Challenges in Sustainability
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SIMURG_CITIES Conceptual Model: Multi-Dimensional and Multi-Layer Performance-Based Assessment of Urban Sustainability at the City Level

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Received: 04-23-2025 **Revised:** 06-20-2025 **Accepted:** 08-05-2025

Citation: Ulker Senkulak, B., Kanoglu, A., & Ozcevik, O. (2025). SIMURG_CITIES conceptual model: Multi-dimensional and multi-layer performance-based assessment of urban sustainability at the city level. *Chall. Sustain.*, *13*(3), 425–444. https://doi.org/10.56578/cis130308.

Abstract: The assessment of urban sustainability and the development of performance-based practical tools for achieving Sustainable Development Goals (SDGs) are key items for discussion on the public agenda. Despite the urgency of the issues, there is a noticeable lack of studies related to a comprehensive model that could holistically assess sustainability performance at the city level. To address this research gap, SIMURG_CITIES conceptual model, the sub-project of "A Performance-based and *S*ustainability-oriented *I*ntegration *M*odel *U*sing *R*elational database architecture to increase *G*lobal competitiveness of the construction industry" (SIMURG), introduces a system-based methodology to evaluate urban sustainability of different cities. SIMURG_CITIES adopts multiple city layers and their associated key performance indicator (KPI) sets within the built environment dimension of 3D Cartesian system architecture to offer new insights. The purpose of this paper is to develop conceptual models at paradigmatic/philosophical, organizational process, interoperability/integrational, and computational/assessment components, paving the way for practical applications with a relational database model. The model and its relationship with interrelated components are explored by an iterative systems approach using "input–process–output–outcome–impact" (IPO) model and the "people-process-technology" (PPT) methodology. This structure steers the integration of humane, procedural, and technological factors into urban sustainability assessment. In addition, the model could help individuals select ideal urban environments to align with their expectations and to enhance accountability, transparency, and legitimacy in the decision-making processes of public authorities. Through this study, a technology-based approach is found to be effective in assessing urban sustainability and a conceptual framework is established in the contexts of Society 5.0 and urban governance.

Keywords: Conceptual model; Performance-based assessment; Multi-layer indicators; Systems approach; Urban governance; Urban sustainability

1. Introduction

The major challenges to planetary sustainability nowadays include the rapidly expanding global population, depletion of natural resources, climate change, technological inequality and disruption, abuse of data and information, ruthless neoliberal economies, global, regional, or local conflicts, as well as corrupt and ineffective governance (Yigitcanlar & Cugurullo, 2020). Traditional urban planning, impacted by these challenges, faces a series of issues that demand solutions, such as conflicts of interest among stakeholders, insufficient certification, poor coordination between organizations of urban development, and lack of control during the phase of implementation (Girardet, 2015; Hall & Pfeiffer, 2000). Decision-makers in urban projects, especially in the developing countries, was claimed to prioritize profits over long-term sustainability, societal benefits, and environmental impact (Harvey, 2013; Swyngedouw et al., 2002). Urban inhabitants suffer due to inadequate zoning and regulations, a lack of information about the performance standards of urban projects, and the weakness of mechanisms intended to protect society (UN-Habitat, 2020; United Nations, 2015). This situation, caused by inefficient use of scarce resources, results in losses in both national and global economic dimensions and increasing challenges in the sustainable urban development process. Therefore, urban planning and development should be considered with caution; alternative approaches supported by computer-based tools should be advocated in the developing countries to enhance accountability and transparency, especially in the decision-making processes (UN-Habitat, 2023).

Cities, as complex social systems, have to address environmental, economic, sociocultural, and technological problems with holistic strategies that could promote polycentrism, participatory governance, and alignment with nature (Feleki et al., 2020). In response to existing global challenges, performance-based strategies and value-based principles become more essential as they employ technology as a tool with a "human-centered" approach, especially to align with Sustainable Development Goals (SDGs) (UN-Habitat, 2020).

Among global priorities, sustainable development remains a major concern and the UN 2030 SDGs (United Nations, 2015) promote a comprehensive framework for addressing this issue (Spiliotopoulou & Roseland, 2020). In this regard, the emergence of "A performance-based and *S*ustainability-oriented Integration Model Using Relational database architecture to increase *G*lobal competitiveness of the construction industry" (SIMURG) framework and its concomitant sub-projects have been developed to support data-driven decision support systems (Kanoglu et al., 2022a; Kanoglu et al., 2022b; Ulker et al., 2018; Ulker et al., 2021). Its focus aligns with the Brundtland definition of sustainability (United Nations, 1987) and supports multiple SDGs, including Goals 3, 4, 8, 9, 11, and 16. Within this framework, the SIMURG_CITIES model specifically addresses Goal 11: "Sustainable Cities and Communities". The relationship among the UN SDGs, SIMURG, and SIMURG_CITIES is illustrated in Figure 1.

Figure 1. Relationship among UN SDGs, SIMURG and SIMURG_CITIES

SIMURG adopts a holistic approach in considering the interactions of facts/entities across the 3D Cartesian system dimensions, which include physical/product-related/built environment, professional/process-related/economic environment, and societal/human-related/social environment. This model proposes a multi-layer/level and multi-dimensional framework to identify the relation between various 3D Cartesian system dimensions and the facts/entities at different hierarchical levels (Figure 2). Key performance indicator (KPI) sets for the 4th dimension encompassing layers such as smart, resilient, etc. are necessary to assess the performance of facts/entities related to sustainability within these dimensions (Kanoglu et al., 2022a; Kanoglu et al., 2022b).

The SIMURG_CITIES conceptual model, focusing at the "city-level" as one of the fundamental levels in the built environment dimension of the 3D Cartesian system, aims to establish a multi-dimensional and multi-layer performance-based sustainability assessment model and its accompanying subcomponents (Figure 2). The model serves as a "decision support system" that could offer an innovative and holistic solution to urban planning and governance by enabling urban users, administrators, investors, experts, and decision-makers to assess sustainability performance in a comparative manner. Moreover, the model was designed to align with Society 5.0, a human-centered societal vision, thus integrating advanced technologies into all aspects of life to solve social problems and promote well-being. In this context, Key Enabling Technologies (KETs) are defined as cutting-edge technologies that act as catalysts for innovation, productivity, and sustainability in multiple sectors, including urban development. KETs, including a wide array of tools such as Artificial Intelligence (AI), Big Data (BD), and Digital Twins (DTs), enable digital transformation of cities and support advanced data-driven decision-making processes. For instance, *DTs* could facilitate real-time monitoring, simulation, and optimization in urban planning via the creation of dynamic virtual models for physical urban systems. Similarly, *AI* and *BD* enhance predictive analytics, stakeholder engagement, and performance assessment within complex urban environments. By combining these technologies, the SIMURG_CITIES model operationalizes the principles of Society 5.0 and provides a forward-looking and technology-enhanced framework for sustainable urban governance.

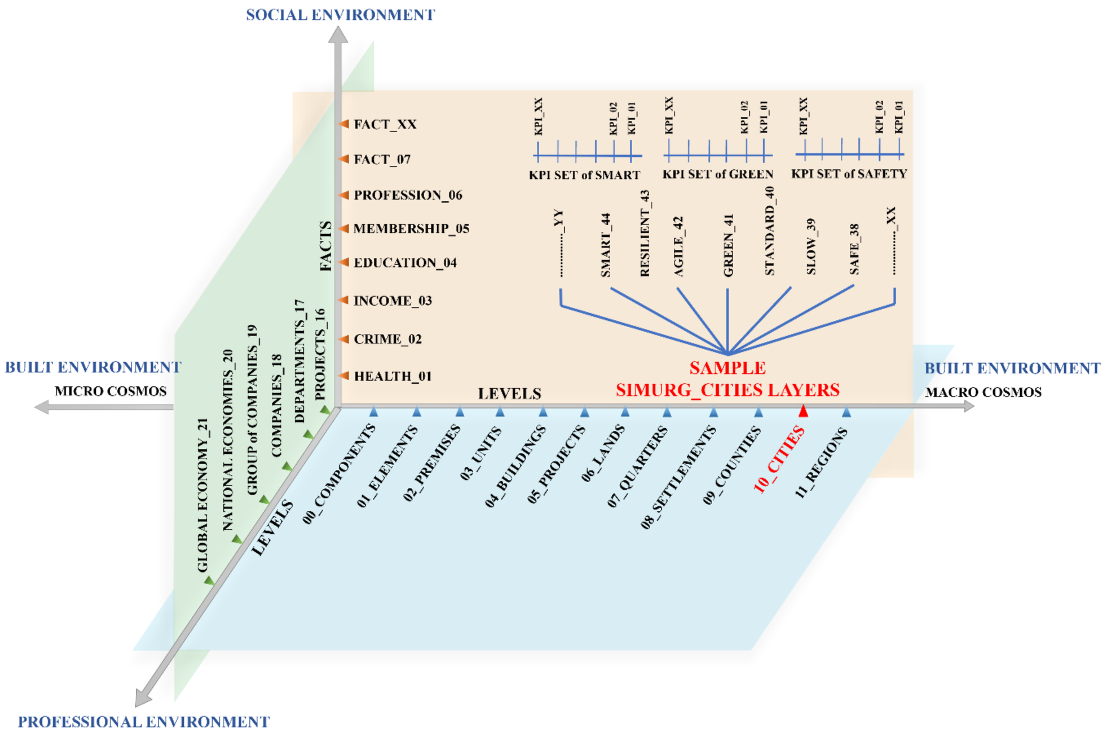

Figure 2. SIMURG and SIMURG_CITIES multi-level/layer, multi-dimensional and performance-based sustainability assessment model

Preious studies on urban sustainability, to a large extent, focused on a single dimension or layer which limited the potential for promoting a comprehensive approach. For example, research on built, economic and social environments typically concentrated on merely one or two dimensions; leading to few interactions with other dimensions or layers (Cohen, 2017; Spiliotopoulou & Roseland, 2020). Although widely used urban indices such as ISO 37120 (Sustainable Development of Communities: Indicators for City Services and Quality of Life) and the Global Liveability Index provide valuable benchmarking tools, they are limited by their predominantly top-down structure and standardized indicator sets. These models often fail to capture context-specific dynamics, inter-layer interactions, or the systemic complexity of urban sustainability challenges. Moreover, they lack mechanisms for performance-based assessment, integration with digital technologies, and support for stakeholder-driven customization to achieve the UN SDGs at the local scale.

