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Interactive Integration of the Policy Laboratory and Policy Simulator in Light of Actor-Network Theory: Reciprocal Calibration and Black Box Formation in the Governance of Complex Adaptive Systems

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ABSTRACT

The root of governance dysfunctions lies in the epistemological rupture between the linear logic of traditional decision models and the nonlinear nature of complex adaptive systems. This gap predisposes policy laboratories to environmental reductionism and simulators to algorithmic rigidity. The "policy laboratory-simulator" model is proposed to address these shortcomings. This article develops a conceptual framework, arguing that interactive integration through reciprocal calibration generates an adaptive decision-making ecosystem. By addressing both blind spots—environmental reductionism and algorithmic rigidity—this ecosystem enables the observation of emergent properties and the prediction of systemic breakdown points. Based on theoretical analysis, it is argued that this methodological synergy can stabilize computational models' agency alongside human actors, bridging the gap between mathematical abstraction and concrete governance reality. Consequently, the proposed model facilitates transition from technocratic management to governance based on recursive dialogue in complex systems. This article is a theoretical reflection presenting a conceptual framework and lacks any case study or implemented simulation model test.

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1. Introduction

In recent decades, increasing complexity, the acceleration of structural transformations, systemic interdependence, and the emergence of nonlinear consequences have created an environment in which governance confronts wicked problems(Rittel & Webber, 1973). Wicked problems in governance have characteristics such as the lack of a definite formulation of the problem, the absence of a stopping rule, solutions being good-or-bad rather than true-or-false, and the planner having no right to be wrong (for further discussion, see Head, 2019; Peters, 2017; Roberts, 2000; Turnbull & Hoppe, 2019). These problems are essentially unique, can be considered symptoms of other problems, and are dependent on the choice of explanation; every solution is a one-shot operation, and trial-and-error learning is not possible.. Affected by these emergent transformations, various governance domains—such as energy, food security, biotechnology, and the digital economy—no longer function as separate sectors but rather as a nexus of intertwined variables, wherein policy intervention in any one of them produces unpredictable, ripple-like effects across the entire system. Consequently, part of the crisis of efficacy in governance stems from the rigidity of analytical tools and reductionism in modeling when confronting a network of co-evolving variables.

The governance laboratory, by creating a controlled and semi-artificial environment, seeks to identify causal relationships between policy interventions and their outcomes through the isolation of variables and the elimination of environmental noise. However, the elimination of environmental noise—which in complex systems carries vital signals and determining feedback—results in the removal from the analytical network of the dynamic agency of actors, social interactions, and institutional feedback. As a consequence, the laboratory suffers from an external validity problem, and its results are difficult to generalize to the macro scale and the turbulent atmosphere of society (Pritchett, 2016).

The policy simulator model, by contrast, employs computational power and agent-based modeling to represent the dynamics of complex systems on a larger scale. Yet, to achieve this and to avoid chaos, qualitative variables, fundamental uncertainties, and the learning and adaptive capacities of actors are reduced to rigid parameters and predetermined rules. As a result, the simulator encounters the problem of referentiality—that is, a lack of correspondence with the changing reality. In light of this, the digital twin produced by the simulator, although mathematically coherent, is not effective for understanding structural transformations or the emergence of novel phenomena (Garrone, 2025).

In response to the shortcomings of these two tools, hybrid models have emerged, such as participative system dynamics (Vennix, 1996), group modeling (Andersen & Richardson, 1997), companion modeling (Barreteau et al., 2003; Étienne, 2011), and participative agent-based modeling (Smajgl & Barreteau, 2017). Nevertheless, these hybrid models remain to some degree reductionist. Participative system dynamics focuses primarily on feedback loops and causal structures but falls into reductionism in representing heterogeneous agencies and the adaptive behaviors of agents at the micro level. Group modeling emphasizes consensus-building processes in small groups but lacks a systematic approach for transforming qualitative narratives into executable parameters; this absence itself creates a form of operational reductionism. Companion modeling incorporates local knowledge through role-playing games but suffers from reductionism in terms of external validity and generalizability of results. Participative agent-based modeling, despite its capacity to represent heterogeneous agents, still faces challenges of calibration and the gap between qualitative narratives and if-then rules; this gap itself is an instance of reductionism at the implementation stage.

Despite the efforts undertaken to remedy the deficiencies of the laboratory and the simulator, and despite the reductionist nature of the models resulting from these efforts, it must be recognized that in confronting wicked problems, the reductionist character of the tools employed is attributable either to the intrinsic nature of the data used, or to the fundamental problem of exclusive reliance on either quantitative or qualitative data in these models, or to the lack of proper integration of these two data types. This is because the policy laboratory model alone is immersed in qualitative data but lacks generalizability. The policy simulator model alone is immersed in quantitative data but lacks referentiality and flexibility. Existing hybrid models, each in their own way, exhibit an imbalance or a gap in the intermediate stages of the modeling process with regard to integrating these two types of data.

In light of this fundamental problem, and in order to enable governance to confront wicked problems effectively, the present article aims to propose a framework that, through the "interactive integration" of the policy laboratory and the policy simulator, overcomes the aforementioned reductionism. In pursuit of this aim, the central research question of this article is: How can a structural articulation and methodological synthesis between the behavioral capacities of the policy laboratory and the computational power of the simulator yield an integrated governance decision-making framework for environments of radical uncertainty—one that simultaneously possesses the capacity to represent adaptive agencies and the inertia of power structures? In response, this article advances a conceptual proposition: the interactive integration of these two paradigms through reciprocal calibration can lead to the emergence of an adaptive decision-making ecosystem. In this decision-making ecosystem, quantitative and qualitative data are integrated not in an imbalanced manner, but rather through a recursive cycle and with the participation of human and non-human actors. This means that the extracted rules, parameters, and even the very definition of variables are never considered final; rather, after being presented to the initial network of actors (the same ones who provided the original narratives), they are subjected to critique, revision, and even rejection. This cycle—which will be formulated later in the paper under the headings of "reciprocal calibration" and "recursive consensus-building"—allows the model to produce temporary and sufficient representations for action in conditions of radical uncertainty, without falling into algorithmic rigidity.

