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## CASAE STUDY RESEARCH PAPER

### Development of Urban Density Model Using an Urban Ecology Approach (Case Study: District 2, Tehran Municipality)

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#### ABSTRACT

Rapid urban growth and uncontrolled expansion, especially in developing countries like Iran, challenge urban planning and traditional Iranian cities emerged through a dynamic interaction between humans and nature, creating urban environments that were in harmony with natural ecosystems. This study aims to develop a sustainable urban density model based on an urban ecology approach, integrating governance, environmental sustainability, and spatial efficiency, with a case study in District 2 of Tehran Municipality. This applied-developmental study employs an analytical modeling approach. Data collection was carried out through documentary research and expert questionnaires. Confirmatory Factor Analysis using SPSS was used to validate the relationships between environmental factors and urban density. Reliability and validity were assessed through Cronbach's alpha and the Kaiser-Meyer-Olkin measure. A structural model was then developed to illustrate the key environmental influences on urban density. Key factors such as green space per capita, land-use patterns, and the built environment influence urban density distribution. The findings underscore the importance of integrating ecological principles into urban planning. The proposed model provides practical recommendations for enhancing environmental resilience and sustainable growth. The study highlights the need for smart density strategies and optimizing land-use efficiency to mitigate urban densification's negative effects. The Urban Density Model offers a framework for policymakers to promote environmental quality and sustainable urban development.

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## **INTRODUCTION**

Historically, traditional Iranian cities emerged through a dynamic interaction between humans and nature, creating urban environments that were in harmony with natural ecosystems. However, with the expansion of urbanization driven by modern technology and engineering advancements, this connection has weakened, leading to urban structures that often disregard ecological principles (Roohipour et al., 2019). In recent decades, the rapid growth and horizontal expansion of cities have become one of the most critical challenges in urban planning, resulting in significant economic, social, and environmental issues. Iranian cities, particularly metropolitan areas, are grappling with problems such as air, water, and noise pollution (Goodarzi and Rasti, 2025), sustainable urban management (Biranvandi et al., 2024), social health (Dabbagh Sakha, 2024), and energy consumption assessment (Johari, 2024), all of which have contributed to the deterioration of urban environmental quality. A key urban management tool to address these challenges is urban density policymaking. Properly implemented, urban density strategies can optimize land use, reduce transportation costs, and improve public spaces (Barati and Saberi, 2022). However, unregulated density increases can place excessive pressure on urban services and infrastructure. For example, in Tokyo, the adoption of intelligent density policies has led to reduced energy consumption and enhanced public transport efficiency, whereas in Mumbai, unbalanced density growth has resulted in worsening pollution, a shortage of green spaces, and declining environmental resilience (Mahmoodzadeh et al., 2022).

Urban ecology, as an interdisciplinary field, examines the complex interactions between humans and the environment within urban contexts, assessing how built structures—such as buildings, roads, and green spaces—impact quality of life and environmental sustainability. The ecological city (ecocity) concept, derived from urban ecology, views cities as intricate

ecosystems influenced by human activities (Mayona and Sutriadi, 2024). In Tehran, rapid population growth and uncoordinated urban expansion have created multiple ecological challenges. Studies indicate that only 6.6% of Tehran's area exhibits favorable ecological resilience, whereas over 42% of the city faces very low resilience levels (Abedini et al., 2022). This alarming situation underscores the urgent need to revise urban development policies and integrate ecological principles into planning strategies. Several factors shape Tehran's ecological conditions, including water resource availability, climate conditions, vegetation cover, and land use patterns. Additionally, high population density and concentrated economic activities in certain districts have placed immense pressure on infrastructure and public services (Xu and Y, 2018). Among these, District 2 of Tehran stands out due to its strategic location and rapid urbanization, making it a suitable case study for understanding the impact of density-related challenges. The increasing demand for residential and commercial spaces has intensified land use, while a lack of integrated ecological planning has led to imbalances in urban development. Key environmental concerns include declining per capita green space, excessive energy consumption, inefficient land use, and deteriorating air quality. These pressures not only reduce residents' quality of life but also contribute to broader environmental issues such as air pollution, the loss of urban greenery, and rising temperatures. In response, adopting an urban ecology approach provides a structured framework to mitigate negative environmental impacts while optimizing urban density. Strategies such as sustainable public space design, expanding vegetation cover, and developing urban green networks can enhance Tehran's ecological resilience (Mahmoodzadeh et al., 2022).