Additionally, many studies have focused solely on one layer, such as smart, green, and resilient cities, without integrating multiple dimensions and layers. Recent studies have attempted to integrate different layers and composite indexes, such as combinations of "smart eco-city" (Tarek, 2023), "smart-resilient city" (Khatibi et al., 2022; Ramirez Lopez & Grijalba Castro, 2020), "smart-green city" (Bashirpour Bonab et al., 2023), "smart-sustainable-green city" (Javidroozi et al., 2023), and "sustainable-smart-resilient city" (Wojewnik-Filipkowska et al., 2024), thus indicating a growing interest in integrated urban sustainability frameworks. However, they still fall short of adopting a truly multi-dimensional and multi-layered perspective grounded in systems thinking. In contrast, the SIMURG_CITIES model is built upon a 3D Cartesian system; it does not only capture the complexity of interrelated urban dimensions and layers but also integrates organizational structure, data integration, and interoperability through a relational database architecture, thus moving beyond descriptive approaches toward actionable and performance-based assessment.

1.1 Problem Statement and Aim of the Research

Decision-making processes of public authorities responsible for policy development in sustainable urban planning and development, are considered not providing sufficient support to transparency, accountability, and consistency (Bovens et al., 2014; UN-Habitat, 2020). In light of the socio-technical revolution, Society 5.0 requires a human-centered vision supported by a grounded paradigmatic/philosophical framework model together with tools to enhance the legitimacy of the entire decision-making process. The core problem centres on insufficient tools and vision which could help: (i) individuals align their priorities in life with urban identities of the built environment facts/entities; and (ii) governmental organizations and investors suggest/perform appropriate actions/projects with convenient urban identities using layers/concepts/labels, outlined with defined KPI sets according to their weights of urban environment facts/entities.

Besides the effects on economic and social dimensions; a comprehensive model should be taken into account for the assessment of urban sustainability within built environment dimension. Existing studies in the literature often discuss only one dimension/layer and address a limited aspect of sustainability problem (Novelo et al., 2021), without offering a holistic solution approach (Feleki et al., 2020). In this context, a detailed analysis of the KPIs used in assessing smart cities was presented in the study titled "SIMURG_CITIES: Meta-Analysis for KPI's of layer-based approach in sustainability assessment" (Ulker et al., 2021). While case studies at the city level might be expanded to encompass the whole environment dimension of sustainability in the 3D Cartesian system, the priority of establishing a comprehensive conceptual model is crucial before delving into particular sections of the entire system. Such a model could help initiate practically applicable models to accurately assess sustainability at the city level.

To address the identified problem, SIMURG framework model was developed to guide the creation of essential conceptual and practical models (Kanoglu et al., 2022a; Kanoglu et al., 2022b). In this study, under the guidance of SIMURG, the components of SIMURG_CITIES conceptual model at the city-level, paradigmatic/philosophical model, organizational/process model, integration/interoperability model, computational/assessment model, and the interactions among these components, are developed as part of an iterative process. The model aims to compare and assess the performance of sustainability indicators at the city-level within multi-dimensional and multi-layer relationships. The methodology of this research uses a "bottom-up" approach adopted in defining the problem, whereas a "top-down" approach is followed in developing the model and integrating it into SIMURG framework. While the model finds solutions to the research problems of the built environment at the city-level by focusing on the concepts of Society 5.0, human-centered approach, governance, technology and sustainability, it assesses the sustainability performance of various entities and layers in cities and presents a system that integrates the built, social and economic environments.

Individuals seldom take on the roles as decision-makers or co-creators by providing feedback (Kitchin, 2018); instead, they are frequently considered as data sources, consumers or elements to be directed (Cardullo & Kitchin, 2019). Rather than perpetuating a chaotic system that primarily supports the ambitions and initiatives of entrepreneurs driven by profit maximization, there is a need for a holistic paradigm underpinning the philosophical approach that integrates sustainability into the design, implementation, and assessment of sustainable urban development. This perspective should acknowledge that planetary resources should be inherited globally, and all agreements and activities should aim at defending the rights of the future generations.

The objective of this study is to develop a decision-supporting model that operationalizes urban sustainability through a value-based and stakeholder-oriented governance mechanism. According to the hypothesis formulated to address the identified problem, urban sustainability should no longer be regarded solely as the responsibility of city administrators. Instead, it should be redefined as a shared responsibility that encompasses all stakeholders under the vision of Society 5.0. This shift should empower the "*learning human*", that is, a technologically empowered and adaptive individual who actively participates in problem-solving and decision-making in line with the vision of Society 5.0, to play an active role in urban governance. This approach fosters a culture in which both individuals and society collectively bear responsibility for the equitable use and distribution of resources. Alongside the evolving typology of urban actors, a decision-making mechanism should be established not only to uphold the rights of individuals to assess and make choices, but also to ensure that policy decisions at the city level, whether made by the local or central governments, are guided by principles of transparency, accountability, and consistency. This mechanism should be integrated and interoperable with a model that incorporates innovative approaches and supports KETs. Consequently, urban sustainability should be approached not merely as a market-oriented strategy focused on urban rent or competitiveness, but as a value-based development paradigm grounded in social justice, inclusivity, and long-term urban resilience.

In alignment with the proposed hypothesis, the following research questions (*RQ 1-4*) are analyzed. Each is directly linked to a specific model component of the SIMURG_CITIES conceptual framework and explored through both literature review and practical applications:

(*RQ1*) How is sustainability performance assessment approached in terms of "urban layers/concepts/labels" and "KPI sets and their weights" addressed in the computational/assessment model?

(*RQ2*) In urban planning and implementation, how are the SDGs and sustainability indicators assessed within a conceptual framework help develop consistent policies, set strategic targets, and formulate action plans based on urban open data? What are addressed in the paradigmatic/philosophical model?

(*RQ3*) How do urban actors participate or will participate in the decision-making level/mechanism of urban governance in conjunction with the concepts of "sustainability," "Society 5.0," and "KETs"? What are addressed in the organizational/process-related model?

(*RQ4*) How could a comprehensive and integrated model be developed to effectively address the multi-dimensional and multi-layer aspects of urban sustainability, which incorporates the roles of various stakeholders and integrates advanced technologies to ensure holistic and sustainable urban planning as well as governance? What are addressed in the interoperability/integrational model?

2. Methodological Approach: SIMURG_CITIES Multi-Dimensional and Multi-Layer Sustainability Assessment Model

Within the global sustainability framework, the complexity and interdependence of industrial, social, and ecological systems necessitate a comprehensive system thinking approach for effective decision-making (Fiksel, 2006; Meadows, 2008). Rather than analyzing components in isolation, this approach focuses on the dynamic interactions, feedback loops, and long-term consequences of urban systems (Oliveira & Pinho, 2010; Sterman, 2002). System-based models such as the input-process-output (IPO) model and its related extensions are widely used in assessing urban development performance (Huovila et al., 2019; Yigitcanlar et al., 2018). One such method, the People-Process-Technology (PPT) framework, integrates human, procedural, and technological dimensions and emphasizes human-centered design, stakeholder participation, and adaptive governance (David et al., 2023; Leavitt, 1965), aligning advanced technologies like AI and BD with societal needs (Brynjolfsson & McAfee, 2014).

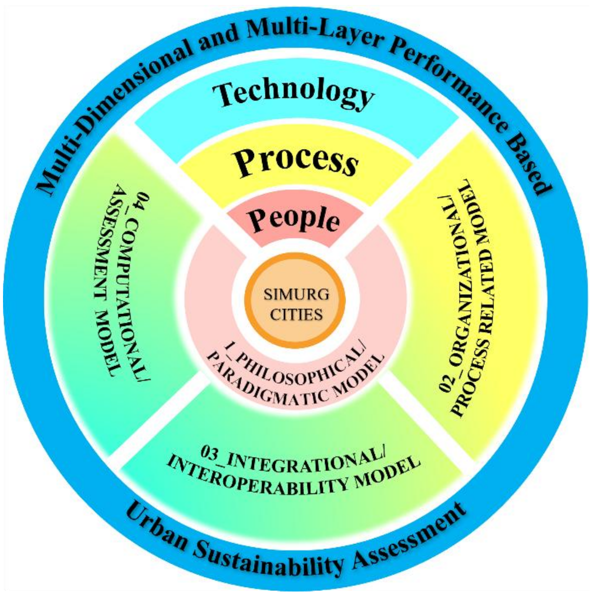

Figure 3. Integration of the SIMURG_CITIES conceptual model components into the People-Process-Technology (PPT) framework

To demonstrate the integration of these system-based methodological foundations into the SIMURG_CITIES model, Figure 3 presents a conceptual mapping between four core components of the model and the PPT structure.

This circular diagram demonstrates that the paradigmatic model is positioned in the "people" domain, the organizational model in "process", and the computational model in "technology" as the interoperability model bridges across them. This structural mapping illustrates the corresponding operation of each component in their respective key methodological domain.

Building on this foundation, the model adopts the input–process–output–outcome–impact (IPO) logic as a system flow structure, illustrated in Figure 4. The diagram visualizes how the model transforms input data such as urban identity, layers, and KPIs into performance outputs and long-term sustainability outcomes through participatory processes and decision-making mechanisms. This framework links the operational mechanisms of the model to the achievement of SDGs by supporting evidence-based and auditable sustainability planning.