Given the nature of the problem and the ontological stance adopted by this article, its contribution to the knowledge system of public administration and governance is conceptual and theoretical. No empirical data, case study, or simulation implementation is presented in this article. Indeed, the arguments advanced herein are theoretical propositions intended to inform future empirical research on the design and evaluation of decision-support systems in contexts of complexity and radical uncertainty.

2. Research Methodology

This article falls within the category of theoretical-reflective research and does not involve empirical or field data. Its nature is that of a conceptual paper with a theoretical-design orientation, which employs a dialectical synthesis method and draws upon Actor-Network Theory (ANT) as a heuristic tool to construct a “policy lab-simulator” model. The steps of reasoning include identifying the epistemological gap, selecting a middle-range theory, logical design of the model, and internal evaluation. The validity of the article is limited to logical coherence and face validity, and the findings make no empirical claims. This research serves as a starting point for subsequent studies, not an end point.

3.Theoretical Framework

Wicked problems in governance entail the entanglement of quantitative and qualitative data within a nonlinear network. However, conventional tools for addressing such problems each rely on only one type of data, thereby falling into methodological reductionism. Due to their holistic and multidimensional nature, wicked problems demand an integrated, network-oriented approach in which quantitative and qualitative data are considered not merely alongside each other but intertwined within a material-semiotic network. To overcome this impasse, Actor-Network Theory (ANT) – originally developed for multidimensional socio-technical phenomena – proves suitable because of its capacity to integrate quantitative and qualitative data into a material-semiotic network. In this perspective, ANT emerges not merely as a descriptive model but as a flat ontology that, by rejecting traditional dichotomies such as subject/object and human/nonhuman, redefines the governance system as a socio-technical assemblage.

Actor-Network Theory emphasizes interaction among human and nonhuman actors—technologies, institutions, objects—and, in the context of wicked governance problems, conceptualizes them as networks and material-semiotic relations, where quantitative and qualitative data are inseparably intertwined. These networks interact with one another. This emphasis makes ANT an appropriate analytical tool for understanding how analytical tools, quantitative models, and human actors become structured in designing a framework to confront wicked problems. ANT provides a suitable mechanism for discussing the intertwined relations and dynamics of actors, which is a central concern for wicked problems in governance precisely because such problems are inherently constituted by the inseparable entanglement of quantitative and qualitative data within a network of nonlinear relations.

Actor-Network Theory was developed in the 1980s through empirical case studies that detailed how phenomena are constructed (Law, 2009). In response to the question of how social work is accomplished (Law, 2009:148), ANT emphasizes the concept of the network and holds that all entities in the world—from nanoparticles to bodies, groups, ecologies, and spirits—interact within changing networks composed of discursive and material relations, and are linked together through "translation" to shape actor-networks. The theory also examines how networks become "stabilized" over time by actors and actions (Latour, 1987). One of the most important concepts of ANT for providing a model to confront wicked problems in governance is the principle of symmetry (Akrich & Latour, 1992; Callon, 2001; Latour, 2005; Law, 2009; Michael, 2016; Mol, 2010). According to this principle, agency is not an intrinsic human property but rather the product of situatedness and the configuration of relations within a network. Through the symmetry principle, material actors (e.g., algorithms, protocols, databases), metaphysical actors (e.g., economic theories), and human actors (e.g., policymakers, data analysts, non-governmental actors, citizens) all become equally important in the production of governance networks and in confronting wicked problems. This ontological equality among different types of actors is a necessary condition for tracing the complex networks within which wicked problems emerge – because in such a perspective, neither the human (with qualitative data) dominates the nonhuman (with quantitative data) nor vice versa; rather, each actor contributes equally to the construction of the problem and the strategies for addressing it, flattening the world as much as possible (Latour, 1988). Only in light of such a flat ontology is it possible to observe and trace every emergent link.

In realizing this, ANT conceives the governance world as a mobile network of material and discursive relations in which a simulation algorithm possesses as much agency as a policymaker (Salter, 2019, p. 5). From this viewpoint, governance in the face of wicked problems is a process of becoming – a process that stabilizes through the continuous interaction between quantitative and qualitative data (Iyamu & Mgudlwa, 2017, p. 3).

From the perspective of ANT, material actors on one hand and human actors on the other do not exist separately and distinctly; rather, there are entanglements between them. This is because actors may mediate the work of other actors (Latour, 1999), influence their form and activity, or act in ways that make other actors dependent on them. Thus, the principle of symmetry invites the researcher to question how problems and components become intertwined, how they become mutually dependent within a complex network, and how reality is produced from these entangled relations (Latour, 2005).