Accordingly, this study aims to develop an optimal urban density model from an environmental perspective, utilizing an urban ecology approach in District 2 of Tehran. This research

seeks to answer the following question: How can urban density be managed to enhance environmental sustainability while minimizing negative ecological impacts? To address this, an analytical modeling approach was employed, integrating applied and developmental methodologies. Data collection included documentary research and field studies, supplemented by expert questionnaires targeting specialists in urban planning, urban ecology, and urban management. The study used Confirmatory Factor Analysis (CFA) in SPSS software to identify key environmental variables affecting urban density and develop a model that balances urban growth with ecological resilience.

### **MATERIALS AND METHODS**

This study is applied-developmental in nature and has been conducted with an analytical-modelling approach. Data collection was carried out using both documentary and field methods. In the documentary section, scientific sources, articles, and official reports were reviewed, while in the field section, data were gathered through questionnaires. The target population of the research consisted of experts in the fields of urban planning, urban ecology, and urban management, selected through snowball sampling. The sample size was determined using the Cochran formula, with 100 questionnaires distributed and collected. For data analysis, Confirmatory Factor Analysis (CFA) was performed using SPSS software. In this process, after examining reliability (with Cronbach's alpha) and validity (with KMO and Bartlett's test), factor analysis was conducted to identify the components influencing urban density from an environmental perspective, and ultimately, the proposed model was developed.

#### *literature review*

Among various urban development models, eco-cities encompass the broadest range of sustainability aspects, including urban form, transportation, safety and security, governance,

and technologies that foster a healthy environment. They also integrate economic, social, cultural, and political dimensions (Khan and Zaman, 2018). The theoretical foundation of this research is based on the ecological city concept, which has evolved over the past four decades from movements such as appropriate technologies, economic development, social ecology, green movements, sustainable development, and bioregionalism (Jomehpour et al., 2020).

The question of how to design cities that balance productivity, livability, and environmental sustainability has long been a subject of scholarly debate (Chen and L, 2010). The concept of the eco-city, first proposed in 1975 (Dong et al., 2016), has since become a prominent theme in urban studies (de Jong et al., 2015). However, the roots of urban ecology trace back even further. Between 1890 and 1925, Patrick Geddes extensively studied and theorized urban ecology, emphasizing the interdependence between cities and their surrounding regions. He argued that sustainable city planning requires a deep understanding of ecological, social, and economic dynamics (Yuen and W, 2011). Geddes also stressed that cities should be designed with consideration for their historical and cultural contexts rather than adopting one-size-fits-all models. His theories remain highly relevant to contemporary urban planning and ecological city development. Eco-cities, also referred to as environmentally friendly cities, aim to create a balance between human activities and the natural environment. These cities are designed to minimize resource consumption (e.g., energy, water, and food) while reducing waste output (e.g., heat, air pollution, and solid waste) (Griffiths and Sovacool, 2020). The principles of eco-cities emphasize compact, safe, and mixed-use land development, urban habitat restoration, social justice, sustainable building materials, urban agriculture, recycling, pollution reduction, and resource conservation (Erfan Noorani Jadaghia and Farnam, 2024). However, an eco-city should not be mistaken for a smart

city, as intelligence does not necessarily equate to sustainability. Instead, the success of an eco-city must be evaluated across the three pillars of sustainability: environment, society, and economy—a balance that is often overlooked (Ahvenniemi et al., 2017).

