

Enhancing urban sustainability through calculative practices and simulations

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Abstract

Purpose – This study investigates the performative role of calculative practices in urban decision-making by combining simulation tools and accounting measures. Specifically, this study proposes both theoretical and practical approaches to support the development of an integrated approach for formulating urban sustainability and circular economy policies.

Design/methodology/approach – This study combines performativity theory with Systems Thinking and System Dynamics, presenting findings from two simulation sessions focused on developing sustainability and circular economy policies for a virtual urban environment. A System Dynamics simulator (interactive learning environment) was used to facilitate the simulations and support decision-making.

Findings – This study demonstrates the potential of combining accounting and simulation principles (specifically, Systems Thinking and System Dynamics) to enhance interactions between human agents and support decision-making through a rigorous and quantified simulation model. It also proposes an approach that fosters the integrative potential of calculative practices in urban sustainability decisions.

Originality/value – This study offers a novel approach by combining accounting concepts with Systems Thinking and System Dynamics principles and tools to facilitate human-agent interaction and support decision-making in complex and dynamic environments, such as urban sustainability. It specifically examines circular economy policies in cities and provides new insights into applying performativity theory in this context, thereby offering novel practical implications.

Keywords System dynamics, Performativity, Accounting, Circular economy, Systems thinking, Urban sustainability

Paper type Research paper

1. Introduction

In recent decades, growing concerns about resource demands and climate change have led city governments and companies to pursue sustainable development—a critical challenge of our time (De Matos and Clegg, 2013). Home to half of the world's population, cities are major contributors to environmental issues, resource use, and emissions (Wang *et al.*, 2018), making them central to addressing sustainability (Zeemering, 2018). Recently, cities' sustainability strategies have been increasingly influenced by the circular economy (CE) concept, which promotes the development of economic systems based on closed loops of materials and energy, rather than the linear take-make-dispose model (Stahel, 1982; Boulding, 1966). In cities, CE initiatives support waste management and help address broader sustainability policy objectives, such as managing water, energy, and transport services, as well as enhancing collaboration between citizens and private organizations (e.g. Bolger and Doyon, 2019; Christensen, 2021).

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Therefore, cities are urged to adopt policies that will transform them into circular and sustainable systems (Bolger and Doyon, 2019). However, debates persist on how to design effective strategies and support decision-makers in achieving urban sustainability goals (Christensen, 2021; Petit-Boix and Leipold, 2018). A central issue is the simultaneous influence of diverse values, visions, and interests of human agents (Bekier and Parisi, 2023a) that often result in partial and localized results or generate negative outcomes and externalities.

Additionally, despite the availability of data, tools, and frameworks for representing, analyzing, and managing sustainability and CE in urban contexts (Yi *et al.*, 2017; Bekier and Parisi, 2023a), there is a notable gap in using calculative practices in a performative role, both to inform decision-makers (as inputs to the process) and to influence their actions (as mediators of the process). Thus, through the interaction between human decision-makers and calculative practices (Bekier and Parisi, 2023b), it would be possible to gather the quantitative results needed to ultimately assess decision-making (with data emerging as a result of the process).

This opens avenues for exploring additional methods and indicators for evaluating and comparing urban sustainability and CE policies (Gravagnuolo *et al.*, 2019; Marin and De Meulder, 2018), while supporting urban sustainability transitions (Fratini *et al.*, 2019; Boedker and Chua, 2009). Further research is needed to enhance integration within decision-making, particularly to clarify the relationship between CE and sustainability paradigms (Bansal *et al.*, 2022; Geissdoerfer *et al.*, 2017) and address the contrast between “silos” and “synergies” that traditionally affect urban strategies (Deslatte and Stokan, 2020; Zhang *et al.*, 2019).

In this context, this study highlights the performative role of scientific models, particularly computer-based simulation models, and accounting-based data.

“Calculative practices” broadly refer to the techniques, methods, and processes that individuals and organizations use to collect, analyze, and interpret data for informed decision-making. The concept may also include systematic and structured approaches to problem-solving and decision-making, typically relying on quantitative analysis, financial modeling, and other tools to assess options and determine appropriate actions. A wide range of accounting literature has extensively discussed the main building blocks of this concept and has explored its boundaries (Power, 1997; Miller, 2001; Espeland and Stevens, 2008; Boedker *et al.*, 2020).

Building on these considerations, this study investigates how calculative practices—based on the joint use of computer simulation tools with accounting-based measures—may play a performative role for decision-makers within an urban sustainability setting. In this context, we advocate for the development and use of both theoretical and practical approaches that combine the principles and tools of Systems Thinking (ST) and System Dynamics (SD) with performativity theory.

Performativity theory has gained significant attention since its origins (e.g. Austin, 1962; Butler, 1988) and continues to be central to ongoing debates through its various interpretations and areas of application (Vosselman, 2022). In accounting, the literature has assigned an “active role” to accounting and calculative practices (Boedker, 2010; Lowe, 2004) in different contexts and for various purposes, such as “in enacting and (re)formulating strategies” (Skærbæk and Tryggstad, 2010, p. 108).

Similarly, simulation models have been explored through the lens of performativity theory, particularly in relation to their increasing use in assisting, informing, and influencing human decision-makers (Khosrowi, 2023; Lane and Rouwette, 2023). This study employs ST (Meadows, 2008; Senge, 1990) and SD (Forrester, 1961), which support a holistic investigation of complex issues and domains both qualitatively and quantitatively, as well as theoretically and practically. These approaches promote a shift from a “linear” to a circular (or feedback loop-based) way of reasoning. They are particularly well-suited for this study due to their potential to drive decision-making (Meadows *et al.*, 2001; Sterman, 1992), their integrated perspective on complex and multi-dimensional issues (Sterman, 2000), and their focus on the concept of the “loop” (a closed chain of cause-and-effect relationships among

variables), aligning with the relational logic underlying the feedback processes of the CE (Stahel, 1982).

Despite contributions from previous research, challenges persist in jointly using simulation models and accounting data performatively to inform decision-making and guide agents' behavior toward actions and decisions that serve the public interest, as is often the case for complex urban environments. Issues such as domain complexity and the nonlinear relationships influencing agents' interactions and decisions complicate this process (Jordan and Messner, 2012; Callon, 2007, 2010; Chua, 1995). Additionally, calculative practices often fall short of their intended performative role due to the difficulties in monitoring all performance dimensions of organizations' activities through accounting (Busco and Quattrone, 2015; Jordan and Messner, 2012; Jørgensen and Messner, 2010).

Previous studies have explored the use of ST and SD to address sustainability and CE issues (Barnabè and Nazir, 2022; Guzzo *et al.*, 2022; Oliver *et al.*, 2016). However, this study differs from them in both theoretical and methodological respects. Theoretically, it proposes an original combination of the aforementioned principles with performativity theory. Methodologically, it adopts a research method based on a virtual urban environment developed within a European project, using the concepts and tools of ST and SD.

Regarding contributions to the literature, this study introduces an original approach to urban decision-making specifically by emphasizing the contrast between siloed and integrated policies and highlighting the role of calculative practices in engaging human actors and fostering cooperation. Furthermore, this study underscores the importance of holistic thinking in sustainability-related decision-making, revealing the interrelationships between sustainability and CE paradigms. It also demonstrates the potential of combining simulations (based on ST and SD principles and tools) with accounting practices to train public-sector decision-makers to address sustainability and CE issues holistically. Finally, this study emphasizes the importance of using appropriate indicators in urban sustainability and CE policies, showing how they function as both inputs and outputs in the decision-making process.

The remainder of this paper is organized as follows. Section 2 discusses the challenges and opportunities of the CE for sustainable cities. Section 3 explores performativity by presenting its concept (Section 3.1), the performative role of simulation models (Section 3.2), and the interplay between accounting practices and performativity (Section 3.3). Section 4 introduces ST and SD as complementary perspectives on performativity. Sections 5 and 6 detail the research method and simulation results, respectively. Sections 7 and 8 present the discussion, conclusions, and limitations of this study.

2. Challenges and opportunities for the CE in sustainable cities

Although defined differently (Kirchherr *et al.*, 2017, 2023; Moraga *et al.*, 2019), a CE broadly refers to an economic system in which goods and services are traded in closed-loop cycles, in contrast to the “linear economy” (Millar *et al.*, 2019) that has traditionally characterized industrial processes. As the name suggests, a CE is regenerative by design to retain value from products, parts, and materials while reducing or eliminating waste (EMF, 2013). In addition to its many short- and long-term benefits (Park *et al.*, 2010), its main strength lies in its ability to build a system that extends the life of resources and reduces the waste produced by human activities (EMF, 2013, 2015; Kraaijenhagen *et al.*, 2016).

The CE has gained global attention, with significant European action plans and national laws worldwide supporting its potential to generate more sustainable processes (Petit-Boix and Leipold, 2018). Previous studies have identified cities as key players or “hotspots” (Petit-Boix and Leipold, 2018) in the implementation of a CE (e.g. Bekier and Parisi, 2023a, 2023b), particularly in areas such as waste management, urban refurbishment, and public procurement (Bernhardt *et al.*, 2018), with some cities even becoming fully “circular cities” (Bekier and Parisi, 2023a; Williams, 2023).