Wicked problems in governance, due to their holistic, multidimensional, and nonlinear nature, can be reduced neither to one type of data (quantitative or qualitative) nor solved by relying on a single actor or institution. Such problems always entail the entanglement of quantitative and qualitative data within a network of complex causal relations and unstable feedback loops. In these circumstances, one of the most critical issues is how to align heterogeneous actors – human and nonhuman, quantitative and qualitative, material and discursive – toward a shared direction. Actor-Network Theory, to explain this alignment, emphasizes the mechanism of translation. Translation is the process through which a problem, with all its complexity and entanglement, becomes an obligatory passage point for all actors, enabling the formation of a temporary order under a black box. Translation comprises four key stages: problematization, interessement, enrolment, and mobilization, explaining how heterogeneous actors are aligned under a single will (Callon, 1986: 15). In the problematization stage, the central actor, by precisely defining the dimensions of a problem, establishes itself as the obligatory passage point, such that solving the problem for other actors depends on passing through the channel defined by it. In this stage, parameters are defined based on which some actors may be excluded or included. In the interessement stage, the central actor uses various tools to lock the interests of other actors into the goals of the network (Fenwick & Edwards, 2010, p. 10). Enrolment involves the precise definition of roles and responsibilities, leading to the acceptance of each actor's position within the network and the establishment of reciprocal relations among them. Mobilization, as the final stage, indicates that all components of the network have been coordinated and that various actors act to realize the demands and goals of the central actor (Rubin et al., 2020, p. 320). With the temporary stabilization of the network, a black box is formed (Callon, 1991). This concept describes a situation in which a new entity has emerged, and previous relations and controversies are forgotten in light of this temporary stabilization (Bueger & Gadinger, 2018, p. 83). The stability of the actor-network created through the translation process depends on how this new network is questioned. The network remains temporarily stable as long as there is no need for re-examination and re-questioning (Callon & Latour, 1981:285).

Despite ANT's applicability to the analysis of complex problems, its use in the governance arena also invites critical considerations. First, the symmetry principle, although ontologically powerful, confronts the actual inequality of power, resources, and access within governance networks. Moreover, despite the emphasis on flat ontology, one cannot always assume that an algorithm has as much agency as a minister or a legal institution in a strategic decision-making context, unless this equality remains at the analytical level of "tracing links." Furthermore, ANT's focus on tracing relations and actors sometimes leads to neglect of normative criteria such as justice, accountability, or the public interest – criteria that play a central role in the analysis of wicked problems. Therefore, this study employs ANT as a heuristic lens to preserve the ability to trace complex links while avoiding the reduction of governance to mere "network effects."

4. Governance Lab–Simulator as an Analytical Framework for Understanding the Dynamics of Complex Systems

The governance policy lab–simulator is an integrative system that combines scattered data, analytical models, and diverse theoretical formulations within a coherent framework. The main function of this system is to create a perceptual-analytical infrastructure capable of representing the actual behaviour of the governance system and revealing the consequences of policies within the dynamic context of relationships, feedback loops, and uncertainties. This system enables policymakers to observe, compare, and evaluate probable future trajectories, tipping points, and the outcomes of different scenarios before implementation. In this way, the lab–simulator becomes an intelligent tool for assessing the quality, coherence, and consequentiality of policies, thereby significantly enhancing decision-making capacity.

4-1 Problem Definition and Stabilization of the Obligatory Passage Point

The main characteristic of wicked problems lies in the interaction between two dimensions: "normative conflict" and "factual complexity." This interaction renders the problem unstable and persistent. In such problems, any normatively preferred solution, due to factual complexity, inevitably creates grounds for disagreement among actors, because each actor, based on their own normative preferences, offers a different factual justification for the problem. Consequently, truth claims and preferred solutions remain perpetually contested (Bannink & Trommel, 2019). Moreover, complex relationships emerge among the actors involved in governance – relationships that cannot simply be assumed away.

This is while, in the ontology of Actor-Network Theory, the governance system is conceived as a network of material-discursive relations, in which the starting point for any effective intervention is the proper identification and definition of the problem and a precise understanding of its multiple dimensions. Furthermore, in the policy lab–simulator as an integrative system, once the focal actor defines the problem, that problem becomes an "obligatory passage point" (OPP) and the central node of the network (Chen & Lin, 2018; Viollet et al., 2020). In realising this, one of the most important mechanisms that ANT offers is the mechanism of translation. Using the translation framework, attention can be directed towards the transformative processes through which entities are combined and linked with one another. For Callon, translation entails creating convergences and alignments by connecting things that were previously different.

Drawing on this mechanism – when confronting wicked problems, where the entanglement of technical, institutional, behavioural dimensions and conflicts of interest make one-dimensional narratives of the problem impossible – the policy lab–simulator creates a network of linkages among different perspectives and experts. As Latour (writing under the pseudonym Jim Johnson, 1988) wrote, translation means displacement, drift, mediation, and the creation of a link that did not exist before (Johnson, 1988); and through it, it induces actors to coexist (Latour, 2005: 108). According to Valler & Blumczynski (2024), translation is not merely a relation but a relation that brings about the coexistence of actors. Based on this, in the policy lab–simulator, as a result of translation, different domains of knowledge, interests, and institutional capacities converge.

Following this convergence, the focal actor, through the mechanisms of interessement and enrolment, seeks to bring together scientific experts, technical specialists, and operational actors relevant to each dimension of the problem around the obligatory passage point (Callon, 1986; Fenwick & Edwards, 2010; Viollet et al., 2020) and engages them within a network of analytical and knowledge-based interactions.

This creates a common field for seeing the problem – a field in which scattered and heterogeneous data from different sub-networks are presented as a single, dynamic, and analysable picture. At this stage, the focal actor does not merely issue a formal invitation but, by intelligently designing the relationships, roles, and benefits that each actor gains from entering the process, actively places them within the problem's orbit. Thus, interessement in the governance lab–simulator means that the focal actor represents the problem in such a way that it appears necessary, attractive, and relevant to the professional concerns of each stakeholder group – from technical and academic experts to operational managers and decision-makers (Scelles et al., 2020). In this regard, enrolment acts as the stage of stabilising roles, where the focal actor specifies what role each actor should play (Callon, 1986; Rubin et al., 2020; Zarkasi & Rahardian, 2022), what information they should provide, and in which part of the analysis or modelling they should participate. Therefore, enrolment in the policy lab–simulator is not merely an allocation of responsibility but the creation of a kind of mutual commitment and network cohesion that encourages actors to actively participate in producing multidimensional and rich explanations of the problem.

