration. It accounts for organisational adaptation, but less directly explains how an organisation uses its capabilities to coordinate multiple autonomous actors across an ecosystem. Regulatory agencies rarely govern immersive retail through hierarchical control alone. They must work through platforms, retailers, technology developers, standards bodies, auditors, consumer organisations, competition authorities, data protection authorities, and international counterparts. This ecosystem-level coordination problem requires an orchestration perspective.

2.5. Regulatory orchestration and adjacent governance concepts

Orchestration research explains how complex systems can be coordinated when no single actor possesses complete hierarchical authority. In innovation networks, orchestration involves aligning heterogeneous actors, facilitating knowledge exchange, managing complementarities, reducing coordination costs, and sustaining legitimacy across interdependent organisations (Dhanaraj and Parkhe, 2006; Nambisan and Sawhney, 2011). In global and regulatory governance, orchestration describes indirect forms of steering through which public authorities or international organisations mobilise intermediaries, incentives, standards, and collaborative arrangements to influence target actors (Abbott et al., 2015). In innovation ecosystems, orchestrators may include platform leaders, intermediaries, innovation agencies, industry associations, or public bodies that convene stakeholders and structure collective action (Howells, 2006; Klerkx and Aarts, 2013; Kivimaa et al., 2019).

The orchestration perspective is useful for immersive retail because the relevant governance challenges cut across regulatory domains and organisational boundaries. AI-driven personalisation implicates data protection, anti-discrimination, consumer law, advertising standards, and competition policy. XR interfaces raise questions of product safety, accessibility, psychological manipulation, content moderation, and user rights. Biometric and affective analytics connect privacy, labour, retail analytics, marketing ethics, and human dignity. Platform-mediated metaverse retail adds interoperability, gatekeeper power, data access, and cross-border enforcement challenges (Nooren et al., 2018; Goldberg and Schär, 2023; Hacker et al., 2024). Regulatory orchestration therefore involves aligning fragmented domains into a coherent governance architecture while maintaining responsiveness to technological change.

This argument must be positioned carefully against adjacent literatures. Regulatory intermediaries research explains how third parties help regulators influence target actors, but pays less attention to the internal capabilities regulators require to select, supervise, and learn through intermediaries (Howells, 2006; Abbott et al., 2015). Mission-oriented governance explains how public actors define societal missions and mobilise innovation around them, but is less specific about the microfoundations of regulatory agency within fast-moving digital markets (Mazzucato, 2018). Responsible innovation foregrounds anticipation, inclusion, reflexivity, and responsiveness, but often remains normative unless linked to organisational capabilities and instruments that operationalise these principles (Stilgoe et al., 2013; Von Schomberg, 2013). Experimental governance and anticipatory regulation explain iterative learning and foresight under uncertainty, but do not fully explain why some regulatory agencies are better able than others to convert experiments into durable institutional capacity (Guston, 2014; Sabel and Zeitlin, 2012; Ranchordás, 2021). Platform governance clarifies how digital platforms govern users and markets, and how public authorities may regulate platforms, but it does not sufficiently theorise the public-sector capabilities required to govern platformised innovation ecosystems (Gillespie, 2018; Gorwa, 2019; van Dijck et al., 2018).

The capability-based orchestration perspective developed here complements rather than replaces these literatures. Its distinctive contribution is to explain orchestration as a capability-based phenomenon in innovation systems. Governance arrangements describe the institutional architecture through which coordination may occur; regulatory instruments describe the mechanisms through which intervention is operationalised; but regulatory capabilities explain how regulators activate, combine, and adapt those arrangements and instruments in practice. This distinction is especially important in immersive retail, where the same nominal instrument - for example, a sandbox, audit, code of conduct, or impact assessment - can produce very different outcomes depending on how regulators design participation, integrate knowledge, monitor learning, include affected publics, and coordinate across agencies.

Accordingly, the remaining theoretical gap is not simply that regulators matter, nor that collaborative governance is needed. The gap is that existing research provides limited explanation of the organisational capabilities through which regulators enact orchestration in complex innovation systems. A capability-based view addresses this gap by asking how regulators sense emerging risks and opportunities, seize them through experimental and collaborative arrangements, coordinate fragmented actors and domains, and transform governance practices