The extant literature has also highlighted the challenges and barriers to designing, implementing, and managing CE initiatives in cities, particularly when carried out by local governments with limited human and financial resources. Overall, this calls for further research on how CE initiatives are integrated into the sustainability policies of cities (Christensen, 2021; Petit-Boix and Leipold, 2018). Additionally, increasing relevance has been placed on identifying indicators to measure CE processes and impacts in cities (Bekier and Parisi, 2023a). Despite numerous contributions to the CE domain (e.g. Birgovan *et al.*, 2022; Papageorgiou *et al.*, 2021), calls for further research on indicators and approaches for the CE in cities persist (Bekier and Parisi, 2023a), particularly regarding the multi-dimensional nature of available measures (Kristensen and Mosgaard, 2020; Moraga *et al.*, 2019). This gap is often attributed to the inability of traditional tools and calculative practices to holistically and dynamically measure an organization's actions in terms of CE results and their side effects (Niero *et al.*, 2021). This has led to several new proposals.

Specifically, recent literature (e.g. Parisi and Bekier, 2022; Arjaliès *et al.*, 2023; Bekier and Parisi, 2023a) has highlighted the important role of calculative practices—including those in the accounting field—in influencing human agents' behavioral responses and supporting CE policy design in cities. However, the multi-dimensional nature of indicators used to inform decisions and drive actions in cities presents additional challenges, specifically regarding the integration of CE and sustainability paradigms (Bansal *et al.*, 2022; Geissdoerfer *et al.*, 2017). Such integration would allow the combination of all “environmental, economic, and social concerns under the general banner of sustainability” (Portney, 2003, p. vii), positioning calculative practices as key drivers of policy design and as tools for making cities measurable, comparable, and governable (Miller, 2001).

Subsequently, new frameworks and integrated methods have been advocated to help cities incorporate CE and sustainability indicators into a unified planning process, addressing the traditional dilemma between synergies and silos in urban strategies (Deslatte and Stokan, 2020; Bulkeley and Betsill, 2003).

This opens avenues for further research, particularly regarding methods capable of representing the circular processes active in specific environments. Despite numerous studies providing examples of CE definitions, processes, and case studies (in general: Korhonen *et al.*, 2018; Kirchherr *et al.*, 2017; or in cities: Petit-Boix and Leipold, 2018), the circular processes (loops) involved in a CE system and their interrelations remain debated. For instance, the European Commission (EU, 2014) and the Ellen MacArthur Foundation (EMF, 2013) developed frameworks to visualize the architecture of a CE. Earlier, Stahel (1982) presented a framework based on four main exercises: Reusing, Repairing, Remanufacturing, and Recycling. Subsequent studies have proposed more complex frameworks, such as the 6R model (adding Recovering and Redesigning; Govindan and Hasanagic, 2018), as well as 9R, 10R, and 11R models (see Reike *et al.*, 2018 for a review). Recent studies have also aimed to develop broad representations of the processes enabling the creation and functioning of circular cities (Alonso *et al.*, 2022).

Furthermore, analyzing and understanding how to enhance cooperation among human agents through calculative practices remains crucial, particularly in supporting the shift from a “silo” to an “integrated approach” in decision-making (Tudose *et al.*, 2021; Zhang *et al.*, 2019; Clay and Martin, 2017).

Additionally, the factors mentioned above (human agents and calculative practices) operate in increasingly complex and dynamic domains, characterized by strong interplays among human agents and variables of different natures. These contexts often lead to wicked and messy problems, with unexpected consequences (Vennix, 1999). This has led scholars to call for tools and methods that can represent and manage the holistic and dynamic impacts of modern organizations' actions in CE terms. Notably, systemic mapping tools and computer-based simulation models (e.g. Kunc *et al.*, 2020; Bassi *et al.*, 2021; Guzzo *et al.*, 2022; Robinson, 2022) have been emphasized for their ability to rigorously analyze, represent, and simulate the interrelationships among variables in urban environments over time, thereby

testing specific policies and providing quantitative results to assist in further analyses and discussion.

In summary, this study addresses the calls for research by exploring the concept of calculative practices used in combination with ST (Meadows, 2008; Senge, 1990) and SD (Forrester, 1961) tools with a performative role. First, we discuss performativity and the performative role of simulation models (e.g. Khosrowi, 2023). Next, we examine the performative role assigned to calculative practices in the accounting literature (e.g. MacKenzie, 2006; Boedker *et al.*, 2020; Revellino and Mouritsen, 2015; Vosselman, 2022). Finally, we outline our theoretical and practical proposal by discussing the potential of combining simulation models and calculative practices to assist decision-making.

3. Performativity and the performativity of calculative practices

3.1 The concept of performativity

The concept of performativity broadly refers to the theory that language and other forms of communication have the power to create social realities, norms, and identities. Thus, by using certain tools and mediums, we can shape and construct the reality around us, not only describing the domain in which we live and operate but also actively influencing it.

Performativity, used in various fields such as gender studies (Butler, 1988; Jenkins and Finneman, 2018), originated from the linguistic turn in the social sciences, particularly the work of Austin. By distinguishing performative utterances from constative utterances in a speech act, Austin (1962) laid the groundwork for a further distinction between declarative forms that simply describe reality (e.g. “it is raining”) and performative forms that change or construct reality while communicating it (such as the marriage declaration, “I now pronounce you wife and husband,” made by a priest; Revellino and Mouritsen, 2015, p. 33). This distinction led to a further development, shifting from an utterance or speech act to a broader discourse (Butler, 1988, 1997).

Overall, the focal point is the “ontological assumption that reality is constituted through our language practices or our discursive constructions” (Vosselman, 2022, p. 138). In this context, “performativity is no longer the discrete action of a subject, but the constitution of a subject through discourses that reiterate norms” (Vosselman, 2022, p. 138, commenting on Butler, 2010).

However, the linguistic dimension of performativity is considered insufficient and should not dominate the formatting and construction of reality. This aligns with the material turn in performativity theory (Vosselman, 2022; Callon, 1998, 2007). Supporting the shift within linguistics from speech acts to discourse, this theory argues that performativity is activated only by associating the discourse with human and non-human actors (Callon, 1998, 2007).

Considering the aims and context of this study, suggesting that a simulation model or accounting data and tools are performative implies that they are somehow constitutive of reality and can allow interaction with human agents to—directly or indirectly—influence and guide their decisions and actions (Vosselman, 2022). Therefore, we first examine the performative role of simulation models, then explore the performativity of accounting practices, and finally present our theoretical and practical proposal.

3.2 The performative role of simulation models

Scientific models can play a significant performative role by causally affecting phenomena and people’s behavior. For example, human agents may adapt their decisions and actions in response to model predictions. Several studies have demonstrated this potential, with examples including human agents’ responses to predictions such as weather forecasts, stock market performance, price expectations, and COVID-19 spread forecasts.

In this context, the meaning of “performativity” can be framed as Khosrowi (2023, p. 374) explained: “A model is performative if and only if it has the capacity to causally affect an

aspect of the world that it is intended to represent.” For example, a simulation model would be performative only if its predictions influence some of the quantities being predicted, for example, by triggering the behavior of human agents toward a specific target of those quantities.

The literature identifies two main responses to model performativity.

The first is the “mitigation approach,” which seeks to maintain the model’s predictive performance by endogenizing, or explicitly modeling, how agents will behave in response to specific model predictions. This approach leads to including human-agent responses in the predictions made. Used by social scientists since the 1950s (e.g. [Simon, 1954](#), in describing bandwagon effects), this approach sees performativity as a phenomenon that can be controlled and used by endogenizing human agents’ responses to model outputs.

The second is the “appraisal approach.” It assigns both epistemic and performative capabilities to models, which are conceived as tools for steering human agents’ behavioral responses. A recent example is the performative effects of simulation models during the COVID-19 pandemic. In this context, performativity is regarded as a beneficial feature of simulation models ([Vergara-Fernandez et al., 2023](#)). However, there is no broad consensus on this approach, as performativity is generally not considered a criterion in model construction.

We agree with [Khosrowi \(2023, p. 374\)](#) that “in understanding model performativity, it is important to note that models are rarely performative as such but typically become performative only when embedded in a concrete context of use, which establishes causal connections between the model and its target.” Therefore, we propose a third category of model use, centered on their interactive application, to actively engage human agents in analyzing complex and dynamic systems, experimenting with the model, and making informed decisions that can then be translated to the real world.

Three key factors must be added and discussed: (1) the “quantities” and “calculative practices” used as inputs to the model (i.e. the data available, as well as their nature and granularity); (2) the agents involved in the process (those influenced by the model’s performative role); and (3) the type of scientific simulation model, with its epistemological and ontological assumptions clearly outlined.

3.3 Accounting practices and performativity

According to a conventional perspective, accounting is traditionally and primarily ([Chabrak et al., 2019](#)) viewed as a technical practice or a calculative process ([Hopwood, 1992](#)), providing information for internal and external stakeholders ([Carnegie et al., 2021](#)). In this “functionalist view,” accounting supports decision-making as “a neutral tool” ([Vosselman, 2014, p. 181](#)). Through its records, it provides a representation of the real world, enabling both the preservation and transmission of knowledge about this world across time and space ([Robson, 1992](#)). Thus, it acts as a mirror of the represented reality, which corresponds to the “truth” ([Vosselman, 2014](#)).

