Design and Develop Sustainable Development Goals (SDG) 11 Indicators Using LADM and GIS

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Abstract

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainability of development, first defined in the Brundtland Report in 1986, has gradually increased in importance over time and has become a constantly emphasized issue on the United Nations (UN) agenda. In this context, SDG 11 is to make cities inclusive, safe, resilient and sustainable. Goal 11 is to make cities and human settlements inclusive, safe, resilient, and sustainable. Cities represent the future of global life. This article aims to design SDG 11 to align with its main objectives and investigate its applicability. In this context, integrating the Land Administration Domain Model (LADM) into land administration systems plays a crucial role in aligning spatial data management with the principles of Sustainable Development Goal 11 (SDG 11) and its sub-targets. SDG 11 emphasizes the need for sustainable, inclusive, and resilient urban development, requiring a robust spatial data infrastructure that effectively represents property rights, restrictions, and responsibilities (RRR) while supporting dynamic land management. This study presents a Unified Modelling Language (UML)-based methodological framework that facilitates the integration of LADM to ensure compliance with SDG 11 indicators. The proposed framework enhances the ability to model, manage, and analyse land tenure, land use, and urban governance, providing structured geospatial representations that align with sustainability objectives.

1. Introduction

The concept of sustainable development was first introduced in the 1987 Brundtland Report, which defined it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(Emas, 2015). Sustainable development requires the integration of economic growth, social equity, and environmental protection (Riak&Bill, 2022). This approach ensures that development is economically viable, socially inclusive, and environmentally sustainable. The origins of this concept began to take shape with the United Nations Conference on the Human Environment held in Stockholm in 1972.

Agenda 21 was established as a non-binding action plan, adopted by 178 countries at the Earth Summit, including the United States, to promote sustainable development globally (Glavič, 2023). The Millennium Development Goals (MDGs), announced in 2000, marked a significant shift in the global development agenda by emphasizing the social dimension of development. The MDGs represented a break from the traditional focus on economic growth, emphasizing social development through specific goals related to health, education, and poverty reduction(Glavič, 2023). However, since the MDGs did not adequately address issues such as sustainability, spatial inequality, and urbanization, the SDGs were adopted in 2015 under 17 main goals.

Among these goals, SDG 11 aims to make cities and human settlements inclusive, safe, resilient, and sustainable (The Sustainable Development Goals, 2015). SDG 11 emphasises the need for cities to be inclusive, ensuring that all residents, including marginalised groups, have access to basic services and opportunities. It includes affordable housing, public transportation, and equitable resource access (Küfeoğlu, 2022). The trend of urbanisation is a defining characteristic of the 21st century, with more than half of the world's population currently residing in urban areas. By 2050, it is anticipated that 66% to 68% of the world's population will reside in cities (Nahrstedt & Catlett, n.d.; Wang et al., 2021). Developing spatial decision support systems to accompany the rapid transformation of cities has become a critical requirement for sustainable urban management.

LADM, formalised as ISO 19152, was developed to address the need for a standardised data model that can be applied globally, allowing for integrating existing knowledge and practices in land administration (C. Lemmen et al., 2013a). LADM supports the integration of land management information from different sources, providing a coherent framework for combining data related to land rights, restrictions, and responsibilities (Sunday Oyetayo et al., 2015). It also facilitates the integration of spatial planning data, enabling the development of comprehensive land management systems that incorporate legal and spatial components (Yilmaz & Alkan, 2023). Since its publication as an international standard in 2012, LADM has been implemented in various countries, including Australia, China, Malaysia, and South Africa, primarily in research and development contexts (Kalantari et al., n.d.). The model has facilitated the development of open-source software for land administration, promoting interoperability and data exchange between different systems (C. Lemmen et al., 2013). It provides a conceptual framework that can be adapted to specific national and regional requirements, enabling the creation of country profiles that reflect local legal and administrative contexts (Shnaidman et al., 2019). Despite its benefits, implementing LADM can be challenging due to the need for logical modelling and adaptation to specific organisational requirements (Kalantari et al., n.d.).