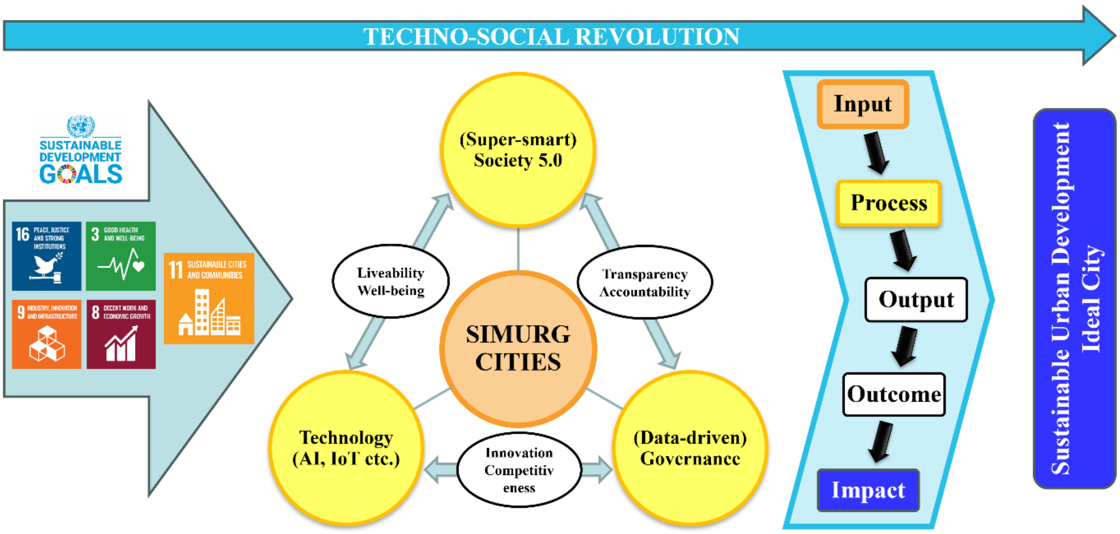

Figure 4. SIMURG_CITIES conceptual model illustrated within the Input–Process–Output–Outcome–Impact (IPO) system logic

The methodological framework of the SIMURG_CITIES conceptual model, therefore, combines both the human-centered adaptability of the PPT framework and the technical traceability of the IPO cycle. This supports a holistic and iterative assessment process, enabling the analysis of dynamic and interdependent relationships among urban sustainability components. These relationships are shaped through iterative development, allowing comparative analysis within the decision-making process of "learning human" of Society 5.0. As a subcomponent of the broader SIMURG framework, the SIMURG_CITIES model has also been developed iteratively to explore and strengthen the interrelations among all system components. This top-down process integrates insights gained from the development to ensure internal coherence and connectivity. The conceptual model categorizes and analyzes system components under five main areas defined below:

- Sustainability environmental dimensions: Contextualized as "physical/product-related/built environment", "professional/process-related/economic environment", and "societal/human-related/social environment".
- Levels within the built environment dimension: Focused on the relationships of "physical/product-related/built environment" and city-level entities.
- Layers/concepts/labels of sustainability assessment: Centered on the identification of KPIs for comparative assessment from a list of potential layers, such as green, smart and others, which could be considered as the 4th dimension to the existing 3D framework.
- Methods/tools of sustainability assessment: Incorporated performance-based approaches as unified metrics for assessment of built environment entities, employing modern methods such as multi-criteria decision-making, principal component analysis and machine learning.
- Key focus areas: Covered critical themes such as sustainability, Society 5.0, technology, governance, integration, interoperability, innovativeness, competitiveness, transparency, consistency, accountability, and legitimacy.

Together, these elements constitute a unified structure that enables the integrated assessment of sustainability indicators and stakeholder dynamics in a data-driven planning context.

2.1 Synthesis of the Proposed Model

To address the defined problem, the SIMURG_CITIES conceptual model introduces a new paradigmatic approach grounded in system thinking and performance-based assessment. Moving beyond traditional planning approaches, this model tackles multi-dimensional issues with a dynamic and adaptable structure designed to respond to diverse urban needs. The model is built upon four interconnected components, i.e., philosophical, organizational, computational, and integrational and each is aligned with specific functions and methodological frameworks. As illustrated in Figures 3 and 4, these components are systematically integrated through the PPT and IPO models, which together form a cohesive structure to support scalable, transparent, and inclusive sustainability assessment and governance processes.

2.1.1 The paradigmatic/philosophical model

Entrepreneurs, financial institutions, and corrupt political systems frequently exploit the built environment as a profitable investment tool, leading to abuse of urban sustainability as a means for commercial gain rather than societal well-being. However, urban sustainability could only be achieved through an integrated approach that considers all fundamental concepts shown in Figure 4, along with the SDGs. In response to *RQ2*, the SIMURG_CITIES conceptual model provides a paradigmatic foundation for embedding SDGs and sustainability indicators in a consistent decision-making framework. The model adopts approaches that align urban development with the authentic identity of the environment, prioritize societal well-being, and support sustainable development, particularly in the context of the techno-social revolution. The model integrates concepts of Society 5.0 (super-smart society), technology like AI and Internet of Things (IoT), and data-driven governance to produce fundamental outcomes such as transparency, accountability, well-being and livability. Targeting at areas such as urban governance, environmental and infrastructure management, as well as strategic planning, the model creates significant impact both locally and globally. This alignment provides the conceptual base for public actors to interpret urban data and establish strategic goals, enabling them to define policies and action plans that are consistent with long-term sustainability visions.

Despite this comprehensive framework, current urban development struggles to evolve due to its persistent resistance to innovative initiatives, hence posing risks to urban sustainability, future cities, and living systems. While the collective consciousness of Society 5.0 may offer a solution, efforts coming from public authorities, NGOs, and individuals remain limited. Fragmented approaches lacking holistic and integrated strategies have so far yielded inadequate outcomes; therefore, one of the core objectives of the model is to transform layers, concepts, and labels, such as smart, green, and safe, with a strong philosophical foundation and integrated strategies, rather than focusing solely on profit-driven commercial concerns.

Modern urban sustainability paradigms conceptualize various city layers and KPI sets, such as smart, resilient, and green. As cities are dynamic and evolving organisms, they could not be reduced to a single identity or assessed through solely one layer, KPI set, or index. The SIMURG_CITIES model introduces a multi-layer performance-based assessment approach by integrating various layers, KPI sets and their corresponding weights, thus distinguishing it from the main SIMURG project.

Neo-liberal policies, globalization, and technological tools continue to reshape individual lifestyles and urban structures. Defining new city layers and their associated KPI sets as they evolve becomes inevitable for addressing diverse urban scenarios. The SIMURG_CITIES model, with its flexible and future-ready structure, supports not only current assessments but also future urban dynamics. Society 5.0 enables individuals with diverse needs and expectations to make informed choices regarding their urban environments through AI-supported simulations. This promotes a shift toward value-based and participatory urban planning. The model aims to shift governance from centralized control to community-wide systems, in which human-centered, value-driven, and performance-based paradigms integrate with technological development to guide future production and promote inclusive governance of urban spaces.

2.1.2 The Organizational/process-related model

The SIMURG_CITIES organizational and process-related model applies a performance-based approach to assess and optimize urban sustainability processes. Selecting multi-dimensional and multi-layered KPI sets with corresponding weights, the model supports diverse users from city administrators to individuals in the assessment of urban facts/entities through data-driven decision-making. Its technological infrastructure incorporates tools such as Building Information Modelling (BIM), Geographical Information Systems (GIS), and BDs to create DTs and enables real-time monitoring and dynamic updates of urban performance (Garau & Pavan, 2018; Leach et al., 2017). This integration guarantees more transparent and effective pursuits of sustainability goals.

In response to *RQ3*, the SIMURG_CITIES model redefines the roles and responsibilities of urban governance actors in line with Society 5.0, and establishes mechanisms for participatory, inclusive, and technology-supported decision-making. These actors are categorized into four groups: public (institutions, administrations), private (firms, investors, industries), experts (universities, R&D organizations), and individuals (unorganized citizens, NGOs, communities) (Ruhlandt, 2018). The model offers tools to support collaboration among these groups in achieving sustainability goals. Individuals wavering in choices could select city layers and KPI sets aligned with their values to create personalized assessments of alternative cities. Local and central governments could use the model for strategic planning, investment alignment, and performance-based policy-making. Investors could use the model to compare growth strategies and policies across different sectors and locations.

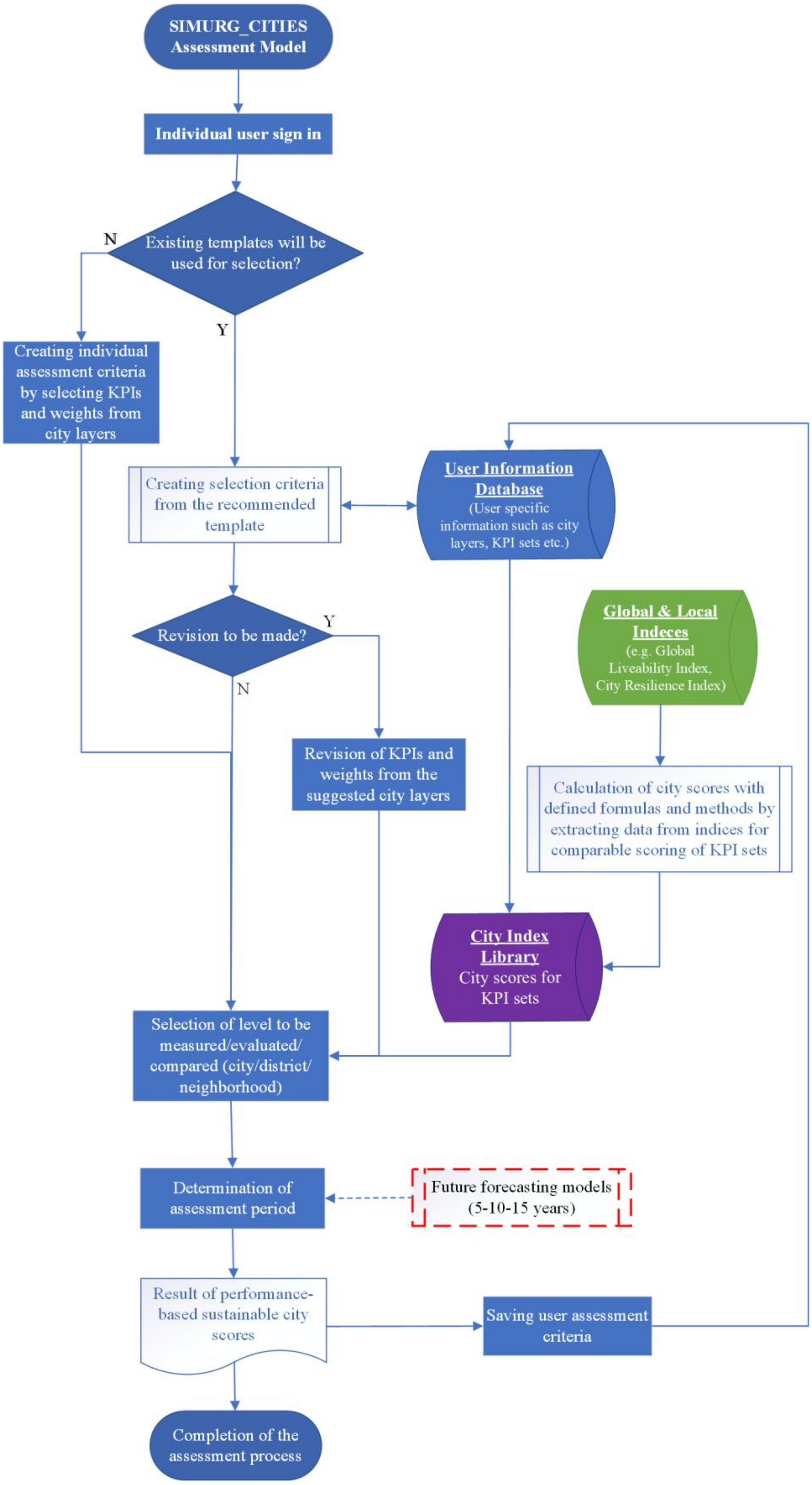

Figure 5. Sample of user flowchart for performance-based assessment at the city level

