

Operationalizing Industry 6.0 for Innovation Management: A Generative Governance Framework for Distributed Autonomy

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ABSTRACT: *The term Industry 6.0 is increasingly used in discussions of emerging industrial paradigms, yet much of the literature still defines it through enabling technologies, future scenarios, or broad normative aspirations. At the same time, research on standardized innovation management systems shows that systematic management can strengthen innovation capability, ambidexterity, openness, and performance, but it does not fully address how distributed human-machine agency and ecosystem interdependence should be governed over time. This conceptual study develops a Generative Governance Framework for Industry 6.0 using a model-building research design and a purposive comparative synthesis of 40 substantive sources across institutional and standardization documents, Industry 6.0 literature, innovation-management and organization research, and prior conceptual work. An abductive derivation identifies six interdependent governance functions: directionality, option preservation, traceable distributed agency, embedded safeguards, recursive learning and reconfiguration, and ecosystem coherence and legitimacy. The framework distinguishes these governance mechanisms from generative capacity, treated as a higher-order outcome concerning the preservation and regeneration of future value-creating possibilities. Six propositions specify conditional, mediating, and moderating relationships that can be empirically tested. The paper contributes to innovation management by positioning ISO 56001 and related standards as systematic management infrastructure while specifying the additional trajectory-level governance mechanisms required when innovation operates under distributed autonomy, uncertainty, and ecosystem dependence.*

KEYWORDS: *Industry 6.0; innovation management; generative capacity; innovation governance; distributed autonomy; innovation ecosystems*

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I. INTRODUCTION

The sequence of numbered industrial paradigms has become an influential way of framing technological expectations, investment narratives, public policy, and managerial practice. Whereas Industry 4.0 established a vocabulary centred on cyber-physical integration, connectivity, data, and automation, Industry 5.0 explicitly brought human-centricity, sustainability, and resilience into the criteria for industrial transformation, extending the debate from technological capabilities to the purposes and conditions of innovation (European Commission, 2021, 2022). Against this background, Industry 6.0 is increasingly invoked as a possible emerging paradigm whose conceptual boundaries nevertheless remain unstable, with recent contributions emphasizing hyper-connected production, digital twins, generative artificial intelligence, quantum-enabled infrastructures, decentralized control, regenerative manufacturing, and possible post-human or eco-symbiotic futures (Duggal et al., 2022; Fernández-Miguel et al., 2025; Madsen et al., 2025a; Verma et al., 2025).

Although this diversity of perspectives makes the breadth of the transition visible, it also poses a conceptual risk: when a paradigm is identified with an ever-expanding catalogue of technologies, its distinctive characteristics, governance requirements, and observable manifestations become difficult to specify. As Madsen et al. (2025b) observe, the Industry X.0 sequence also operates as management discourse, through which labels may mobilize attention before their conceptual content stabilizes. This dynamic matters for innovation management because it can accelerate investment and experimentation while leaving decision architectures, accountability arrangements, and evaluation criteria insufficiently defined.

A parallel body of work on innovation management systems (IMSs) provides a more systematic starting point. ISO 56001:2024 establishes requirements for an innovation management system, while empirical and case-based research indicates that standardized IMSs can support innovation capability, ambidexterity, openness to external collaboration, and innovation performance (Arslan et al., 2025; Giordano et al., 2025; Silva, 2021). Case evidence also shows that innovation strategy and the IMS can co-evolve, and that integration with other

management systems requires a system-of-systems perspective without over-optimizing the innovation system to the point of losing flexibility (Kihlander et al., 2024). Fernandez and Swart (2025) similarly position the ISO 56000 family as systematic infrastructure for innovation rather than as a technology-specific prescription. These findings strengthen the case for disciplined innovation management, but they do not by themselves specify how advanced autonomy, cross-organizational dependencies, lock-in, externalities, and contestability should be governed.

Earlier conceptual contributions proposed a governance-oriented formalization of Industry 6.0, interpreting it as an organizational and governance mode rather than another technology catalogue (Casale et al., 2026a), and developed generative capacity as a systemic alternative to productivity-centred evaluation, emphasizing the ability of socio-technical systems to generate and regenerate value, learning, options, and enabling conditions over time (Casale et al., 2026b). Although they provide definitional and theoretical foundations, these contributions leave a specific innovation-management problem open: how can this governance orientation be translated into a parsimonious set of functions that managers, innovation systems, supply chains, and institutions can design, observe, critically challenge, and test?

The need for such operationalization grows as digital innovation redistributes agency, with consequential decisions increasingly emerging from interactions among human judgment, algorithmic recommendations, autonomous software, connected assets, platform rules, and ecosystem dependencies. Digital innovation research already documents the extension of innovation beyond firm boundaries through recombinable technologies, actors, and distributed infrastructures (Nambisan et al., 2017; Vial, 2019), while ecosystem studies show that value creation depends on the alignment of interdependent actors and positions rather than solely on the capabilities of the focal organization (Adner, 2017; Jacobides et al., 2018). Under these conditions, innovation governance cannot be exhausted by project selection, process compliance, or output efficiency; it must also encompass decision rights, reversibility, externalities, interdependencies, and the preservation of future options. Because the boundaries of decision-making, implementation, and consequences may diverge across organizations, territories, systems, and time horizons, governance needs to follow the propagation of effects beyond the formal perimeter of the initiating decision.

Against this background, the research question guiding the analysis is the following: how can Industry 6.0 be operationalized as an innovation-governance architecture capable of managing distributed autonomy and uncertainty while preserving long-term generative capacity? The investigation does not seek to present Industry 6.0 as an already consolidated historical stage or to predict its technological endpoint; rather, it translates an emerging governance perspective into a theoretically grounded model that can be integrated with established innovation-management infrastructures and subjected to empirical testing.

In pursuing this objective, the analysis develops five complementary contributions: it connects the emerging Industry 6.0 debate to the literature on systematic and systemic innovation management, clarifying what ISO 56001 and related standards can provide and where an additional governance layer is required; it distinguishes innovation performance, innovation capability, antifragile response, and generative capacity without treating them as interchangeable; it identifies six interdependent governance functions as antecedent mechanisms rather than components of the outcome they are intended to explain; it formulates six theoretical propositions expressing conditional, mediating, or moderating relationships; and it sets out an observable evidence architecture and research agenda for future empirical validation without reducing the complexity of Industry 6.0 to a single synthetic score.