This approach simplifies organizational analysis by reducing the complexity of the domain under investigation ([Boedker, 2010](#)). However, such simplification of reality also limits the depth that can be devoted to strategic issues and the variety of problems that can be analyzed, reducing accounting to a passive device ([Vosselman, 2014](#)). Furthermore, how accounting functions within the social sciences and shapes individual and group behaviors in complex decision-making settings remains a fertile area of study for managerial scholars. Recently, the literature has emphasized accounting’s potential as a “performative” agent in the business field ([Lowe, 2004](#); [Boedker, 2010](#); [Vosselman, 2014, 2022](#); [Revellino and Mouritsen, 2015](#)), playing an active role, for example, “in enacting and (re)formulating strategies” ([Skærbæk and Tryggestad, 2010, p. 108](#)). Thus, the literature envisions a performative role for accounting, explicitly when used to support decision-making in complex real-world settings ([Boedker, 2010](#)).

The roots of the research stream focused on the performative role of accounting trace back to Austin’s work and his distinction between declarative and performative linguistic forms

(Austin, 1962). Since then, the concept has gained attention in the accounting literature, including in reference to sustainability and environmental domains (Yu and Huber, 2023; Bebbington and Larrinaga, 2024).

Despite this, the notion of performativity in accounting remains debated due to its multifaceted nature, to the point where the term is used in almost diametrically opposed ways (Yu and Huber, 2023) and at different levels. For example, MacKenzie (2006, pp. 16–19) identified three levels of performativity: “generic,” when an aspect of economics (a theory, model, procedure, etc.) is used by market participants in real-world economic processes; “effective,” when its use produces an effect in economic processes, thereby making “a difference” in some relevant way; and “Barnesian,” when the use of an economic concept alters reality “in ways that bear on their conformity to the aspect of economics in questions.” Vosselman (2022, p. 140) further categorized the use of performativity regarding speech acts, discourses, networks of associations between humans and non-humans, and intra-actions. Based on this, he proposed four conceptions of accounting connected to performativity (Vosselman, 2022, p. 144): accounting as an intentional act of calculation (similar to a speech act); as a discourse (as meaning or framing); as an actor in heterogeneous networks; and as a material-discursive practice.

In particular, this study focuses on accounting as an actor in the process, viewing it not as the “destination” but as part of an ongoing journey centered on performativity (Garud and Gehman, 2019). This involves examining accounting’s position as a relational entity (Vosselman, 2022) within a specific network, and how it interacts with other actors—both human and non-human—within the same network.

Two additional elements are particularly relevant.

First, the interaction between accounting and other actors in a performative role is dynamic. As Lowe (2004, p. 614) noted, the “idea of performativity refers to the dynamics through which actants become defined through the performance of network relations.” These dynamics condition the essence of strategy and decision-making as social objects whose form is not “something that can be determined once”—i.e. with stable properties—but depends on how it is realized as “a practical and revisable matter” (Latour, 1986, p. 264). From this perspective, performativity theory argues that accounting and calculative practices also participate in this network and contribute to organizations as actants (Latour, 2005). Thus, accounting is no longer a mere destination of the journey but rather a core part of it (Vosselman, 2022). In other words, accounting is “both an input to and an output,” and the relevance of its role depends on the capacity of non-human actants to activate humans’ actions (Boedker, 2010, p. 609). More specifically, following the differentiation between intermediaries and mediators suggested by Latour (2005, pp. 38–39), accounting is a mediator actant (also see Vosselman, 2022) as its role is not to transmit meaning without transformation, but to interpret, aggregate, and modify prior significances to produce new and even surprising knowledge. It must allow the unpacking of the “black-boxing” of decision-making as a social object, thereby assisting action in business domains, as synthesized by the concept of accounting performativity (Revellino and Mouritsen, 2015).

Second, adopting this approach requires methodologies that support action through calculative practices while addressing the limitations traditionally associated with accounting information. These include its static nature (Boedker, 2010; Healy and Palepu, 2001), incompleteness (Boedker, 2010), and focus on financial transactions and the past (Merchant, 1998). Regarding methodologies, this study proposes the use of Systems Thinking and System Dynamics principles and tools, as detailed in Section 4.

4. The complementary perspective

4.1 Overview of systems thinking and system dynamics

ST is a perspective for framing, understanding and analyzing complex domains and problems. Rooted in General System Theory (Von Bertalanffy, 1950), ST provides a holistic view of how

systems function and can be managed. It also offers techniques and tools to support analysts, learners, and decision-makers in facing problem-solving tasks and complex issues.

While “systems” are the broad objects of analysis, ST focuses on the relationships among system components, based on the fundamental idea that the whole (the system) is greater than the sum of its parts (Meadows, 2008).

The academic literature has highlighted that ST is useful for several reasons (Maani and Cavana, 2000). It is especially applicable in domains characterized by high levels of complexity and wicked problems (Kim, 1999; Vennix, 1999). Previous research has also emphasized that ST is recommended when: the issue is relevant; interactions among system parts generate the specific behavior (or problem) under analysis; the problem is difficult to analyze and may stem from causes distant in space and time; and trade-offs exist among possible solutions (Maani and Cavana, 2000; Meadows, 2008).

When these factors characterize a specific system, ST can effectively support shifts in thinking among analysts and learners, enabling them to better inspect, investigate, and evaluate problems. This facilitates the development of policy insights and supports both learning and decision-making.

Key to this technique are the concepts of causal connections and feedback loops, which entail a shift from linear or event-oriented thinking to circular, loop-oriented thinking. Two relevant ST tools are causal loop diagrams (CLDs) and stock-and-flow diagrams (SFDs).

A CLD illustrates variables connected by arrows denoting causal influence, with each link assigned a polarity—positive (“+”) or negative (“-”)—to indicate how the dependent variable (the “effect”) changes in response to changes in the independent variable (the “cause”). These polarities describe the system’s structure, not behavior; they describe what would happen “if” a change occurred. Such changes are often caused by human decisions. Unlike CLDs, SFDs distinguish between stocks (the accumulation of resources in a system) and flows (the rates at which those resources change). Specifically, resources are represented as stocks (state variables) that characterize the system’s state, generate the information upon which decisions and actions are based, and change through inflows and outflows. Both types of maps support the identification of interlinked substructures known as “feedback loops” (Richardson, 1999; Sterman, 2000), as well as more complex “systemic archetypes” (Senge, 1990; Wolstenholme, 2004). Specifically, a “feedback loop” is created when two or more variables are circularly connected, creating a closed cause-and-effect chain—for example, X affects Y, then Y affects Z, and Z affects X (see Figure 1).

Feedback loops are basic systemic structures (Sterman, 2000) either reinforcing (denoted by an “R,” leading to exponential growth or decay) or balancing loops (indicated by a “B,” determining limited growth or decay and promoting equilibrium).

While CLDs and SFDs reveal feedback loops—that is, visible circularity—and complex patterns of interconnections, they do not display the dynamics (and their magnitude) arising from those substructures, including the effects generated by time delays and nonlinearities (Sterman, 2000; Richardson and Pugh, 1981). This requires the use of simulations for deeper analysis (Ford, 2019). For this reason, ST is frequently combined with SD, a methodology

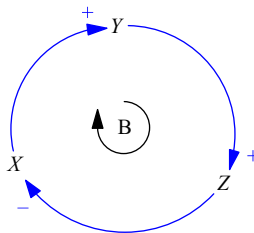


Figure 1. An example of a casual loop diagram (CLD). Source: Authors’ own work

developed by Forrester (1961) that enables the formal and rigorous simulation of complex systems. While ST provides the main mapping tools to represent complex systems, SD provides the operational tools to formally quantify those systems and perform computer-assisted simulations. As a result, policy analysis and strategy formulation are supported. According to Vennix (1990), SD modeling involves three main phases: (1) constructing a model of the reference system (abstraction); (2) analyzing the model, thereby revealing certain conclusions (deduction); and (3) applying the conclusions within the reference system (realization and implementation). Hence, the SD model represents the real system under analysis using historical data and allows for dynamic reproduction (over time) of the effects generated by the complex hierarchy of interrelationships among variables in the closed system (Vennix, 1996; Sterman, 2000). Despite criticism of its determinism (Lane, 2000), this approach provides significant opportunities to foster interaction, discussion, and alignment among human decision-makers (Senge, 1990; Sterman, 2000; Meadows, 2008; Morecroft, 2015).

In management studies, several scholars (from Forrester, 1961 onward) have emphasized that the primary role of SD modeling is to gain insight into complex problems while revealing and influencing management teams' thinking and actions, such as managers' and employees' mental models and strategic thinking skills (Senge, 1990; Vennix, 1996). Notably, a recent stream of literature, "Behavioral System Dynamics," has focused on the behavioral implications of SD models (Lane, 2017; Lane and Rouwette, 2023).

Specifically when embedded within an "interactive learning environment" (ILE, also known as microworlds or management flight simulators; Morecroft, 1988; Sterman, 2000), SD models serve as future-oriented tools for decision-makers, facilitating team interaction and discussion, as well as supporting the exploration of feasible options to support policy analysis and strategy formulation (Davidsen and Spector, 2015).

4.2 Combining systems thinking and system dynamics with performativity theory: precedents and novelties

This study combines ST and SD with performativity theory, relying on three elements.