The concept of the ecological city functions as an overarching framework that incorporates diverse strategies for transforming modern cities into more sustainable and livable environments. These strategies inform long-term environmental, social, and institutional policymaking (Bibri and Krogstie, 2020). A notable example is Masdar City, envisioned as a prototype for future eco-cities (Dabbagh Sakha et al., 2024). Critical determinants of eco-city success include water quality, climate conditions, vegetation coverage, and land use configuration. Furthermore, high population density and concentrated economic activities impose substantial strain on infrastructure and public services, exacerbating problems such as air pollution, the reduction of green spaces, and increased urban heat (Xu and Y, 2018). Within this context, urban density becomes a key factor influencing both the quality of urban life and environmental sustainability. When strategically managed, density can enhance infrastructure efficiency, optimize land utilization, and improve urban services. In contrast, unregulated density growth can overwhelm ecological systems and deteriorate environmental conditions. Therefore, integrating principles of urban ecology into density policies is imperative for achieving sustainable urban development and responsible natural resource management.

•Positive Impacts of Urban Density on Urban Ecology: Controlled urban density offers several ecological benefits, primarily through efficient land use, which reduces the need for horizontal expansion and helps preserve surrounding ecosystems and agricultural land. Additionally, high-density areas can lower per capita carbon footprints by promoting sustainable transportation options such as public transit, walking,

and cycling, thereby reducing greenhouse gas emissions and traffic congestion (McManus et al., 2000). Urban density also supports energy-efficient systems, such as district heating and cooling, by optimizing shared infrastructure (Niemelä, 1999). Moreover, well-managed urban density encourages the integration of green infrastructure—such as rooftop gardens and urban forests—which enhances biodiversity and improves air quality (Marzluff, 2008). Furthermore, compact and thoughtfully designed urban areas improve access to essential services, minimizing long commutes and enhancing overall urban resilience.

•Negative Impacts of Uncontrolled Urban Density on Urban Ecology: Conversely, unmanaged urban density can pose significant ecological challenges. The loss of green spaces and biodiversity is a major concern, as rapid urban expansion often replaces natural habitats with concrete structures, disrupting local ecosystems (Barton et al., 2006). Additionally, the urban heat island (UHI) effect is exacerbated in densely built environments, where increased heat absorption and retention lead to higher temperatures and greater energy consumption (Oke, 2017). High-density areas also contribute to air pollution due to increased emissions from transportation and industrial activities, adversely affecting public health (Piracha and Chaudhary, 2022). Moreover, excessive impermeable surfaces in densely populated zones hinder water infiltration, elevating flood risks and depleting groundwater resources (Zhou et al., 2018). Without proper urban planning, these challenges can significantly undermine ecological sustainability.

### *Strategies for Balancing Urban Density and Urban Ecology*

Achieving a balance between urban density and ecological sustainability requires strategic planning. Approaches such as smart density and vertical urbanism, which integrate high-rise

buildings with green spaces, can help mitigate urban sprawl while preserving natural areas (Lehmann, 2016). The incorporation of green infrastructure, including green roofs, urban forests, and sustainable drainage systems (SUDS), plays a crucial role in reducing the environmental impact of high-density developments (Barton et al, 2006). Furthermore, promoting eco-friendly transportation—such as cycling, walking, and electric public transit—can significantly lower pollution levels and enhance urban mobility (Bibri and Krogstie, 2020). Additionally, sustainable resource management strategies, including energy-efficient buildings and waste recycling programs, are essential for minimizing the ecological footprint of densely populated urban environments (Griffiths and Sovacool, 2020).