II. RELATED WORK

2.1 From Industry 4.0 to Industry 5.0: the governance turn

Industry 4.0 is commonly associated with cyber-physical systems, industrial connectivity, data analytics, and intelligent automation, whose managerial promise has been framed primarily through efficiency, visibility, flexibility, and productivity. Although these capabilities remain important, digital transformation has reshaped organizational structures, work, decision-making processes, and ecosystem relationships in ways that increasingly expose the limitations of a purely technology-centred interpretation (Vial, 2019), since technological adoption does not automatically create value without complementary capabilities, managerial choices, and an appropriate socio-technical configuration.

Industry 5.0 represents a significant normative and governance turn insofar as European policy documents identify human-centricity, sustainability, and resilience as core pillars and explicitly position industry as a contributor to societal well-being and prosperity beyond narrow growth or efficiency objectives (European Commission, 2021, 2022). The future-of-work agenda extends this logic by emphasizing job quality, skills, participation, and the design of human-technology collaboration (European Commission, 2023). The European Economic and Social Committee further stresses implementation, arguing that the paradigm must be translated into actionable measures for enterprises, workers, supply chains, and industrial policy (European Economic and Social Committee, 2025).

An especially relevant organizational point of reference is the Italian practice UNI/PdR 155:2023, which addresses sustainable innovation through an integrated management perspective and connects the Industry 5.0 challenge with the ISO 56000 family and open innovation (UNI, 2023). As argued in earlier work, the practice can be interpreted as a governance-oriented formalization compatible with the Harmonized Structure of management-system standards (Casale et al., 2025). This has an important implication for the present study: innovation within Industry 5.0 is evaluated not only by what it produces but also by its effects on people, environmental constraints, resilience, and legitimacy.

At the same time, Industry 5.0 does not resolve all governance problems created by the increasing autonomy and interdependence of digital systems. Human-centricity can specify an orientation, yet it does not by itself determine how decision rights should be distributed between people and autonomous systems, how algorithmic actions should be traced and contested, how path dependence should be reduced, or how ecosystem-level externalities should be allocated, thereby identifying unresolved issues that provide an important conceptual bridge to the Industry 6.0 discussion.

2.2 Emerging Industry 6.0 literature: convergence without conceptual closure

Although the Industry 6.0 literature is expanding rapidly, it remains heterogeneous, as illustrated by technical surveys that emphasize ubiquitous and hyper-connected manufacturing, advanced digital twins, next-generation communication, generative AI, quantum technologies, metaverse-assisted production, and highly autonomous orchestration (Verma et al., 2025). Earlier roadmaps similarly projected greater machine autonomy, human-machine integration, renewable energy, and new production configurations (Duggal et al., 2022). Sustainability-oriented work adds antifragility, planetary constraints, resource circularity, and the need for industrial systems that remain viable under systemic shocks (Chourasia et al., 2022; Kuosmanen & Villman, 2021).

Alongside predominantly technological visions, another stream turns towards organizational and control architectures: Fernández-Miguel et al. (2025) propose a framework for AI-driven decentralized manufacturing control, examining interactions among advanced technologies, decentralized organizational structures, sustainability, cultural transformation, and innovation, while Gomaa (2025) develops a strategic perspective based on technological convergence, ethical governance, inclusion, organizational agility, and sustainability. Taken together, these contributions suggest that the conceptual frontier of Industry 6.0 increasingly concerns the interaction between autonomy and governance rather than any particular enabling technology.

A third stream foregrounds uncertainty rather than convergence through scenario-based research describing substantially different possible Industry 6.0 futures, including biofused production, post-work automation, peer-to-peer micro-factories, and eco-symbiotic production (Madsen et al., 2025a). Although these scenarios should not be treated as forecasts, their analytical value lies in demonstrating the inadequacy of defining Industry 6.0 by one predicted technological endpoint. If multiple futures are plausible, the managerial problem becomes one of governing trajectories, preserving options, and maintaining the ability to redirect innovation as evidence and social priorities change.

Across these streams, recurring themes include greater autonomy, stronger interdependence, sustainability as a design condition, new skill requirements, and accountability across human and machine action (Oleśków-Szłapka, 2025; Zhironkin et al., 2025). What remains less developed is an innovation-management architecture that connects these themes to a coherent set of governance mechanisms and distinguishes those mechanisms from the outcomes they are intended to produce.

2.3 From systematic to systemic innovation management: what the ISO 56000 family adds

The ISO 56000 family provides a systematic management architecture for innovation within which ISO 56001:2024 specifies requirements for establishing, implementing, maintaining, and improving an IMS, while ISO 56000:2025 provides the underlying vocabulary and principles. Fernandez and Swart (2025) describe the family as infrastructure for systematically managing innovation rather than as a prescription of innovative content or a specific technology. The architecture connects strategic direction, leadership, culture, opportunity and concept development, portfolios, operations, performance evaluation, and continual improvement. ISO 56008:2024 complements this system by providing tools and methods for innovation-operation measurement.

The value of systematic innovation management receives growing support from empirical research, in which Silva (2021) finds substantial correspondence between ISO 56002 and determinants of firm innovation capacity, linking the standard to dynamic capabilities and the ability to reconfigure competences. Arslan et al. (2025), using data from 178 manufacturing firms, report positive relationships between standardized IMSs and innovation ambidexterity, innovation capability, and innovation performance. Giordano et al. (2025), using 139 medium-to-large Italian firms, find that IMS maturity is positively associated with innovation performance and with openness to innovation, with openness acting as a partial mediator. Emerging evidence on ISO 56001 itself also points to a positive interaction between strategic dimensions and the IMS, although the available study is

based on a small single-organization sample and should therefore be interpreted cautiously (Özkan & Özmutaf, 2025).

Complementing this empirical evidence, case-based research provides a systems perspective particularly relevant to the present argument: Gueorguiev (2023) shows how the ISO 56000 family can be integrated with existing quality and education management systems and with specific standards for partnerships, intellectual property, strategic intelligence, and assessment. Kihlander et al. (2024), following an early adopter over seven years, show that innovation strategy and the IMS can co-evolve, that the IMS interacts with other management systems as a system of systems, and that the innovation system must adapt rather than become over-optimized if it is to retain the flexibility required to innovate. Together, these studies support a distinction between systematic management—deliberate structures, roles, processes, measurement, and review—and systemic management—attention to interdependence, emergence, multiple system purposes, and cross-boundary effects.

