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Simulating Natural Systems for Urban Intelligence: A Case Study of Dora Municipality, Baghdad, for Sustainable Urban Development

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ABSTRACT

The rapid sprawl in urban areas caused by excessive production and consumption of goods (as driven by local poor social choices) has inevitably resulted in a major burden due to environmental degradation worldwide. Unfortunately, these traditional models of urban planning fail to properly account for the intricacies that permeate a modern city and are deficient in terms of their approach as they shape themselves within an environment largely divorced from natural systems, resulting in vast mismanagement of resources, guiding cities down trajectories where growth destroys both physical and cultural landscapes. As cities suffer from increasing scarcity, we advocate for regeneration and resilience to be embedded in advanced urban design approaches based on natural systems principles. This study explores how engineering synthetic natural systems can be employed to influence the development of urban intelligent frameworks expressed in terms of adaptive solutions that support environmental and social needs for cities. The main objective of this research is to test, explore, and validate the way natural systems (like ecosystems) can be simulated in order to support an improvement in urban intelligence and a qualitatively better quality of life. Through a computational study, the objective of developing models is to mimic important aspects found in natural systems, such as resource use efficiency and resilience, including the separation of adjoining land areas within the urban planning domain. To bridge this gap, we propose an integrated natural system design in urban intelligence to develop a comprehensive platform that deals with multi-faceted urban challenges, including but not limited to air and water quality, and green space accessibility. The research confirms that when natural systems are incorporated into urban landscapes, the outcomes have considerable benefits in terms of resources, environment, and quality of life. This results in better air quality, reduced urban heat islands, and an improved use of resources for cities as they develop green infrastructure or adaptive water management systems, which directly impact temperatures. They also enhance social fairness, as the stimulation of natural systems results in an increase in availability and proximity to green places, which altogether boosts public health. The study also underscores the need for urban intelligence systems that leverage real-time data to dynamically adjust infrastructure planning and operation in response to their environment as well as population changes, ultimately aiming towards long-term resilience for cities. These are the types of insights that can deliver a model for sustainable urban development strategies at scale to policymakers and city planners.

1. INTRODUCTION

As cities across the globe expand and take shape, the opportunities presented are as great as the challenges they pose. Today, more than half of the world's population lives in cities, a number that is expected to increase substantially over the coming decades, underscoring the urgent need to focus on sustainability at the urban level. While cities grow and expand, their development should be at a crossroad between growth, inclusivity, and environmental preservation to remain sustainable over time. Thus, sustainable urban planning is crucial as an approach for creating and maintaining adaptable, resilient, and livable urban systems while combating destructive environmental patterns.

Answering this question is part of sustainable development, which is inextricably linked to urban living standards, providing clean air and water, equitable green space, public transport, decent housing. However, over the years, these ambitions are increasingly challenged within the urban centres themselves — environmental degradation, infrastructural decay, and social inequity threaten their sustainability. Cities generally overuse resources and generate disproportionately high waste, creating an environmental premium that threatens the world's ecological equilibrium and biodiversity. This calls for tackling these interrelated challenges, as we need proactive urban planning measures to embrace sustainability alongside

the welfare of citizens living in urban areas.

1.1 Problem statement

Urban sprawl continued, from developments to the floes surrounding cities, even when the trend has been to deliver more sustainable urban design. Together with poor planning, it leads to environmental damage, depletion of natural resources and urban inequalities, as seen in problems such as clogged streets, pollution and lack of services. These challenges are further exacerbated by an increasing disconnect between urban expansion and natural systems.

1.2 Significance of natural systems

One finds in nature sustainable, regenerative systems formed by evolutionary processes of adaptation. Such principles inform urban planning in a way that interweaves conservation of nature in the city and its resources, repurposes the material with the environment to create a better and more sustainable way of living. Incorporating sustainable infrastructure, increasing green areas, and using renewable energy, cities can tackle challenges such as climate change and population growth, in addition to enhancing public health and global urban livability.

1.3 Research objectives

This research explores using natural system simulations to enhance urban intelligence and quality of life by integrating efficiency, resilience, and connectivity into urban planning. It provides a framework to address resource challenges and offers recommendations for improving air quality, expanding green spaces, and promoting social equity.

1.4 Research questions

This study addresses key questions: how simulating natural systems can enhance urban intelligence and quality of life, what lessons cities can learn from natural systems, and how these principles can improve resource efficiency, reduce environmental footprints, and optimize open spaces to enhance air quality, water management, and greenery in urban areas.