LADM's role in formalising SDG indicators, such as secure and women's agricultural land rights, highlights its contribution to sustainable development. The model's extensions facilitate the

computation and reporting of these indicators, ensuring accurate reflection of progress towards SDG realisation (Chen et al., 2024). LADM provides a conceptual model with three main packages: parties, rights, responsibilities, restrictions, and spatial units. This structure supports the integration of diverse land-related datasets, promoting interoperability and consistency across different systems (C. H. J. Lemmen et al., n.d.; C. Lemmen & Van Oosterom, n.d.). LADM's modular and interoperable classes, such as LA_Party, LA_Right, LA_BAUnit, and LA_SpatialUnit, facilitate secure land tenure, transparency, and efficient land use planning, aligning with global development goals like the SDGs. By enabling efficient land use planning and infrastructure development, LADM supports broader SDG objectives, such as reducing inequalities and promoting sustainable urban growth (Chen et al., 2024). LADM supports secure land tenure and transparency and enables more efficient land use planning, infrastructure development, and public service delivery. Its adaptability makes it a powerful tool for countries seeking to modernise their land administration infrastructures while aligning with global development goals such as the SDGs.

This study proposes a comprehensive system for monitoring the indicators related to SDG 11 through the LADM and presents a UML-based methodological framework. The study aims to design a spatial data model based on LADM that is structured in alignment with the targets of SDG 11 and to evaluate the possibilities for integrating this model with the national-level local system. In this context, the UML-based methodological framework aims to enhance data modelling and analytical capabilities required for building sustainable cities.

2. Requirement analysis

Integrating the LADM into land administration systems can significantly contribute to achieving SDG 11 by enhancing urban sustainability and promoting efficient land management practices. LADM provides a standardised framework that facilitates the formalisation of land rights, improves data interoperability, and supports the computation of relevant SDG indicators, thereby fostering sustainable urban development. LADM offers a standardised model that facilitates the integration and sharing of land data across different systems and agencies, promoting interoperability and reducing redundancies (Lemmen & Van Oosterom, 2013). Integrating the LADM into land administration systems can significantly contribute to achieving SDG 11, which focuses on making cities inclusive, safe, resilient, and sustainable. LADM's role in formalising SDG indicators, such as secure land rights and economic loss valuation, ensures more accurate and efficient computation, reflecting progress towards SDG 11 (Chen et al., 2024). Global guidelines like the UN-GGIM's Framework for Effective Land Administration (FELA) emphasise that transparent and secure land and property rights for all are crucial for a sustainable society (FELA, UN-GGIM) (Content, 2020).

This study proposes an integrated information infrastructure to support monitoring the sub-targets defined under SDG 11. The proposed framework aligns with international standards, specifically the LADM, and incorporates Turkey's national spatial data infrastructure, known as TUCBS. This integration aims to enable the collection, organisation, and analysis of spatial and administrative data necessary for tracking the progress of SDG 11 indicators, particularly those related to housing, infrastructure, land use, and urban resilience.

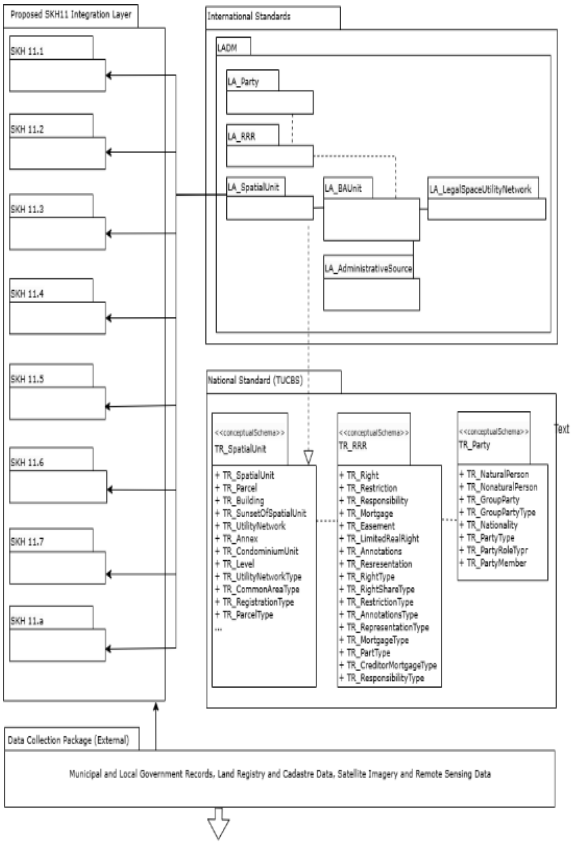

Figure 1. Conceptual Integration Framework for SDG 11 Monitoring Based on LADM and TUCBS