This distinction also clarifies the contribution boundary of the present paper, since ISO 56001 can provide disciplined organizational infrastructure for innovation, and its systems approach can reduce uncertainty and strengthen the feasibility of innovation initiatives. Yet an organization can operate a mature IMS while still becoming locked into a platform, transferring externalities to partners, delegating consequential decisions without adequate traceability, or participating in an ecosystem whose interfaces and incentives undermine long-term adaptability. The challenge addressed here therefore begins where systematic management alone becomes insufficient: the governance of trajectories under distributed autonomy and ecosystem interdependence.

2.4 Generative capacity, antifragile response, and the governance gap

Within innovation-management research, the tension between exploitation of existing competences and exploration of new possibilities is well established: March (1991) showed the need to balance refinement with experimentation, while dynamic capabilities theory emphasizes sensing, seizing, and transforming in response to changing environments (Teece, 2007). These perspectives remain central, but the distribution of agency across digital infrastructures raises a further question, since organizations are called upon not only to adapt resources but also to govern the decision architectures through which adaptation takes place.

Generative capacity extends this concern from innovation output or organizational adaptation to the systemic ability to preserve and regenerate the conditions for future value creation. Prior work defines it as an emergent property of socio-technical systems that generate and regenerate value across economic, social, cognitive, institutional, and environmental dimensions while maintaining future options and enabling conditions (Casale et al., 2026b). This is deliberately different from innovation performance, which concerns realized innovation outcomes, and from innovation capability, which concerns the organization's ability to perform innovation activities. A system may exhibit high innovation output yet reduce generative capacity if it creates irreversible dependencies, depletes critical resources, concentrates decision rights, or erodes ecosystem legitimacy.

A further distinction concerns ecosystem antifragility, described by Equihua et al. (2020) as a response property through which a system benefits from relevant environmental variability rather than merely resisting or recovering from disturbances. A complementary terminological reference is ISO 56000:2025 (§3.2.14), which associates antifragility with an ability to gain from stressors, uncertainty, and risk. Capability gain under variation may therefore provide useful empirical evidence, but it is not equivalent to generative capacity: in the proposed framework, an antifragile response is one possible manifestation of generativity under stress, whereas generative capacity is a broader higher-order outcome that can also be observed through preserved optionality, reconfigurability, continued learning, and legitimate coordination in the absence of major shocks.

Against this background, the research gap can be specified by bringing the relevant streams into dialogue: Industry 6.0 research identifies technologies, principles, scenarios, and emerging control architectures; IMS research demonstrates the value of systematic and systemic innovation management; organization theory explains learning, capability renewal, digital recombination, and ecosystem interdependence; prior work establishes generative capacity and a governance-oriented Industry 6.0 definition. What is missing is a parsimonious model that specifies which governance mechanisms should connect these bodies of knowledge and how those mechanisms can be observed without defining the outcome in circular terms.

III. METHOD: CONCEPTUAL MODEL DEVELOPMENT

3.1 Research design and source selection

Consistent with the aim of constructing an empirically testable middle-range model, the study adopts an explicit conceptual research design that clarifies how existing theories and documentary domains are employed, following the methodological guidance of Jaakkola (2020). This approach also reflects Whetten's (1989) emphasis on specifying which constructs matter, how they are connected, and why those relationships provide explanatory advances, without attempting an exhaustive synthesis of the entire Industry 6.0 literature.

The analytical corpus was purposively assembled from scholarly studies, conference contributions, standards, and institutional documents relevant to model development, with sources retained for their ability to identify governance constraints, expose tensions in the Industry 6.0 debate, provide explanatory mechanisms from innovation-management and organization research, or anchor constructs in prior work. On the basis of documents available through 30 September 2026, the corpus comprises 40 substantive references and two methodological sources supporting the research design. For descriptive purposes, each substantive source was assigned to the analytical family corresponding to its primary role, as summarized in Table I, whereas Appendix Table A1 presents representative evidence supporting the retained functions. The procedure is conceptual rather than exhaustive, and no claim is made to systematic coverage, a preregistered protocol, or a reproducible database search log.

Table I: Source families used in the conceptual derivation

<i>Source family</i>	<i>n</i>	<i>Selection logic</i>	<i>Role in framework development</i>
Institutional and standardization core	11	Official EU, UNI, ISO/IEC, ISO/UNDP and NIST documents relevant to 5.0, innovation management, AI governance, or sustainability	Defines governance perimeter, management-system infrastructure, and implementation constraints.
Industry 6.0 literature	10	Technical, organizational, sustainability, skills, energy, management-fashion, and scenario contributions	Identifies recurrent transition characteristics and unresolved tensions around autonomy, sustainability, and future trajectories.
Innovation-management and organization research	16	Empirical, conceptual, and policy-analytical work on IMSs, dynamic capabilities, ambidexterity, digital innovation, ecosystems, polycentric governance, and antifragile response	Provides established constructs, empirical evidence, and boundary conditions for the six functions.
Prior conceptual antecedents	3	Only prior contributions that introduce the Industry 5.0 formalization, Industry 6.0 definition, or generative-capacity construct	Supplies antecedent definitions while maintaining a clear boundary with the new operational contribution.

Note. The corpus is purposive rather than systematic. Counts refer to each source's primary analytical role, not to exclusive thematic membership. The two methodological references are excluded from the 40-source counts.

3.2 Construct derivation and retention criteria

The derivation is reconstructed through four analytical stages, beginning with a comparative reading of the corpus to identify tensions that become especially salient when innovation is more autonomous, uncertain, and ecosystem-dependent. The comparison focused on the management problem implied by each tension, the organizational or ecosystem level at which it operates, and the theoretical or documentary evidence supporting it. Six tensions were retained: efficiency versus directionality; commitment versus option preservation; autonomy versus accountability; acceleration versus safeguards; adaptation versus recursive learning; and firm-level optimization versus ecosystem coherence.

In the second stage, candidate tensions were translated into governance functions formulated as management questions rather than technological requirements. Each function was retained where it was supported by at least two analytical source families, distinguishable from the others, connectable to observable mechanisms or evidence, and capable of providing additional explanatory leverage under distributed autonomy without merely restating IMS requirements. These declared construct-selection criteria do not represent the results of statistical coding or formal inter-rater reliability testing; Appendix Table A1 instead documents representative conceptual support for each function.

The third stage separates the governance functions from the dependent construct, so that generative capacity is treated as a higher-order outcome, not as the sum of the six functions. Intermediate outcomes—accountable autonomy, reconfigurability, preserved optionality, and legitimate coordination—provide more proximate pathways through which the governance mechanisms may affect generative capacity. Antifragile capability gain under relevant stress or variability is treated as a possible manifestation of that outcome rather than as a seventh function.