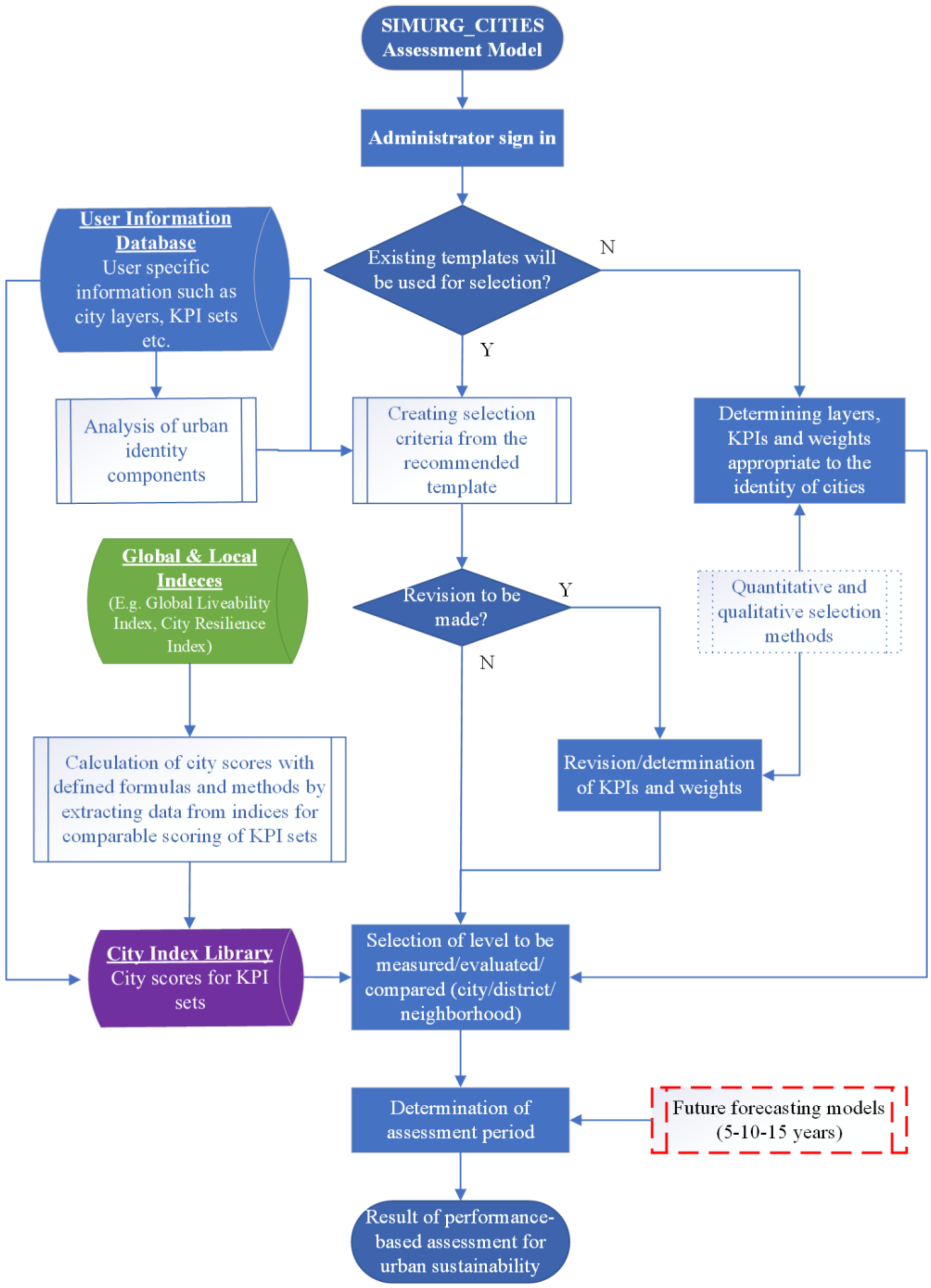

Figure 6. Sample of administrators (local and central governments) flowchart for performance-based assessment at the city level

The model is adaptable and flexible to incorporate new functions based on the needs of urban actors. Integrating KETs and AI into urban governance is expected to enhance decision-making as AI plays a key role in optimizing processes and accelerating data analysis (Son et al., 2023; Xu et al., 2024). The model employs a system-based IPO framework to evaluate indicators in domains such as urban and innovation policies (Huovila et al., 2019; Yigitcanlar et al., 2019), enabling complete measurement of inputs (resources), processes (implementation), outputs (results), outcomes (intermediate effects), and impacts (long-term effects).

The model is not limited to the specified use cases and offers two interfaces tailored to different user groups. The first interface is designed for individuals, experts, investors, and NGOs whereas the second is directed toward local and central governments and public institutions. Designed as a strategic tool, the model allows urban governance actors to analyze the strengths and weaknesses of cities, thus enabling grouping, ranking, and comparison within diverse contexts. As illustrated in Figure 5, the individual interface of the model provides a user-friendly platform where users could select sustainable city layers, KPI sets, and corresponding weights to create personalized assessments from recommended templates. These assessments align with users' profiles, lifestyles, or scenarios for purposes such as education or work. For instance, a user may prioritize the "green city" layer due to environmental values while another might focus on the "smart city" layer for technological advancement. This flexibility ensures that assessments reflect individual sustainability goals. At the governance level, as depicted in Figure 6, actors engage in strategic urban planning and long-term sustainability evaluations. This process includes analyzing "urban identity components" to ensure that city layers, KPIs, and weights align with the unique characteristics and identity of each city. To this end, qualitative and quantitative selection methods encompassing expert interviews, user surveys, data analysis, and public participation should be employed to improve the model for an enhanced reflection of urban diversity while offering practical insights for governance-level actors.

The integration of individual preferences with large-scale urban strategies results in a holistic framework that bridges personal goals and collective urban development plans. The model generates "city performance scores", weighted from the perspectives of both experts and users, to provide a flexible and customizable assessment process. This approach ensures that assessment results could be tailored to specific scenarios and user needs. The "city index library" serves as a repository for these scores and offers a comparative foundation for city assessments. User-specific criteria and selection preferences are stored in a secondary dataset, "user information database", which facilitates the analysis of trends, needs, and predictive modeling for future scenarios (e.g., 5-10-15 years) with KETs. Furthermore, the "city index library" could integrate with global databases, such as those maintained by European Telecommunications Standards Institute (2020) and the International Organization for Standardization (ISO) from which city scores are calculated by defined formulas and methods based on quantitative and qualitative data. This integration allows the model to generate globally comparable scores for cities and KPI sets, hence enhancing its credibility and scope. The model, through accommodating both local and global user requirements, demonstrates its adaptability and potential for large-scale applications.

2.1.3 The interoperability/integrational model

In response to *RQ4*, the SIMURG_CITIES integrational and interoperability model provides a unified framework to manage multi-dimensional, multi-layer, and multi-actor challenges in urban sustainability through system-wide consistency, cross-platform data integration, and scalable architecture. It enables interoperability among diverse tools, databases, and actors, ensuring a coherent urban sustainability assessment and governance process.

(1) Conceptual level interoperability: Information classification systems

The model employs information classification systems to allow semantic and functional compatibility among different structural and social components. Tools such as BIM (Liu et al., 2024), Urban BIM or City Information Modeling (CIM) (Souza & Bueno, 2022) and City Geography Markup Language (CityGML) (Tan et al., 2023) emerge as essential methodologies for modeling urban facts/entities. These systems, particularly at the 6D BIM level, play a remarkable role in integrating sustainability metrics and ensuring consistent data structures (Charef et al., 2018; Liu et al., 2024). The model, with the assistance of these tools, provides a holistic assessment that encompasses not only performance data at the city level but also information from lower and upper hierarchical levels of products and processes.

In the SIMURG_CITIES model, databases could be aligned with technologies such as CIM, GIS and DTs. The integration, supported by KETs such as IoT, BD, and AI, enhances data sharing and collaboration among urban governance systems by integrating databases such as Turkey's National Smart Cities Open Data Platform, the Smart City Index, and the Quality-of-Life Index. Through this integration, sustainability performance in cities could be dynamically measured and managed in real time using live data. DT technology plays an important role in this process by enabling real-time performance monitoring and optimization, as well as compiling environmental, social, and economic data into "city index library". These integration approaches create digital models of urban facts/entities and offers a system that is compatible with BD management, consequently generating more effective urban sustainability.

(2) Conceptual level interoperability: Solar system simulation

The SIMURG_CITIES integrational and computational models utilize the 3D Cartesian system based on SIMURG Solar System Simulation (Kanoglu et al., 2022b) to assess the performance of facts/entities across the built, economic, and social dimensions. Similar to the "gravitational force" equation in the solar system, the impact factors of facts/entities in this simulation are represented by "weights" or "masses" whereas KPI scores are represented by "distances". This approach facilitates the assessment of urban components in an interactive, multi-dimensional, and multi-layer structure. While assessing entities at the city level, this methodology considers the impacts of economic and social dimensions on the city and offers a holistic assessment. During the process, once the urban facts/entities to be assessed are identified, a KPI set containing the associated layer/label/concept and impact factors/weights are selected. Based on the chosen layers/concepts/labels, both "subjective" evaluations reflecting individual value judgments and "objective" evaluations defined by scientific expert insights could be conducted. This computational method facilitates performance assessment using social, educational, and cultural data linked to governmental databases. Solar System Simulation accounts for interactions between "masses" and "distances" of facts/entities across hierarchical levels, serving as an integrated model for sustainable urban governance.