Figure 1 presents a conceptual integration framework designed to support the monitoring of SDG 11 indicators by aligning international standards—specifically the LADM—with Türkiye's national geographic information infrastructure (TUCBS). The framework introduces an SDG 11 specific integration layer that maps individual targets to corresponding LADM classes such as LA_BAUnit, LA_SpatialUnit, and LA_Right, while also linking these elements to thematic layers within the TUCBS standard. By incorporating data from municipal and cadastral sources, as well as satellite imagery and remote sensing, the framework enables a standardized and spatially-aware approach to SDG 11 monitoring.

The conceptual model consists of four main layers: the SDG 11 Indicator Integration Layer, the International standards layer LADM, the TUCBS, and the External Data Collection Layer. Each layer plays a critical role in linking global objectives with local implementation. The framework enhances data interoperability, supports the spatial representation of land rights, restrictions, and responsibilities (RRR), and facilitates indicator-based governance. Through this multi-layered structure, the study provides a scalable and transferable approach for sustainable urban monitoring and land administration aligned with the goals of SDG 11.

This diagram presents a multi-layered integration framework for systematically monitoring indicators aimed at creating sustainable, inclusive, and resilient cities under SDG 11. Based on the principle of interoperability, the international applicability of LADM and the local specificity of TUCBS are combined, enabling the spatial modelling, comparison, and management of SDG indicators.This framework serves not only as a model for Turkey but also as a reference for aligning other countries'

national spatial data infrastructures with the objectives of the Sustainable Development Goals.

In the first step of the SDG 11 monitoring process, a methodology was applied to extract key terms by filtering out redundant or non-essential words within the relevant target statements. This process enabled the identification of meaningful keywords for each SDG 11 indicator. As a result, the following conceptual diagrams were produced for individual indicators. In these diagrams, some extracted terms exhibit semantic generality, while others reflect variations arising from synonymy. For instance, secure housing encompasses physical safety and tenure security. Similarly, adequate housing requires distinct metrics to render its adequacy measurable.

To ensure that such terms can be classified and quantified, each indicator's metadata was reviewed in detail to understand the intended meaning behind the terminology used. During the keyword extraction process, the semantic interpretations of terms were derived based on these metadata descriptions, ensuring consistency with international definitions and indicator frameworks.

SDG 11.1 Indicator: Proportion of urban population living in slums, informal settlements, or inadequate housing

SDG 11.1 aims to ensure everyone's access to adequate, safe, and affordable housing and basic services by 2030. This target is a critical component of SDG 11, which focuses on making cities and human settlements inclusive, safe, resilient, and sustainable. Implementing SDG 11.1 involves addressing various challenges, including housing adequacy, access to basic services, and urban governance. The research highlights the importance of integrating SDG 11.1 with broader urban development strategies and international frameworks to achieve its objectives effectively.

The New Urban Agenda and other international frameworks provide normative guidance for implementing SDG 11.1, but inherent contradictions, such as balancing safety and inclusiveness, pose challenges (Aust, 2018). The metadata about SDG indicator 11.1.1, which assesses the ratio of the urban populace residing in slums, informal settlements, or inadequate housing, offers a comprehensive conceptual and methodological framework for evaluating global housing conditions (The SDG Target 11.1, 2021). In alignment with the UN-Habitat definition, a household is deemed to reside in a slum or informal settlement if it experiences at least one of the following deprivations: lack of access to enhanced water sources, inadequate sanitation facilities, insufficient living space (overcrowding), poor structural integrity, or lack of security of tenure. These five dimensions not only constitute the fundamental basis for the identification of slums but also serve as the primary criteria for calculating national and global estimates. Furthermore, inadequate housing transcends physical conditions to encompass affordability, accessibility, and cultural adequacy, as international human rights standards delineate. The metadata additionally proposes affordability as a measurable criterion—specifically, when housing expenditures surpass 30% of a household's monthly income. This nuanced interpretation of housing inadequacy underscores the interconnections between physical infrastructure, legal tenure, and socioeconomic access, reinforcing the imperative for integrated spatial and statistical models. Consequently, the UN-Habitat framework facilitates the establishment of standardised, scalable monitoring instruments capable of informing evidence-based urban policy and sustainable land governance strategies across various urban contexts.