Fourth, propositions were formulated to specify conditional, mediating, or moderating relationships rather than simple normative associations. These propositions, understood as theoretical claims rather than already-tested hypotheses, are intended to expose the causal logic to empirical challenge and to identify measurement strategies that can support future case, survey, network, and longitudinal research.

3.3 Scope, boundary conditions, and analytical status

The framework is intended for innovation configurations in which at least one of three conditions is material: consequential technological autonomy, high uncertainty, or substantial ecosystem interdependence. It is therefore not proposed as a universal maturity model for every innovation activity. The functions may also operate

at different levels: directionality, options, traceability, safeguards, and learning can be designed within organizations, while ecosystem coherence necessarily crosses organizational boundaries.

The model is deliberately technology-neutral and configurational, without assuming that increasing the intensity of every governance function will automatically improve outcomes. Excessive reversibility can delay commitment; excessive traceability can create latency and documentation burden; excessive safeguards can suppress useful experimentation; and excessive coordination can produce rigidity, capture, or groupthink. The theoretical task is therefore to identify viable configurations and boundary conditions, not to maximize a single governance score.

As regards its analytical status, Industry 6.0 is treated as an emerging governance logic rather than an institutionally settled historical stage: the model is intended to be more operational than a paradigm definition while remaining less prescriptive than a management-system standard. From this perspective, ISO standards can provide implementation infrastructure and auditable processes without determining the substantive direction of the paradigm or validating the theoretical propositions advanced here.

IV. A GENERATIVE GOVERNANCE FRAMEWORK FOR INDUSTRY 6.0

The proposed framework treats Industry 6.0 as the governance of innovation trajectories under conditions of distributed agency, high uncertainty, and ecosystem interdependence. Its unit of analysis is not the technology, project, or firm in isolation, but the configuration of decision rights, commitments, safeguards, learning mechanisms, and cross-boundary interfaces that determines whether innovation expands or constrains future possibilities.

Figure 1 summarizes this architecture, in which contextual conditions create the governance problem; the six functions operate as mechanisms; intermediate outcomes provide proximate manifestations; and generative capacity remains the higher-order outcome to be explained. The architecture is recursive: evidence from outcomes can revise directionality, options, safeguards, and decision rights. Ecosystem coherence and legitimacy operate both as a distinct function and as a cross-boundary condition affecting the viability of the other mechanisms.

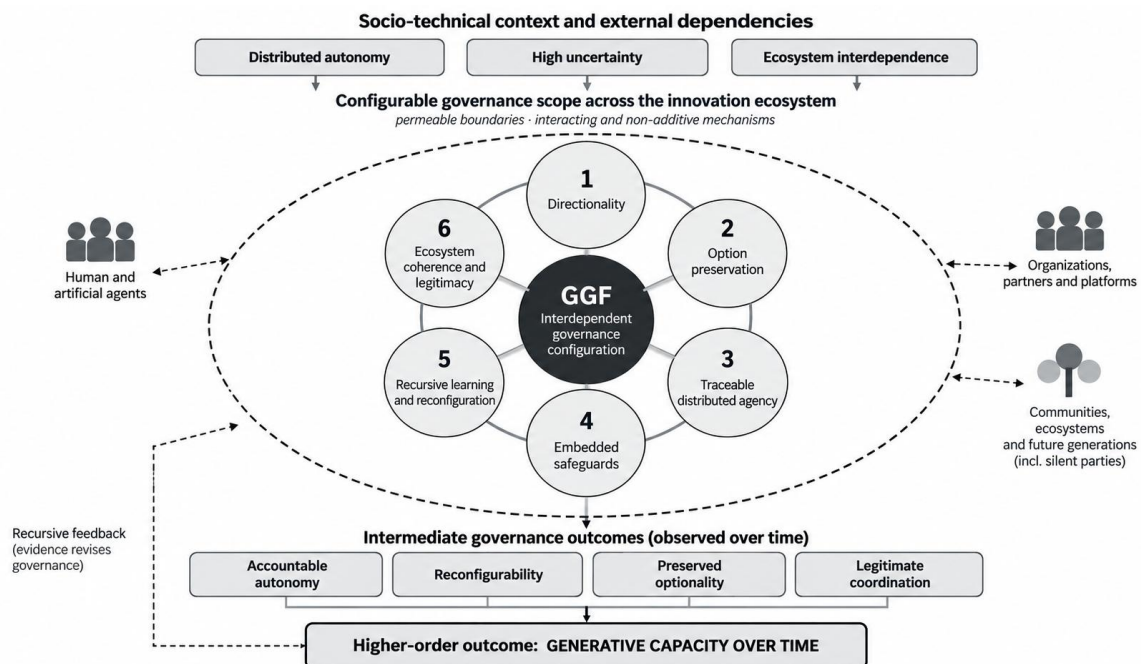


Figure 1: Configurational architecture of the Generative Governance Framework in innovation ecosystems.

Note. The dashed boundary indicates a configurable and permeable governance scope; arrows illustrate cross-boundary interactions and recursive feedback. The relationships are conceptual and configurational, not empirically established causal sequences.

Table II: Stylized shift in the dominant innovation-governance question

Dimension	Industry 4.0 logic	Industry 5.0 governance turn	Proposed Industry 6.0 governance logic
Dominant question	How can operations be optimized through connectivity and automation?	How can industrial innovation serve people, sustainability, and resilience?	How can distributed autonomy and uncertainty be governed while preserving future generative capacity?
Primary unit of governance	Process, plant, connected value chain	Organization and human-technology system	Decision architecture and innovation ecosystem

<i>Dimension</i>	<i>Industry 4.0 logic</i>	<i>Industry 5.0 governance turn</i>	<i>Proposed Industry 6.0 governance logic</i>
Evaluation emphasis	Efficiency, productivity, quality, availability	Human-centricity, sustainability, resilience, shared value	Directionality, options, traceability, safeguards, learning, ecosystem coherence
Role of autonomy	Automation as operational capability	Technology supports and augments people	Autonomy is valuable only when it remains accountable, contestable, and reconfigurable
Treatment of uncertainty	Operational uncertainty addressed through prediction, control, and flexibility	Disruption addressed through resilience and adaptive capacity	Persistent uncertainty governed through learning, reversibility, and option preservation
Sustainability	Efficiency benefit or parallel target	Core paradigm pillar	Ex ante design boundary and externality-allocation rule
Time horizon	Current and near-term performance	Continuity and resilient prosperity	Trajectory quality and preservation of long-term possibilities

Note. The comparison is conceptual rather than chronological; the three logics can coexist within the same organization or ecosystem.