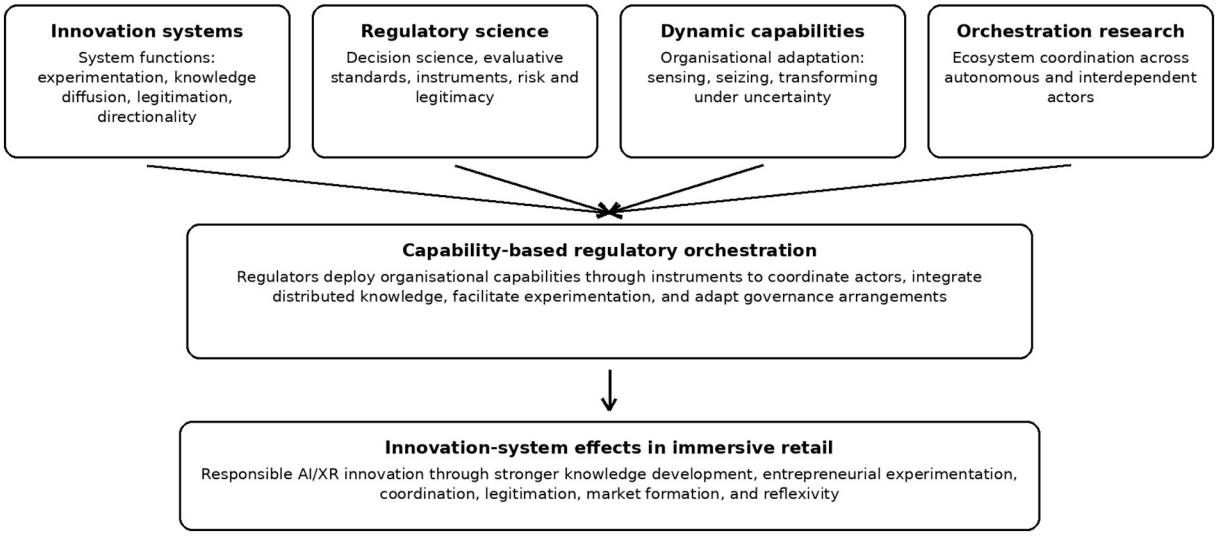

Fig. 1. Theoretical synthesis underpinning capability-based regulatory orchestration.
(Source: Authors' own elaboration)

through reflexive learning. This provides the bridge between regulatory science and innovation systems theory.

2.6. Towards a capability-based theory of regulatory orchestration

The preceding review shows that no single theoretical perspective is sufficient on its own. Innovation systems theory explains the functions through which innovation systems develop, but it under-specifies the organisational agency of regulators. Regulatory science explains decision-making, evaluative standards, and instruments, but often gives less attention to the capabilities through which instruments are deployed. Dynamic capabilities theory explains organisational adaptation, but must be translated from private competitive advantage to public regulatory value. Orchestration research explains ecosystem coordination, but often focuses on governance arrangements rather than the capabilities that make coordination possible. Integrating these perspectives therefore provides a stronger theoretical foundation than any one of them could provide independently.

This synthesis rests on three theoretical assumptions. First, regulators are capability-bearing organisational actors, not merely institutional environments or legal authorities. Their ability to influence innovation-system functions depends on internal and relational capacities for knowledge generation, judgement, coordination, experimentation, and learning. Second, regulatory instruments and regulatory capabilities are analytically distinct. Instruments such as sandboxes, audits, impact assessments, standards, codes of conduct, and post-market monitoring are carriers or sites of regulatory action; capabilities are the organisational capacities that determine how these instruments are interpreted, combined, and adapted. Third, orchestration is not simply a governance arrangement but a dynamic capability-based process through which regulators coordinate heterogeneous actors, integrate distributed knowledge, and shape innovation trajectories under uncertainty.

Building on these assumptions, we define regulatory orchestration as the purposeful deployment of organisational capabilities through which regulators coordinate heterogeneous actors, integrate distributed knowledge, facilitate experimentation, and continuously adapt governance arrangements under conditions of technological uncertainty. This definition clarifies why the paper's contribution is not a general governance overview of immersive retail. Rather, it is a capability-based theory of how regulators influence innovation-system functions in an AI/XR domain marked by platform power, embodied consumer interaction, data intensity, and uncertain harms.

The proposed framework identifies five mutually reinforcing regulatory orchestrator capabilities. Sensing and sensemaking allow regulators to detect technological signals, interpret emerging risks, and anticipate societal expectations. Experimental and adaptive capability enables regulators to create controlled spaces for learning, testing, and iterative rule development. Co-creation and boundary-spanning capability supports knowledge exchange among regulators, firms, platforms, experts, consumers, and civil society. Orchestration and coordination capability enables alignment across fragmented legal domains, agencies, standards, and jurisdictions. Reflexive learning and meta-regulatory capability supports evaluation, feedback, rule revision, and the governance of self- and co-regulatory arrangements. Together, these capabilities shape innovation-system functions such as knowledge development, entrepreneurial experimentation, directionality, legitimation, market formation, coordination, and system reflexivity (Hekkert et al., 2007; Bergek et al., 2008).

This synthesis advances the literature in three ways. It extends innovation systems theory by specifying regulators as active organisational actors that shape system functions. It advances regulatory science by shifting attention from instruments to the capabilities that make instruments effective. It extends dynamic capabilities theory by translating sensing, seizing, and transforming into a public-sector regulatory context oriented towards public value rather than competitive advantage. The following section builds on this synthesis by developing the conceptual framework of regulatory orchestrator capabilities in immersive retail innovation systems.

Fig. 1 summarises this theoretical synthesis by showing how the four literature streams jointly motivate a capability-based account of regulatory orchestration.