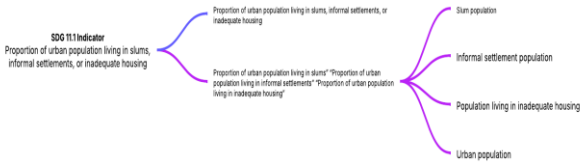

Figure 2. Keyword Extraction and Semantic Decomposition of the SDG 11.1 Indicator

Figure 2 illustrates the keyword extraction and semantic decomposition of the SDG 11.1 indicator, which focuses on the proportion of the urban population living in slums, informal settlements, or inadequate housing. By breaking down the composite indicator into its core components—namely, slum population, informal settlement population, and the population living in inadequate housing—the figure enables a clearer understanding of the indicator's conceptual structure. This decomposition facilitates the alignment of each subcomponent with relevant spatial and administrative data structures, such as those defined in the LADM. Moreover, this analytical breakdown provides a foundation for developing robust data models and monitoring frameworks that support evidence-based policymaking for sustainable urban development.

Given that terms such as slum, secure housing, and informal settlement are all distinct definitions used to describe types of human settlements, the need for a standardized framework to make these concepts measurable becomes evident. In this context, the five core criteria defined in the metadata of SDG 11.1 have been adopted as the foundational basis. According to the SDG 11.1 metadata, housing adequacy is determined by five main conditions: access to improved water sources, access to improved sanitation, sufficient living space, structural durability, and security of tenure.

The threshold of at least 20 litres per person per day has been set to define access to improved water sources. Furthermore, additional sub-criteria have been specified to assess the quality of the water system, including the presence of piped connections, whether a connection serves no more than five households, the availability of a rainwater collector, and the existence of a protected well or borehole. In the proposed SDG 11.1 class model, only the hasWaterAccess attribute is implemented as an example. However, the model is designed to be flexible and extensible, allowing for additional attributes to be defined and implemented by decision-makers according to their national or local practices.

Similarly, for structural durability, key indicators such as compliance with building codes, permanence of the structure, and the use of durable materials for walls, roofs, and floors have been included. These definitions support the assessment of whether a dwelling meets the criteria for structural safety and qualifies as secure housing under SDG 11.1.

SDG 11.1 Component (Keyword)	Related LADM Classes	Context and Description
Slum	LA_BAUnit, LA_Right	Refers to the legal spatial units of dwellings as represented in LADM.
Secure Housing	LA_BAUnit, LA_Right	LADM supports the representation of legal tenure security but does not explicitly include physical safety. In the context of SDG 11.1, secure housing encompasses both legal tenure security and structural safety.
Informal Settlement	LA_BAUnit, LA_Right	Represents housing units or areas lacking formal legal recognition, mapped through LADM administrative units and rights.
Inadequate Conditions	LA_BAUnit, LA_LegalSpaceUtilityNetwork	Associated with the lack of access to basic services and infrastructure. Utility networks in LADM support this dimension.
Population	LA_BAUnit, LA_Right, LA_LegalSpaceUtilityNetwork, LA_Party	Refers to the number of people residing within spatially defined areas classified as slums, informal settlements, or inadequate housing.
Urban Population	LA_Party	Refers to the total population residing within administratively or spatially defined urban boundaries.

Table 1. Linking SDG 11.1 Components with LADM Structure

Table 1 provides a detailed mapping of the core components of the SDG 11.1 indicator—specifically those related to inadequate housing conditions such as slums, informal settlements, and insecure housing—onto the relevant classes within the LADM. This alignment demonstrates how the LADM, through its standardised representation of spatial units (LA_BAUnit), rights (LA_Right), and utility infrastructures (LA_LegalSpaceUtilityNetwork), can serve as a robust foundation for modelling the legal and spatial dimensions of urban housing issues. The table highlights that secure housing, in the context of SDG 11.1, must go beyond legal tenure also to incorporate structural and physical safety, requiring multidimensional data integration. Furthermore, the distinction between urban populations and subcategories such as slum or informal settlement populations reflects the need for disaggregated spatial data linked to administrative and legal units. By offering a systematic correspondence between SDG 11.1 components and LADM classes, this framework enables the development of integrated land administration systems capable of supporting evidence-based policymaking and facilitating the monitoring of sustainable urban development at national and local scales.