4.1 Governance function 1: directionality

Innovation systems require a criterion for deciding not only whether an innovation works, but whether the trajectory it reinforces remains desirable, legitimate, and strategically coherent. Industry 5.0 makes this question explicit by connecting industrial transformation to human well-being, sustainability, and resilience (European Commission, 2021). ISO 56001 also requires strategic direction and an innovation strategy, while emerging empirical evidence links the strategic dimensions of organizations to ISO 56001 implementation (Özkan & Özmütâf, 2025). Longitudinal case evidence further shows that innovation strategy and the IMS can co-evolve rather than operate as separate layers (Kihlander et al., 2024).

Directionality therefore concerns the explicit articulation, periodic review, and contestability of the value criteria that guide innovation. In practical terms, it connects innovation portfolios to stakeholder value, strategic purpose, sustainability commitments, acceptable impact boundaries, and conflict-escalation mechanisms. ISO 56000:2025 (§3.7.9) defines the common good as a benefit for all interested parties, notes its economic, environmental, governance, social and cultural dimensions, and recognizes ethics in value distribution. ISO/UNDP 53001:2026 (§3.39) explicitly adopts this definition, retaining Note 1 but replacing Note 2 to link the term to the current Sustainable Development Goals (SDGs) and successor global goals. The terminological connection does not equate the standards' requirements or settle competing stakeholder claims. Its distinctive contribution is not the existence of strategy, which is already part of systematic innovation management, but the requirement that the criteria used to judge trajectory quality remain visible and revisable as conditions and consequences change.

Proposition 1. Among innovation configurations with comparable innovation-management-system maturity, those governed through explicit and revisable directionality criteria will be more likely to preserve generative capacity than configurations governed primarily through output, adoption, or efficiency targets.

4.2 Governance function 2: option preservation

Innovation necessarily involves commitment, since resources must be allocated, architectures and platforms selected, and capabilities built; the same commitments, however, may also create path dependence and lock-in. The exploration–exploitation literature indicates that organizations need both refinement and search (March, 1991), while empirical IMS research shows that standardized innovation management can support innovation ambidexterity (Arslan et al., 2025). The governance question, therefore, is not whether to commit but how to prevent commitments from generating unnecessary irreversibility.

Option preservation manages this trade-off through modularity, staged investment, diversified critical dependencies, interoperable data and interfaces, controlled parallel experimentation, and explicit exit or switching criteria. It is compatible with dynamic-capability logic but places greater emphasis on the architecture of future choice. Options should also be assessed relationally: flexibility gained by the focal organization can create dependencies or foreclose choices for others. The systems literature on antifragility also reinforces the importance of balancing robustness and adaptability rather than maximizing one side of the system (Equihua et al., 2020).

Proposition 2. Under higher uncertainty and dependency concentration, option-preservation mechanisms will reduce reconfiguration costs and path-dependent lock-in, thereby supporting generative capacity relative to otherwise comparable configurations with more irreversible commitments.

4.3 Governance function 3: traceable distributed agency

Industry 6.0 literature increasingly assumes that decisions will be distributed across humans, autonomous systems, data platforms, and interconnected production assets (Fernández-Miguel et al., 2025; Verma et al., 2025). Although the ISO 56000 family is technology-agnostic and can accommodate AI-supported innovation processes

(Fernandez & Swart, 2025), the governance issue concerns not whether AI can support innovation, but whether consequential actions can be initiated, modified, or executed without direct intervention by a single accountable human actor and still remain reconstructable and contestable. This concern is consistent with contemporary AI-governance frameworks that treat documentation, transparency, human oversight, accountability, and lifecycle risk management as governance properties rather than post-hoc controls (International Organization for Standardization & International Electrotechnical Commission, 2023; National Institute of Standards and Technology [NIST], 2023).

Traceable distributed agency requires clarity about decision rights, delegation boundaries, data provenance, model responsibility, escalation thresholds, override mechanisms, and post-hoc reconstruction of consequential decisions. Human oversight is therefore treated as an architecture rather than a ceremonial approval step. Effective oversight depends on informed judgment, appropriate competencies, access to relevant evidence, and a practical ability to challenge or interrupt action. The relevant question is whether the configuration makes it possible to identify who or what had authority to act, on what information, under which rule, with which constraints, and with what route for contestation or correction.

Proposition 3. Where technological autonomy improves innovation performance, those gains will contribute to generative capacity only when consequential decisions remain sufficiently traceable, contestable, and overridable to permit diagnosis, correction, and reconfiguration.

4.4 Governance function 4: embedded safeguards and externality allocation

Sustainability, circularity, safety, security, and social impact are often treated as parallel objectives assessed after technical or commercial decisions have been made. A generative governance approach treats them instead as boundary conditions that shape the design space from the beginning. This is consistent with Industry 5.0 and with Industry 6.0 contributions that position sustainability and regenerative constraints as constitutive rather than additive (Chourasia et al., 2022; Gomaa, 2025).

Embedded safeguards include risk thresholds, life-cycle criteria, human-rights and work-quality requirements, cybersecurity constraints, resource and energy considerations, and explicit rules for allocating externalities across actors and time horizons. Their purpose is not to eliminate experimentation but to prevent local innovation gains from being financed by hidden fragility elsewhere in the system. Assessment should therefore trace not only direct effects at the intervention point but also indirect, cumulative, and cascading effects as they propagate across actors, places, systems, and time horizons. Safeguards can also express care for living systems by supporting prevention, maintenance, repair, and, where feasible, regeneration of the conditions on which future value creation depends. ISO/UNDP 53001:2026 links this governance orientation to beneficial and adverse impacts, trade-offs, measurement, and continual improvement. Under §3.2, Notes 2–3, interested parties include the planet, society, the environment, ecosystems, and future generations. A "silent interested party" unable to advocate for itself may be represented by another party or organization, which should act in good faith and verify the assertions made on its behalf. Such recognition broadens the range of interests to be considered without, in itself, conferring legal personality.

Proposition 4. Ex ante safeguards and explicit externality-allocation rules will reduce the likelihood that local innovation gains erode generative capacity through transferred or irreversible harms; this effect will be stronger where impacts cross organizational boundaries or have long time horizons.