3. Conceptual framework: Regulatory orchestrator capabilities in immersive retail

Building upon the theoretical synthesis presented in Section 2, this section delineates the paper's conceptual framework. The framework articulates the capability-based mechanisms through which regulatory agencies may influence the functions of innovation systems within immersive retail environments. Three assumptions guide the model. First, regulators are capability-bearing organisational actors whose influence depends on expertise, judgement, routines, and relational capacity, not only on formal legal authority. Second, regulatory instruments - such as sandboxes, audits, impact assessments, standards, codes of conduct, and cross-agency forums - are enactment sites through

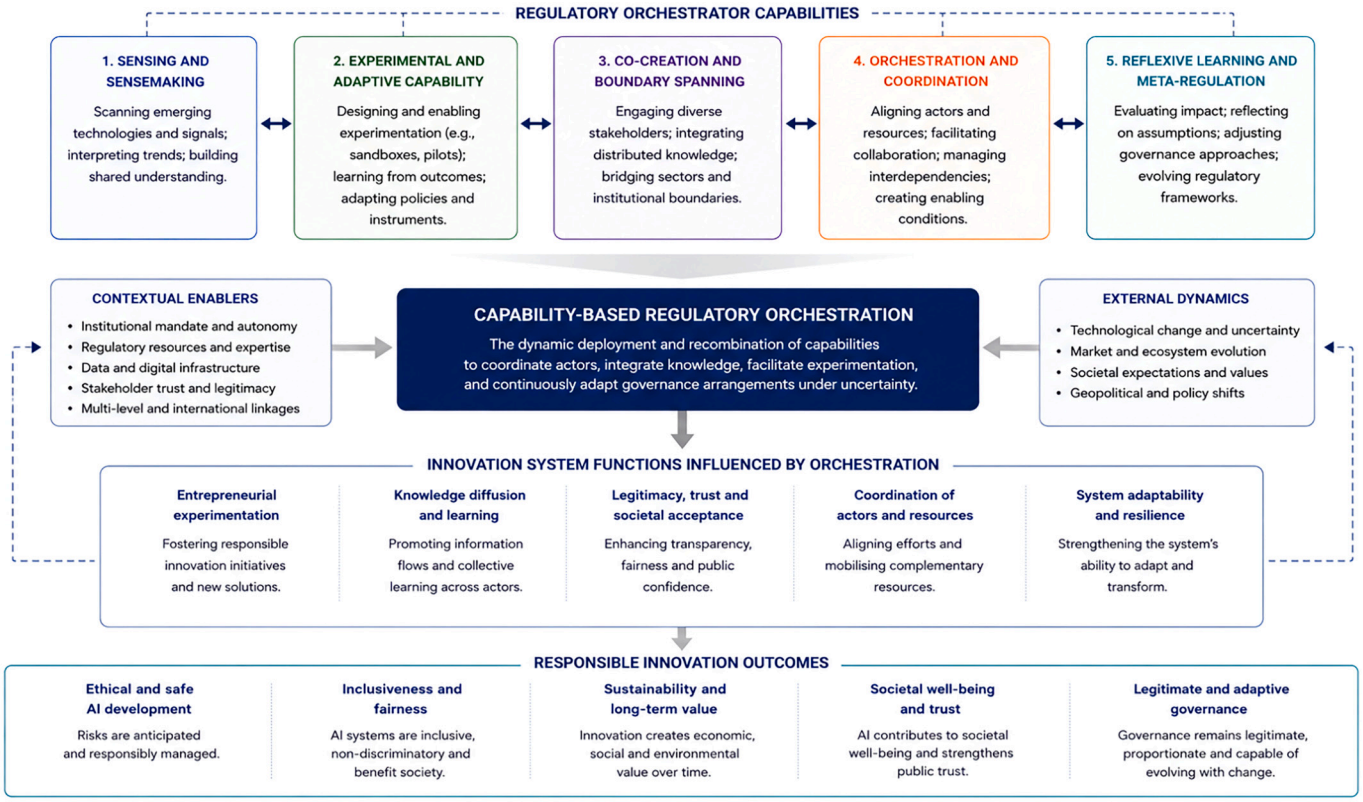

Fig. 2. Capability-based regulatory orchestration framework for immersive retail.
(Source: Authors' own elaboration)

which capabilities are deployed, but they are not capabilities in themselves. Third, orchestration is treated as a dynamic, capability-based process through which regulators coordinate heterogeneous actors, integrate distributed knowledge, facilitate experimentation, and reconfigure governance arrangements under uncertainty.

This framing extends the argument that immersive retail is a suitable empirical and theoretical context because AI-driven personalisation, XR interfaces, biometric and affective analytics, spatial computing, and platform infrastructures converge directly within consumer decision environments. As a result, governance problems are not only legal or technological; they are systemic problems of knowledge, coordination, legitimacy, and learning. Fig. 2 visualises this logic by linking contextual uncertainty, regulatory orchestrator capabilities, the instruments through which those capabilities are enacted, the innovation-system functions affected, and the responsible innovation outcomes expected. The figure is therefore intended to clarify relationships, and the following subsections focus on the mechanisms and propositions that connect each capability to innovation-system dynamics. Bidirectional arrows indicate reciprocal interactions among capabilities, whereas dashed lines represent continuous feedback and adaptive learning processes.

The framework connects the organisational level of regulatory capability to the system level of innovation-system functions. Innovation-system theory identifies functions such as knowledge development, entrepreneurial experimentation, knowledge diffusion, market formation, legitimation, resource mobilisation, directionality, coordination, and reflexivity (Hekkert et al., 2007; Bergek et al., 2008). In immersive retail, these functions are shaped by how regulators

Table I
Regulatory orchestrator capabilities and innovation-system functions.