2. LITERATURE REVIEW

2.1 Urban intelligence

Urban intelligence is a new and evolving concept that combines the best of urban planning with technology, data analysis to build not only more efficient cities but sustainable ones. With the advent of modern urbanization, Urban intelligence is a response able to address increasing complexities in cities using advanced technology and analytics for enhancing many aspects such as transportation, energy conservation, etc. This is how the urban intelligence should work together with more to improve daylighting while relation a sustainable environment and so quality of life for city dwellers [1].

The concept of urban intelligence is deeply rooted in the idea of "smart cities," where digital technologies are integrated into the urban fabric to make cities more livable and responsive to the needs of their residents [2]. Urban intelligence is the ability of a city to monitor and manage urban systems in real-time through sensors, IoT (Internet of Things), data analytics all work together. Cities are built upon resilient and adaptive technologies that allow them to react in real-time to shifts in everything from environmental conditions to population density, scarcity of resources which greatly facilitate the smooth functioning and efficiency [3]. In more recent times, the scope of urban intelligence has broadened to call for technological advancements and also incorporate natural systems in city planning. By inspiring from ecosystems, urban intelligence can foster sustainability by reproducing the resilience, adaptiveness and resource allocation like nature has. Cities can plant green infrastructure (e.g., parks, urban forests and green roofs) to improve air quality and mitigate the widely recognized "urban heat island effect" while also achieving a myriad of other environmental health benefits [4]. By incorporating natural systems into urban design, cities can become more sustainable and resilient to the impacts of climate change [5].

Studies have shown that urban intelligence, when applied effectively, can significantly improve urban sustainability. Research published in highly ranked journals highlights that urban intelligence systems are crucial in optimizing energy use, reducing emissions, and enhancing public services through more efficient resource management [3]. Additionally, the use of intelligent transportation systems has been proven to reduce traffic congestion and minimize pollution levels, contributing to improved life quality in cities [6].

Incorporating the principles of natural systems into urban intelligence also plays a critical role in achieving sustainability goals. Ecosystem-inspired urban design can enhance resource circulation, biodiversity, and resilience, all while supporting human well-being [7]. Recent research demonstrates that urban areas that incorporate ecosystem principles experience lower carbon footprints and higher life quality metrics [8]. Such approaches are increasingly recognized as essential for creating smart, sustainable cities capable of adapting to environmental and social challenges [9]. And the overall purpose of urban intelligence is better understanding this harmonization between technology and ecology in their ways to sustainable urban development. Combining big-data technologies with natural systems and social organization, urban intelligence represents a promising path to improve quality of life in cities while tackling the major threats from environmental degradation or resource depletion [10].

2.2 Simulating natural systems

The simulation of natural and ecological systems in urban planning has proven essential in addressing challenges such as water flow management, heat regulation, and ecological mobility. Previous studies have shown the value of simulating natural systems to enhance urban sustainability and improve quality of life by mimicking processes found in nature.

One of the most widely studied applications is the management of water flow in urban environments. Butler and Schütze [11] developed an integrated wastewater system model that combines different sub-models (sewer systems, treatment plants, rivers) to optimize performance and improve water quality in urban areas [11]. Similarly, Winz et al. [12] explored system dynamics simulation to manage water resources in river basins and urban environments, providing

valuable insights into long-term sustainability [12].

Heat regulation in cities has also benefited from natural system simulations. Endreny [13] introduced a framework for stormwater management that balances societal and ecological services by integrating ecohydrology principles. The model simulates the impact of runoff management on various environmental factors, including heat regulation and habitat viability [13].

Furthermore, simulations of ecological mobility models have been utilized to enhance urban sustainability. Willuweit and O'Sullivan [14] developed a dynamic urban water simulation model that integrates land use and climate dynamics, enabling planners to assess the feasibility of water recycling and stormwater management strategies in densely populated urban areas [14, 15].

Overall, simulating natural systems in urban planning has demonstrated substantial potential for improving urban infrastructure and creating sustainable, resilient cities. These tools offer urban planners a means to adapt natural processes for urban benefit, addressing complex issues like water scarcity, heat stress, and ecological balance.

2.3 Sustainable urban planning

Most importantly, it ensures the ability of provision for human existence without any destruction to our surrounding environment: that is where sustainable urban planning comes into play. Studies in this field have suggested that urban areas not only need to be livable; they should also cope with environmental issues. More sustainable approaches in urban planning tend to better account for the interrelated economic, social and environmental dimensions of a city that need to be catered for long-term urban sustainability along with improved living standards [16].