Through these two mechanisms, a network of knowledge-based, computational, and operational interactions is formed, in which different narratives of the problem – instead of leading to conflict and fragmentation – are organised and brought together around the obligatory passage point (Salter, 2019; Bueger & Gadinger, 2018). This co-location produces a common analytical structure, which is an epistemological necessity for the problem to enter the modelling cycle; because only through such a coherent network can one obtain a multilayered, valid, and reliable picture of the problem's behaviour in the real context of governance.

Transforming the problem into an obligatory passage point by the focal actor causes the problem to be formulated not as a one-dimensional issue but as a multidimensional situation (Lidskog & Sundqvist, 2002). In this regard, enrolment is not a ceremonial membership process but the entry of an actor into an algorithmic-analytical mechanism in which each actor must take on a specific role in producing, interpreting, and feeding data on the situation. Based on the institutional position and knowledge capacity of each actor, a specific analytical role is assigned to them – a role that may include data production, interpretation of key trends, alignment of definitions and concepts, or definition of agents' behavioural rules.

The outcome of this process is the juxtaposition of valid narratives, necessary data, and specialised explanations within a common platform – a platform that enables the multidimensional formulation of the problem and ultimately leads to a more accurate representation of the problem's behaviour in the real governance context. In this sense, each actor, depending on their institutional or specialised nature, is responsible for clarifying specific dimensions of the problem. In the policy lab–simulator, these actors determine the logical structure of the problem by providing decision rules, interaction rules, policy scenarios, and success indicators. Individuals and representatives of executive bodies and organisations are also responsible for formulating infrastructural constraints, mapping operational realities, and defining implementation behaviours; they depict the complexities of the implementation environment, structural barriers, and the actual capacities of the governance system.

In this progressive convergence, the network – formed through the mechanism of "translation" and in the form of an obligatory passage point – provides the ground for the meeting and alignment of heterogeneous actors, the integration of conflicting interests, and the balancing of institutional rules, operational realities, and epistemic validity. Consequently, the lab–simulator becomes a reference point in which each specialised role – not in isolation but in alignment with other roles and based on agreed propositions – actively and sustainably participates in producing and refining the picture of the governance situation.

At this stage, raw and processed data and information flow through various channels to create a comprehensive picture of the problem. The first channel for data provision is the questionnaire. Questionnaires are designed purposefully and structurally to systematically collect experts' views, priorities, subjective assessments, and the uncertainties present in each dimension of the problem. This tool allows the focal actor to gather quantitative and qualitative data from a wide range of actors without the bias of face-to-face interactions. The second channel is the interview. In-depth, semi-structured interviews are conducted with key actors, especially those who possess tacit knowledge, operational experience, or unique institutional understanding. These interviews make it possible to explore hidden narratives, uncover unspoken assumptions, and record details that do not fit into closed-ended questionnaires. In this way, deeper layers of the problem – including hidden conflicts of interest, behavioural barriers, and informal power relations – are revealed.

The third channel for data provision at this stage is the lecture. Specialised lectures by experts in each field provide an opportunity to present research findings, preliminary modelling results, alternative policy scenarios, and proposed success indicators. These lectures not only help share explicit knowledge but also create a platform for public critique and review by other actors. The fourth channel is debate. Organised debates among actors who hold conflicting or complementary narratives of the problem are among the most important pillars of the conference room. In debate, the fundamental assumptions of each narrative are challenged, the blind spots of each explanation are exposed, and the possibility of reaching a shared understanding of the problem's complexities is facilitated. Debate provides a space to test the logical robustness of each claim and to discover areas of convergence among seemingly divergent perspectives.

Finally, the fifth and most critical channel is the final review and analysis with an emphasis on consensus-building. After the previous stages, at this stage the data enters the final phase of summarisation, synthesis, and analysis. Here, efforts are made to formulate agreed propositions, remaining uncertainties, points of convergence and divergence among actors, and final operational recommendations in the form of a collective and documented analysis (Deutsch et al., 2024). This final analysis is not a simple minority or majority opinion, but the result of a structured consensus-building process in which multiple narratives – rather than eliminating one another – are placed side by side, constructing a multilayered and as-complete-as-possible picture of the problem. Thus, at this stage of the conference room, data and information are not produced haphazardly or randomly but through these five interactive and structured channels – questionnaire, interview, lecture, debate, and final review with a consensus-oriented approach – and are then exchanged, critiqued, and finally stabilised. Each of these channels has a unique function, and together they cover a complete cycle from micro-level data collection to the production of collective knowledge at the macro level. The result is a valid, dynamic, and reliable picture of the problem that can improve everyone's understanding of the problem and facilitate decision-making under conditions of governance complexity.

4- 2 Mediator versus Intermediary: Transformation, Translation, and the Production of Computational Order

In confronting wicked problems, at the problem definition stage where diverse actors come together with their narratives, normative conflicts, factual complexity, and conflicting interests, a portion of the information consists of rich but fragmented qualitative dataThese data include perceptions, subjective judgments, lived experiences, hidden assumptions, value priorities, perceived conflicts of interest, as well as linguistic propositions and discursive arguments (Will et al., 2024). Unlike quantitative data, which are numerical and straightforward, these qualitative data are saturated with meaning, context-dependence, multi-layeredness, and institutional/cultural embeddedness. In other words, what is gathered at the problem definition stage is not mere figures and statistics, but a rich and complex picture of how actors understand, interpret, and respond to the problem.

This is while, in the policy lab–simulator model, the realisation of expected functions requires a set of institutional and technical mechanisms that can systematically steer the process of converting data, knowledge, and analysis into policy decisions, moving beyond mere gathering of experts or production of abstract models. For these data to be used in the decision-making process, they must pass through a loop of transformation and meaning production. This loop is the procedural mediator that transforms qualitative data – without eliminating their semantic richness and contextual grounding – into a coherent, logical, and computable structure, and serves as the translation loop between qualitative data and the quantitative model, and between the quantitative model and the decision. In this process of mediation, behavioural rules extracted from actors' narratives are transformed into parameters and if-then rules. Thus, the overflows resulting from the initial framing – instead of being discarded – enter the analytical network and participate in the meaning-production process (Callon, 2007: 143). This stage, by performing three fundamental functions – steering the analysis and simulation process, selecting and validating baseline scenarios, and interpreting quantitative outputs in relation to institutional realities – establishes a bridge between computational results and the non-linear logic of decision-making in complex systems.