According to the metadata associated with SDG 11.1, the adequacy of housing is evaluated through five fundamental criteria, each of which addresses a significant aspect of living conditions (see Table 2). These criteria encompass access to enhanced water sources, improved sanitation facilities, adequate living space, structural resilience, and security of tenure. Whether a dwelling is categorised as inadequate hinges on the presence or absence of any of these essential conditions. This multidimensional framework encapsulates the intricate nature of housing deprivation, integrating physical infrastructure and legal safeguards. For example, access to water and sanitation ensures essential hygiene and public health. At the same time, the adequacy of living space and structural integrity is directly correlated with safety and habitability. Conversely, tenure's security transcends the physical dwelling, providing legal guarantees and protection against involuntary displacement. By systematising these elements, the metadata facilitates uniform global monitoring. It enhances spatial and legal information integration within frameworks such as the LADM, thereby bolstering evidence-based policy formulation in urban housing.

Criterion	Description
Access to Improved Water Source	Access to a minimum of 20 litres of water per person per day from protected sources such as piped connections, protected wells, boreholes, or rainwater harvesting systems.
Access to Improved Sanitation	Availability of sanitation facilities that hygienically separate human excreta from contact, such as flush toilets connected to sewer or septic systems, or improved pit latrines.
Sufficient Living Area	A maximum of three persons per habitable room; alternative metrics may include square meters per person or number of persons per bed.
Structural Durability	Use of permanent construction materials for walls, roofs, and floors; compliance with building codes; location in areas not prone to environmental hazards.
Security of Tenure	Protection against forced eviction and harassment, demonstrated through formal documentation or publicly recognized evidence of tenure security.

Table 2 Core Criteria for Housing Adequacy under SDG 11.1

After analysing the UML diagrams that define the LADM classes and their interrelationships, the class VO_SDG11_1 has been proposed as a versioned object for SDG 11.1, as illustrated below.

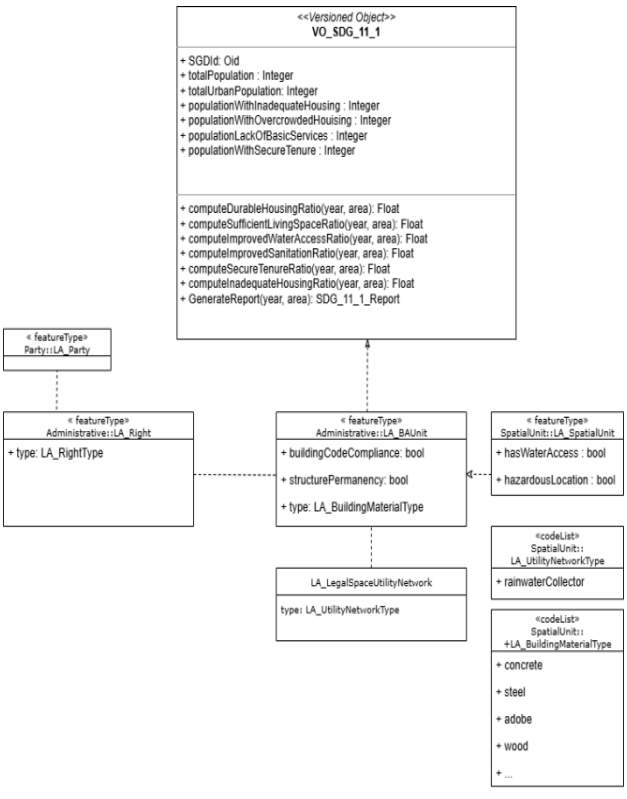

Figure 2. UML-Based Data Model for Monitoring SDG 11.1

Figure 3 showcases an intricate data model that employs the UML as its foundational framework, meticulously crafted to facilitate the operationalisation of monitoring efforts about

Sustainable Development Goal 11.1, which is particularly focused on ensuring inclusive and sustainable urbanisation by strategically leveraging the fundamental classes and structural components that are inherent to the LADM. At the heart of this model lies the pivotal class VO_SDG_11_1, which serves as a comprehensive aggregation point for critical indicators that are predominantly population-based; these indicators encompass not only the total urban population but also detailed sub-populations that reside in slum conditions, informal settlements, or substandard housing environments, while simultaneously capturing deficiencies related to essential services, such as the lack of access to fundamental utilities or situations of overcrowding. Furthermore, these essential indicators are intricately associated with legal and spatial representations through well-defined associations with LADM classes, including but not limited to LA_BAUnit, LA_Right, LA_SpatialUnit, and LA_LegalSpaceUtilityNetwork, thereby enhancing the model's robustness and applicability.