Capability	Primary regulatory task	Illustrative enactment instruments	Primary innovation-system functions	Proposition
Sensing and sensemaking	Detect, interpret, and prioritise technological signals, risks, and societal expectations.	Horizon scanning; expert panels; complaint monitoring; sandbox observation; platform-data monitoring.	Knowledge development; guidance of the search; legitimation.	P1
Experimental and adaptive capability	Create controlled settings for learning, testing, and iterative rule development.	Regulatory sandboxes; pilots; testbeds; temporary waivers; adaptive guidance.	Entrepreneurial experimentation; uncertainty reduction; market formation.	P2
Co-creation and boundary-spanning	Integrate distributed expertise and translate expectations across firms, platforms, regulators, experts, and publics.	Multi-stakeholder forums; living labs; co-regulatory codes; standards workshops; boundary objects.	Knowledge diffusion; resource mobilisation; standard formation; legitimation.	P3
Orchestration and coordination	Align fragmented legal domains, agencies, standards, and jurisdictions.	Inter-agency task forces; memoranda of understanding; regulatory mapping; harmonised standards.	Coordination; directionality; market formation; fragmentation reduction.	P4
Reflexive learning and meta-regulation	Evaluate interventions, revise rules, and govern self- and co-regulatory arrangements.	Post-market monitoring; ex post evaluation; algorithmic impact assessments; audit follow-up; recursive rulemaking.	System reflexivity; learning; accountability; reconfiguration.	P5

Source: Authors' own elaboration.

interpret emerging risks, support controlled experimentation, convene actors, align fragmented legal domains, and institutionalise learning. Dynamic capabilities theory provides the organisational microfoundation for this process, while orchestration research explains how these capacities are exercised across ecosystems without relying exclusively on hierarchy. Recent work on digital innovation ecosystems similarly shows that orchestration should not be reduced to governance structures alone, because sensing, seizing, and reconfiguring routines are needed to coordinate evolving digital ecosystems (Kindermann et al., 2024; **Khizar et al.,** 2025).

Table I summarises the framework's operational logic. Each capability has a primary regulatory task, is enacted through a set of instruments, and affects specific innovation-system functions. The mapping is analytical rather than deterministic: the same instrument can enact different capabilities depending on how regulators use it. For example, a sandbox can be a narrow compliance exemption, a sensing infrastructure, an experimental learning venue, or a boundary-spanning forum. This distinction responds directly to the paper's central theoretical claim: regulatory value depends less on the mere presence of instruments than on regulators' capacity to deploy, combine, and adapt them.

3.1. Sensing and sensemaking capability

Sensing and sensemaking refer to regulators' capacity to detect, interpret, and prioritise technological trajectories, emerging risks, and societal expectations before they become embedded in dominant market designs. In immersive retail, this capability is especially important because relevant signals emerge from the convergence of AI inference, spatial interface design, biometric and affective data, platform infrastructures, and situated consumer behaviour. Horizon scanning, foresight exercises, technical expert networks, consumer-complaint analysis, platform monitoring, and sandbox observation allow regulators to transform dispersed signals into shared regulatory problem definitions. In this way, sensing and sensemaking support knowledge development, guidance of the search, and legitimation within the innovation system (Hekkert et al., 2007; Bergek et al., 2008).

This capability also clarifies why immersive retail is not simply a subcase of digital platform governance. A misleading recommendation, a biased dynamic price, or a manipulative interface cue may be present in ordinary e-commerce, but immersive environments can combine these risks with spatial presence, emotional salience, biometric inference, and real-time behavioural adaptation. Regulators therefore need sensemaking routines that connect technical evidence with consumer-protection, competition, accessibility, data-protection, and public-value concerns. Regulatory science becomes decision science at precisely this point: regulators must decide which emerging signals deserve attention, which uncertainties require experimentation, and which practices require immediate constraints.

Proposition 1. *The stronger regulators' sensing and sensemaking capability, the more likely immersive retail innovation systems are to develop legitimate and socially aligned expectations about acceptable AI/XR applications.*

3.2. Experimental and adaptive capability

Experimental and adaptive capability refers to regulators' capacity to design controlled spaces for testing, learning, and iterative rule development. Regulatory sandboxes, pilots, testbeds, temporary waivers, and adaptive guidance are relevant not because they relax rules per se, but because they allow regulators and innovators to test assumptions about technological performance, consumer harm, data governance, transparency, and market readiness under supervised conditions. Evidence from regulatory sandbox research shows that regulator-regulatee interaction can increase innovators' legitimacy, regulatory knowledge, and risk-management capability while improving regulators' understanding of technological constraints, support needs, and emerging risks (Alaassar et al., 2020; Lee and Seo, 2022). Recent work on AI Act sandboxes likewise emphasises regulatory learning, multi-agency coordination, realistic testing, risk-classification updates, and post-testing transition support (Novelli et al., 2026).

For immersive retail, experimentation is particularly valuable because harms may be difficult to identify through ex ante legal analysis alone. Spatial manipulation, emotional AI, biometric profiling, children's exposure to immersive advertising, and algorithmic discrimination may only become visible when technologies are tested in realistic consumer journeys. Experimental and adaptive capability therefore supports entrepreneurial experimentation while reducing regulatory uncertainty. It also prevents sandboxes from becoming symbolic innovation-friendly labels: their value depends on how regulators define eligibility, specify safeguards, include affected stakeholders, collect evidence, and translate lessons into broader guidance or rule revision.

