Systematic Map Protocol

Title
What is the state of the art in modelling systemic changes in social-ecological-technological systems?

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Keywords
system; change; social-ecological-technological; urban; modelling

Background
Urban systems are social-ecological-technological systems (SETS), linking individual components at multiple scales and levels (Elmqvist et al, 2019; McPhearson, Pickett et al., 2016; Wolfram & Frantzeskaki, 2016). They include legal, functional, infrastructural and social components that are interrelated and interact with each other (Acuto et al., 2018; Frank, 2017; McPhearson, Pickett, et al., 2016; Meerow et al., 2016). The SETS concept combines resilience thinking and socio-technological transition management into a common perspective in addressing sustainability transformations (Olsson et al., 2014). Analysing urban systems as SETS provides a better understanding of their interrelated components and thus insight into the possible consequences of implementing spatial policies and actions in a compound urban environment (Grimm et al., 2017; Krueger et al., 2022; McPhearson et al., 2022). Intrinsic characteristics of urban systems perceived as SETS include: (1) complexity, (2) highly dynamic and distributed structure, and (3) indeterminism and non-linearity of the processes taking place (Oughton et al., 2018). Thus, the creation or implementation of new institutions, rules or behavioural norms can lead to fundamental changes in the system's behaviour or structure – to a systemic change (Polhill et al., 2016). From a modelling perspective, such a change cannot be simulated using a fixed model structure or parametrization. The ability of urban systems to move between multiple equilibrium states affects uncertainty in urban growth projections (Verstegen et al., 2016), and thus should be taken into account in modelling practice (Grimm et al., 2017; Meerow et al., 2016; Polhill et al., 2016; Van Strien et al., 2019). Therefore, the concept of including the non-stationary nature of urban systems in their model representations requires a deeper analysis of the current state of knowledge on modelling systemic change in urban systems, including trends in current applications and identification of potential knowledge gaps.

Theory of change or causal model
Attached as a graphic

Stakeholder engagement
None

Objectives and review question

The primary review question is: What is the current state of knowledge on implementing the non-stationary nature of socio-ecological-technological systems in models representing urban systems? Secondary questions: RQ1. What is the distribution, and what are the trends, dynamics and thematic domains of research addressing systemic change in urban systems in the context of modelling? RQ2. Which properties of SETS are present in the urban system modelling framework and how are they conceptualised and implemented? RQ3. What are the knowledge gaps; what is their geographic and thematic distribution, and how can they be addressed?

Definitions of the question components
Population: Urban systems worldwide and their individual components. Intervention: The use of modelling systems implementing the non-stationary nature of socio-ecological-technological systems Comparison: The use of modelling systems that do not implement the non-stationary nature of socio-ecological-technological systems Outcome(s): Identification of urban growth models better reflecting the reality and having greater predictive power, identification of model characteristics that influence its performance Context: Distribution and temporal trends of studies based on the geographical and thematic domains covered. Distribution and temporal trends of the state-of-the-art of the assessed research on modelling systemic changes in urban systems, including the modelling techniques, implementation techniques, definitions and knowledge gaps.

Search strategy
Strategy used for collecting studies related to modelling systemic change in urban systems is based on systematic literature review. We plan to use two search databases for this study: Google Scholar and Scopus. No time constraint for the searched studies is assigned. Query used for the search is based on the combination of phrases capturing: 1. the systemic component, 2. the urban environment, 3. the connotation of the change in the environment and 4. the modelling component, marking the conceptualization of the change in the urban system. Detailed search terms and strings are provided in point 8.1.

Bibliographic databases
Databases were queried using Publish or Perish search software (Harzing, 2007) for the words in title only. Database: GoogleScholar Search domain: Words in title, No patents, No citations Query: ("system” OR "systems" OR "systemic" OR “stationary” OR “stationarity”) AND ("cities" OR "urban" OR "social-ecological-technological") AND ("change" OR "changes" OR "shift" OR "shifts" OR "tipping point" OR "tipping points" OR "growth") AND ("modeling" OR "modelling" OR “model”) Database: Scopus Search domain: Words in title Query: ("system*” OR “stationar*”) AND ("city" OR "cities" OR "urban*" OR "social-ecological-technological" OR "social-ecological" OR "socio-ecological") AND ("chang*" OR "shift*" OR "tipping point*" OR "growth") AND ("model*")

Web-based search engines
None

Organisational websites
None

Comprehensiveness of the search
In the initial part of the search, various combinations of searching string queries were tested, in order to select the searching terms with an adequate level of generality, generating exhaustive responses, while at the same time being precise enough to limit the results to studies on modelling urban systems. The search query was refined until the search results included the following papers: • Li, X., Liu, X., & Yu, L. (2014). A systematic sensitivity analysis of constrained cellular automata model for urban growth simulation based on different transition rules. International Journal of

Geographical Information Science, 28(7), 1317-1335. • Masson, V., Marchadier, C., Adolphe, L., Aguejdad, R., Avner, P., Bonhomme, M., ... & Zibouche, K. (2014). Adapting cities to climate change: A systemic modelling approach. Urban Climate, 10, 407-429. • McGarigal, K., Plunkett, E. B., Willey, L. L., Compton, B. W., DeLuca, W. V., & Grand, J. (2018). Modeling non-stationary urban growth: The SPRAWL model and the ecological impacts of development. Landscape and urban planning, 177, 178-190. • Polhill, J. G., Filatova, T., Schlüter, M., & Voinov, A. (2016). Modelling systemic change in coupled socio-environmental systems. Environmental modelling & software, 75, 318-332.