In addition to these core indicators, the model incorporates a range of supplementary attributes that facilitate a more nuanced and comprehensive assessment of housing adequacy, which includes criteria such as compliance with building codes, the permanence of structural integrity, and the types of materials utilised in construction. Moreover, the model is equipped with a suite of computational functions, exemplified by functions such as computeAdequateHousingRatio and computeSecureTenureRatio, which are designed to aid in the automated generation of reports about SDG 11.1, explicitly tailored to defined geographic areas and temporal frameworks. By seamlessly integrating legal-administrative and physical-spatial dimensions into its schema, this sophisticated framework lays a solid and comprehensive groundwork for monitoring policies based on empirical evidence, thereby contributing significantly to the overarching goals of sustainable urban management.

3. Results and Conclusion

Integrating LADM into land administration systems enhances transparency, reduces fraud, and promotes efficient governance, thereby supporting affordable housing and sustainable urban development. This alignment with SDG 11 fosters inclusive, resilient cities through improved land management and stakeholder engagement (Ahsan et al., 2024). The multi-tiered integration framework articulated in this research is delineated according to the interoperability of global standards (LADM), national geographic information infrastructure (TUCBS), and external data repositories, thereby facilitating the traceability of the sub-objectives associated with SDG 11. The model illustrated in the accompanying Figure delineates a distinct “SDG 11 Integration Layer” that permits the individualized monitoring of objectives ranging from SDG 11.1 to 11.a. This layer supports the comprehensive integration of legal, spatial, and managerial information by facilitating the alignment of LADM classifications (e.g., LA_spatialUnit, LA_baunit, LA_Right) with the national data architectures of TUCBS (e.g., TR_SpatialUnit, TR_RRR, TR_Party).

Another salient characteristic of the model is the incorporation of external data sources (such as municipal records, cadastral information, satellite imagery, etc.) which is conceptualized in a dedicated layer termed “Data Collection Package.” This methodology elucidates the manner in which external data can be synthesized with standardized data models and aspires to empower spatial decision support systems to accommodate the heterogeneity of data. Consequently, the model serves as both a sophisticated conceptual framework and a foundational structure accessible for database integration at a technical level.

This research articulates a detailed framework for the surveillance of Sustainable Development Goal (SDG) 11.1, which aspires to guarantee access to sufficient, secure, and economically feasible housing for all individuals by the year 2030. The suggested model employs the Land Administration Domain Model (LADM), codified as ISO 19152, alongside Türkiye’s national spatial data infrastructure (TUCBS), to reconcile the dichotomy between global standards and local execution. The strategy for integration is organized into four stratified layers: a specific indicator integration layer for SDG 11, an international standards layer (LADM), a national standards layer (TUCBS), and a layer dedicated to external data collection. Each constituent is indispensable in facilitating the systematic monitoring and spatial depiction of urban housing conditions.

The UML-based class architecture formulated in this research, particularly the VO_SDG_11_1 class, exemplifies how fundamental LADM elements such as LA_BAUnit, LA_Right, LA_SpatialUnit, and LA_LegalSpaceUtilityNetwork can be correlated with the essential components of the SDG 11.1 indicator—specifically, secure tenure, enhanced service accessibility, structural resilience, and residential density. This multifaceted methodology synthesizes both legal-administrative and physical-spatial data, thus enabling the development of dynamic, automated monitoring functions (e.g., computeAdequateHousingRatio, computeSecureTenureRatio) capable of producing reports that are specific to both area and time.

In summary, the advocated incorporation of the LADM for monitoring SDG 11.1 represents a replicable and scalable paradigm for effective urban governance. This framework permits meticulous assessment of housing adequacy and promotes the alignment of national land management frameworks with international developmental agendas. The model's stratified architecture is versatile, accommodating diverse institutional contexts. It can be a benchmark for other nations aspiring to synchronise their national geographic information infrastructures with the Sustainable Development Goal framework. Subsequent research should investigate the creation of decision-support systems, the integration with real-time urban monitoring technologies, and the extension to additional SDG 11 indicators, including transport accessibility (11.2), land consumption (11.3), and the preservation of cultural heritage (11.4).

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