(3) Interoperability at the software level: Communication with governmental databases

The SIMURG_CITIES model proposes an assessment system based on "objective" approaches integrated with governmental databases for sustainable urban governance. The model supports real-time analyses by utilizing data on the social, economic, and built dimensions of the urban environment obtained from governmental databases. Simultaneously, “subjective” assessments from individuals could be provided anonymously by subscribed users through the platform. This approach protects users’ privacy while allowing performance assessments at the quarter/county/city levels based on data from governmental databases in respect of social activities, healthcare, education, and crime (Shmelev & Shmeleva, 2019). Databases in Turkey, such as the Land Registry and Cadaster Information System and the Address-Based Population Registration System are utilized for assessing the built environment and analyzing the social, cultural, and economic activities of individuals. This integrated analysis provides a comprehensive understanding of the relationships between social dynamics and structural variables at the quarter, county, and city levels. The model promotes transparency and optimization in decision-making by ensuring equal access to digital tools for all actors. This enables more efficient resource allocation and contributes to long-term urban planning. By integrating governmental databases and maintaining up-to-date social and economic data, the model facilitates flexible, multi-layered assessments aligned with the SDGs and enhances the effectiveness of city planning and sustainable urban governance at both local and global scales.

2.1.4 The computational/assessment model

In response to *RQ1* and *RQ4*, the SIMURG_CITIES conceptual computational/assessment model demonstrates how urban sustainability performance could be quantitatively and comparatively assessed across multiple cities and layers. The model offers an integrated approach for assessing scenario-specific sustainability at the city level. Built environment entities are assessed by model using KPI combinations specific to dimensions/layers within the 3D Cartesian system, incorporating the perspectives of both experts and users. This enables the comparison and analytical assessment of subjective criteria such as individuals’ education, income levels, cultural values, and beliefs, with objective data based on scientific indicators defined by authorities/experts.

The model assesses built environment entities across various hierarchical levels (e.g., quarter/county/city) and layers using dedicated KPI sets. This system-based evaluation is grounded in the Solar System Simulation method, which provides a holistic, multi-dimensional, and multi-layer sustainability assessment by considering inter-layer relationships and product-process interactions.

The model utilizes the Simple Additive Weighting (SAW) method and the equations presented below (Eqs. (1)–(4)) to calculate the comparative overall performance of building units or similar urban facts/entities located in various positions across different cities:

- Eq. (1) calculates the performance of built/physical environment (BE) dimension.
- Eq. (2) calculates the performance of professional/economic environment (PE) dimension, focusing on actors such as producers and designers involved in the production process of these entities.
- Eq. (3) calculates the performance of cultural/social environment (SE) dimension, specifically assessing social facts.
- All three equations incorporate different layers and their corresponding KPI sets to calculate the performance of social facts and entities.
- The overall performance of selected entities is then calculated using Eq. (4), which integrates the weighted performance scores of the sustainability dimensions (BE, PE, SE) within the 3D Cartesian system. It also combines the weights of the various layers (LYR) associated with these dimensions. Additionally, KPI-specific scores and weights determined by users and experts are included in the final assessment.

$$\text{Score of Built Environ. (BE) Dimension} = \sum_{i=1}^{r} \text{W\_LYR}_i \times \left[\sum_{i=1}^{l} \text{W\_BE}_i \times \sum_{i=1}^{k} (\text{W\_KPI}_i \times \text{S\_KPI}_i)\right] \tag{1}$$

$$\text{Score of Profess. Environ. (PE) Dimension} = \sum_{i=1}^{r} \text{W\_LYR}_i \times \left[\sum_{i=1}^{n} \text{W\_PE}_i \times \sum_{i=1}^{k} (\text{W\_KPI}_i \times \text{S\_KPI}_i)\right] \tag{2}$$

$$\text{Score of Social Environ. (SE) Dimension} = \sum_{i=1}^{r} \text{W\_LYR}_i \times \left[\sum_{i=1}^{f} \text{W\_SE}_i \times \sum_{i=1}^{k} (\text{W\_KPI}_i \times \text{S\_KPI}_i)\right] \tag{3}$$

$$\text{Total Score of Built Environ. (BE) Entity to be Assessed} = \sum_{i=1}^{d} \text{W\_DIM}_i \times \text{EQ\_DIM}_i \tag{4}$$

where,

r = Count of layers (KPI sets; i.e., slow, smart, etc.)

l = Count of hierarchical levels at BE dimension

k = Count of KPIs in layer for assessment

n = Count of entities of level (l) at PE dimension that are involved in production of BE entity

f = Count of facts at SE dimension to be used in assessment of BE entity

d = Count of dimensions to be used in assessment

W_BE_i = Weight of entity specified at level (i)

W_PE_i = Weight of entity specified at (i) involved in production of BE entity

$W\_SE i$ = Weight of social fact specified (i) at SE dimension

W_KPI_i = Weight of KPI specified (i) in layer given by user/expert

S_KPI_i = Score of KPI specified (i) in layer given by user/expert

W_LYR_i = Weight of layer specified (i)

W_DIM_i = Weight of dimension specified (i)

EQ_DIM_i = Equation relevant to dimension specified (i)

In addition to computational Eqs. (1)–(4), Figure 7 presents a schematic overview of the SIMURG_CITIES computational model logic. It visually outlines how sustainability dimensions (BE, PE, SE) are organized under different city layers, how user and expert-defined weights are assigned to each KPI set, and how performance scores are calculated. These scores are synthesized into an overall sustainability score. This figure explicitly displays the multi-layered and multi-dimensional architecture of the model and enhances its methodological transparency.

Figure 7. SIMURG_CITIES conceptual computational/assessment model

To demonstrate the practical application of the SIMURG_CITIES conceptual computational/assessment model, a simulated dataset has been generated in Table 1. In this scenario, an individual evaluates and compares three hypothetical cities (City A, B, and C) to decide one for settlement, investment, or educational/work-related relocation. This dataset demonstrates different urban layers (e.g., smart, creative, and resilient) weighted by individuals and evaluated using city-specific KPI scores retrieved from the "*city index library*". The table compares three hypothetical cities (City A, B, and C) across three dimensions of sustainability, generating total performance scores based on user-defined priorities and KPI sets. Expert weights and user preferences are integrated simultaneously to ensure the SIMURG_CITIES model remain both inclusive and adaptable to different use cases.

In addition to quantitative comparison, the model could be used as a scenario-based filtering tool for "indispensable criteria". For example, if proximity to a rail transportation system, e.g., metro or tram, is marked as a mandatory KPI under the "mobility" criterion, a city with high overall performance might still be excluded by failing to meet this specific condition. In the simulated scenario, although City A receives the highest score under "KPI 1" of the smart city layer when compared to Cities B and C, it has the lowest overall sustainability performance score. If this specific "KPI 1" reflects a non-negotiable requirement such as rail-based public transport access, the model enables users to override the overall score and select City A based on their prioritized needs. This flexibility reinforces the decision-support capacity of the model, which allows users to balance holistic performance with individual priorities.

Table 1. Simulated sustainability assessment comparing three cities across user-defined KPIs and weights

Smart Layer – (LYR 1)			**User Layer Weight 40%**			**Cities' Scores**		
User Sustainability Assessment			**Scores of City Index Library ***					
User Dimension Selection	User KPI selection	User Weight (%100)	City A	City B	City C	City A	City B	City C
Professional/ Economic Environment	KPI 1	60	5	4	2	50	40	20
	KPI 2	20	3	2	1	10	7	3
	KPI 3	20	4	3	3	13	10	10
		100		Total Score		73	57	33
Creative Layer – (LYR 2)			**User Layer Weight 25%**			**Cities' Scores**		
User Sustainability Assessment			**Scores of City Index Library ***					
User Dimension Selection	User KPI selection	User Weight (%100)	City A	City B	City C	City A	City B	City C
Cultural/Social Environment	KPI 1	25	4	4	4	17	17	17
	KPI 2	10	2	4	4	3	7	7
	KPI 3	65	2	4	4	22	43	43
		100		Total Score		42	67	67
Resilient Layer – (LYR 3)			**User Layer Weight 35%**			**Cities' Scores**		
User Sustainability Assessment			**Scores of City Index Library ***					
User Dimension Selection	User KPI selection	User Weight (%100)	City A	City B	City C	City A	City B	City C
Physical/Built Environment	KPI 1	45	2	4	5	15	30	38
	KPI 2	30	2	3	3	10	15	15
	KPI 3	25	2	4	5	8	17	21
		100		Total Score		33	62	73

User Sustainability Assessment	**Cities Scores** City A	City B	City C
Smart Layer – (Lyr 1)	29	23	13
Creative Layer – (Lyr 2)	10	17	17
Resilient Layer – (Lyr 3)	12	22	26
TOTAL PERFORMANCE SCORES	51	61	56

* Scores of City Index Library (6-point Likert scale: 1 very bad - 6 very good)

Note: Scenario 1: An individual compares the alternative quarters/counties/cities he/she would like to live among three different quarters/counties/cities.

This example of the model illustrates personalized city selection processes and advocates it as a decision-support tool for individuals. By combining objective expert data with user-defined values, the SIMURG_CITIES model bridges micro-level preferences with macro-level governance strategies, thus contributing to sustainable urban development.

3. Results

Studies on the fundamental concept of "urban sustainability", which integrates different aspects of urban life, were not completely explored due to insufficient interdisciplinary interactions. Analysis of a discipline is generally conducted by disintegrating problems into smaller components from its perspective to fulfill the requirements of scientific research, yet this approach overlooks the bigger picture in solving complex problems. This situation leads to a lack of integrated tools that could enhance the transparency and accountability of the decision-making process in the political arena. There are a limited number of studies proposing solutions that could incorporate a holistic understanding of the nature and components of a problem, so as to address complementary and interrelated elements at both conceptual and practical levels (Ahmad et al., 2015; Ahmad & Thaheem, 2017; Ahmad & Thaheem, 2018). The SIMURG_CITIES model helps address these gaps at the conceptual level, serves as a guide at the practical level and upholds the concept of sustainability, offering a novel approach to performance-based assessment at the city level when compared to other studies in the literature. The integration of the model into the SIMURG framework further enhances its uniqueness and puts the overall picture into the limelight through examining all facts/entities in the 3D Cartesian system.

4. Discussion

This section analyses the conceptual foundations of the SIMURG_CITIES model through a "bottom-up" approach and discusses relevant studies in the literature under three main topics. The limitations of the model are dealt with in a separate section. Discussions in support of the methodological foundation of the proposed model are summarized by taking into account of concepts like Society 5.0, urban governance, and KETs, which are crucial for assessing urban sustainability in a holistic framework. The model has been developed with a holistic perspective based on the existing literature in response to the identified problems of *RQ (1-4)*.

