RESEARCH IN PROGRESS

TEACHING A SYSTEMS APPROACH TO MANAGE SMART SUSTAINABLE CITIES

DOI
https://doi.org/10.18690/um.fov.4.2026.64

ISBN
978-961-299-152-4

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Cities are pushing their boundaries to transform into smart and sustainable urban spaces, where factors such as ecological conservation, economic development, and democratic equity should be considered at the same time. Systems thinking is therefore among the most needed skills for practitioners managing smart sustainable cities. The purpose of this paper is to initiate the development of a curriculum for a systems approach to manage smart sustainable cities, leveraging theoretical concepts of systems thinking. Our framework will enable learners to view societal challenges as outcomes of social-ecological system behaviour over time, so that key leverage points for interventions can be identified.

Keywords:
systems thinking,
smart sustainable cities,
skills development,
social-ecological system,
system behaviour,
leverage points

University of Maribor Press

1 Introduction

"Smart city" has transpired to address challenges and possibilities in urban planning and city development for a vast majority of the population across several disciplines (Kutty et al., 2020). Simply speaking, cities that strive to make themselves "smarter" are termed as smart cities (Chourabi et al., 2012). Meanwhile, modern societies face many sustainability challenges from the environment (e.g., air quality, water quality, and waste handling), the economy (e.g., unemployment, wealth gap, and economic inequality), and the society (e.g., food security, water scarcity, and poverty) (Zander & Mosterman, 2017). Cities are therefore pushing their boundaries to transform into smart and sustainable urban spaces, where factors such as ecological conservation, economic development, and democratic equity should be considered at the same time (Kutty et al., 2020). This is in line with the finding of *Smart Communities Skills Development in Europe* (SMARCO, 2025) that systems thinking is among the most needed skills for practitioners managing smart sustainable cities.

Teaching a system approach (to manage smart sustainable cities) encourages learners to engage in nonlinear, synthetic and adaptive thinking founded upon systems thinking (Capra, 1996). Systems thinking is defined as "a discipline for seeing wholes. ... a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'" (Senge, 2006, p. 68). It calls for managerial decision-making based on insight into the complex dynamics of social-ecological systems to broaden horizons for understanding and addressing societal challenges in new and different ways (Sterman, 1994).

The purpose of this paper is to initiate the development of a curriculum for a systems approach to manage smart sustainable cities, leveraging theoretical concepts of systems thinking. With reference to Kennedy et al. (2026), our framework comprises four conceptual moves: *developing a complex adaptive systems (CAS) mindset, identifying structure and form of systems, understanding behavioural dynamics of systems over time,* and *intervening in systems*. In addition, we discuss one illustrative example (Breukelman et al., 2022) to make the approach more tangible and domain-specific.

2 The Learning Framework

Below, we offer guidance through a learning framework that integrates problem-solving approaches of systems thinking (Ackoff, 1974; Forrester, 1994; Meadows, 2008; Senge, 2006; Sterman, 2001).

2.1 Developing a CAS Mindset

Societal challenges are dynamic, changing through a process of coevolution involving multiple entities (such as population, governance quality, budget, solid waste management performance, etc.) within complex entanglements (Kennedy et al., 2026). A CAS mindset therefore enables learners to embrace complexity and understand different entities as inherently situated and interdependent within broader contexts (Shrivastava & Kennelly, 2013). Below, we will use the example about Solid Waste Management (SWM) in cities (Breukelman et al., 2022) to illustrate such interdependency.

SWM research has mostly focused on symptoms (such as lack of resources, infrastructure, awareness, and institutional strength), while underlying reasons have attracted little attention (Breukelman et al., 2019). In fact, the performance of waste collection can be considered as the product of a complex urban system in which processes on demographics, economics, and physical (infra)structures interact with social and political processes (Breukelman et al., 2022). For instance, the combined effect of economic growth and urbanisation drives an increase of build-up area, population density, traffic, and consumption (Mangi et al., 2020). In many cases, such growth overtakes the capacity-building of administrative organisations to adapt themselves and their cities (Mason et al., 2020). Where this happens in an urban context with low institutional quality (Beard et al., 2016), fragmented governance (Ahrend et al., 2017), discontinuities in management (Ezeah & Roberts, 2014), and absence of stable leadership (Cornea et al., 2017), tax incomes and urban investments start to shrink (Rice & Rice, 2012). In turn, this leads to diseconomies of agglomeration (Venables, 2017), initiating a vicious circle (Beard et al., 2016).

2.2 Identifying Structure and Form of Systems

A systems approach teaches learners to exercise caution before intervening in societal challenges (Kennedy et al., 2026). Learners are taught to explore underlying structures and causalities of social challenges and the values and beliefs that shape this structuring (Kennedy et al., 2026). For this purpose, understanding the concepts of feedback and delays is the starting point.

A feedback loop is a "closed chain of causal connections" (Meadows, 2008, p. 27) typically categorized as those that amplify an effect (reinforcing or positive feedback loops) and those that dampen an effect (balancing or negative feedback loops). Feedback loops help learners develop closed-loop thinking about why societal challenges persist and how entities are part of these causal connections and act to reinforce or break feedback loops. Delays refer to the time lag between cause and effect as materials and information flow through the system (Sterman, 2001). Recognizing delays helps learners understand long-term consequences and reduce the risk of instability or breakdowns by taking corrective action when unnecessary (Senge, 2006). Figure 1 shows a simplified model for the example from Breukelman et al. (2022), with "R" denoting a reinforcing loop, "B" denoting a balancing loop, and "‖" denoting a delay.