4.5 Governance function 5: recursive learning and reconfiguration

Although feedback, evaluation, and continual improvement are already familiar elements of innovation management, Industry 6.0 requires a stronger form of reflexivity: feedback must be capable of changing not only the innovation initiative but also the assumptions, metrics, portfolio rules, and governance architecture that produced it. ISO 56001 and ISO 56008 provide systematic infrastructure for measurement and review, while implementation research shows that innovation processes should remain iterative rather than be treated as mechanically linear (Gueorguiev, 2023).

Recursive learning is necessary because highly interconnected systems can generate effects that were not visible at approval. A governance architecture that treats objectives and metrics as fixed can optimize itself against obsolete criteria. By contrast, a generative system institutionalizes review of objectives, thresholds, decision models, portfolio assumptions, and stakeholder impacts. Learning therefore becomes a mechanism for reconfiguring the conditions of innovation, not simply for correcting local deviations. Such learning becomes institutionally meaningful when affected actors can question the adequacy of existing rules and evidence can legitimately trigger their revision. Capability gain following disruption can provide evidence of an antifragile response, but recursive learning also operates in ordinary experimentation and does not require a crisis.

Proposition 5. Outcome feedback will contribute to generative capacity through recursive learning when evidence is permitted to modify portfolio assumptions, metrics, decision rules, and governance arrangements rather than being confined to local corrective action.

4.6 Governance function 6: ecosystem coherence and legitimacy

As Industry 6.0 extends the effective perimeter of innovation beyond the focal enterprise, cross-boundary governance requires identifying where impacts are experienced, who can observe them, and which actors have the authority and capacity to prevent, correct, or repair their consequences. Data infrastructures, supply chains, standards, energy systems, platforms, regulators, universities, technology providers, and communities may become constitutive elements of innovation configurations, so that the ecosystem is not merely their external context but participates in the production and governance of innovation itself.

Ecosystem coherence concerns the compatibility of interfaces, incentives, responsibilities, evidence, and conflict-resolution mechanisms across interdependent actors. Adner (2017) conceptualizes ecosystems through the alignment structure needed for a value proposition, while Jacobides et al. (2018) emphasize roles and complementarities. Empirical IMS evidence adds that openness to innovation can partially mediate the relationship between IMS maturity and innovation performance (Giordano et al., 2025), indicating that strong internal systems and external collaboration are complementary rather than substitutable. Fernandez and Swart (2025) likewise treat the ISO 56000 family as relevant to innovation beyond organizational boundaries.

Polycentric governance provides a complementary perspective because complex systems can be governed through multiple centers of decision making connected by shared rules and learning processes (Ostrom, 2010). At the innovation-management level, this suggests interoperable standards, shared evidence protocols, cross-organizational risk and dependency registers, governance forums, and escalation arrangements for common infrastructures. Where purposes, knowledge, and effects are distributed, co-design can help frame problems and alternatives across actors while preserving differentiated responsibilities and the possibility of dissent. Legitimacy is included because coordination that is technically coherent but persistently unacceptable to workers, communities, regulators, or partners is unlikely to remain viable over time.

Proposition 6. In ecosystem-dependent innovation, the contribution of organizational innovation-management capability to generative capacity will be contingent upon interoperable interfaces, shared evidence protocols, explicit cross-boundary responsibilities, and workable conflict-resolution mechanisms.

4.7 Configurational logic, complementarities, and trade-offs

The six functions are not conceived as independent checklist items or as components of an additive maturity score, because their significance depends on the relationships established within the overall governance configuration. Directionality without options can harden into mission lock-in; options without directionality can produce costly diffusion of effort; autonomy without traceability can become opacity; traceability without proportionality can become administrative burden; safeguards without experimentation can block learning; learning without stable decision rights can produce governance churn; and ecosystem coherence without contestation can become capture or groupthink.

The framework therefore recognizes both complementarities and potentially countervailing effects, consistent with the evidence presented by Kihlander et al. (2024), who show empirically why an IMS should adapt rather than become over-optimized if it is to preserve room for innovation. Equihua et al. (2020) similarly emphasize balance among robustness, adaptability, redundancy, and complexity in systems exposed to variability. These findings support a configurational interpretation: the question is not how much governance an organization has, but whether the combination of mechanisms remains proportionate to uncertainty, autonomy, interdependence, and the reversibility of consequences.

This configurational logic also makes it possible to test boundary conditions, since, for example, traceability requirements should be stricter where autonomous decisions are consequential or difficult to reverse, while option-preservation mechanisms should be stronger where switching costs and dependency concentration are high. Where experimentation has limited consequences, by contrast, a proportionately lighter form of control may be justified.

4.8 From functions to observable governance evidence

For the six functions to inform innovation management, they must be connected to observable evidence without being collapsed into a single synthetic Industry 6.0 score, which would reproduce precisely the reductionism that the concept of generative capacity seeks to overcome. Instead, Table III links each function to mechanisms, indicative evidence, and a countervailing risk that should be monitored alongside the intended benefit.

ISO 56008:2024 and the broader ISO 56000 family are relevant because they reinforce the role of measurement, analysis, and systematic innovation management. The framework can accordingly be understood as a set of additional governance questions capable of integration into existing systems, establishing a complementary relationship in which standards can provide disciplined management infrastructure, while the framework specifies what should remain visible when innovation operates under distributed autonomy and ecosystem dependence.

To enable empirical testing without prematurely imposing a validated scale, generative capacity is provisionally represented through four outcome domains: (1) regeneration of critical capabilities and resources; (2) preservation of feasible future options; (3) reconfiguration without disproportionate destruction of accumulated value; and (4) continuity and legitimacy of value creation across actors and time horizons. These domains are proposed as provisional empirical manifestations, not as a validated generative-capacity scale; future research should test whether they form a higher-order construct, a configurational outcome, or a family of complementary indicators. To prevent construct contamination in empirical applications, governance mechanisms should be measured from ex ante decision rules, controls, and documented arrangements, whereas generative-capacity manifestations should be assessed through later system-level consequences and, wherever feasible, evidence independently corroborated by affected actors. The same observation should not serve simultaneously as an indicator of both a proposed mechanism and its outcome.