Proposition 2. *The stronger regulators' experimental and adaptive capability, the more effectively immersive-tech sandboxes and pilot regimes will enable safe experimentation while reducing regulatory uncertainty for innovators.*

3.3. Co-creation and boundary-spanning capability

Co-creation and boundary-spanning capability refers to regulators' capacity to convene and integrate knowledge across actors that possess different forms of expertise, authority, and vulnerability. Immersive retail ecosystems involve retailers, platform providers, technology developers, data brokers, payment providers, standards organisations, auditors, consumer organisations, accessibility advocates, civil society groups, researchers, and multiple public agencies. Because no single actor can fully understand the technological, legal, ethical, and experiential implications of AI/XR retail, regulators need routines for translating knowledge across communities. Boundary objects such as risk taxonomies, testing protocols, audit templates, design principles, and shared standards can help stakeholders coordinate without eliminating their different interests.

This capability should not be confused with uncritical co-regulation or industry self-regulation. Boundary-spanning creates value only when regulators can manage information asymmetries, protect public-interest objectives, and prevent dominant platforms from defining acceptable risk on their own terms. The additional literature on catalytic regulatory review is helpful here because it shows that regulatory agencies can become active contributors to innovation processes through bundles of collaborative, review, and market-transition practices, rather than remaining external gatekeepers (Boakye et al., 2026). In immersive retail, co-creation can therefore support knowledge diffusion, standard formation, resource mobilisation, and legitimacy while preserving accountability.

Proposition 3. *The stronger regulators' co-creation and boundary-spanning capability, the more effectively immersive retail ecosystems will develop shared standards, credible safeguards, and multi-stakeholder alignment around responsible AI/XR innovation.*

3.4. Orchestration and coordination capability

Orchestration and coordination capability refers to regulators' capacity to align fragmented legal domains, agencies, standards, and jurisdictions into a coherent governance architecture. Immersive retail cuts across data protection, consumer law, competition policy, advertising regulation, product safety, children's rights, accessibility, cybersecurity, and AI governance. Without coordination, innovators face fragmented expectations and consumers face uneven protection. Coordination mechanisms such as inter-agency task forces, memoranda of understanding, joint guidance, harmonised standards, regulatory

mapping, shared technical expertise, and international cooperation enable regulators to reduce fragmentation while preserving the specialised mandates of different authorities.

This capability is also where the proposed framework differs most clearly from platform governance models. Platform governance explains how private platforms organise users, complementors, data access, interfaces, and market rules. Regulatory orchestration instead concerns how public authorities coordinate the public governance of platformised innovation ecosystems. This distinction matters in immersive retail because dominant platforms may possess privileged access to behavioural, biometric, interface, and market data. Regulators need coordination capability to counterbalance epistemic and infrastructural power, align public values across domains, and provide clearer directionality for ecosystem actors (Nooren et al., 2018; Hacker et al., 2024).

Proposition 4. *The stronger regulators' orchestration and coordination capability, the more effectively immersive retail innovation systems will mitigate regulatory fragmentation and develop coherent directionality for responsible AI/XR governance.*

3.5. Reflexive learning and meta-regulatory capability

Reflexive learning and meta-regulatory capability refers to regulators' capacity to evaluate interventions, learn from outcomes, revise governance approaches, and supervise self- or co-regulatory arrangements. In fast-moving immersive environments, rules and instruments can become obsolete if they are not connected to feedback loops. Ex post evaluation, post-market monitoring, algorithmic impact assessments, audit follow-up, public reporting, incident analysis, and recursive rulemaking allow regulators to determine whether sandboxes, audits, standards, or codes of conduct are producing public value or merely procedural compliance (Black, 2008; Rangoni and Zeitlin, 2021; Laine et al., 2024).

Meta-regulation is particularly relevant because immersive retail governance will often rely on hybrid arrangements involving platforms, standards bodies, auditors, certification providers, and industry codes. Regulators therefore need the capability to govern these governance mechanisms: setting expectations, monitoring performance, correcting failures, and limiting capture. This transforms regulatory instruments from one-off interventions into learning infrastructures. It also aligns the framework with dynamic capabilities theory: sensing identifies emerging signals, experimental and boundary-spanning capabilities seize learning opportunities, and coordination plus reflexive meta-regulation reconfigure the governance system over time (Teece, 2007; Piening, 2013; Cerchione et al., 2026).

Proposition 5. *The stronger regulators' reflexive learning and meta-regulatory capability, the more effectively immersive retail governance will adapt to technological evolution while maintaining accountability, legitimacy, and public-value alignment.*

3.6. Recursive interaction among capabilities

The five capabilities are analytically distinct but operationally recursive. Sensing and sensemaking identify emerging issues; experimentation tests regulatory and technological assumptions; co-creation and boundary spanning integrate distributed expertise; orchestration and coordination translate learning across fragmented domains; and reflexive learning updates both the regulatory knowledge base and the design of future interventions. The sequence is therefore not linear. A sandbox may generate new risk signals that reshape sensing priorities; an audit may reveal the need for new standards; cross-agency coordination may expose capability gaps inside regulatory organisations; and stakeholder engagement may alter the legitimacy conditions under which an innovation can scale.