In the policy lab–simulator model, from an epistemological perspective, the situation analysis room is responsible for translating discrete and heterogeneous data into a dynamic and negotiable representation of system behaviour; a representation that provides policymakers not merely with a numerical output, but with a shared, multi-layered, and pre-tested picture of the governance situation. In this way, the analysis room is not an added managerial layer, but the very condition of possibility for moving from model production to decision support under conditions of radical uncertainty and emergent behaviours.

Since, in actor-network theory, agency is not an intrinsic property but the product of situatedness and the configuration of relations within a network, this stage of the policy lab–simulator model should be defined as a socio-technical collective in which mechanisms such as agent-based algorithms and scenario design rules, as actants, actively delineate the boundaries of policy possibility and, under the principle of symmetry, become endowed with agency to the same extent as a human expert, a parameter, or a policy judgment (Nallur et al., 2024; Dudek, 2024). From the perspective of ANT's flat ontology, at this stage an actor in the form of a socio-technical collective emerges, and human agency and non-human agency (algorithms, parameters, databases) are placed side by side in a symmetrical and equivalent configuration. Without this, qualitative data can never be transformed into an executable model. Therefore, transformation and meaning production are precisely the processes that enable the transition from problem definition to the decision-making process (Latour, 2005: 108; Johnson, 1988), and conversely, they turn the produced formulations into feedback for revising practical narratives. From this viewpoint, this socio-technical structure is the pivot that links theory and practice in a recursive cycle.

At this stage, when a behavioural rule extracted from actors' narratives is turned into an if-then parameter, this not only describes that rule but also transforms it into a computational reality that influences the reproduction of the problem and offers a statement of what "ought" to happen in the governance system. This is achieved not as a linear prescription but as a dynamic framework. The policy lab–simulator, at this stage, by enabling the simulation of alternative scenarios and recursive calibration, poses the question to the governor: if we change the current behavioural rules (e.g., incentives, constraints, information flows), what emergent consequences will the system have? Thus, this stage is not a passive intermediary but a reflexive performative agent that both represents the rules and allows their rewriting in the face of misfires.

In the policy lab–simulator model, this process, by bringing together the scattered and heterogeneous components produced in the conference room within an integrated computational architecture, makes it possible to achieve a shared picture of the system's state and its key trends – a picture that is not merely an aggregate of data, but a representation of causal relationships, feedback mechanisms, actors' behavioural rules, infrastructural constraints, and features of the institutional environment. It pre-evaluates unintended consequences, unwanted turbulences, and emergent behaviours in multi-level governance layers, and finally, by covering the blind spots of environmental reductionism in the lab and algorithmic rigidity in the simulator, enables the observation of emergent properties and prediction of systemic crisis points, thereby filling the epistemological gap between the linear logic of models and the non-linear reality of governance.

To realise the above-mentioned process, the policy lab–simulator at this stage first collects and reviews all qualitative data output from the conference room. These data may take the form of transcribed audio files of interviews, transcribed debate texts, open-ended questionnaire responses, and analytical notes from consensus sessions. In the second step, these data undergo directed content analysis to extract key concepts, recurring categories, hidden variables, and the causal relationships perceived by actors (Will et al., 2024). The third step is behavioural mapping: key agents, their attributable behaviours, decision rules, and interactions are identified. This behavioural map is essentially a qualitative model of the governance system relevant to the problem. The fourth step is transforming this qualitative map into an implementable formulation. In this step, qualitative data (e.g., interview and debate transcripts) are open-coded using MAXQDA software. Then, the initial codes are converted into main categories in structured consensus sessions (with at least three independent experts), and the inter-coder agreement coefficient (Cohen's Kappa $\geq$ 0.70) is calculated. At this step, from each category a behavioural rule of the form "if [condition] then [action]" is extracted. For example, "if inter-organisational distrust is high, then executive coordination decreases". These rules are validated using the Fuzzy Delphi technique in two rounds. Furthermore, instead of point values, for each rule a confidence interval is defined based on the distribution of experts' responses. The inherent uncertainty in qualitative data is modelled using type-2 fuzzy logic. The initial model output (agent-based simulation) is evaluated using Monte Carlo sensitivity analysis (1000 iterations) and critical parameters are identified. The results are then fed back to the problem definition stage for a reverse Delphi process to revise rules and update parameters. To bridge the gap between qualitative themes (abstract concepts) and quantitative parameters, cognitive consensus mapping is used, in which each qualitative concept is transformed into a latent variable with several observable indicators (derived from interview texts). This method is rooted in the mixed-methods literature (Creswell & Clark, 2017) and participatory agent-based modelling (Smajgl & Barreteau, 2017)