Table III: Generative Governance Framework: mechanisms, evidence, and countervailing risks

<i>Governance function</i>	<i>Illustrative mechanisms</i>	<i>Indicative evidence</i>	<i>Countervailing risk / diagnostic</i>
1. Directionality	Portfolio purpose criteria; stakeholder challenge; objective-conflict escalation; periodic purpose review	Documented trade-offs; portfolio alignment reviews; records of objective revision; stakeholder-challenge outcomes	Mission lock-in, purpose rigidity, or symbolic values not connected to allocation decisions
2. Option preservation	Modularity; staged investment; exit criteria; supplier diversity; reversible experiments; interoperable data	Dependency concentration; switching feasibility; share of staged/reversible commitments; alternative-pathway tests	Indecision, redundancy cost, chronic experimentation, or failure to commit when evidence is sufficient
3. Traceable distributed agency	Decision-rights matrix; agent/AI logs; provenance; escalation thresholds; human override; contestation route	Time to reconstruct a decision; provenance completeness; unresolved accountability gaps; override effectiveness	Latency, documentation overload, ceremonial oversight, or excessive centralization
4. Embedded safeguards	Life-cycle criteria; risk thresholds; security-by-design; work-quality criteria; externality allocation	Guardrail breaches; externalities with assigned owners; life-cycle evidence; exception closure time	Over-constraint of experimentation, compliance theater, or safeguards displaced to less visible actors
5. Recursive learning and reconfiguration	Governance retrospectives; assumption logs; portfolio rebalancing; metric revision; post-deployment learning loops	Rules/metrics revised after evidence; invalidated assumptions; learning-cycle time; capability gains after disruption	Governance churn, unstable criteria, superficial retrospectives, or learning not translated into changed decisions
6. Ecosystem coherence and legitimacy	Interoperability standards; joint risk/dependency registers; shared evidence; governance forums; escalation agreements	Interface failures; unowned cross-boundary risks; dispute-resolution time; shared-control coverage; partner participation	Coordination cost, dominant-actor capture, groupthink, or formally aligned interfaces with low trust

V. DISCUSSION: IMPLICATIONS FOR INNOVATION MANAGEMENT

5.1 Theoretical implications

A first theoretical implication is to extend the object of innovation governance beyond traditionally assessed ideas, portfolios, projects, capabilities, and outcomes to encompass trajectories formed by the commitments, dependencies, decision rules, infrastructures, and externalities that accumulate throughout innovation. Such an extension matters because even a sequence of individually successful innovations may produce a collectively fragile trajectory.

A second theoretical contribution is to distinguish innovation performance, innovation capability, antifragile response, and generative capacity more sharply rather than regarding these dimensions as equivalent. Although empirical IMS research indicates that systematic management can strengthen performance, capability, ambidexterity, and openness (Arslan et al., 2025; Giordano et al., 2025; Silva, 2021), generative capacity also requires examining whether those achievements preserve and regenerate the conditions for future value creation. Accordingly, the six functions are positioned as governance antecedents, intermediate outcomes represent proximate pathways, and generative capacity remains the higher-order dependent construct; keeping these analytical levels separate helps limit the risk of tautological propositions.

The interpretation of autonomy yields a further implication: although Industry 6.0 often associates autonomy with expanding automation and autonomous systems, it is not treated here as a maturity indicator in its own right because its governance value depends on decision traceability, contestability, safeguards, and reconfigurability. This extends digital innovation research, in which agency is increasingly distributed across infrastructures and platforms (Nambisan et al., 2017), by specifying the mechanisms through which that distributed agency can remain accountable.

Finally, at the level of analysis, the framework connects organization-level IMSs with ecosystem governance by relating the requirements-based infrastructure for systematic innovation management provided by ISO 56001 to the interdependencies of value creation described in ecosystem theory, without collapsing the two

domains. Even an organization with a mature IMS may participate in an ecosystem whose interfaces, dependencies, externalities, or decision architecture undermine generative capacity.

5.2 Managerial and standardization implications

For managers, the framework can be used as a design and review lens layered onto existing innovation-management infrastructure. Directionality can be incorporated into portfolio criteria; option preservation into architecture, sourcing, and investment decisions; traceable agency into AI and agent governance; safeguards into stage gates and design requirements; recursive learning into post-implementation reviews; and ecosystem coherence into supplier, platform, and partnership governance.

The framework also distinguishes compliance evidence, which shows that required processes exist and are followed, from generative evidence, which concerns whether those processes enhance an organization's ability to learn, redirect its trajectory, collaborate, and preserve future options; the two forms of evidence are complementary without being interchangeable. Case evidence from ISO 56002 implementation reinforces the need for proportionality: innovation systems should be systematic without being over-optimized, because excessive formalization can erode the maneuvering space required for innovation (Kihlander et al., 2024).

The Harmonized Structure used across ISO management-system standards is relevant because it supports integration among innovation, quality, environmental, occupational health and safety, compliance, and sustainability management. A system-of-systems view may reduce duplicated controls and make trade-offs more visible, although formal integration does not in itself guarantee coherence among potentially incompatible objectives; directionality and recursive learning therefore remain necessary to identify and revise those tensions.

For standardization bodies, the six functions suggest research questions rather than immediate normative requirements. Since ISO 56001 and ISO 56008 already provide systematic requirements and measurement infrastructure, the additional question is how future guidance can address option preservation, distributed-decision traceability, ecosystem-level interfaces, and generative evidence without prescribing particular technologies or suppressing experimentation.

5.3 Policy and ecosystem implications

From a policy perspective, Industry 6.0 should not be operationalized solely through incentives for adopting advanced technologies, since such measures may accelerate investment while also entrenching proprietary platform lock-in, capability gaps, and asymmetric dependencies. Instruments supporting interoperability, open standards, skills, shared testbeds, contestation procedures, regulatory sandboxes, and trusted data infrastructures can instead increase ecosystems' capacity to experiment without weakening accountability.

This perspective is consistent with calls for a more systemic European research and innovation policy that integrates long-term sustainability and competitiveness rather than treating them as separate agendas (Richardson et al., 2024). It is also relevant to SMEs, which can face disproportionate costs from technology transition and compliance while remaining highly dependent on platforms and lead firms. Ecosystem-level instruments can reduce these asymmetries by providing shared capabilities rather than requiring each organization to internalize the full cost of governance infrastructure.

In distributed innovation systems, legitimacy is a condition for sustained viability, since continuing acceptance by workers, communities, customers, regulators, and partners cannot be secured through post-deployment communication alone but requires meaningful opportunities for affected stakeholders to understand, challenge, and influence consequential innovation decisions. This obligation also entails consideration of future generations and ecosystems through credible forms of representation supported by evidence rather than symbolic consultation (ISO/UNDP 53001:2026, §3.2). Decision traceability and ecosystem coherence thus extend beyond control functions to become conditions for maintaining the social legitimacy of innovation over time.