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#### *Proposed Urban Density Model with an Urban Ecology Approach*

Urban density and urban ecology are deeply interconnected and must be considered holistically in urban planning. A sustainable and environmentally friendly city requires an urban density model that optimizes land use efficiency while maintaining ecological balance. Emerging approaches such as smart density, green technologies, and ecological urbanism can help create urban environments that are both livable and resilient. Therefore, an integrated model is proposed, focusing on four main dimensions: managerial (sustainable urban governance), environmental (preservation and enhancement of urban ecosystems), physical (sustainable urban design), and spatial (optimal density distribution). Modeling urban density to achieve a sustainable urban environment requires integrating ecological considerations across various dimensions. In the managerial dimension, developing legal regulations for optimal density management must consider the ecological capacity of urban areas. Incentive policies for balanced density distribution and increasing citizen participation in decision-making processes can contribute to the development of sustainable neighborhoods (Barton et al., 2006). In the environmental dimension, expanding and improving urban green spaces can enhance quality of life and reduce air pollution. Implementing ecological restoration projects in biodiversity-rich areas and promoting green roofs in high-density zones play a significant role in strengthening urban ecosystems (Lehmann, 2016). From a physical perspective, increasing smart density while preserving open spaces helps mitigate the urban heat island effect. Developing energy-efficient buildings using sustainable materials and implementing an infill development model minimize urban sprawl. The compact city approach reduces urban dispersion and promotes efficient land use, aligning with sustainable urban development principles (Oke et al., 2017). In the spatial dimension, establishing guidelines for appropriate urban density distribution based on ecological capacity is crucial. Protecting environmentally

sensitive zones prevents uncontrolled urban expansion, while concentrating density along public transit corridors (Transit-Oriented Development, TOD) reduces car dependency and enhances urban mobility (Janeeh and Merabtene, 2024). This multidimensional approach ensures that urban density contributes to ecological resilience, sustainability, and improved urban living conditions, balancing the needs of development with environmental stewardship. (Fig.1)

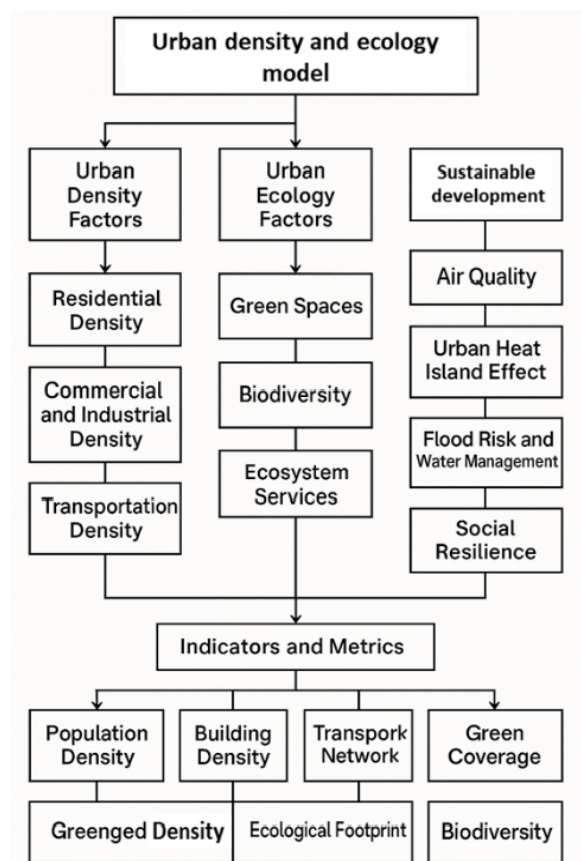


Figure 1: Influential factors in the urban Density Model Using an Urban Ecology Approach

This multidimensional framework provides a strategic approach to integrating ecological principles within urban density planning. By aligning governance, environmental, physical, and spatial considerations, cities can achieve a balanced urban form that supports sustainability, resilience, and enhanced quality of life.