The framework's contribution is thus conceptual integration and theory extension. It extends innovation systems theory by specifying the organisational capabilities through which regulators influence system functions. It advances regulatory science by explaining why instruments create value only when regulators possess the capabilities to interpret, combine, and adapt them. It extends dynamic capabilities theory by translating sensing, seizing, and transforming into a public regulatory context oriented towards public value rather than competitive advantage. Finally, it extends orchestration research by showing that regulatory orchestration in immersive retail is not merely a structural governance arrangement, but a capability-based process through which public authorities shape the legitimacy, directionality, experimentation, coordination, and reflexivity of AI/XR innovation systems.

4. Discussion of integrated framework

The integrated framework explains how regulatory orchestration operates within immersive retail innovation systems by linking regulatory capabilities to innovation-system functions. Rather than treating regulation as an external constraint or a set of isolated instruments, the framework shows how regulators shape the conditions under which innovation becomes legitimate, experimental, coordinated, and socially aligned. Its central contribution is therefore to specify the organisational mechanisms through which regulatory action affects system-level processes such as knowledge development, entrepreneurial experimentation, legitimation, market formation, coordination, and reflexive learning (Hekkert et al., 2007; Bergek et al., 2008).

This interpretation strengthens the paper's alignment with regulatory science and innovation studies. The framework shifts attention from the existence of regulatory tools to the organisational conditions under which those tools create public value. This is consistent with work that treats regulatory agencies as actors shaping innovation trajectories, market expectations, legitimacy, and uncertainty reduction rather than only as sources of delay or constraint (Boakye et al., 2022; Roca, 2024). A regulatory sandbox, for example, may support entrepreneurial experimentation only when regulators can select participants transparently, elicit technical and consumer knowledge, monitor emerging risks, and translate experimental evidence into broader guidance. Similarly, audits, impact assessments, standards, and codes of conduct become consequential only when regulators can interpret evidence, challenge information asymmetries, coordinate follow-up action, and learn from implementation.

The framework also clarifies why immersive retail requires more than a generic platform-governance model. In AI/XR retail, platform power intersects with embodied interaction, biometric and affective data, spatial interfaces, real-time personalisation, and consumer decision environments. These features create epistemic asymmetries because dominant platforms and technology providers often possess deeper knowledge than regulators, retailers, consumers, or civil society about how immersive systems operate. Regulatory orchestration therefore has a corrective function: it helps regulators build knowledge infrastructures, convene countervailing expertise, and coordinate interventions across data protection, consumer law, competition policy, advertising regulation, product safety, and AI governance.

Fig. 2 advances this argument by visualising the recursive relationship among regulatory capabilities, instruments, innovation-system functions, and responsible innovation outcomes. The model is not linear. Sensing and sensemaking identify emerging risks and opportunities; experimentation tests governance responses; co-creation and boundary spanning integrate distributed knowledge; orchestration and coordination align fragmented domains; and reflexive learning feeds evidence back into future regulatory action. This recursive structure reflects the adaptive logic of dynamic capabilities, translated here from firm-level adaptation to public regulatory action oriented towards public value (Teece, 2007; Piening, 2013).

Taken as a whole, the framework specifies the microfoundations of regulatory agency in innovation systems. Innovation systems theory explains the functions through which innovation develops, regulatory

science explains the instruments and evaluative practices through which public authorities intervene, and dynamic capabilities theory explains how organisations adapt under uncertainty. The proposed framework connects these levels by showing how regulators' sensing, experimental, co-creative, coordinative, and reflexive capabilities translate regulatory action into system-level effects. In this respect, it complements responsible innovation, experimental governance, and anticipatory regulation by specifying the organisational capabilities through which anticipation, inclusion, experimentation, and responsiveness are made operational in regulatory practice (Ranchordás, 2021; Johnson, 2023).

5. Theoretical and practical implications

Although immersive retail is rapidly emerging through AI-driven personalisation, VR/AR interfaces, and metaverse-based customer experiences, there remains only a fragmented understanding of how these socio-technical systems are governed. Innovation systems theory recognises the systemic nature of technological development (Hekkert et al., 2007; Bergek et al., 2008), yet regulators continue to be conceptualised primarily as external constraints rather than as system actors capable of shaping technological directionality (Blind, 2012; Edler and Fagerberg, 2017). This is problematic because immersive retail ecosystems are characterised by heightened complexity, including converging AI/VR/AR systems, biometric analytics, consumer protection concerns, and platform concentration. These dynamics require regulatory agencies to act not merely as rule-enforcers but as orchestrators who coordinate actors, manage uncertainty, and guide innovation trajectories.

Similarly, regulatory science has expanded to include instruments such as sandboxes, audits, impact assessments, and risk-based frameworks (Ranchordás, 2021; Zetzsche et al., 2017), but has seldom examined the organisational capabilities required for regulators to deploy these tools effectively in immersive retail contexts (Johnson, 2023; Novelli et al., 2026). Most studies focus on instruments in isolation and do not sufficiently conceptualise the systemic role of regulators in enabling innovation-system functions such as legitimation, experimentation, coordination, and reflexivity. Dynamic capabilities theory (Teece et al., 1997; Teece, 2007) offers a promising foundation for rethinking regulatory agency in rapidly evolving technological environments, but its application to regulatory bodies remains underdeveloped (Piening, 2013; Meijer, 2015).