First, applying ST and SD principles in the accounting field is not entirely new. Previous studies have demonstrated the value of integrating these principles with accounting data to accurately calculate, in financial terms, the impacts of business policies (e.g. Bianchi, 2016; Kunc *et al.*, 2023) and to enhance strategic management control (Barnabè, 2011; Bianchi, 2002). For example, in urban contexts, previous research has used SD modeling to support decision-making (Forrester, 1969), improve performance management in local government settings (Bianchi and Rivenbark, 2014), and analyze urbanization policies and scenarios (Tan *et al.*, 2018). Notably, SD studies have used many accounting-related concepts, such as costs, revenues, profits, and marginality, to inform policy and strategy-making (Meadows *et al.*, 2001; Sterman, 1992). However, accounting data and accounting-based reports often played an ancillary role (Kunc *et al.*, 2023), with financial calculations (e.g. costs, revenues, and profit) seen as merely consequences of business strategies.

In contrast, this study introduces a novel approach by combining ST and SD principles, maps, simulations, and ILEs with performativity theory. This integration enables a deeper investigation into the significant role of accounting in shaping strategies.

This approach extends to the broader category of "calculative practices," specifically in domains characterized by dynamic complexity and the interaction of multiple variables and agents, thereby suggesting avenues for further research.

A second element supporting this combination is the ability of ST and SD to provide both a theoretical framework and a comprehensive toolkit for analyzing complex domains and problems (Sterman, 2000). Previous studies have applied ST and SD principles to address complex, multi-dimensional issues at a global level (Meadows *et al.*, 1972; Forrester, 1971) or have focused on urban domains (Lane and Videira, 2019; Forrester, 1969). Furthermore,

research has demonstrated how ST and SD can support analysts and decision-makers in exploring sustainability-related issues in contexts characterized by high interconnectedness across environmental, economic, and social dimensions (Cavana and Ford, 2004; Ford, 1999). In these contexts, it is crucial to adopt a holistic approach that moves beyond “simple” and typical event-oriented thinking. This study underlines a specific element since cities are traditionally characterized by the tension between silos and synergies in urban policy planning (Deslatte and Stokan, 2020).

The third element supporting this study’s approach concerns CE issues, which are grounded in the concept of circularity. Building on the similarity between circularity and feedback loops, a growing body of ST and SD literature focuses on CE patterns and options (Kunc *et al.*, 2020; Franco, 2019). This literature provides a core set of principles and tools for representing and quantitatively analyzing circularity in systems (Bassi *et al.*, 2021; Barnabè and Nazir, 2022). Additionally, previous studies have shown how ST maps, SD models, and ILEs can effectively incorporate sustainability or CE concepts (Guzzo *et al.*, 2022; Barnabè and Nazir, 2021; Oliver *et al.*, 2016). Our study builds on and contributes to this knowledge by integrating these concepts and tools into a unique process through which human agents make decisions in a dynamic context.

5. Research method

5.1 Overview

The research design entailed the use of an SD ILE for decision-makers in urban sustainability.

The ILE was developed as part of a joint European project aimed at creating both a physical board game and a computer-assisted simulation model to help players address urban sustainability challenges.

For this study, two simulation sessions were organized with groups of decision-makers selected for their expertise in a public management program. Participants were divided into two groups. The first group included 11 decision-makers from various public organizations (e.g. four of whom were from municipalities) and two consultants who work professionally with public organizations. The second group comprised 12 managers and consultants from private companies.

Separate research designs were used in this study. In the first group, participants played a single-user game in two steps:

- (1) Acting as the Head of a City Department (for each of the five departments or just a selection of them).
- (2) Subsequently, assuming the role of Mayor, overseeing all sectors and designing investment policies for the entire city.

These stages represent a siloed and integrated approach to decision-making, respectively (Deslatte and Stokan, 2020; Zhang *et al.*, 2019). A lengthy debriefing session (approximately 1.5 hours), including interviews, followed the simulations to discuss the results and gather in-depth feedback on the experience and on decision-making regarding urban sustainability. All participants provided feedback and interacted extensively with the authors, who took on multiple roles, as explained below.

In the second group, participants played a multiplayer game as Heads of City Departments, with no designated Mayor. They were free to discuss the creation of this role during the simulation. Unlike the first group, during the debriefing, this group was asked to identify and discuss the CE strategies they had developed during the simulation to pursue urban sustainability. As a result, the second simulation offered greater opportunities for discussion and cooperation.

As mentioned above, the authors played different roles: they supported model development and validation during the initial phases of the project and acted as facilitators throughout all

stages of the simulations (Vennix, 1996) for both groups, thereby providing guidance and support to participants. During the debriefing sessions, the authors served as both facilitators and researchers, fostering the analysis and discussion of participants' decisions (Crookall, 2010, 2014) and enhancing the generation of key policy insights (Lane, 2012). The simulation sessions were not designed as controlled experiments to collect statistical data on participants' decisions. Instead, they aimed to explore participants' modes of reasoning, inform group debates, and examine the performative role of accounting data and the simulation model. Specifically, the data analysis focused on how participants used calculative practices to create sustainability and CE strategies in a virtual city.

Below, we provide an overview of the simulation model and the ILE.

5.2 The system dynamics model

The SD model and the ILE were designed to replicate and simulate urban sustainability policies and their associated accounting and calculative practices.

From a technical standpoint, a participatory modeling approach was adopted (Videira *et al.*, 2017), involving several experts and various stakeholders in the conceptual development of the model. This approach leveraged their knowledge and increased confidence in the model's validity, realism, and usefulness (Barlas, 1996). After several focus group meetings, the simulation model was structured into five main sectors representing key urban departments: (1) Public buildings; (2) Public housing; (3) Transport; (4) Water management; and (5) Waste management and environment.

These sectors were selected due to their critical roles. Public buildings and housing are vital parts of a city's infrastructure and are fundamental to daily activities and citizens' well-being (Kramer, 2018). Transportation, water management, and waste management are equally crucial for the quality of life and the overall sustainability of the urban environment (Bania *et al.*, 2003).

Each sector can be managed as a standalone module, but their combined use allows for the representation of a typical integrated "city," with its full range of sustainability-related options and challenges. Figure 2 provides an aggregated view of the virtual city.

Figure 2 specifically uses ST language (causal links and polarities) to describe the structure of the underlying system. For example, the "attractiveness of the city" is positively influenced by GDP per capita, available jobs, industries and services, green areas, and parking spaces, while it is negatively impacted by pollution and water shortage (see the causal links with negative polarities). All variables in the model were discussed during the meetings, which served to define the inclusions, exclusions, and boundaries of the system (Stermann, 2000). The CLD was subsequently translated into an SFD and then into a quantified computer simulation model. This model was developed using Stella Architect and calibrated to mirror a typical medium-sized European city (Bologna). To this end, data from various sources, including the city's website (e.g. number of citizens) and Eurostat (e.g. average consumption data) were used. The model can be calibrated and customized using data from any city.

5.3 The interactive learning environment

The SD model was embedded within an ILE that allowed participants to manage the city using a given budget and to develop tailored strategies to ensure sustainable urban management. Participants were required to pursue urban sustainability by simultaneously increasing the city's population (*social aspect*), enhancing environmental well-being (*environmental aspect*), and maximizing the use of available financial resources (*economic aspect*).

The time horizon for this simulation model was 20 years, with decisions made annually. This time horizon allowed for the simulation of long-term strategic planning, allowing the design of policies that significantly impact the city's future sustainability, and enabling participants to observe the results of their actions and analyze the interactions among model components in the short, medium, and long term. Additionally, a 20-year span allows for the

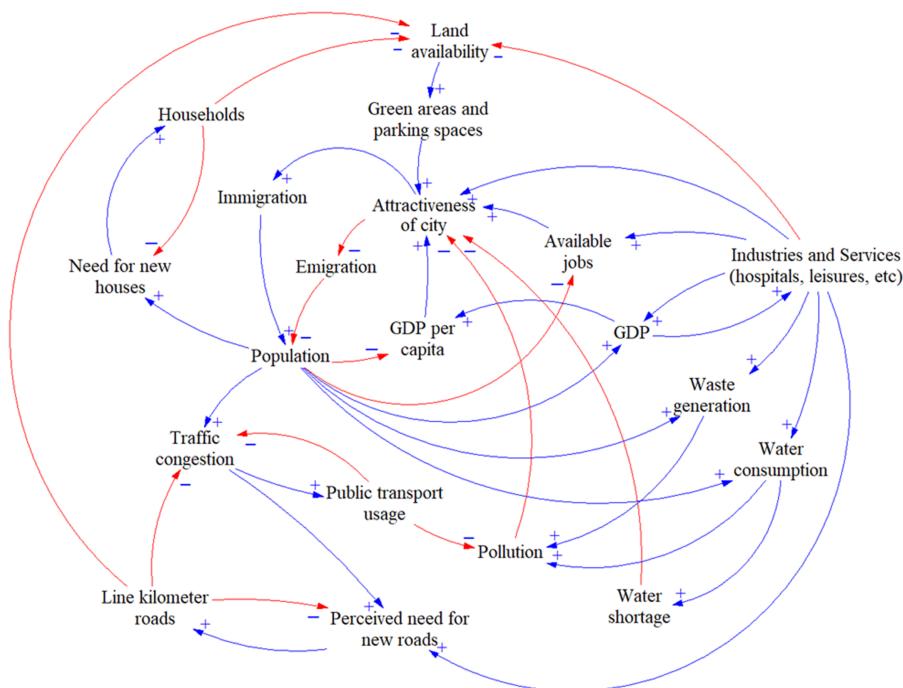


Figure 2. Aggregated causal loop diagram of the SD model used in this study. Source: Authors' own work

proper evaluation of specific projects, such as infrastructure and development projects (e.g. buildings and new transportation systems).