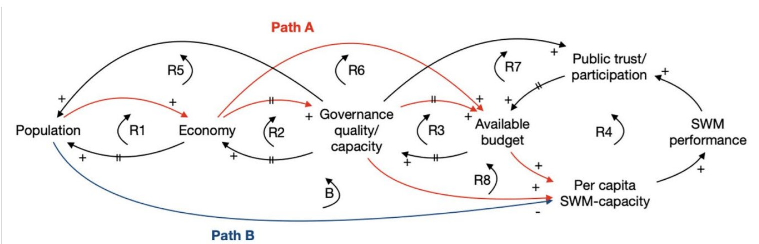

Figure 1: A simplified SWM model
Source: Breukelman et al. (2022)

2.3 Understanding Behavioural Dynamics of Systems Over Time

Building on an understanding of the structure of a system, learners can seek to gain an appreciation for the state of societal challenges and their patterns of change over time (Kennedy et al., 2026). Rather than viewing single events of societal challenges in isolation, learners understand them as behavioural patterns in systems influenced by fast-paced effects of temporally proximate actions combined with slow-paced effects of those from the distant past (Meadows, 2008). Learners gain an appreciation for nonlinear dynamics of change and the crossing of potential threshold points whereby underlying dynamics driving behaviour of societal challenges may fundamentally transform (Kennedy et al., 2026).

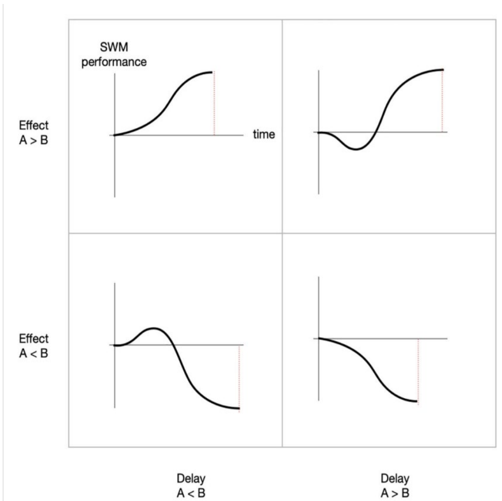

Figure 2: Projections of SWM performance under different regimes of effects and delays in the dominant paths

Source: Breukelman et al. (2022)

In the example from Breukelman et al. (2022), the expected behaviour may be either continued growth or decline in SWM performance, which may be strongly influenced by the pace of population growth. Figure 1 shows two important paths starting from "Population": Path A going through "Economy", "Governance quality/capacity", and "Available budget" towards "Per capita SWM capacity" (which are all reinforcing loops), while Path B going directly to "Per capita SWM capacity" (which is a balancing loop). The effects and delays in both paths dominate the evolution of SWM performance over time, which can be further simplified as the interaction between the effect of a reinforcing loop (i.e., Path A) and the effect of a balancing loop (i.e., Path B) with delays respectively. Such a structure is a typical Limits to Growth system archetype (Senge, 2006). The plots in Figure 2 demonstrate such system behaviour over time (under different regimes of effects and delays in

Paths A and B). A huge effect and short delay in Path A may be the most beneficial scenario for SWM performance. Longer delay in Path A will lead to an initial reduction in SWM performance, but will gradually be overcome in the long run. A small effect and long delay in Path A do the opposite.

2.4 Intervening in Systems

The purpose of this conceptual move is to understand how systems may be transformed by appreciating what is governing stability and what forces enable change. Learners are invited to search for leverage points for change (Meadows, 2008) and to consider broad ranges of impacts and unintended consequences (Sterman, 2002).

For example, when identifying leverage points to improve SWM performance (Breukelman et al., 2022), it is important to consider: (1) the population and economy part (on the left-hand side of Figure 1) is not useful for interventions, as these processes are autonomous, difficult to manage, and any intervention may lead to counter effects (i.e., via both Path A and Path B). For instance, lowering the inflow of new inhabitants may seem attractive, but it will also hurt the economy and reduce available budgets. (2) The SWM part (on the right-hand of Figure 1) may be a good point for interventions, but it is not. For example, any investment in capacity (i.e., shorten the delay of Path A) may lead to an improved performance in the short run, but if this is not followed by improvements in governance and yearly budgets (i.e., improve the effect of Path A), the upswing will not last long and may even cause the decrease of public trust and a reluctancy on further improvements. (3) The key to success is in the hands of governance. Political and administrative processes should focus on budget availability, which should keep pace with population and city growth. The most promising way to do so is to implement and enforce taxation schemes and, at the same time, safeguarding service availability and quality to prevent eroding public trust (i.e., the upper left corner of Figure 2).

3 Discussion and Future Work

Our framework may enable learners to view societal challenges as outcomes of social-ecological system behaviour over time. Early pilot evidence—such as classroom tests, practitioner reactions, or preliminary learning outcomes—would make our contribution more concrete. In addition, Breukelman et al.'s (2022) example is mainly about sustainability, while the "smart" side is not fully reflected. A further inclusion of illustrative examples, such as the one in Kutty et al. (2020), is in our plan to link between information systems (IS) and socio-technical system design, with clearer implications on IS education and digital decision support tools.

Acknowledgment

Special thanks to Dr. Mohamed Eledeisy (HU University of Applied Sciences Utrecht), for his efforts on proofreading.

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