## RESULTS AND DISCUSSION

### Area of study

District 2 of Tehran Municipality, located in the northwest of the capital, is one of the city's 22 districts and stands out as a key urban area due to its strategic position and distinctive characteristics. Covering approximately 64 square kilometers, it constitutes nearly 10% of Tehran's total area (Manafzadeh et al., 2024). Its advantageous geographical location ensures excellent access to public transportation networks and major highways, reinforcing its central role in the city's urban fabric. According to the 2016 Iranian census, the district had a population of approximately 701,303, distributed across 239,742 households (Hosseinzadeh Moghdam and Joodaki, 2022). However, despite its significance, District 2 faces pressing environmental challenges. Rapid population growth and unregulated urban expansion have contributed to a decline in green spaces, increased air pollution, and inefficiencies in waste management. Field observations further highlight these concerns, as a significant number of residents reported a noticeable deterioration in their quality of life due to environmental degradation and the scarcity of green spaces. (Fig.2)

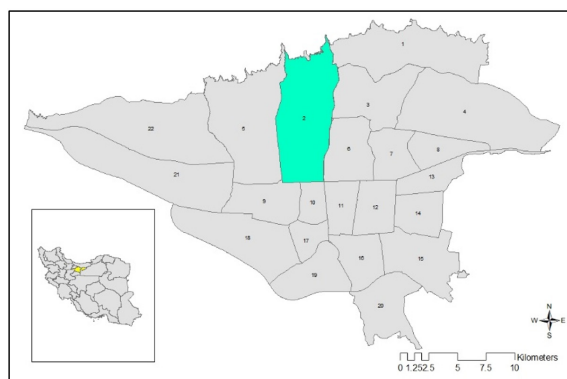


Figure 2: Location of the 2nd district of Tehran

### Questionnaire Analysis

The research questionnaire consisted of 20 items designed to assess the impact of urban density across four key dimensions: managerial, environmental, physical, and spatial. A stratified

random sampling method was used to survey 100 residents of District 2 in Tehran, ensuring a diverse and representative sample. In factor analysis, a common recommendation is to have a sample size at least five times the number of latent variables. Given that this study includes four main dimensions, a minimum of 80 respon-

dents (20 per dimension) would be required. To enhance the robustness and validity of the results, 100 respondents were included in this study. Table 1 presents the survey questions that measure each indicator using a Likert scale (1 = Strongly Disagree to 5 = Strongly Agree).[\(Tab.1\)](#)

**Table 1:** Measuring latent and overt research variables

Main Dimension	Latent Variable	Indicator (Survey Question)
<b>Managerial</b>	Sustainable Policies	- There are clear regulations for managing urban density. - Incentive policies exist for balanced density distribution.
	Public Participation	-Citizens participate in urban development decision-making. -Public opinions are considered in urban planning processes.
<b>Environmental.0</b>	Green Infrastructure	-Expanding green spaces improves urban quality of life. -Green roofs and ecological projects are promoted in dense areas.
	Air Quality	-High urban density affects air quality and pollution levels.
	Ecosystem Restoration	-Urban areas implement biodiversity conservation projects.
<b>3.Physical</b>	Smart Density	-High-density areas maintain open spaces to reduce urban heat.
	Sustainable Design	-Energy-efficient buildings are a priority in urban planning.
	Compact Urban Form	-The city follows a compact growth model to limit sprawl.
	Infill Development	-Redeveloping underutilized spaces is preferred over expansion.
<b>Spatial</b>	Optimal Density Allocation	-Density distribution follows ecological capacity guidelines.
	Transit-Oriented Development (TOD)	-High-density zones are concentrated along public transport corridors.
	Land Use Efficiency	-Urban expansion does not negatively impact sensitive areas.
	Mobility and Accessibility	-Urban density improves accessibility to services and infrastructure.

Table 2 provides descriptive statistics, including mean values and standard deviations, for each indicator in the survey.[\(Tab.2\)](#)

**Table 2:** Descriptive Statistics of Respondents

Variable	Mean (M)	Standard Deviation (SD)
Regulations for urban density	3.85	0.91
Incentive policies for balanced density	3.62	0.87
Citizen participation in urban decisions	3.41	1.02
Consideration of public opinions	3.78	0.95
Expansion of green spaces	4.12	0.88