Participants' success was measured by a core set of parameters:

1. The budget, which represents available funds. It increases with tax collections, revenue from public transport, and the value recovered from recycled materials. The budget was subsequently reinvested across departments and activities.
2. The level of pollution, which affects citizens' quality of life and their decision to remain in or leave the city. Pollution was measured by NO_x (oxides of nitrogen) and PM₁₀ (particulate matter) emissions.
3. Water and resource availability, which ensures the sustainable management of the city.

Population changes based on net birth rate, immigration, and emigration flows. It reflects the "attractiveness of the city" and general well-being.

The model inputs for each of the five sectors were selected and thoroughly discussed during project team meetings. All inputs were "Investments," representing the decisions made by participants on how to allocate the budget to define strategies and take action. Table 1 lists the investment decisions for the five city departments.

Two main types of investments were available: (1) investments that directly build the city's resources (such as constructing a new school or hospital), which increase its attractiveness (e.g. new hospitals enhance the services provided to citizens and are appreciated); and (2) investments aimed at maintaining the existing infrastructure's efficiency or supporting CE initiatives (such as recycling, water purification, and electric vehicle incentives).

A customized dashboard facilitated the interaction between participants and the simulation model.

Table 1. Investment decisions

Investment policies	
Public buildings	• new schools • new hospitals • new business units • new hectares for leisure and sport activities
Public housing	• new houses • new NZ (near zero) houses • conversion of houses into NZ
Transport	• new traditional public vehicles • new electric public vehicles • incentives for private electric vehicles adoption • new lane kilometers of roads
Water management	• investments in wastewater infrastructure
Waste and environment	• investments in water purification • investments in recycling processes • new parks

Source(s): Authors’ own work

6. Results and insights from the simulations

The simulation results offer valuable insights into how calculative practices—through the combined use of simulation tools (from ST and SD) and accounting measures—can play a performative role in urban sustainability decision-making. Specifically, the key findings of this study are presented below, based on the simulation data (stored in the software) and participants’ feedback in the form of quotes. These data were kept separate for the two groups and coded to ensure anonymity.

6.1 First simulation and first stage: silo approach, single-player game, limited measures, and generic role of performativity

The first simulation was a single-user and symmetric session in which participants interacted directly, exclusively, and in a non-mediated manner with the simulation model. Adopting a silo approach to decision-making (Deslatte and Stokan, 2020), participants made decisions solely in one sector, with no control over investments in other sectors. Full control over all levers was granted in the second part of the session, when participants acted as the Mayor. All participants had professional experience in public organizations and in the fields of sustainability and the CE. This provided a pool of human agents with prior knowledge of issues and decisions that are increasingly relevant to cities and the provision of public services (Bernhardt et al., 2018). Table 2 presents the results common to the performance of many participants.

Specifically, Table 2 shows that participants were unable to positively influence the entire urban environment, as their sustainability policies were designed only for their department, resulting in limited scope and impact. These sector-specific, “siloed” (Deslatte and Stokan, 2020) decisions had minimal large-scale effect, leading to a decline in population and city’s attractiveness over time. To inform their decisions, participants relied on qualitative information (e.g. displayed through the CLDs) and quantitative data provided by the simulator.

Although participants had access to the entire budget, the results showed poor performance across key city variables, even when correct investments were made within individual departments. Without interaction with other human agents and with limited levers, the performative effect of the calculative practices proved inefficient or even misdirected (Busco and Quattrone, 2015; Jørgensen and Messner, 2010). In particular, participants’ decisions were driven by individual interests and localized goals (Bekier and Parisi, 2023a), failing to comprehensively consider the reality under investigation. Specifically, they did not (and, to

Table 2. Examples of simulation results (first group, first step – silo approach)

Department	KPIs
Public buildings	Budget = 1.32B NOx = 2.7K PM10 = 303 Water = 66.2 Population = 330K Δ Values t_0 - t_{20} (population) = –58K
Public housing	Budget = 1.73B NOx = 2.68K PM10 = 3.00 Water = 65.2 Population = 319K Δ Values t_0 - t_{20} (population) = –69K
Transport	Budget = 2.39B NOx = 2.29K PM10 = 213 Water = 73.3 Population = 342K Δ Values t_0 - t_{20} (population) = –46K
Water management	Budget = 2.43B NOx = 2.69K PM10 = 304 Water = 197 Population = 336K Δ Values t_0 - t_{20} (population) = –52K
Waste and environment	Budget = 2.19B NOx = 2.51K PM10 = 305 Water = 75.4 Population = 335K Δ Values t_0 - t_{20} (population) = –53K

Source(s): Authors' own work

some extent, could not) account for the nonlinear network of relationships among agents (and variables) affecting the definition of sustainability strategies (Law, 1999; Chua, 1995). This led to ineffective strategies at the global level and even reduced the city's attractiveness, producing a case of “counter-performativity” (Callon, 2010; MacKenzie, 2007) in terms of the overall goal of urban sustainability.

Some participants noted that focusing solely on their departments hindered a comprehensive view of sustainability and limited their ability to detect CE processes and leverage points (Marin and De Meulder, 2018), which emerged only as a perceived “lack” during the debriefing:

- (1) “I would have needed help from the other areas of the city,” (Participant 4, an urbanist).

Despite having the budget to invest, the lack of inter-sectoral interaction made it impossible to influence (or control) other relevant “quantities” within the model (Khosrowi, 2023). During this step of the simulation, participants expressed a sense of disconnection and incompleteness, as noted by Participant 4:

- (2) “Something was always missing.”

This was due to the incomplete information provided by the available indicators (Jordan and Messner, 2012) and the inability to use the simulator and data as real mediators in interactions with other actors (Vosselman, 2022).

In this first stage, performativity was constrained. The simulation model played a limited role, essentially endogenizing past and expected decisions (Khosrowi, 2023) while accounting and calculative practices generating a performative role only at the weakest level of “generic” performativity (MacKenzie, 2006, p. 16), as evidenced by several factors.

First, the participants’ use of these practices failed to sustainably manage the urban environment or leverage CE opportunities, even when combined with ST and SD principles (Meadows, 2008; Sterman, 2000).

Second, the accounting and calculative practices provided by the simulator were considered merely as “an ‘output’” of the decision-making process (Boedker, 2010, p. 596):

- (3) “I was mainly interested in seeing the final value of the parameters,” (Participant 1, an urbanist).

Third, the shift from speech to discourse in performativity theory (Vosselman, 2022) was nearly absent, as the available calculative practices only marginally supported participants in constructing any meaningful reality.

These results were largely due to the research design, particularly the adoption of a silo approach to decision-making (Tudose *et al.*, 2021; Deslatte and Stokan, 2020) which limited the usefulness of associating calculations with ST and SD principles, as it disabled the simulator’s potential for inspecting interconnections among variables and dimensions in the virtual urban domain (Lane and Videira, 2019; Ford, 1999; Senge, 1990). The silo approach also prevented human agents from engaging in meaningful discourse and discussion (Butler, 1988, 1997), either with other human agents or non-human actors (Callon, 1998, 2007).

However, this step was crucial in revealing the limitations of silo-based decision-making, which is typical in public organizations and often hinders the design of effective policies while preventing cross-sectoral harmonization (Tudose *et al.*, 2021). Additionally, despite the availability of key financial data, the lack of interconnections among sectors and decision-makers prevented the analysis and exploitation of sustainability and CE parameters (e.g. Bansal *et al.*, 2022; Geissdoerfer *et al.*, 2017), highlighting an opportunity for further exploration.

6.2 First session and second stage: silo approach, single-player game, wide set of measures, and effective role of performativity

In the second phase of the simulation, participants (the first group) were encouraged to fully engage with the simulator by assuming the role of Mayor and overseeing all investment decisions with full access to the budget. The simulation was single-player and symmetric, with all players having the same levers.

Moving beyond the silo approach required a shift from sector-specific analysis to considering linkages and *nexi* among various sectors (Zhang *et al.*, 2019). It also entailed a shift in mindset, adopting a holistic approach to decision-making (Tudose *et al.*, 2021) and transitioning from siloed thinking to a comprehensive and integrated sustainability strategy formulation (Deslatte and Stokan, 2020). To this end, participants were provided with broader data, including not only traditional financial data (budget and investment-related parameters) but also multi-dimensional information (see Figure 3 for a screenshot of the dashboard from this simulation).

Figure 3 shows a simulation in which one of the participants implemented a set of green and sustainability-related investments, such as new public electric vehicles and new NZ houses, along with a CE strategy for resource maintenance and regeneration (e.g. wastewater treatment and recycling).