Against this background, the framework extends innovation systems theory by conceptualising regulators as active participants whose capabilities shape innovation trajectories, rather than simply as constraints. In this way, regulators are interpreted as active co-enablers of innovation systems. Second, the framework extends the scope of dynamic capabilities theory by translating sensing, experimentation, coordination, and reconfiguration into a public-sector regulatory context (Teece, 2007; Piening, 2013). Capabilities traditionally associated with firms take on a collective and public-value-oriented form when applied to complex digital ecosystems. Third, the study connects regulatory science with innovation systems by showing how regulatory tools perform system-level functions such as legitimation, experimentation, coordination, and reflexivity. This highlights the centrality of knowledge integration, boundary spanning, and reflexive learning in the governance of immersive retail.

The framework also offers practical implications for immersive retail innovators, platforms, and regulatory agencies. Immersive retail innovators benefit when they treat regulators as partners in experimentation rather than as adversaries. Participation in sandboxes and testbeds can help firms anticipate regulatory expectations, reduce uncertainty, and accelerate safer deployment. Co-creation can help platforms and retailers shape emerging governance norms in areas such as extended reality (XR) transparency, biometric data use, emotional AI, and safeguards against manipulation. For regulatory agencies, the framework indicates the need to strengthen capabilities in technical expertise, data science, immersive technology literacy, horizon scanning, stakeholder engagement, and evaluation processes. These capabilities are essential if regulators are to assume orchestrator roles rather than merely enforce compliance after technologies have already diffused.

Facilitating coordination among agencies, such as data protection authorities, consumer regulators, competition commissions, advertising standards bodies, product safety authorities, and AI governance institutions, can help reduce fragmentation. International collaboration, particularly concerning immersive technology sandboxes, shared standards, and cross-border learning, may also reduce compliance burdens and promote greater consistency across jurisdictions. This is especially important because immersive retail ecosystems rarely remain confined within national regulatory boundaries.

From a policy perspective, the framework suggests that effectively governing immersive retail is no longer a matter of defining rules ex ante or implementing them ex post. Rather, the ecosystem perspective highlights the need to develop institutional capacity for experimentation, interdisciplinary coordination, and learning through regulatory sandboxes, testbeds, anticipatory impact assessments, audits, and post-market monitoring. Through these mechanisms, regulators can manage uncertainty and guide innovation trajectories while preserving consumer protection and public values. In this sense, the conceptual framework calls for strengthening regulatory knowledge infrastructures to reduce power asymmetries. This requires investments in data access, technical expertise, independent auditing capacity, expert networks, and collaborative platforms that allow regulators to interact more symmetrically with the ecosystem's diverse actors. For immersive retail companies, this also requires a shift in perspective: regulation is not simply a compliance burden, but a structuring force that shapes innovation opportunities, ecosystem stability, and consumer trust. Therefore, proactive engagement with regulators through co-creation, data sharing, experimentation, and standard setting can increase trust, reduce uncertainty, and support more sustainable innovation paths.

6. Conclusion and future research

This paper developed a capability-based framework of regulatory orchestration in immersive retail innovation systems. Its central argument is that regulators should not be understood only as external rule-setters or ex post compliance authorities. In AI/XR-enabled retail, regulators increasingly participate in the conditions through which innovation becomes intelligible, legitimate, experimental, coordinated, and socially aligned. The framework therefore reconceptualises regulators as capability-bearing organisational actors whose sensing, experimental, co-creative, coordinative, and reflexive capacities help shape innovation-system functions under conditions of technological uncertainty.

The paper makes three main contributions. First, it extends innovation systems theory by specifying how regulators contribute to functions such as knowledge development, entrepreneurial experimentation, legitimation, coordination, market formation, and reflexive learning. Second, it advances regulatory science by distinguishing regulatory instruments from the capabilities through which those instruments are enacted. Sandboxes, audits, impact assessments, standards, and codes of conduct are not effective simply because they exist; they become consequential when regulators can use them to generate knowledge, coordinate actors, and revise governance arrangements over time. Third, it extends dynamic capabilities theory into a public regulatory context by showing how sensing, seizing, and transforming can be oriented towards public value rather than competitive advantage.

The immersive retail context makes these contributions particularly salient. AI-driven personalisation, XR interfaces, biometric and affective analytics, spatial computing, and platform infrastructures create governance challenges that cannot be addressed through a single regulatory domain or a purely static model of control. They require regulators to integrate technical, legal, ethical, commercial, and societal

Table II
Future Research Agenda: key inputs and directions.