Green roofs and ecological projects	3.95	0.93
Impact of density on air quality	4.05	0.89
Biodiversity conservation projects	3.82	0.96
Open spaces to reduce urban heat	3.88	0.94
Energy-efficient buildings	3.99	0.91
Compact growth model	3.76	0.92
Infill development strategies	3.71	0.98
Density based on ecological capacity	3.89	0.90
TOD and high-density zones	4.08	0.85
Protection of sensitive areas	3.92	0.89
Accessibility improvements	4.02	0.87
Air pollution and traffic congestion	3.56	1.05
Public transport availability	3.80	0.88
Noise pollution management	3.64	1.02
Waste management and recycling systems	4.00	0.91

*Exploratory Factor Analysis (EFA) and Variable Categorization*

To examine the internal correlations of variables and categorize them into a smaller number of factors, Exploratory Factor Analysis (EFA) was employed. In the second stage, based on expert feedback, 20 refined indicators were selected from interviews and quantified using a five-point Likert scale (ranging from strongly agree

to strongly disagree). The questionnaire was then completed by residents, passersby, and local business owners in District 2 of Tehran Municipality. To ensure the data's suitability for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were conducted. The significant result from Bartlett's test (Sig = 0.0001) and the KMO value of 0.809 confirmed the appropriateness of the data for factor analysis (Table 3).

Table 3 : KMO Test and Bartlett's Test of Sphericity

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy	0.809
Bartlett's Test of Sphericity	Chi-Square: 2386.043
Degrees of Freedom (df)	210
Significance Level (Sig.)	0.000

The KMO value of 0.812 indicates that the sample size is suitable for factor analysis (values above 0.7 are considered acceptable). Furthermore, the significance level of Bartlett's test is below 0.05, confirming that the correlation matrix is appropriate for factor analysis.

*Extracted Factors and Variance Explanation*

Table 4 presents the extracted factors along with their variance explanation. Three factors with eigenvalues greater than one were identified, accounting for a cumulative 57% of the total variance in the dataset. The breakdown of eigenvalues and the percentage of variance explained by each factor are as follows:

**Table 4 :** Extracted Factors, Eigenvalues, and Variance Explanation

Initial Eigenvalues		Rotation Sums of Squared Loadings
Factor	Total	% of Variance
1	17.780	31.160
2	9.619	16.857
3	5.396	9.457

*Factor Rotation Method*

An orthogonal rotation (Varimax) method was used after an initial oblique rotation (Direct Oblimin) revealed no significant correlation be-

tween factors. The final rotated factor loadings, presented in Table 5, show how each indicator loads onto its respective factor.(Tab.5)

**Table 5 :** Rotated Component Matrix (Varimax Rotation with Kaiser Normalization)

Variable	Factor 1	Factor 2	Factor 3
V14	0.789		
V7	0.747		
V13	0.743		
V16	0.728		
V11	0.623		
V1	0.603		
V15	0.585		
V8	0.575		
V12	0.552		
V2	0.476		
V6	0.435		
V17		0.843	
V18		0.811	
V19		0.794	
V21		0.760	
V20		0.738	
V4	0.440		
V3			0.848
V5			0.834
V9			0.777
V10			0.543

*Factor Naming and Interpretation*

Based on Table 6, three primary factors and their corresponding indicators are categorized as follows:

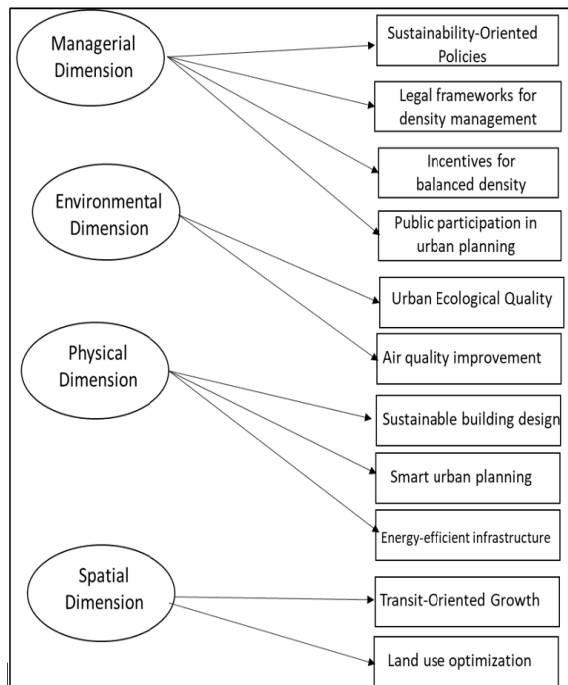
Table 6: Factor Naming and Indicator Classification