One of the most important aspects for a sustainable urban planning is transit. Research studies have proved that the efficacious implementation of sustainable transportation strategies can largely help enhance urban life quality by decreasing pollution, upholding air quality and mitigating traffic congestion. Some studies focused on making use of big data to create new solutions around sustainable transportation in cities like those by Wey and Huang [17] for designing sustainable transport strategy through the mobility patterns observing from Taipei, thus able to contribute positively towards an agenda where a more liveable city can be improved or better urban sustainability could be shaped them [17]. Similarly, the application of sustainable urban mobility plans (SUMPs) in European Union cities has been shown to reduce congestion and emissions, improving the overall livability of urban environments [18].

Environmental health and quality of life improvement through the integration of urban nature, and sustainable green spaces is a crucial component in sustainable urban planning. The capacity of urban green spaces to ameliorate the urban heat island effect, mitigate air pollution and provide recreation for residents have long been acknowledged as contributing to quality of life. For example, Borrego et al. [19] demonstrated the potential of the sustainable planning with URBAIR model explored in this study to improve air quality and health through urban land-use policies from an assessment based evaluation point of view. Additionally, sustainable landscape planning is essential for protecting ecosystems and ensuring the long-term sustainability of urban areas.

Finally, sustainable urban planning translates into human-oriented and opportunity filled development as well as disenfranchising environment for all. Findings shows living in a city that is socio-economical inclusive and offers accessibility to all citizens contributes positively for them, over-all perceived wellbeing [20]. According to Mouratidis [21], urban planning serves as a way of improving city living working towards higher accessibilities and tying potential features such that noise abolishment or public service provision equity are enhanced [21].

In contemporary cities, sustainable urban planning that includes transportation planning, green infrastructure, and equitable resource access is needed to enhance the quality of life while reducing environmental effects. There is a need for urgent tactics that will help cities stay resilient and livable in the face of urbanization pressure and the challenges of climate impact.

2.4 Application of natural systems simulations in urban planning: Global case studies

In numerous cities all over the world, simulating natural systems within urban planning has become increasingly significant, and each city has adopted different models to utilize this potential in order to improve sustainability and quality of life. The case studies below highlight the application of natural systems simulation in different city planning processes, ranging from water management to heat regulation.

1) **Wuhan, China**: The city of Wuhan, China, has used a game-theory-based approach in which an agent-cellular model is used to simulate urban growth with particular emphasis on both socio-economic driving forces and environmental sustainability. An exploratory urban expansion model was developed for social conflicts among stakeholders to better understand the mechanisms and determinants of influence on stakeholder behaviour. The method described in the study for simulating urban expansion (to which they attribute nearly all change) showed an ingenious and fairly realistic approach to combining human action with environmental considerations, providing us with a great deal of understanding [22].
2) **Nanjing, China**: This case study scenario-based spatial dynamic modeling method have been applied to predict urban growth patterns. The experiment of land-use changes based on the different planning policies revealed how spatial dynamics can facilitate urban planning as a decision-making tool. The model demonstrated how a planning policy impacts urban morphology and helps planners with having healthier cities [23].
3) **Zhengzhou, China**: Using a spatial error-based cellular automata (CA) model, this study simulated urban expansion by incorporating spatial autocorrelation to predict land-use patterns. The model provided insights into the impact of urban planning decisions on future urban landscapes, helping guide sustainable urban development efforts [24].
4) **Athens, Greece**: The Messoghia Plain, a peri-urban area of Athens, utilized simulation modeling to explore future urban dynamics under different economic scenarios. The simulations projected potential urban growth and land-use changes, helping policymakers assess trade-offs between development

and conservation efforts [25].

These case studies illustrate the potential of natural systems simulations in enhancing urban planning. By applying models that account for environmental and socio-economic factors, cities can anticipate future challenges, optimize resource use, and promote sustainable development.

2.5 Research gaps: Identification of gaps in the existing literature

Despite significant advancements in the field of urban intelligence and natural systems simulations, there are several critical gaps in the literature that this research aims to address:

1) While the literature emphasizes that both urban intelligence and natural systems are critical towards planning for cities, a gap is observed because studies incorporating these two concepts in their entirety lack. Existing research in this area often segregates the concept of urban intelligence (concentrated around data, technology and smart systems) from one that revolves around natural systems such as ecosystems or environmental management. To our knowledge, this research is the first of its kind to develop an urban-adaptive model incorporating both natural adaptive systems and data-driven approaches (i.e., Urban Intelligence) for sustainable cities in any developing country particularly those already experiencing rapid climate change impacts on infrastructure.
2) However, few studies combine assessments of organically closed systems providing a holistic evaluation of how such strategies affect life quality in general rather than having only detailed knowledge about large scale sustainability measures mainly focused on reducing pollution and waste, water resources management or urban heat island impacts to our environment. The aim of this study is to fill a gap in current simulations by including broader life quality measures such as social equity, green space accessibility and mental health into existing models.
3) Most existing models simulate static or ex-ante urban scenarios and do not consider the dynamic nature of cities in adapting to real-time environmental and social changes. A modeling of that kind sound void, and there is considerable lack that has to be applied for developing models in terms metro cities which are much more adaptive towards dynamic factors such as population density, climate change and energy demand or supply. This study aims to fill this gap by making efforts on integrating and evolving urban intelligence models equipped with adaptive capacity in response to dynamics changes for increased resilience and sustainability of the city.
4) It is worth noting that most studies, and case examples presented in this paper are derived from cities of developed countries especially in Western context as the subject area reflects on the use of reconfiguration policy. Research has not explored this potential application of natural system simulation for urban studies in low- and middle-income countries where the effects of rapid urban growth are particularly strong, together with severe environmental constraints. This will provide additional data to help fill the gap in research by testing generality of its models across different urban contexts; from regions that exhibit a wide range of economic, social and environmental challenges.