5.4 Empirical research agenda

The propositions are formulated to support a cumulative empirical research programme in which Proposition 1 can be examined through comparative longitudinal cases or survey models that test whether revisable directionality moderates the relationship between IMS maturity and longer-term adaptive outcomes. Proposition 2 can be studied through dependency maps, switching-cost data, staged-investment portfolios, and event histories that observe whether optionality reduces reconfiguration cost under uncertainty.

For Proposition 3, particularly relevant to agentic and AI-intensive settings, decision logs, provenance records, override events, and decision-reconstruction times can be related to error correction, incident recovery, and portfolio revision. Proposition 4 can be examined through life-cycle and cross-boundary impact data, especially where environmental, safety, or labour effects are difficult to reverse, while Proposition 5 calls for longitudinal event-based designs to observe whether disruptions and unexpected outcomes lead to revisions of assumptions, metrics, portfolio rules, and governance arrangements rather than merely local corrective actions.

Testing Proposition 6 calls for multi-level designs in which network analysis, ecosystem surveys, interface-failure data, joint risk registers, and dispute-resolution records can examine whether ecosystem coherence strengthens the contribution of organizational innovation-management capability to generative outcomes. In parallel, measurement research should compare empirically whether generative capacity is better modelled as a formative higher-order construct, a configurational outcome, or a family of complementary indicators without presupposing any of these alternatives. Rival explanations also need to be considered by controlling for baseline IMS maturity, organizational size, sector, autonomy intensity, and initial ecosystem position, while establishing temporal ordering between governance mechanisms and observed outcomes.

5.5 Boundary with prior formalization

The distinct contribution of this study becomes apparent in comparison with the earlier formalization of Industry 6.0 (Casale et al., 2026a), which addressed the definitional question of which governance characteristics distinguish the paradigm from a technology-centred successor narrative. The question pursued here is instead operational: which innovation-governance mechanisms can make that formalization actionable and testable? The response comprises a new three-level architecture, six conditional propositions, an evidence-and-trade-off matrix, and explicit integration with the empirical IMS literature, without reproducing the earlier definition or its interpretative notes.

A related distinction concerns the generative-capacity contribution (Casale et al., 2026b), which developed the theoretical construct and its implications for assessing value beyond productivity. In Industry 6.0 innovation configurations, generative capacity is instead positioned as a higher-order outcome and examined in relation to the mechanisms through which it may be governed, thereby shifting the scientific contribution from conceptual redefinition towards operationalization, construct separation, and theoretical integration.

VI. CONCLUSION AND LIMITATIONS

If Industry 6.0 is defined solely through an ever-expanding inventory of advanced technologies, it risks remaining conceptually weak, because the more consequential transformation concerns the redistribution of agency and interdependence that arises when data, models, autonomous systems, organizations, and infrastructures jointly produce innovation outcomes. The proposed framework responds to this transformation by operationalizing Industry 6.0 as a problem of generative governance within innovation management.

The framework identifies six mechanisms—directionality, option preservation, traceable distributed agency, embedded safeguards, recursive learning and reconfiguration, and ecosystem coherence and legitimacy—whose contribution depends on their overall configuration rather than on the sum of their individual intensities. Considered in their interdependence, these mechanisms connect systematic innovation-management infrastructure to trajectory-level governance while keeping generative capacity distinct as a higher-order outcome; the six propositions are therefore formulated conditionally, so that the hypothesized relationships can be empirically challenged rather than accepted as a normative checklist.

The study's limitations arise primarily from the purposive rather than systematic selection of the corpus and the absence of empirical validation, compounded by the still-emerging and contested nature of the Industry 6.0 discourse. Accordingly, the model should be treated as a proposed governance logic rather than a description of a settled industrial stage, particularly because relationships among its functions may be nonlinear, vary across sectors, and require evidence that is costly or difficult to collect. Different levels of formalization may also be appropriate depending on firm size, regulation, technological intensity, and the severity of consequences.

The central claim is therefore modest but consequential: systematic innovation management provides necessary infrastructure, but it is not sufficient for distributed-autonomy innovation. The organizational idea of dynamic coherence—keeping purpose, knowledge, decisions, processes, and results aligned yet revisable as circumstances change—thus acquires an ecosystem dimension in Industry 6.0, as governance must follow consequential effects propagating across actors, places, systems, and time horizons. Industry 6.0 becomes meaningful for innovation management when organizations and ecosystems can govern not only the production of innovations, but also the preservation and regeneration of the conditions that make future innovation possible.

APPENDIX A. CONSTRUCT-DERIVATION TRACEABILITY MATRIX

Table A1 makes explicit the cross-source traceability used to retain the six governance functions. It is not intended as a frequency count or systematic-review coding table; it documents the minimum conceptual support used in the model-building process.

Table A1: Traceability of retained tensions and governance functions

<i>Retained tension</i>	<i>Governance function</i>	<i>Relevant evidence streams</i>	<i>Representative evidence</i>
Efficiency vs directionality	Directionality	Institutional/standardization; IMS/organization; Industry 6.0	European Commission (2021, 2022); ISO 56001:2024; Kihlander et al. (2024); Gomaa (2025)

Retained tension	Governance function	Relevant evidence streams	Representative evidence
Commitment vs option preservation	Option preservation	IMS/organization; Industry 6.0; antifragility/complex systems	March (1991); Teece (2007); Arslan et al. (2025); Equihua et al. (2020)
Autonomy vs accountability	Traceable distributed agency	Industry 6.0; digital innovation; AI governance/standardization	Fernández-Miguel et al. (2025); Verma et al. (2025); Nambisan et al. (2017); NIST (2023); ISO/IEC 42001:2023
Acceleration vs safeguards	Embedded safeguards and externality allocation	Institutional/standardization; Industry 6.0; sustainability	European Commission (2021); Chourasia et al. (2022); Gomaa (2025); ISO/UNDP 53001:2026
Adaptation vs recursive learning	Recursive learning and reconfiguration	IMS/standardization; organization theory; implementation research	ISO 56001:2024; ISO 56008:2024; Teece (2007); Gueorguiev (2023)
Firm-level optimization vs ecosystem coherence	Ecosystem coherence and legitimacy	Ecosystem theory; IMS/open innovation; polycentric governance	Adner (2017); Jacobides et al. (2018); Giordano et al. (2025); Ostrom (2010); Fernandez & Swart (2025)

AI DISCLOSURE STATEMENT

During the preparation of this work, the author used OpenAI ChatGPT to support literature organization, manuscript restructuring, drafting, language editing, and consistency checks. The author reviewed and verified the resulting output and takes full responsibility for the content, argumentation, sources, and final text.

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