This simulation ended with the following parameters:

- (1) Budget = 476M;
(2) NOx = 2.23K;

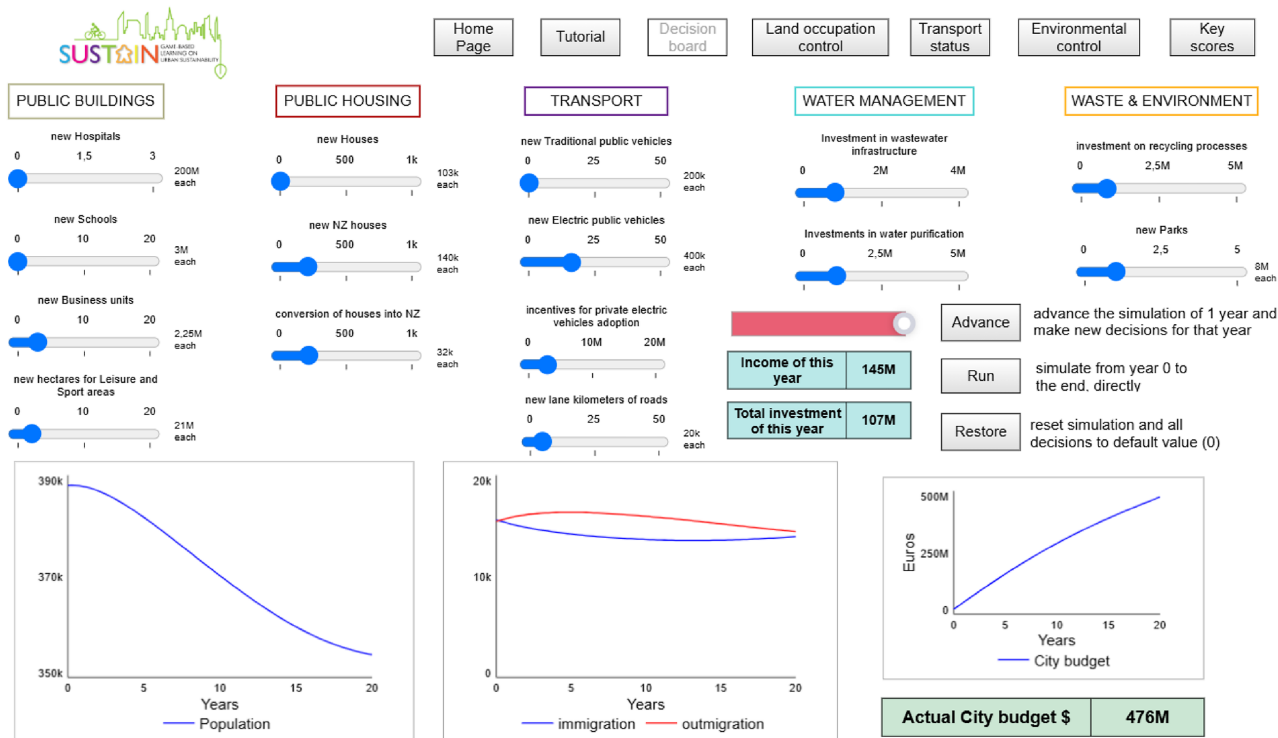


Figure 3. Example of simulation results. Source: Authors' own work

- (3) PM10 = 216;
- (4) Water = 73.2;
- (5) Population = 354K.

The results and feedback from this stage demonstrated that participants paid more attention to the reasons behind the calculations provided by the simulator and the cause-effect relationships characterizing the different sectors of the city, in line with the results of other urban simulation studies (e.g. [Forrester, 1969](#)).

In this regard, Participant 1 noted:

- (4) “When I acted as the Mayor, I was interested also in the reasons for the changes that occurred in the parameters because, for each decision, I had to consider the effects on the other ones.”

The quantitative data dynamically generated by the simulator prompted participants to delve deeper into the causes behind the results, encouraging them to move beyond simple analysis and the use of typical decision-making variables.

The investigation of cause-effect relationships was particularly facilitated by the combined use of ST and SD. Participants appreciated CLDs for their ability to identify interlinked substructures ([Stermann, 2000](#); [Richardson, 1999](#); [Senge, 1990](#)). During the debriefing, facilitators investigated players’ experiences using ST and SD concepts and tools, including the CLD shown in [Figure 2](#) and additional causal maps (e.g. [Figure 4](#)), to highlight relationships across variables and sectors of the model.

[Figure 4](#) illustrates a set of feedback loops highlighting “circularity” as key in the simulation environment. The map includes two reinforcing loops (promoting exponential growth over time) and five balancing loops (promoting goal-seeking behavior and equilibrium). Participants and facilitators discussed these loops extensively.

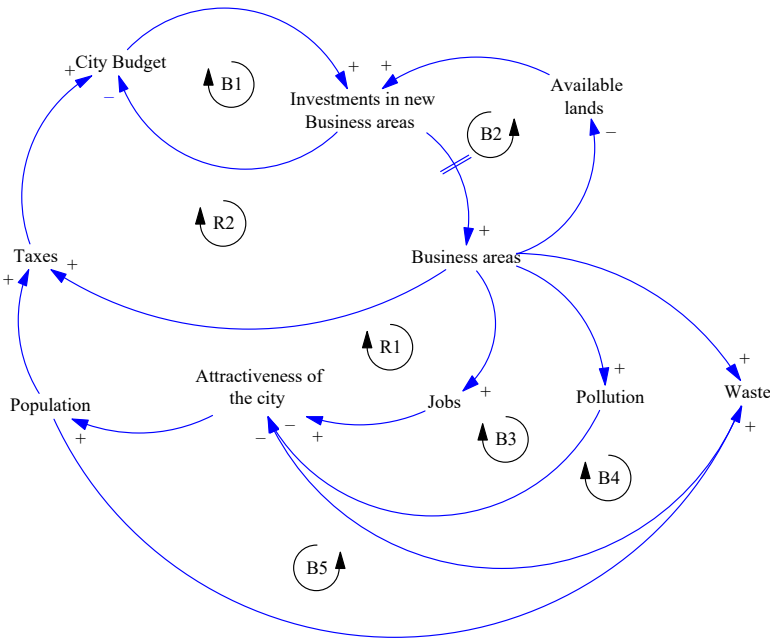


Figure 4. Causal loop diagram used during the debriefing sessions. Source: Authors’ own work

For example, reinforcing loop R2 shows the effect of investments in a specific area of the city:

(1) An increase in investments in new business areas, (2) increases (with a delay) in the number of business areas, (3) increases the number of jobs available, (4) increases the attractiveness of the city, (5) increases the population level, (6) increases the amount of taxes being collected, and (7) increases the city budget, which, in turn, will allow (8) increasing (new) investments, thereby closing the feedback loop.

During the debriefing, participants also examined the balancing loops that may limit growth.

For example, loop B1 shows how new investments drain the available budget, thereby limiting future investments. Loop B2 highlights how land use restricts future investments and development. Loops B4 and B5 explain how increased business activities and population growth lead to more waste, negatively impacting the city's attractiveness.

Overall, the causal maps helped participants explore and discuss complexity, allowing them to further inspect the model structure and reflect on their decisions. Specifically, CLDs provided participants with a language (Butler, 1988), enhancing their ability to explore the complex relationships across variables and city departments. This made it clear how investment decisions at one specific leverage point would subsequently affect other areas, helping participants "seeing interrelationships and feedback loops" (Ford, 2019, p. 378) among variables (identified by the causal links). For example:

- (5) "The map provided a visual aid that gained relevance as soon as we had to make decisions during the second stage of the simulation. We needed support to make sense of the interrelationships among the various departments of the city."

Thus, by combining calculations with the CLDs, participants were able to discover connections and paths within a "new reality," thereby gaining support in visualizing them and making critical decisions (Lowe, 2004). This demonstrates the "effective" role (MacKenzie, 2006) of calculative practices (in this case, enhanced by the simulator and the maps) in providing "a specific type of visibility to events and processes" (Miller, 2001, p. 393). This "visibility" extended to identifying, understanding, and managing CE patterns in the city (Barnabè and Nazir, 2022; Bassi *et al.*, 2021).

CLDs and quantitative data from the simulations were also used jointly during the debriefing to highlight potential trade-offs among variables in the model (Serman, 2000; Maani and Cavana, 2000). The diagrams used polarities to show the influence between variables (positive for a direct effect and negative for an indirect effect), helping participants elaborate on the meaning of the simulator's calculations (the quantities and behavior of the model's variables over time) and understand the contrasting effects produced by their sustainability strategies:

- (6) "Looking at the map and the numbers jointly allowed me to see how much results depend on the combination of multiple and sometimes conflicting effects," (Participant 1).

Financial data, discussed as both the main input and output, further reinforced the need for an integrated approach that comprehensively combines multiple calculative practices within the simulation. This step enabled a thorough analysis of the feedback structures (Forrester, 1961) in the simulated urban environment.

The feedback loops in the CLDs made circularity and sustainability visible, manageable, and actionable, supporting the participants in developing a "feedback thought" (Richardson, 1999) that was immediately applied to inform decision-making (Boedker, 2010). At the same time, they provided insights into the potential future dynamics associated with such structures (Meadows, 2008; Senge, 1990), demonstrating how a simulation model can be performative according to the appraisal approach, stimulating human agents toward desired behaviors and favorable targets (Vergara-Fernandez *et al.*, 2023; Khosrowi, 2023).

This was reflected in comments from the participants, such as:

- (7) “The map helped me to understand that the effects of a [sustainability] strategy spread over time and space,” (Participant 1).
- (8) “The simulated data and their dynamics over time pushed me to keep some decisions or change them,” (Participant 4).