Based on the processes described above, for each extracted behavioural rule, measurable parameters are defined, decision functions are formulated as if-then logic or mathematical equations, and boundary scenarios and possible initial values are estimated based on qualitative data. At this stage, qualitative data acquire a structured quantitative form without losing their semantic richness (Nallur et al., 2024); rather, that richness is preserved as multi-valued and interval parameters. The initial version is fed back to the conference room to ensure its consistency with the actors' subjective understandings. This feedback loop reduces the gap between actors' tacit knowledge and the explicit model formulation. Thus, what is produced at this stage is a "behavioural formulated package" that includes identification of agents, definition of their states and behaviours, specification of interaction and learning rules, determination of input and output variables, as well as definition of policy scenarios and success indicators (which were partially determined at the problem definition stage but are operationalised here). Therefore, the relationship between this stage and the problem definition process is complementary and sequential: the problem definition stage produces rich but fragmented and context-dependent qualitative data, and the subsequent stage transforms these data into a coherent, logical, and computable structure for entry into the simulation cycle. Without this stage, the qualitative data from problem definition cannot be converted into an executable model and remain merely a set of descriptive reports; without the qualitative data from problem definition, behavioural formulation in the current stage would be devoid of real content, based on abstract and unrealistic assumptions, thus reducing rather than increasing governance effectiveness. From this perspective, the current stage acts as a bridge between the subjective-discursive lifeworld of actors and the formal-algorithmic world of simulation models. This bridge enables the systematic translation of actors' concerns, experiences, and practical rationality into a language that a computing machine can process, thereby representing system behaviour across different scenarios. Thus, the policy lab–simulator, in its horizontal integration – from problem definition and interessement to the production of qualitative data, then behavioural formulation, and finally output delivery – implements a complete and coherent cycle for effective intervention in the governance system.

The formulation of qualitative data in the policy lab–simulator involves two overlapping effects: intermediation and mediation (Latour, 2005: 39). In the ontology of actor-network theory, an intermediary is a messenger that "transports meaning or force without transformation", just as data from the problem definition process are transferred to final formatting and formulation without being altered. In this mode, the task of this stage is to describe how the stakeholders and elements of a wicked problem are structured within a network of issue-systems. In contrast, when the meaning or elements to be carried are translated, distorted, or modified, this stage performs a mediator function. This implies that the policy lab–simulator mediates actors' experiences by helping them to narrow down policy options, redefine scenarios on their behalf, and provide analytical feedback to them (Besbris, 2020: 113).

4-3 Recursive Consensus-Building, Black Box Formation, and Agency Attribution in the Laboratory-Simulator

After converting the scattered, context-dependent qualitative data from the problem definition stage into a behavioural formulation and an implementable computational package in the intermediate stage, the decisive final step is to return these outputs to the very same network of actors who originally defined the problem and provided their narratives. This return is the heart of the translation mechanism and the condition of possibility for the transition from a pluralistic, contested network to a black box (McArthur, 2023; Minniti & Magaudda, 2024). A black box in which previous controversies are forgotten and a new entity emerges – until it is called into question – as an output for decision-making. Without this presentation and recursive consensus-building, the output of the policy lab–simulator would lack agency, because agency is not a product of mathematical precision but of the configuration of relations within a network and acceptance by the human and non-human actors present in that network (Qin et al., 2025). In this regard, the principle of symmetry is of particular importance, since according to this principle, a model possesses agency to the same extent as a human expert within the network and has the capacity to change the behaviour of human actors. In the causal chain of decision-making, the model appears as an indispensable mediator. On this basis, from a practical policy perspective, the output of the situation analysis room, once transformed into a black box, is no longer a purely technical proposition but becomes part of the cognitive infrastructure of governance.

The produced behavioural formulated package – which includes identification of agents, decision rules, interaction functions, policy scenarios, and success indicators – is by no means an objectively discovered reality. Rather, it is a translation of actors' narratives into the language of computation (McArthur, 2023). A translation that is always accompanied by a reduction in semantic richness, a reduction in context-dependence, and a reduction in creative ambiguities. Therefore, this package must be returned to the same community of experts, executive managers, institutional analysts, and other actors who gathered in the conference room and from whom the initial narratives emerged. Through this return, the behavioural formulated package, as a non-human actant, is placed before the questions of human actors (Azadi et al., 2025). This is not a flaw but the condition of possibility for the stabilisation of the network, because a network becomes stabilised only when heterogeneous actors – both human and non-human – can resolve their differences not through elimination but through realignment. In this process, human actors critique the model's outputs, uncover hidden assumptions, and offer corrective suggestions. In turn, the model as an actant also displays its own resistance. This two-way dialogue between the logic of the lifeworld and the logic of the algorithm ultimately leads to a practical agreement on an acceptable representation for action (Qin et al., 2025; Minniti & Magaudda, 2024) – an agreement that remains in force as long as the black box is not called into question. In the policy lab–simulator model, the recursive consensus-building process is precisely designed to achieve such a black box.

In the trajectory of black box formation in the policy lab–simulator model, first, the output is presented to the actors involved in the problem definition stage. At this stage, each actor has the opportunity to compare the model with their own narrative. This encounter often begins with a conflict between the model and the actors' interests or lived experiences. In the second step, which can be called negotiation and adjustment, in response to these critiques, the technical team present in the session (itself a member of the network) examines the proposed modifications. These modifications are applied in the same session or shortly thereafter in the situation analysis room, and the revised version is returned again to the conference room. The third step is gradual convergence, through which a shared proposition emerges: that the model, despite its shortcomings, constitutes an acceptable representation of reality and can serve as a basis for decision-making. At this stage, remaining controversies are recorded as margins of uncertainty but no longer hinder action. The fourth step is black boxing: actors become accustomed to using the model repeatedly, and each time it is referenced, there is no need to reopen previous controversies – until it is called into question. At this stage, the model becomes a stable interface that different actors, even those who were not present in the consensus process, accept as a reference.

5. Conclusions

Drawing on the conceptual framework of Actor-Network Theory (ANT) and employing a dialectical synthesis method, the present article has grounded its theoretical argument on the proposition that the interactive integration of the policy laboratory and the policy simulator – through reciprocal calibration – can reduce the epistemological gap between the linear logic of traditional decision-making models and the non-linear, emergent nature of complex adaptive systems. Within this framework, the principle of symmetry enables the ontological equivalence between human and non-human actors (including simulation algorithms), while the process of recursive consensus-building and black box formation leads to the temporary stabilisation of acceptable policy options for action, while maintaining readiness for reopening in the face of external shocks and new data.