4.1 City Layers/KPI Sets and Weights

Cities successfully achieved sustainability goals are closely linked to various urban layers and their contributing areas (Ahvenniemi et al., 2017). Many studies employed a KPI-based approach to accessing and integrating different dimensions of urban smartness and sustainability, as well as assessing global cities (Akande et al., 2019; Phillis et al., 2017). Ulker et al. (2021) conducted a meta-analysis, though conceptually immature, to reveal that definitions of smart city often rely on measurable KPIs. Long-standing critiques highlighted the dominance of a "technology-oriented" approach over a "people-oriented" one and showed disapproval to the underrepresentation of social sustainability issues (Novelo et al., 2021) when commercial and economic concerns were prioritized (Ahvenniemi et al., 2017; Huovila et al., 2019). In contrast to these limitations, the SIMURG_CITIES model—addressing *RQ1* and *RQ4*—emphasizes a pluralistic structure that includes not only smart layers but also creative, cultural, and ecological layers within its 3D Cartesian system.

The concept of "metaphor cities" symbolically links urban forms to abstract goals such as sustainability, thus defining relevant KPI sets and their weights (Joss et al., 2019). Schraven et al. (2021) identified 35 urban layers and demonstrated varying levels of maturity; however, mainstream research still prioritized "techno-cluster" (smart city) and "eco-cluster" (green city) paradigms. Cultural and social dimensions, being critical to inclusivity, remained underrepresented in both academic and policy frameworks (Yigitcanlar et al., 2019). In response to this gap, the model extends to the metaphor city approach by incorporating diverse and evolving urban layers into its architecture, allowing users and experts to dynamically select and weigh indicators.

Multi-criteria decision-making (MCDM) techniques such as Analytic Hierarchy Process (AHP) (Carli et al., 2018), Analytic Network Process (ANP) (Wey & Peng, 2021), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Chen & Zhang, 2021), Elimination and Choice Translating Reality (ELECTRE) (Shmelev & Shmeleva, 2019) and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) (Sotirelis et al., 2022) have been widely adopted in urban sustainability studies for KPI selection and weighting and often enhanced through fuzzy and hybrid models (Ozkaya & Erdin, 2020). For instance, Akande et al. (2019) used principal component analysis (PCA) to evaluate sustainability of European capitals based on urban audit indicators, thus highlighting the value of combining statistical and decision-making tools. Approaches integrated with traditional MCDM and PCA enable multi-layer and multi-dimensional sustainability assessments (Hajek et al., 2022; Sáez et al., 2020). However, these models generally lack the ability to completely analyze complex urban datasets consisting of multiple layers and composite indices. While these methods offer methodological robustness, they typically reflect top-down and expert-oriented perspectives. In contrast, the model adopting a hybrid structure could merge expert-driven methods with user-defined priorities, thereby enabling more inclusive, participatory, and context-sensitive sustainability assessments for addressing *RQ2* and *RQ4*.

4.2 Urban Sustainability Indicators and Performance-Based Assessment Models

The concept of sustainable cities, which initially emphasized environmental aspects in the 1970s, has evolved into an elaborate framework by integrating economic, social, and governance dimensions in the 21^{st} century (Ahvenniemi et al., 2017; Shmelev & Shmeleva, 2018; Shmelev & Shmeleva, 2019). In line with this evolution, international standardization initiatives, e.g., ISO and ETSI and global indexes such as the Global Liveability Index (The Economist Intelligence Unit, 2024) and the City Resilience Index (ARUP, 2019) have provided comparative frameworks to assess city performance. A number of these tools continue to rely on static and one-size-fits-all indicators; their incapacity to operationalize the interdependencies among sustainability dimensions or reflect regional diversity results in the negligence of social inclusivity and participatory governance (Huovila et al., 2019; Yigitcanlar et al., 2018). Performance-based models such as the European Union (EU) framework address multiple domains such as economy, mobility, and living conditions, but lack a truly multi-layered structure to accommodate the complexity of real-world urban systems. In response, scholars have called for frameworks that could capture sectoral diversity and interconnectivity (Garau & Pavan, 2018) and proposed integrative approaches linking goals, indicators, and systemic components (Leach et al., 2017).

Addressing *RQ1*, the SIMURG_CITIES model uses a 3D Cartesian structure to conduct tailored and performance-based assessments across sustainability dimensions. It distinguishes itself from existing performance models by enabling users to construct context-sensitive indicator sets, allowing dynamic cross-layer analysis. Open data support this balance by helping policymakers analyze the current situation, set performance goals, and develop strategic action plans (Ahvenniemi et al., 2017; Huovila et al., 2019), while promoting transparency, enhancing stakeholders' participation and improving data-based decision-making (Yigitcanlar et al., 2019). The integration of AI technologies and BD into open urban data systems allows real-time and localized monitoring of sustainability indicators (David et al., 2023; Son et al., 2023). Challenges arising from the enforcement of local governments and the incorporation of region-specific indicators remain critical, yet the model aligned with global standards (e.g., ISO 37125 (International Standard, 2024), ETSI TR 103455 (European Telecommunications Standards Institute, 2020)) to comply with open-data-based policies could tackle these difficulties. The model evaluates urban sustainability on a broader and integrated scale, when considering diverse factors like economic development, geography, lifestyles, policies, and technological advancement. This holistic and adaptive approach responds to *RQ2* and *RQ4* by linking indicators to evolving urban realities and corresponding data governance structures.

4.3 Sustainable Urban Governance, Society 5.0 and Technology

Society 5.0, regarded as a techno-social revolution of the 21st century, represents a human-centered technological vision aiming to address social challenges while improving the quality of life and aligning with SDGs (Narvaez Rojas et al., 2021; Patil et al., 2022; Roblek et al., 2021). By encouraging digital transformation, it emphasizes values like transparency, accountability, and inclusivity in governance processes (Deguchi, 2020; Zengin et al., 2021). However, growing reliance on digital systems in urban governance raises concerns about cybersecurity, corporatization, and surveillance risks (Appio et al., 2019; Hajek et al., 2022), which necessitate the development of more robust mechanisms to counter these threats (Floridi, 2023).

Building on this vision, Society 5.0 seeks to transform individuals from passive users into active decision-makers and co-creators of societal value (Aquilani et al., 2020; De Felice et al., 2021). This vision promotes inclusive governance through digital platforms and data-driven systems that enable broader participation, including "unorganized individuals" (David et al., 2023; Son et al., 2023). Emerging technologies such as BD, DTs, AI and the metaverse are progressively integrated into urban governance; for instance, DTs simulate urban infrastructure to support scenario modeling and planning decisions, thus contributing to real-time monitoring and strategic decision-making. Despite their benefits in infrastructure, energy, and mobility sectors, effective integration of these technologies requires stronger ethical oversight, cybersecurity, and public trust (Floridi, 2023).

Society 5.0 reshapes the typology of urban actors in the relationships among individuals, society and the state by fostering bottom-up participation and accepting ideas from active urban actors in policy design. In this context, the SIMURG_CITIES model reconceptualizes the roles, rights, and responsibilities of public, private, expert, and individual governance actors within the sustainability-focused decision-making mechanisms. This aligns with *RQ3*, which investigates the ways for urban actors to participate in governance under transformative paradigms. The literature identified a persistent gap: although technologies support decision-making, the existing models often lack integrated and relational data structures to accommodate multi-actor collaboration and real-time responsiveness (Deguchi, 2020; Xu et al., 2024).

In response *to RQ3*, the SIMURG_CITIES model adopts a PPT methodology, ensuring that governance is not only tech-driven but also human-centered and process-aware. Unlike existing tools that focus on technical capacity and administrative control, the model emphasizes active participation across all user groups by allowing real-time data interaction, transparent processes, and inclusive decision-making frameworks. Combining People (super-smart society), Process (data-driven governance), and Technology (KETs), the model deals with both functional and ethical dimensions of governance; a novel, multi-actor, and integrated approach is ultimately offered as a solution to urban sustainability.

4.4 Limitations of the SIMURG_CITIES Conceptual Model

The implementation of a rational model requires a two-stage process encompassing both conceptual and practical dimensions to tackle the defined problem. In the first stage of this study, a comprehensive conceptual model composed of four sub-models was developed and they collectively established the theoretical foundation for a data-driven urban sustainability assessment system.

Conceptual limitations primarily arise from the attempt to generalize complex urban systems in a structured framework. Although the 3D Cartesian structure and layer-based assessment offer flexibility, there is a risk of overgeneralization, particularly when applying the uniform model architecture across cities with diverse socio-political and cultural contexts. Allowing users to define their KPI sets and assign weights could enhance personalization, yet this introduces user subjectivity and may result in inconsistent or biased outcomes if not guided properly by standardized applications. Inconsistent assessments and bias may be caused by the inadequate enforcement of standardized methods for value-based customization. The use of computational tools and the potential integration of AI for indicator scoring or city ranking also raise concerns about algorithmic bias, particularly in weighting mechanisms and data interpretation processes. Without transparency in the design and training of algorithms, the model may accidentally reinforce existing inequalities or misrepresent urban facts. Accordingly, ethical clearance and continuous recalibration mechanisms are essential for ensuring fairness and inclusivity.

From a practical perspective, the transition of the conceptual model to actual implementation faces challenges, including data standardization, interoperability, and system integration across diverse national and institutional settings. Social challenges such as collaboration with public authorities and concerns about personal data protection may arise. Besides, the model relies on anonymized data from national and global open-access databases, given external extensions of the system, to generate outputs such as "*city index libraries*" and "*city performance scores*". However, differences in data structures, legal frameworks, and privacy protocols may limit the adaptability of the model on an international scale. Issues of interoperability are likely to emerge when evaluating and comparing cities governed by distinct regulatory and institutional environments.

Despite these limitations, the model integrates Society 5.0, KETs, and open data principles as key enablers to remove some of the barriers. Ultimately, the credibility and practical value of SIMURG_CITIES depend on future efforts to develop transparent algorithms, implement recalibration mechanisms against biases, and establish international cooperation frameworks for data compatibility and governance integration. These improvements are essential to enhance the reliability and global scalability of the model.