As [Richardson and Pugh \(1981\)](#) noted, the ST and SD approaches take the philosophical position that feedback structures are responsible for the changes (dynamic behavior) we experience over time. However, as clarified in the literature, when SD models and simulators are used to challenge human decision-makers, the inherent determinism of such tools ([Lane, 2000](#)) gives way to new forms of experimentation driven by users’ behavioral responses ([Lane, 2017](#); [Lane and Rouwette, 2023](#)). In this simulation, these approaches informed policy design ([Meadows et al., 2001](#); [Sterman, 1992](#)), making calculative practices not just “an ‘output’” but “an ‘input’ and transformer” of participants’ decisions ([Boedker, 2010](#), p. 596), subsequently shaping their behavioral response to the model ([Khosrowi, 2023](#)) and, ultimately, their behavior ([Lane, 2017](#); [Lane and Rouwette, 2023](#)). By combining calculative practices with ST and SD tools, such as the ILE, participants leveraged all the information available to jointly assess sustainability and CE effects of their decisions, as highlighted in the following comment:

- (9) “If we talk about sustainability and circular economy activities, we should have proper parameters and data,” (Participant 2, a consultant).

This highlighted the importance of using an extended set of multi-dimensional measures for the CE ([Bekier and Parisi, 2023a](#); [Papageorgiou et al., 2021](#); [Kristensen and Mosgaard, 2020](#); [Moraga et al., 2019](#)). In the simulation, participants had the opportunity to make decisions and allocate resources using a broad set of parameters, initially centered on key financial parameters (mainly the budget) and later incorporating many other measures. On this point, participants noted that the “budget” served as the ultimate “anchor” for strategy design and evaluation:

- (10) “In the end, it is about money. [...] This is the ultimate challenge for us,” (Participant 4).

This reaffirmed the “constitutive” role of accounting and calculative practices ([Burchell et al., 1980](#)), which maintained their relevance in “influencing the actions of individuals” ([Miller, 2001](#), p. 379) when defining policies and strategies in cities.

In conclusion, the participants performed better in the second phase of the simulation. By highlighting “a difference” in the pursued objectives of urban sustainability, these results further support the thesis of “effective” performativity of calculative practices ([MacKenzie, 2006](#), p. 16) when used to draft integrated sustainability and CE policies combined with ST and SD principles.

6.3 Second session: integrated approach, multi-player game, wide set of measures, and full effect of performativity

In the second session, participants engaged in an online multiplayer mode, each taking on the role of a Head of Department (assigned before the simulation), thereby adopting a silo approach to decision-making ([Deslatte and Stokan, 2020](#); [Tudose et al., 2021](#)). The participants were consultants or managers of private companies, with limited knowledge of sustainability and CE in the public sector. Their investment decisions simultaneously impacted the available budget. The results were mixed: while some parameters improved (pollution decreased, population and city attractiveness increased), others worsened (financial resources decreased, thereby limiting new investments necessary for the growing population).

Similar to the first simulation, the performative effect of calculative practices and simulation tools was limited, mainly functioning at a “generic” level (Mackenzie, 2006), focused on understanding the language associated with the available information and maps (Butler, 1988; Vosselman, 2022). In this case, the calculations provided by the simulator revealed the inefficiency of a silo approach to urban sustainability decisions (Deslatte and Stokan, 2020; Tudose *et al.*, 2021). During the debriefing, this became evident when participants independently requested:

- (11) “Some kind of coordination,” (Participant II, a manager).

Despite their limited public sector experience, participants recognized the contrast between synergies and silos characterizing urban decision-making (Deslatte and Stoka, 2020; Zhang *et al.*, 2019) and the need to “integrate” all the calculations provided by the simulator in “a functioning calculative network” (Miller, 2001, p. 382). This shift also required moving from data ownership to information sharing (Clay and Martin, 2017), and from sector-centric analysis to the consideration of linkages and interdependencies.

In particular, Participant VI (a manager) emphasized the limitations of their sustainability calculations:

- (12) “To achieve a common aim as the sustainability of the overall city, I could not decide only based on my numbers and the interest of my department. I had to interact with the other players and their numbers”.

Following a plenary meeting, the group appointed a coordinator (a role similar to the Mayor) to promote more aligned decision-making supported by multi-dimensional data. The effect of this decision was twofold, affording the participants:

- (13) “[An] escape from a local or sectorial way of thinking,” (Participant VI).

This was in order to embrace a:

- (14) “Comprehensive approach to the management of the city,” (Participant II).

This approach resulted in improved performance across all parameters and was subsequently discussed in detail during the debriefing. The model and the integrated set of calculative practices stimulated participants at two distinct moments: during the simulation, when they engaged in discussion and sought to cooperate (thus reflecting the shift from speech to discourse previously mentioned; Callon, 1998, 2007), and afterward, when they reviewed their decisions and made sense of what had occurred in the “new” simulated reality they jointly and progressively constructed through interaction with the non-human aid. Additionally, since these participants had less knowledge of urban contexts than the first group, they were asked to identify CE processes in their decisions. Specifically, with the support of facilitators and the use of CLDs, participants discussed the CE principles and pathways in the model and assessed how they applied them while pursuing urban sustainability (Table 3).

The “R principles” in Table 3 explain “circularity” and are based on specific feedback loops. After discussing them by examining the city’s comprehensive CLD (Figure 2), the simulator was used again to objectively analyze the quantitative data generated by the participants’ decisions. Their feedback highlighted the effectiveness of this exercise in integrating sustainability and CE paradigms (Bansal *et al.*, 2022; Geissdoerfer *et al.*, 2017). Specifically, combining simulation calculations with “the narrative of sustainability” (Brorström, 2023, p. 6) allowed participants to understand the role of the CE in their decisions, as one noted:

- (15) “Thanks to the map, I ‘saw’ the [concept] of circular economy and I was able to find it in my decisions,” (Participant IV).

Table 3. Circular economy R-principles in the model (debriefing for the second group)

Circular economy R-principle	Description in the general context	Examples in the model
Refuse (R0)	Avoiding products that harm the environment or generate waste	Investments in NZ houses or electric buses instead of building traditional less efficient houses or buses
Reduce (R1)	Doing an action fewer times or with increased care to decrease usage	Transforming traditional houses into NZ houses to reduce energy use
Resell, reuse (R2)	Using items multiple times, buying second-hand and using recycled materials	Increasing investments to collect more recycled materials thereby reducing the overall need for new virgin raw materials
Repair (R3)	Repairing old products instead of discarding them	Investments in wastewater infrastructures to prevent leakages and enhance efficiency
Refurbish (R4)	Refurbishing discarded products or materials, sanitized to serve their original functions	Investments in water sanitization to increase wastewater reuse
Remanufacture, reproduce (R5)	Rebuilding a product to the specifications of the original product	Collecting more discarded products for remanufacturing
Repurpose, redesign, rethink (R6)	Using discarded and old items for a different purpose	Allocating areas for leisure and sports and converting traditional houses into NZ
Recycle (R7)	Recycling materials for a second life	Recycling general waste for treatment
Recover (R8)	Recovering value from the items recycled or (re)used	Burning waste in incinerators to recover energy
Remine (R9)	Recovering value from materials after the landfilling	Increasing remining of landfilled items
Source(s): Authors' own work		

In particular, they learned about the importance of making sustainability-related decisions by considering the interconnections and loops that characterize their accounting and calculative practices:

- (16) “I have understood that to reach sustainability in cities, the capitals at disposal were not only in the budget but were spread in many other parts of the city,” (Participant VI).

In other words, the simulator and maps played a performative role that extended beyond both the mitigation and appraisal approaches (Vergara-Fernandez *et al.*, 2023), challenging participants to engage in discussion and cooperation in a specific context. This process established strong causal connections between the model, its users, the quantities (data), and the intended targets (Khosrowi, 2023). The combination of the simulator and maps, availability of financial and non-financial measures, and analysis of a concrete, challenging, complex, and dynamic environment were all critical factors in supporting participants in adopting a holistic approach to sustainability and CE decisions, framed by ST and SD principles. Overall, this approach enabled the achievement of a “Barnesian” performativity—the highest level of performativity as theorized by MacKenzie (2006, p. 19)—with strong behavioral responses from participants (Khosrowi, 2023; Lane and Rouwette, 2023).

Table 4 summarizes the insights gained from the simulations and their interactions with participants.