The theoretical inferences of the article suggest that the methodological synergy of the lab and the simulator can facilitate the observation of emergent properties, the prediction of systemic rupture points, and the bridging of the gap between mathematical abstraction and the empirical reality of governance. However, these inferences are confined to the domain of internal and logical validity and make no empirical or case-based claims. The most significant limitation of the article is the absence of any practical test, case study, or systematic simulation implementation; therefore, the external generalisability of the proposals requires, as a first step, an empirical research design.

The future research agenda should focus on the following axes:

1. Designing a step-by-step case study of the application of the "lab–simulator" model in a specific policy domain (e.g., energy, food security, or the digital economy) in order to assess feasibility and implementation challenges.
2. Developing evaluation indicators to measure the quality of "recursive consensus" and the "black box" within networks of heterogeneous actors.
3. An empirical investigation of the conditions under which computational models (as non-human actors) can be as effective as human experts in changing the behaviour of network actors.
4. Comparative research between the proposed model and existing hybrid approaches (e.g., participatory system dynamics modelling, companion modelling, and participatory agent-based modelling) in order to identify relative strengths and weaknesses.

Finally, this article is intended as a starting point for future empirical research, not an end point. The proposed "lab–simulator" model offers a new episteme for governance in the age of complexity, but its ultimate validity depends on its ability to confront real-world situations of radical uncertainty. Researchers interested in this field can shape the next steps in the realisation of this framework by employing longitudinal studies, agent-based simulations grounded in real data, and structured consensus-building processes.

6- Adherence to Publication Ethics: The Role of Artificial Intelligence in This Paper

In the preparation of this manuscript, generative artificial intelligence tools have been used solely in the stage of language editing and improving writing fluency – a practice permitted by the journal's author guidelines. These assists have been limited to rewriting sentences for greater clarity, resolving syntactic ambiguities, and standardizing paragraph structure; they have never been employed to generate scientific ideas, analyze data, derive conceptual insights, or shape the main arguments of the paper. All substantive content, theoretical framework, findings, and conclusions are the result of the authors' own intellectual work and independent writing. The use of artificial intelligence is declared solely as an auxiliary tool for language editing, in line with the principles of transparency and ethical responsibility in scientific publication.

References

Akrich, M., & Latour, B. (1992). A summary of convenient vocabulary for the semiotics of human and nonhuman assemblies. In W. Bijker & J. Law (Eds.), *Shaping Technology/Building Society*. MIT Press.

Andersen, D. F., & Richardson, G. P. (1997). Scripts for group model building. System Dynamics Review, 13(2), 107–129. https://doi.org/10.1002/(sici)1099-1727(199722)13:2<107::aid-sdr120>3.0.co;2-7

Azadi, S., Kasraian, D., Nourian, P., & van Wesemael, P. J. V. (2025). Stakeholder-specific urban digital twins as means for participatory planning: Evaluation of the FMU ontology. In *CUPUM 2025: The 19th International Conference on Computational Urban Planning & Urban Management*. OSF. https://doi.org/10.2139/ssrn.6571117

Bannink, D., & Trommel, W. (2019). Intelligent modes of imperfect governance. Policy and Society, 38(2), 198–217. https://doi.org/10.1080/14494035.2019.1572576

Barreteau, O., Bousquet, F., Attonaty, J.-M., & Souchon, I. (2003). Our companion modelling approach. Journal of Artificial Societies and Social Simulation, 6(2), 1-16.

Besbris, M. (2020). Upsold: Real estate agents, prices, and neighborhood inequality. University of Chicago Press. https://doi.org/10.25285/2078-1938-2021-13-2-297-299

Bueger, C., & Gadinger, F. (2018). *International Practice Theory*. Palgrave Macmillan.

Callon, M. (1986). The sociology of an actor-network: The case of the electric vehicle. In M. Callon, J. Law, & A. Rip (Eds.), *Mapping the Dynamics of Science and Technology*. Macmillan Press. https://doi.org/10.1007/978-1-349-07408-2_2

Callon, M. (1991). Techno-economic networks and irreversibility. In J. Law (Ed.), *A Sociology of Monsters: Essays on Power, Technology and Domination*. Routledge.

Callon, M. (2001). Actor network theory. In N. J. Smelser & P. B. Baltes (Eds.), International encyclopedia of the social & behavioral sciences (pp. 62–66). Elsevier. https://doi.org/10.1016/b0-08-043076-7/03168-5

Callon, M. (2007). An essay on the growing contribution of economic markets to the proliferation of the social, Theory, Culture & Society, 24, pp. 139–163. https://doi.org/10.1177/0263276407084701

Callon, M., & Latour, B. (1981). Unscrewing the big Leviathan: How actors macro-structure reality and how sociologists help them to do so. In K. Knorr-Cetina & A. V. Cicourel (Eds.), *Advances in social theory and methodology: Toward an integration of micro- and macro-sociologies* (pp. 277–303). Routledge & Kegan Paul. https://doi.org/10.1177/000169938302600107

Chen, H. W., & Lin, F. R. (2018). Evolving obligatory passage points to sustain service systems: The case of traditional market revitalization in Hsinchu City, Taiwan. *Sustainability, 10*(7), 2540. https://doi.org/10.3390/su10072540

Creswell, J. W., & Clark, V. L. P. (2017). Designing and conducting mixed methods research (3rd ed.). Sage Publications.

Deutsch, A. R., Frerichs, L., Perry, M., & Jalali, M. S. (2024). Challenges and recommendations for developing high-complexity participatory system dynamics models. *System Dynamics Review, 40*(1). https://doi.org/10.1002/sdr.1765

Dudek, M. (2024). On flat ontologies and law. *Jagiellonian University Repository*.