5. Conclusions

The SIMURG_CITIES model offers a multi-dimensional, multi-layer performance-based assessment approach to support sustainable urban development paradigms by integrating technology-based tools into decision support systems within the context of Society 5.0. It aims to strengthen sustainable urban governance processes by fostering active participation of individuals, experts, investors and local governments. The model is expected to transform individuals from passive users into active decision-makers, hence enhancing transparency and accountability in urban governance while protecting civil rights and utilizing public resources effectively.

On this basis, the model confronts challenges from urban sustainability by integrating dynamic systems thinking with PPT and IPO methodologies as well as offering Society 5.0 a “holistic view” and “comparative ability” for urban sustainability assessments. The model also creates a dynamic and adaptable assessment framework by incorporating open data related to economic, sociocultural, and built dimensions of cities with technologies such as BD, AI and IoT. The advancement of the model is indispensable to create personalized urban scenarios, support governments in sustainable policies, and stimulate investors to consider societal needs when making decisions. The holistic approach of this research contributes to economies, societal welfare, and scientific knowledge while aiding public institutions in making informed choices of urban growth, identity and development.

By extending the conceptual framework to technical functionality, the model is designed as a multi-layer decision-support tool for urban sustainability assessment, thus promoting effective use of digitalization and technology in urban management. The model, with the integration of open data principles and KETs, facilitates the development of urban scenarios tailored to individual needs and the promotion of urban governance processes both locally and globally. A key component of the current approach is effective management of public data, which would be instrumental in understanding the values and needs of the "super-smart human" and shaping future urban paradigms and scenarios. The model processes extensive urban datasets through its relational database model, thus continuously providing updated open data about city layers and KPI sets via KETs. This dynamic data infrastructure supports trend analysis and forecasting so as to align with the future needs of Society 5.0. Individuals and "super-smart humans" progress to utilize and analyze open data with digital equity, while local governments compete to use KPI-based data and central governments focus on developing digital infrastructure systems in areas such as health and education for building sustainable cities.

6. Recommendations

While the current study presents SIMURG_CITIES as a conceptual framework, its practical value could be fully realized through future implementation and empirical validation. To this end, a structured research and development agenda should be followed, covering short-, medium-, and long-term actions.

In the short term, pilot studies should be launched in collaboration with local and central governments as well as their affiliates. Preliminary meetings should be conducted to initiate practical applications. The following preparatory steps are recommended:

- Developing a prototype of the computer-based relational database infrastructure;
- Proposing and establishing an urban certification system;
- Defining a customizable sustainability KPI pool for city layers;
- Ensuring compatibility between public databases and the plug-in architecture of the model.

In the medium term, the model should be tested through pilot projects involving urban governance actors, including local governments, NGOs, and private-sector stakeholders to enhance the practical applicability of the proposed conceptual framework. Interviews, focus group discussions, and scenario-based simulations are recommended to evaluate the practical validity and reliability of the model. A pilot focus group with a firm providing engineering, consultancy, and planning services to local governments could evaluate the practical benefits and limitations of the model. Subsequently, a snowball sampling method should be used to engage additional urban actors for diverse input. Fieldwork could help compare theoretical findings with expert insights from practical applications in anticipation of a comprehensive analysis of their alignment.

In the long term, the priority should be placed on the integration of sustainable city layers, KPI sets, city index libraries, and performance scores into an interoperable software framework. This requires interdisciplinary collaboration among experts from the fields like architecture, urban planning, software engineering, and data science. The development of AI-powered modules to support indicator scoring, trend analysis, and city ranking should be explored. Though these tasks exceed the scope of the present study, they are identified as complementary research directions heading towards full-scale implementation.

To conclude, this phased agenda enables empirical validation of the SIMURG_CITIES model while supporting its scalability and real-world applicability across different urban and governance contexts.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

References

Ahmad, T. & Thaheem, M. J. (2017). Developing a residential building-related social sustainability assessment framework and its implications for BIM. *Sustain. Cities. Soc.*, *28*, 1–15. https://doi.org/10.1016/j.scs.2016.08.002.

Ahmad, T. & Thaheem, M. J. (2018). Economic sustainability assessment of residential buildings: A dedicated assessment framework and implications for BIM. *Sustain. Cities. Soc.*, *38*, 476–491. https://doi.org/10.1016/j.scs.2018.01.035.

Ahmad, T., Thaheem, M. J., & Azhar, S. (2015). Turning BIM into a holistic sustainability assessment tool. In *Eighth International Conference on Construction in the 21st Century (CITC-8), Thessaloniki, Greece* (pp. 790–797).

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., & Airaksinen, M. (2017). What are the differences between sustainable and smart cities? *Cities*, *60*, 234–245. https://doi.org/10.1016/j.cities.2016.09.009.

Akande, A., Cabral, P., Gomes, P., & Casteleyn, S. (2019). The Lisbon ranking for smart sustainable cities in Europe. *Sustain. Cities. Soc.*, *44*, 475–487. https://doi.org/10.1016/j.scs.2018.10.009.

Appio, F. P., Lima, M., & Paroutis, S. (2019). Understanding smart cities: Innovation ecosystems, technological advancements, and societal challenges. *Technol. Forecast Soc. Change*, *142*, 1–14. https://doi.org/10.1016/j.techfore.2018.12.018.

Aquilani, B., Piccarozzi, M., Abbate, T., & Codini, A. (2020). The role of open innovation and value co-creation in the challenging transition from industry 4.0 to society 5.0: Toward a theoretical framework. *Sustainability*, *12*(21), 8943. https://doi.org/10.3390/su12218943.

ARUP. (2019). City resilience index—Understanding and measuring city resilience. https://www.arup.com/insights/city-resilience-index/

Bashirpour Bonab, A., Bellini, F., & Rudko, I. (2023). Theoretical and analytical assessment of smart green cities. *J. Clean Prod.*, *410*, 137315. https://doi.org/10.1016/j.jclepro.2023.137315.

Bovens, M., Goodin, R. E., & Schillemans, T. (2014). *The Oxford Handbook of Public Accountability*, *1st ed*.

Oxford University Press.
Brynjolfsson, E. & McAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York: WW Norton & Company.
Cardullo, P. & Kitchin, R. (2019). Being a 'citizen' in the smart city: Up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal*, *84*(1), 1–13. https://doi.org/10.1007/s10708-018-9845-8.
Carli, R., Dotoli, M., & Pellegrino, R. (2018). Multi-criteria decision-making for sustainable metropolitan cities assessment. *J. Environ. Manage.*, *226*, 46–61. https://doi.org/10.1016/j.jenvman.2018.07.075.
Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *J. Build. Eng.*, *19*, 242–257. https://doi.org/10.1016/j.jobe.2018.04.028.
Chen, Y. & Zhang, D. (2021). Evaluation and driving factors of city sustainability in Northeast China: An analysis based on interaction among multiple indicators. *Sustain. Cities Soc.*, *67*, 102721. https://doi.org/10.1016/j.scs.2021.102721.
Cohen, M. (2017). A systematic review of urban sustainability assessment literature. *Sustainability*, *9*(11), 2408. https://doi.org/10.3390/su9112048.
David, A., Yigitcanlar, T., Li, R. Y. M., Corchado, J. M., Cheong, P. H., Mossberger, K., & Mehmood, R. (2023). Understanding local government digital technology adoption strategies: A PRISMA review. *Sustainability*, *15*(12), 9645. https://doi.org/10.3390/su15129645.
De Felice, F., Travaglioni, M., & Petrillo, A. (2021). Innovation trajectories for a society 5.0. *Data*, *6*(11), 115. https://doi.org/10.3390/data6110115.
Deguchi, A. (2020). From smart city to Society 5.0. In *Society 5.0—A People-Centric Super-Smart Society* (pp. 43–65). Springer Singapore. https://doi.org/10.1007/978-981-15-2989-4.
European Telecommunications Standards Institute. (2020). Human Factors (HF); Smart cities and communities; Standardization for citizens and consumers. https://www.etsi.org/deliver/etsi_tr/103400_103499/103455/01.01.01_60/tr_103455v010101p.pdf
Feleki, E., Vlachokostas, C., & Moussiopoulos, N. (2020). Holistic methodological framework for the characterization of urban sustainability and strategic planning. *J. Clean Prod.*, *243*, 118432. https://doi.org/10.1016/j.jclepro.2019.118432.
Fiksel, J. (2006). Sustainability and resilience: Toward a systems approach. *Sustain. Sci. Pract. Policy*, *2*(2), 14–21. https://doi.org/10.1080/15487733.2006.11907980.
Floridi, L. (2023). *The Ethics of Artificial Intelligence*. New York, USA: Oxford University Press. https://doi.org/10.1093/oso/9780198883098.001.0001.
Garau, C. & Pavan, V. (2018). Evaluating urban quality: Indicators and assessment tools for smart sustainable cities. *Sustainability*, *10*(3), 575. https://doi.org/10.3390/su10030575.
Girardet, H. (2015). *Creating Regenerative Cities, 1st ed*. London: Routledge.
Hajek, P., Youssef, A., & Hajkova, V. (2022). Recent developments in smart city assessment: A bibliometric and content analysis-based literature review. *Cities*, *126*, 103709. https://doi.org/10.1016/j.cities.2022.103709.
Hall, P. & Pfeiffer, U. (2000). *Urban Future 21: A Global Agenda for Twenty-First Century Cities, 1st ed*. Routledge.
Harvey, D. (2013). *The Right to the City*. Routledge.
Huovila, A., Bosch, P., & Airaksinen, M. (2019). Comparative analysis of standardized indicators for smart sustainable cities: What indicators and standards to use and when? *Cities*, *89*, 141–153. https://doi.org/10.1016/j.cities.2019.01.029.
International Standard. (2024). *Sustainable cities and communities—Environmental, social and governance (ESG) indicators for cities*. ISO 37125:2024. https://www.iso.org/standard/85198.html
Javidroozi, V., Carter, C., Grace, M., & Shah, H. (2023). Smart, sustainable, green cities: A state-of-the-art review. *Sustainability*, *15*(6), 5353. https://doi.org/10.3390/su15065353.
Joss, S., Sengers, F., Schraven, D., Caprotti, F., & Dayot, Y. (2019). The smart city as global discourse: Storylines and critical junctures across 27 cities. *J. Urban Technol.*, *26*(1), 3–34. https://doi.org/10.1080/10630732.2018.1558387.
Kanoglu, A., Ozcevik, O., Yazicioglu, D., Erkovan, N., Softaoglu, H., Ulker, B., Yazicioglu, E., & Varlier, N. (2022a). SIMURG: Performance-based model for the assessment of sustainability: Synthesis of the paradigmatic and frame models. In *Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism-ICCAUA* (pp. 343–354). https://doi.org/10.38027/ICCAUA2022EN0082.
Kanoglu, A., Yazicioglu, D., Ozcevik, O., Erkovan, N., Softaoglu, H., Ulker, B., Varlier, N., & Yazicioglu, E. (2022b). SIMURG: A new model for the integrated assessment of sustainability. *Budow. Archit.*, *21*(1), 31–57. https://doi.org/10.35784/bud-arch.2902.
Khatibi, H., Wilkinson, S., Eriwata, G., Sweya, L. N., Baghersad, M., Dianat, H., Ghaedi, K., & Javanmardi, A. (2022). An integrated framework for assessment of smart city resilience. *Environ. Plan B Urban Anal. City Sci.*, *49*(5), 1556–1577. https://doi.org/10.1177/23998083221092422.