7. Discussion

This study aimed to investigate how calculative practices, based on the combined use of simulation tools and accounting measures, may play a performative role for decision-makers within an urban sustainability context. To achieve this, we suggested adopting a theoretical and

Table 4. Insights from the simulations

Excerpt code	Participant code	Background	Topic(s) covered	Insight
A	4	Urbanist	Silo-approach Lack of interaction among decision-makers	Lack of interaction with other human agents reduces policy effectiveness and hinders interaction with the non-human agent
B	4	Urbanist	Silo-approach Exclusive reliance on financial data	Need for a broader, interconnected set of parameters to inform decision-making
C	1	Urbanist	Silo approach Use of accounting data during simulation	Accounting data viewed as a mere output in decision-making
D	1	Urbanist	Integrated approach to decision-making	Data and interconnections influence decision-making
E	5	Public administration employee	Integrated approach Support from ST/SD maps and language	ST/SD tools play a performative role
F	1	Urbanist	Integrated approach Availability of multi-dimensional parameters	Visualising connections and the behavior of multi-dimensional parameters over time is crucial for understanding and guiding decisions
G	1	Urbanist	Performative role of SD maps and simulation models	Acquisition of feedback thought and ability to combine theoretical and practical strengths of the approach
H	4	Urbanist	Performative role of SD maps and simulation models	Performative role of simulation models in the appraisal approach
I	2	External consultant	Broad dataset to inform decision-making in sustainability and circular economy	Role of accounting and non-accounting data in decision-making
J	4	Urbanist	Use of accounting data	Accounting data as an anchor for decision-making
K	II	Manager	Decision-making within the network of human agents	Interaction and cooperation within the network as critical
L	VI	Manager	Interplays between participants' decisions and resources available	Use of simulation data to cooperate with human decision-makers
M	VI	Manager	Multi-player process with a Mayor coordinating decision-makers	Alignment of human agents and coordinated decision-making
N	II	Manager	Holistic approach to decision-making	Holistic approach to decision-making using multi-dimensional data
O	IV	Manager	Theoretical and practical approach to integrate sustainability and circular economy data and decisions	Opportunity to combine calculations with the narratives of sustainability and circular economy
P	VI	Manager	Challenges in decision-making in complex and dynamic domains	Importance of considering interconnections and loops in sustainability decisions

Source(s): Authors' own work

practical approach integrating ST, SD, accounting, and performativity theory, offering several insights.

First, the use of this approach led to the “generic” performativity (MacKenzie, 2006) of accounting and calculative practices in supporting urban sustainability policies through a siloed approach (Deslatte and Stokan, 2020). Despite the integration of calculative practices with ST and SD, the lack of communication and limited data prevented participants from fully considering the interdependencies within the city, leading them to act on other agents (Law, 1999). Consequently, their decisions proved not only globally ineffective but also led to worse sustainability outcomes, producing a form of “counter-performativity” (Callon, 2010; MacKenzie, 2007).

Next, our results confirmed the effectiveness of the suggested approach in enhancing the performativity of accounting and calculative practices, shifting from a “generic” to an “effective” level (MacKenzie, 2006). In particular, this shift occurred when human agents interacted fully with the non-human agent (the simulator) and had access to the full set of indicators for the urban domain (Bekier and Parisi, 2023a). This step demonstrated that calculative practices—here enhanced through the use of the simulator and ST or SD maps and concepts—can provide “a specific type of visibility to events and processes, and in so doing helps transform them” (Miller, 2001, p. 393). As we emphasized, this “visibility” also facilitated the identification of circularity and the management of CE patterns (Barnabè and Nazir, 2022; Bassi et al., 2021).

Finally, the last simulation demonstrated the full performative effect of the proposed integrated approach. The combined use of all calculative practices in the form of the simulator, the complete set of measures, and the many maps at disposal promoted a performative role in enhancing participants’ interaction and fostering a holistic approach to decision-making. This led them to incorporate ST and SD principles into their sustainability and CE decisions. This integrated approach resulted in “Barnesian” performativity—the highest level of performativity described by MacKenzie (2006, p. 19)—with strong behavioral responses from participants (Khosrowi, 2023; Lane and Rouwette, 2023).

Overall, the simulation results support both the theoretical and practical advancements in the relevant literature, starting with a debate on the *performative role of simulation models*. As mentioned, this debate essentially identifies two main approaches to model performativity (Vergara-Fernandez et al., 2023; Khosrowi, 2023): the “mitigation approach,” where models endogenize how agents will behave in response to specific model predictions, and the “appraisal approach,” which assigns both epistemic and performative capabilities to models, conceived as tools to steer human agents’ behavioral responses. By focusing on the use of SD and ST, this study addresses calls for a third approach (e.g. Khosrowi, 2023), where simulation models are actively used to engage human agents in the process of analysis and inspection of complex and dynamic systems. This approach promotes experimentation with the model and informs decision-making to be translated into real-world actions. Specifically, our results further support Behavioral System Dynamics (Lane, 2017; Lane and Rouwette, 2023), which envisions SD not only as a means to model systems behaviors dynamically (and sometimes deterministically) (Lane, 2000), but also as a way to trigger and discuss human agents’ behavioral responses. The findings also confirm the importance of both financial and non-financial data, assigning a central role to accounting in the process (Kunc et al., 2023).

With reference to the *accounting literature on performativity, sustainability, and circular economy* issues, the results of this study demonstrate that accounting data can play a performative role in urban decision-making by overcoming disconnections and misalignments in values, interests, and agendas, which are typical in this domain (Bekier and Parisi, 2023a, b). In this regard, this study reaffirms the view that accounting is not merely a “destination” but an active participant in an ongoing journey centered on performativity (Garud and Gehman, 2019). As previously mentioned, this perspective requires considering accounting not only as a relational element (Vosselman, 2022) in a specific network but also in terms of its interactions

with other actors, both human and non-human, within the network. In these terms, this study specifically advocates for both a theoretical and practical approach based on an integrated use of calculative practices. This approach is designed to enhance interaction among human decision-makers, support the development of urban sustainability and CE decisions, and help actors acquire a holistic view of the reality under analysis. It does this by unpacking the “black-boxing” of sustainability and CE policies and strategies as social objects (Revellino and Mouritsen, 2015), thereby generating new perspectives and representations (Yi *et al.*, 2017).

Moreover, our results stress that the concept of the CE should be grounded in the analysis, representation, measurement, and management of processes and policies that are “circular” in essence—that is, based on the concept and operation of feedback loops and feedback thought (Richardson, 1999). Thus, our research reinforces both the need to develop and use circular metrics tailored to urban domains (e.g. Bekier and Parisi, 2023a) and to combine them with other tools and principles (in this case, ST and SD) to enhance their combined performative effects (MacKenzie, 2006).

In this regard, this study also contributes to the debate on accounting’s limitations, such as its static nature (e.g. Boedker, 2010; Healy and Palepu, 2001), its incompleteness (Boedker, 2010), and its focus on financial transactions and the past (Merchant, 1998).

Regarding *performativity theory*, our results reaffirm the existence of multiple notions of performativity that can be connected to different contexts, domains, agents, and literature streams (Vossleman, 2022). Furthermore, they support the exploration of the performative role of calculative practices—whether directly or indirectly—within a network of decision-makers and within a specific context (in this case, sustainability and the CE in urban settings; Bekier and Parisi, 2023a). Thus, this study uses a simulation model to test how “performativity refers to the dynamics through which actants become defined through the performance of network relations” (Lowe, 2004, p. 614), with the simulator and accounting practices acting as mediator actants (Latour, 2005) of the process.

8. Conclusion, limitations, and further research

By investigating how calculative practices based on simulations and accounting measures may play a performative role within an urban sustainability context, this study proposed a theoretical and practical approach to assist decision-makers. The insights gathered can be summarized as contributions in both theoretical and practical terms.

First, this study provides an original approach to analyzing urban decision-making, particularly by highlighting the contrast between siloed and integrated policies (Deslatte and Stokan, 2020; Tudose *et al.*, 2021). Specifically, it demonstrates how calculative practices play a key performative role in engaging human actors and fostering cooperation. Moreover, by clearly showing the difference between siloed and integrated policies, this study contributes to building new awareness of the need for holistic thinking in sustainability decision-making and discovering the interrelationships between sustainability and CE paradigms.

Second, the research sheds light on how human decision-makers interact to allocate resources and develop policies in urban contexts (Deslatte and Stokan, 2020; Clay and Martin, 2017), thereby emphasizing the necessity of integrating various “concerns under the general banner of sustainability” to obtain “sustainable cities” (Portney, 2003, p. vii; Bulkeley and Betsill, 2003).

This also confirms the potential of the approach proposed here for training public sector decision-makers to holistically address sustainability and CE issues.

Additionally, this study demonstrates the relevance of appropriate indicators in the context of sustainability and the CE, showing how they function as both inputs and outputs in decision-making. This reinforces the need for further research in this area. Specifically, an integrated approach that combines simulation models with a broad set of metrics tailored to urban contexts can help operationalize sustainability strategies and support the urban sustainability transition (Fratini *et al.*, 2019; Boedker and Chua, 2009). Such an approach contributes to

developing “a mode of action” that transforms actors into “calculative agents” (Boedker *et al.*, 2020, p. 3) and organizes them into “a functioning calculative network” (Miller, 2001, p. 382).

Finally, the approach and the SD model presented in this study can be customized to fit different urban contexts, data, and decision-makers. This flexibility supports research on CE policies in cities (Bernhard *et al.*, 2018; Petit-Boix and Leipold, 2018), allowing for comparisons and fostering a better understanding of the relationship between CE and sustainability paradigms, as highlighted in the literature (Bansal *et al.*, 2022; Geissdoerfer *et al.*, 2017) and recognized as necessary in practice (Bekier and Parisi, 2023a, b).

This study has some limitations, primarily due to the results being based on two simulation sessions with a limited number of participants. While this was considered adequate for gaining valuable insights, testing the suggested theoretical and practical approach, and activating intense debate between participants and facilitators, it did not provide enough data for quantitative analysis or statistical evaluation. Future research could move in this direction and explore how to apply the same approach in contexts beyond training programs.

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