Étienne, M. (Ed.). (2011). Companion modelling: A participatory approach to support sustainable development. Éditions Quæ.

Fenwick, T., & Edwards, R. (2010). *Actor-Network Theory in Education*. Routledge.

Garrone, R. (2025). An adaptive, data-integrated agent-based modeling framework for explainable and contestable policy design. *arXiv*, arXiv:2511.19726.

Head, B. W. (2019). Forty years of wicked problems literature: Fording closer links to policy studies. Policy and Society, 38(2), 180–197. https://doi.org/10.1080/14494035.2018.1488797

Iyamu, T., & Mgudlwa, S. (2017). Transformation of healthcare big data through the lens of actor network theory. *International Journal of Healthcare Management, 11*(3), 182–192. https://doi.org/10.1080/20479700.2017.1397340

Johnson, J. (1988). Mixing humans and nonhumans together: The sociology of a door-closer. Social Problems, 35(3), 298–310. https://doi.org/10.2307/800624

Latour, B. (1987). Science in action: How to follow scientists and engineers through society. Harvard University Press.

Latour, B. (1988). *The Pasteurization of France*. Harvard University Press.

Latour, B. (1999). Pandora‘s hope: Essays on the reality of science studies. Harvard University Press.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford University Press.

Law, J. (2009). Actor network theory and material semiotics. In B. S. Turner (Ed.), *The New Blackwell Companion to Social Theory*. Blackwell Publishing. https://doi.org/10.1002/9781444304992.ch7

Lidskog, R., & Sundqvist, G. (2002). The role of science in environmental regimes: The case of LRTAP. *European Journal of International Relations, 8*(1), 77–100. https://doi.org/10.1177/1354066102008001003

McArthur, J. (2023). *Enrolment, technical mediation, and the obligatory passage point: A socio-technical examination of the Canada Green Building Council* (Doctoral dissertation). University of Edinburgh.

Michael, M. (2016). Actor-network theory: Trials, trails and translations. SAGE Publications.

Minniti, S., & Magaudda, P. (2024). The ‘obligatory passage point’ in knowledge co-production: Italy's participatory environmental monitoring platform. *Science as Culture, 33*(3). https://doi.org/10.1080/09505431.2024.2317236

Mol, A. (2010). Actor-network theory: Sensitive terms and enduring tensions. *Kölner Zeitschrift für Soziologie und Sozialpsychologie, 52*(1), 253–269.

Nallur, V., Aghaei, P., & Finlay, G. (2024). Systematic experimentation using scenarios in agent simulation: Going beyond parameter space. *arXiv*, arXiv:2407.16294.

Peters, G. B. (2017). What is so wicked about wicked problems? A conceptual analysis and a research program. Policy and Society, 36(3), 385–396. https://doi.org/10.1080/14494035.2017.1361633

Pritchett, L. (2016). *Where did all the data go? External validity and the quest for development impact* (Faculty Research Working Paper Series). Harvard Kennedy School.

Qin, C., Sun, F., Rong, Y., Wang, W., Zhang, X., Chen, Y., & Liu, Y. (2025). Developing a web-based participatory approach to model evaluation for environmental decision-making. *Environmental Modelling & Software, 185*, 106312. https://doi.org/10.1016/j.envsoft.2025.106790

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. Policy Sciences, 4(2), 155–169. https://doi.org/10.1007/bf01405730

Roberts, N. (2000). Wicked problems and network approaches to resolution, 1 International Public Management Review, 1, 1–19.

Rubin, J., Land, C., & Long, S. (2020). Mobilising new understandings: An actor-network analysis of learning and change in a self-directed professional development community. *Professional Development in Education, 47*(2–3), 315–330. https://doi.org/10.1080/19415257.2021.1879227

Salter, M. (2019). Security actor-network theory: Revitalizing securitization theory with Bruno Latour. *Polity, 51*(2). https://doi.org/10.1086/701885

Scelles, N., François, A., & Dermit-Richard, N. (2020). The engagement of actors during the formulation of a national federation sport policy: An analysis within the French Rugby Union. *International Journal of Sport Policy and Politics, 12*(1), 49–71. https://doi.org/10.1080/19406940.2019.1634621

Smajgl, A., & Barreteau, O. (2017). Empirical agent-based modelling – challenges and solutions: Volume 1, methods and protocols. Springer. https://doi.org/10.1007/978-1-4614-6134-0

Turnbull, N., & Hoppe, R. (2019). Problematizing ‘wickedness’: A critique of the wicked problems concept from philosophy to practice. Policy and Society, 38(2), 315–337. https://doi.org/10.1080/14494035.2018.1488796

Valler, M., & Blumczynski, P. (2024). Reassembling the ruins: revisiting Latour’s concept of translation in Modernity’s growing aftermath. The Translator, 30(3), 334–351. https://doi.org/10.1080/13556509.2024.2312613

Vennix, J. A. M. (1996). Group model building: Facilitating team learning using system dynamics. John Wiley & Sons.

Viollet, B., Scelles, N., & Ferrand, A. (2020). The engagement of actors during the formulation of a national federation sport policy: An analysis within the French Rugby Union. *International Journal of Sport Policy and Politics, 12*(1), 49–71. https://doi.org/10.1080/19406940.2019.1634621

Will, M., Bartkowski, B., Schwarz, N., Wittstock, F., Grujić, N., Li, C., … & Müller, B. (2024). From primary data to formalized decision-making: Open challenges and ways forward to inform representations of farmers' behavior in agent-based models. *Ecology and Society, 29*(4), 22. https://doi.org/10.5751/es-15400-290431

Zarkasi, I., & Rahardian, R. (2022). Actor-network theory in policy change of environmental permit policy for the construction of a cement factory in Pati, Indonesia. *Jurnal Ilmu Pemerintahan, 12*(1), 41–51. https://doi.org/10.26618/ojip.v12i1.5998