Kitchin, R. (2018). Towards a genuinely humanizing smart urbanism. *SocArXiv Pap*. https://doi.org/10.31235/osf.io/5jkx4.
Leach, J. M., Lee, S. E., Hunt, D. V. L., & Rogers, C. D. F. (2017). Improving city-scale measures of livable sustainability: A study of urban measurement and assessment through application to the city of Birmingham, UK. *Cities*, *71*, 80–87. https://doi.org/10.1016/j.cities.2017.06.016.
Leavitt, H. J. (1965). Applied organizational change in industry: Structural, technological and humanistic approaches. In *Handbook of Organizations (RLE: Organizations)* (pp. 1144–1170). Routledge.
Liu, Z., Liu, Y., & Osmani, M. (2024). Integration of smart cities and building information modeling (BIM) for a sustainability oriented business model to address sustainable development goals. *Buildings*, *14*(5), 1458. https://doi.org/10.3390/buildings14051458.
Meadows, D. H. (2008). *Thinking in Systems: A Primer*. Chelsea Green Publishing.
Narvaez Rojas, C., Alomia Peñafiel, G. A., Loaiza Buitrago, D. F., & Tavera Romero, C. A. (2021). Society 5.0: A Japanese concept for a superintelligent society. *Sustainability*, *13*(12), 6567. https://doi.org/10.3390/su13126567.
Novelo, R. A. A., Romero, S. O. Á., Suárez, G. A. C., & Ramírez, J. D. M. (2021). Social sustainability in the planning, design, and construction in developing countries: Guidelines and feasibility for México. *Civil Eng. Archit.*, *9*(4), 1075–1083. https://doi.org/10.13189/cea.2021.090410.
Oliveira, V. & Pinho, P. (2010). Evaluation in urban planning: Advances and prospects. *J. Plan Lit.*, *24*(4), 343–361. https://doi.org/10.1177/0885412210364589.
Ozkaya, G. & Erdin, C. (2020). Evaluation of smart and sustainable cities through a hybrid MCDM approach based on ANP and TOPSIS technique. *Heliyon*, *6*(10), e05052. https://doi.org/10.1016/j.heliyon.2020.e05052.
Patil, A. R., Thakur, K., Gandhi, K., Savale, V., & Sayyed, N. (2022). A review on industry 5.0: The techno-social revolution. *Int. J. Mech. Eng.*, *7*(5), 1–5.
Phillis, Y. A., Kouikoglou, V. S., & Verdugo, C. (2017). Urban sustainability assessment and ranking of cities. *Comput. Environ. Urban Syst.*, *64*, 254–265. https://doi.org/10.1016/j.compenvurbsys.2017.03.002.
Ramirez Lopez, L. J. & Grijalba Castro, A. I. (2020). Sustainability and resilience in smart city planning: A review. *Sustainability*, *13*(1), 181. https://doi.org/10.3390/su13010181.
Roblek, V., Meško, M., & Podbregar, I. (2021). Mapping of the emergence of Society 5.0: A bibliometric analysis. *Organizacija*, *54*(4), 293–305. https://doi.org/10.2478/orga-2021-0020.
Ruhlandt, R. W. S. (2018). The governance of smart cities: A systematic literature review. *Cities*, *81*, 1–23. https://doi.org/10.1016/j.cities.2018.02.014.
Sáez, L., Heras-Saizarbitoria, I., & Rodríguez-Núñez, E. (2020). Sustainable city rankings, benchmarking and indexes: Looking into the black box. *Sustain. Cities Soc.*, *53*, 101938. https://doi.org/10.1016/j.scs.2019.101938.
Schraven, D., Joss, S., & de Jong, M. (2021). Past, present, future: Engagement with sustainable urban development through 35 city labels in the scientific literature 1990–2019. *J. Clean Prod.*, *292*, 125924. https://doi.org/10.1016/j.jclepro.2021.125924.
Shmelev, S. E. & Shmeleva, I. A. (2018). Global urban sustainability assessment: A multidimensional approach. *Sustain. Dev.*, *26*(6), 904–920. https://doi.org/10.1002/sd.1887.
Shmelev, S. E. & Shmeleva, I. A. (2019). Multidimensional sustainability benchmarking for smart megacities. *Cities*, *92*, 134–163. https://doi.org/10.1016/j.cities.2019.03.015.
Son, T. H., Weedon, Z., Yigitcanlar, T., Sanchez, T., Corchado, J. M., & Mehmood, R. I. (2023). Algorithmic urban planning for smart and sustainable development: Systematic review of the literature. *Sustain. Cities Soc.*, *94*, 104562. https://doi.org/10.1016/j.scs.2023.104562.
Sotirelis, P., Nakopoulos, P., Valvi, T., Grigoroudis, E., & Carayannis, E. (2022). Measuring smart city performance: A multiple criteria decision analysis approach. *J. Knowle. Econ.*, *13*, 2957–2985. https://doi.org/10.1007/s13132-021-00847-1.
Souza, L. & Bueno, C. (2022). City information modelling as a support decision tool for planning and management of cities: A systematic literature review and bibliometric analysis. *Build. Environ.*, *207*, 108403. https://doi.org/10.1016/j.buildenv.2021.108403.
Spiliotopoulou, M. & Roseland, M. (2020). Urban sustainability: From theory influences to practical agendas. *Sustainability*, *12*(18), 7245. https://doi.org/10.3390/su12187245.
Sterman, J. D. (2002). System dynamics: System thinking and modeling for a complex world. In *Engineering Systems Division (ESD) Working Paper Series* (pp. 1–29). Massachusetts Institute of Technology, Engineering Systems Division.
Swyngedouw, E., Moulaert, F., & Rodriguez, A. (2002). Neoliberal urbanization in Europe: Large–scale urban development projects and the new urban policy. *Antipode*, *34*(3), 542–577. https://doi.org/10.1111/1467-8330.00254.
Tan, Y., Liang, Y. & Zhu, J. (2023). CityGML in the integration of BIM and the GIS: Challenges and opportunities.

Buildings, *13*(7), 1758. https://doi.org/10.3390/buildings13071758.
Tarek, S. (2023). Smart eco-cities conceptual framework to achieve UN-SDGs: A case study application in Egypt. *Civil Eng. Archit.*, *11*(3), 1383–1406. https://doi.org/10.13189/cea.2023.110322.
The Economist Intelligence Unit. (2024). The global liveability index 2024 the world's most liveable cities. https://www.eiu.com/n/campaigns/global-liveability-index-2024/
Ulker, B., Kanoglu, A., & Ozcevik, O. (2018). SIMURG_CITIES: A performance-based integrated model for design and evaluation of sustainable and sophisticated solutions at cities level: Determination of KPIs and principles of model at conceptual dimension. In *5th International Project and Construction Management Conference (IPCMC 2018)* (pp. 282–289).
Ulker, B., Kanogu, A., & Ozcevik, O. (2021). SIMURG_CITIES: Meta-analysis for KPI's of layer-based approach in sustainability assessment. *J. Contemp. Urban Affairs*, *5*(1), 59–76. https://doi.org/10.25034/ijcua.2021.v5n1-5.
UN-Habitat. (2020). World cities report 2020: The value of sustainable urbanization. https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization.
UN-Habitat. (2023). Enabling meaningful public participation in spatial planning processes. https://unhabitat.org/enabling-meaningful-public-participation-in-spatial-planning-processes.
United Nations. (1987). Our common future: Report of the World Commission on Environment and Development. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.
United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. https://sdgs.un.org/2030agenda.
Wey, W.-M. & Peng, T.-C. (2021). Study on building a smart sustainable city assessment framework using big data and analytic network process. *J. Urban Plann. Dev.*, *147*(3), 1–21. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000704.
Wojewnik-Filipkowska, A., Gierusz-Matkowska, A., & Krauze-Maślankowska, P. (2024). Fundamental power of the city—A proposition of a new paradigm and index for city development. *Cities*, *144*, 104630. https://doi.org/10.1016/j.cities.2023.104630.
Xu, H., Omitaomu, F., Sabri, S., Zlatanova, S., Li, X., & Song, Y. (2024). Leveraging generative AI for urban digital twins: A scoping review on the autonomous generation of urban data, scenarios, designs, and 3D city models for smart city advancement. *Urban Inf.*, *3*(29), 1–44. https://doi.org/10.1007/s44212-024-00060-w.
Yigitcanlar, T. & Cugurullo, F. (2020). The sustainability of artificial intelligence: An urbanistic viewpoint from the lens of smart and sustainable cities. *Sustainability*, *12*(20), 8548. https://doi.org/10.3390/su12208548.
Yigitcanlar, T., Kamruzzaman, M., Buys, L., Ioppolo, G., Sabatini-Marques, J., da Costa, E. M., & Yun, J. J. (2018). Understanding 'smart cities': Intertwining development drivers with desired outcomes in a multidimensional framework. *Cities*, *81*, 145–160. https://doi.org/10.1016/j.cities.2018.04.003.
Yigitcanlar, T., Kamruzzaman, M., Foth, M., Sabatini-Marques, J., Da Costa, E., & Ioppolo, G. (2019). Can cities become smart without being sustainable? A systematic review of the literature. *Sustain. Cities. Soc.*, *45*, 348–365. https://doi.org/10.1016/j.scs.2018.11.033.
Zengin, Y., Naktiyok, S., Kaygın, E., Kavak, O., & Topçuoğlu, E. (2021). An Investigation upon Industry 4.0 and Society 5.0 within the context of sustainable development goals. *Sustainability*, *13*(5), 2682. https://doi.org/10.3390/su13052682.