Factor	Indicator	Factor Loading
Governance and Social Engagement	Clear regulations for managing urban density	0.789
	Incentive policies for balanced density distribution	0.747
	Citizens' participation in urban development decision-making	0.805
	Consideration of public opinions in urban planning	0.783
Environmental Sustainability	Expansion of green spaces	0.843
	Promotion of green roofs and ecological projects	0.811
	Impact of high urban density on air quality and pollution	0.820
	Implementation of biodiversity conservation projects	0.832
Smart Urban Density and Spatial Efficiency	Maintenance of open spaces in high-density areas	0.848
	Prioritization of energy-efficient buildings	0.834
	Adoption of a compact urban growth model	0.829
	Preference for infill development over urban expansion	0.817
	Density distribution based on ecological capacity guidelines	0.850
	Concentration of high-density zones along public transport	0.823
	Prevention of urban expansion in sensitive environmental areas	0.819
	Improvement of accessibility to services and infrastructure	0.84

## CONCLUSION

An ecological city is one that is sustainable and capable of providing its residents with a meaningful life, without depleting the ecological resources upon which it depends. This perspective must be integrated into the regeneration of existing urban fabrics, new developments surrounding cities, and the design of new urban areas. This study examines the challenges and environmental consequences of urban density in District 2 of Tehran Municipality, with a focus on the urban ecology approach.

The findings indicate that the urban ecology approach is an effective tool for managing environmental challenges in cities. Considering the complex interactions between humans and the environment, it is crucial to incorporate social, economic, and cultural dimensions into urban planning. The proposed Urban Density Model demonstrates that urban density can have both positive and negative impacts on the urban environment. However, with proper planning, the negative effects of density can be minimized.



**Figure 3:** Proposed Urban Density Model with an Urban Ecology Approach

This model integrates four key dimensions—managerial, environmental, physical, and spatial—to balance urban density with ecological sustainability. The managerial dimension emphasizes sustainable governance, legal regulations, and community participation in urban decision-making. The environmental dimension focuses on enhancing urban green spaces, promoting ecological restoration, and mitigating urban heat islands. The physical dimension prioritizes smart density, energy-efficient urban design, and compact city growth to limit urban sprawl. Finally, the spatial dimension ensures optimal density distribution, transit-oriented development, and protection of environmentally sensitive areas.

Ultimately, this model serves as a framework for sustainable urban development, ensuring that urban growth does not come at the cost of environmental degradation. The research results further indicate that, in order to achieve an ecological city in District 2, special attention

must be given to management and physical components. According to the analyses, social and environmental components performed better than management components, but still did not meet the desired standards. This highlights the necessity of creating educational and cultural programs to raise citizens' awareness of environmental issues. Proposed Strategies for Implementing the Model Based on the research findings, the following strategies are proposed for integrating the Urban Density Model:

- Reforming urban density regulations to maintain a balance between building density and green spaces.
- Increasing vegetation cover and developing the urban green network to mitigate the effects of urban heat islands.
- Utilizing modern technologies in urban design, such as green facades and green roofs.
- Implementing integrated urban management for better coordination between density and environmental factors.
- Controlling pollution resulting from increased population density through the development of sustainable public transportation systems.
- Promoting community-based initiatives to encourage responsible consumption and waste management practices.
- Encouraging citizen participation in urban planning and decision-making to foster more resilient and adaptive cities.
- Strengthening the enforcement of environmental laws and regulations to ensure the effective implementation of sustainable policies.

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