Research stream	Core research questions	Theoretical intersections	Methodological approach	Expected contributions
Institutional variation of regulatory orchestrator capabilities	How do regulatory capabilities differ across jurisdictions, legal traditions, agency mandates, and market structures?	Innovation systems; regulatory science; comparative institutionalism	Comparative case studies; policy analysis; expert interviews; cross-country comparison	Identifies institutional conditions that enable or constrain regulatory orchestration.
Regulatory capability development over time	How do regulators build, stabilise, or lose capabilities through sandboxes, enforcement, policy experiments, and stakeholder interaction?	Dynamic capabilities; public-sector studies; experimental governance	Longitudinal case studies; process tracing; archival analysis; repeated interviews	Explains the temporal dynamics of regulatory learning, adaptation, and meta-regulation.
Configurations of capabilities, instruments, and outcomes	Which combinations of capabilities and instruments support responsible innovation in different immersive retail settings?	Regulatory science; innovation systems; configurational theory	Qualitative comparative analysis; mixed methods; multi-actor case studies; network analysis	Shows that responsible innovation may depend on different capability bundles rather than a single best model.
Knowledge infrastructures and platform power	How can regulators build knowledge infrastructures that reduce information asymmetries and counterbalance dominant platforms?	Knowledge management; platform governance; political economy of digital ecosystems	Document analysis; data-access studies; organisational ethnography; stakeholder mapping	Clarifies how regulatory knowledge infrastructures shape data access, standards, interoperability, and market legitimacy.
Extension to adjacent AI-intensive domains	Which elements of regulatory orchestration are specific to immersive retail, and which travel to health, smart cities, education, creative industries, fintech, or digital public services?	Responsible innovation; socio-technical transitions; public value governance	Comparative domain studies; sectoral case studies; design science; policy experiments	Develops boundary conditions and improves the transferability of the framework across emerging technology ecosystems.

Source: Authors' own elaboration.

knowledge while responding to emerging risks such as manipulation, bias, surveillance, platform concentration, and consumer vulnerability. The proposed framework therefore offers a conceptual basis for understanding how regulators can support responsible innovation without reducing regulation to either permissive innovation support or restrictive compliance enforcement.

At the same time, the framework should be understood as a starting point for cumulative theory-building rather than as a closed model. Future research can extend and test the framework along four main lines. A first stream concerns the institutional variation of regulatory orchestrator capabilities. Comparative research across countries, regions, or regulatory regimes could examine how legal traditions, agency resources, political accountability, market structures, and administrative cultures shape regulators' ability to sense, experiment, coordinate, and learn. Such studies would clarify whether regulatory orchestration depends mainly on formal mandates, organisational routines, technical expertise, or wider institutional ecosystems.

A second stream concerns the development of regulatory capabilities over time. Longitudinal research could trace how regulators learn through sandboxes, policy experiments, enforcement actions, public consultations, and interaction with firms, platforms, consumers, and civil society. This would make it possible to examine whether capability development is cumulative, path-dependent, episodic, or vulnerable to disruption when technologies, political priorities, or organisational resources change. Longitudinal designs are particularly important for studying reflexive learning and meta-regulation, because these capabilities become visible only through repeated cycles of intervention, evaluation, and adaptation.

A third stream concerns the configurations of capabilities, instruments, and outcomes. Future studies could use comparative case studies, qualitative comparative analysis, network analysis, or mixed-method designs to examine which combinations of sensing, experimentation, co-creation, coordination, and reflexive learning are associated with stronger responsible innovation outcomes. This configurational approach is important because different immersive retail settings may require different capability bundles. For instance, biometric retail analytics may require stronger auditing and data-protection capabilities, while metaverse retail platforms may require stronger coordination, interoperability, and platform-governance capabilities.

A fourth stream concerns the integration of adjacent research fields. Regulatory science could be more closely connected with knowledge management to examine how regulators build, store, share, and update technical and social knowledge about emerging technologies. Platform governance and innovation systems research could be combined to analyse how regulatory capabilities counterbalance platform power and influence access to data, standards, infrastructures, and markets. Public-sector dynamic capabilities research could develop more precise measures of regulatory sensing, experimentation, coordination, and reflexive learning. These connections would help move the framework from conceptual integration towards empirical operationalisation.

The framework may also be extended beyond immersive retail to other AI-intensive domains, including health technologies, smart cities, education platforms, creative industries, mobility systems, financial technologies, and digital public services. These domains differ in their risks, institutional arrangements, and innovation dynamics, but they share a common challenge: regulators must govern fast-moving technologies while preserving public value, legitimacy, accountability, and innovation quality. Studying these adjacent domains would help clarify which elements of regulatory orchestration are context-specific and which are transferable across emerging socio-technical systems.

Overall, the paper positions capability-based regulatory orchestration as a research programme for studying regulation, innovation systems, and emerging digital technologies. By focusing on the organisational capabilities through which regulators shape innovation-system functions, the framework provides a basis for analysing how regulatory agencies can reduce uncertainty, counterbalance knowledge and power asymmetries, support responsible experimentation, and guide immersive retail innovation towards more accountable and socially desirable outcomes. This does not imply that regulators replace firms, platforms, or users as innovation actors. Rather, it highlights their distinctive role in shaping the conditions under which innovation can develop responsibly within complex and rapidly evolving ecosystems.

The main research directions are summarised in the following table (Table II), which outlines the theoretical lens, the method, and the expected results of the analysis.

CRediT authorship contribution statement

Lucia Pizzichini: Writing – original draft, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Federica Caboni:** Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Conceptualization. **Rosa Palladino:** Writing – original draft, Formal analysis, Data curation. **Demetris**

Vrontis: Supervision.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with language refinement, structural editing, and improving the visual presentation. The authors critically reviewed, revised, and validated all content, references, interpretations, and conclusions and take full responsibility for the final manuscript.

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