Search update
N/A

Screening strategy
During the screening of the search results the duplicate records; records, which contained an incorrect reference (e.g. a reference with incorrect title and without identifier, untraceable); invalid type of references (e.g. book reviews, Master's theses), sources published in language other than English, sources without available abstract and sources unavailable in full text will be removed from the database.

Eligibility criteria
To be considered eligible for the systematic mapping, the results had to pass the following eligibility criteria, referring to the specific components of PICO framework: Population: • studies related to urban systems or SETS or social-ecological-systems (SES); or to their individual components. Intervention / Comparison: • studies considering substantial changes in the behaviour and/or structure of systems ("systemic change", as defined in Polhill et al., 2016), including the causes and outcomes of these changes Study design: • Studies using modelling methods, techniques and tools, in particular studies on land use, land cover, or other spatially explicit environmental models. • Studies modelling a process or phenomena taking place over given period of time

Consistency checking
Reviewer 1 will screen the abstracts of collected studies. Reviewer 2 will screen titles and abstract of 10% of randomly selected studies. Reviewer 3 will screen titles and abstracts of 10% of randomly selected studies, not overlapping with Reviewer 2. In case of substantial inconsistencies in the eligibility check between the reviewers, the full abstract screening will be conducted by Reviewers 2 and 3.

Reporting screening outcomes
Screening outcomes will be reported using ROSES diagram, indicating number of articles in the database in each review step. Database of accepted and excluded articles will be added to the review as a supplementary material.

Study validity assessment
N/A

Consistency checking
N/A

Data coding strategy
Works selected for mapping will be stored in an Excel data sheet. The data sheet will contain one work per row, with the columns indicating: - journal name - article name - year of publication - authors - abstract

Meta-data to be coded
The following information will be extracted from the publications and stored in the columns: - geographic (i.e. country, region, city) and temporal domains (i.e. simulation period) of the applications/case studies (if any) - notion of a substantial change in the system's behaviour or structure, e.g. increased occurrence of heavy rains related to the climate change; paradigm shift in urban energy systems through distributed generation; modal shift in rapid transit system; transformation of unused land to production and living land. Works will be categorised according to study themes pre-defined on the basis of analyses of the abstracts of the current literature on systemic changes (Goch, Śleszyński and Affek, 2023). 1. Land-use change 2. Planning and policies for sustainable development 3. Climate change 4. Resilience 5. Infrastructure 6. System's approach 7. Global scale models Each analysed publication will be quantitatively assessed for fit into the relevant thematic groups, according to the scoring method proposed by Śleszynski et al., 2023. For each thematic group, publications will be scored on a scale of 1-3 based on the amount of text devoted to an issue related to that group: - 0 points: no reference to a thematic group; - 1 point: at least one-two sentences (a few lines, but not a wholeparagraph); - 2 points: at least several sentences (1-2 paragraphs, but not aseparate subsection); - 3 points: the whole or a substantial part of the publication (e.g. a subsection). Points assigned will be stored in columns dedicated for each group.

Consistency checking
A pilot of 10% of the search results will be carried out by Reviewer 1 in consultation with Reviewer 2 and Reviewer 3. The rest of the papers will be analysed by Reviewer 1 (50%), Reviewer 2 (20%) and Reviewer 3 (20%). A randomly selected 10% of the papers will be analysed by a second reviewer. In case of substantial inconsistencies in data extraction, a rereview will be conducted resulting in each publication reviewed by at least 2 reviewers.

Type of mapping
Extracted metadata will be reported in form of tables, charts and maps for geographic data.

Narrative synthesis methods
Result of the thematic groups extraction will be a two-dimensional matrix representing the quantitative share of research papers in each thematic grouping, visualized as a heatmap. Synthesis results will be presented in form of a conceptual model of recommendation for inclusion of non-stationary character of urban systems in the modelling practice.

Knowledge gap identification strategy
Collected studies will be analysed in terms of the structure continuity between the properties of SETS and the model assumptions; in terms of the understanding about how SETS properties affect the predictive and descriptive capabilities of models; and in terms of the methods used to incorporate the systemic changes in the modelling framework or identify their presence in the modelling outcomes.

Demonstrating procedural independence
Review team members will have no role in decisions regarding inclusion or critical appraisal of the studies they authored.

Competing interests
N/A

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Author's contributions
KG search and screen the data. KG, PS and AA analyze and interpret the data. All authors read and approve the final manuscript.

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