By addressing these gaps, this research aims to provide a more holistic and integrated approach to sustainable urban planning, enhancing both environmental sustainability and urban life quality.

3. METHODOLOGY

This study employs an integrative methodology combining qualitative and quantitative approaches to examine the role of natural systems in enhancing urban sustainability. The primary focus is to investigate the impact of incorporating elements such as green spaces, efficient water systems, and waste management on improving urban life quality. The research was conducted in the Al-Dora district of Baghdad, an area facing significant challenges in environmental quality and infrastructure development.

3.1 Research framework

The study adopts a two-phase approach: data collection through surveys, interviews, and field observations, followed by an analysis of urban challenges and feedback. Key methods include:

- **Data Collection:**

Conducted with 200 residents and 30 stakeholders to assess air quality, green space accessibility, waste management, and sustainable development.

Semi-structured interviews explored policies, successful practices, and feasibility of natural system solutions.

Evaluated green spaces, waste facilities, and water infrastructure for contextual validation.

- **Data Analysis:**

Descriptive statistics and chi-square tests identified demographic variations in satisfaction levels.

Highlighted challenges and opportunities in sustainable development.

PCA identified key indicators affecting quality of life and sustainability.

- **Evaluation Criteria:**

Environmental quality, public health, social equity, resource efficiency, and community satisfaction were used to measure the impact of natural systems on urban challenges and solutions.

3.2 Case study: Dora Municipality

Dora Municipality is a dense residential, industrial and agricultural region including palm groves in southern Baghdad on the western bank of the Tigris river. It is an area that has experienced immense urban transformation in the past decades, directly or indirectly influenced by Iraq's political and economic course changes (Figure 1).

In Dora, industrial areas are the main source for environmental challenges especially air pollution. Research has already confirmed that the industrial units, also due to traffic congestion, play a major role in deteriorating air quality of this region. Moreover, high-speed urbanization massively depleted the green space too; tersely causing extensive environmental pressure on this area [5].

The water management landscape was similar in Dora, with most residents significantly suffering from the poor quality of

services due to an outdated system on top that had been failing for too long. There are innovative approaches to address and potentially reduce the water scarcity challenges through smarter management such as rainwater harvesting; in addition, some of these new models may also help deal with relief problems such as floods.

To conclude, there were Dora pollution problems-Less green paces-Insufficient water system The question of how to address this with sustainability urban planning strategies, can help create better living and environmental circumstances for everyone who wants to live in a city.

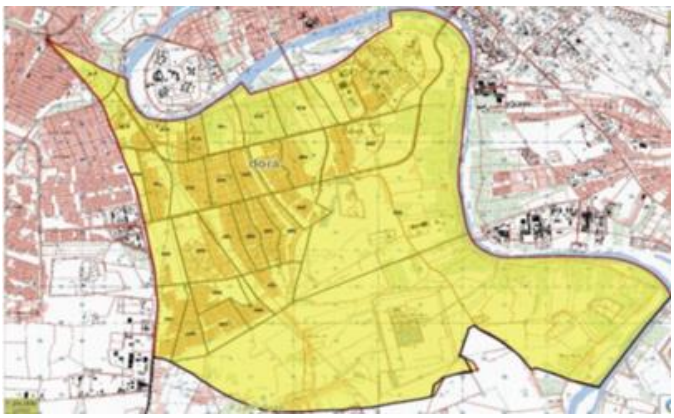

Figure 1. Dora Municipality

4. RESULTS

4.1 Overall quality of life

The survey results show a varied perception of the overall quality of life among the residents in Dora. Table 1 illustrates the distribution of responses regarding their general satisfaction with life quality:

Table 1. Overall quality of life

Overall Quality of Life	Percentage (%)
Average	36.0
Good	30.5
Poor	23.0
Excellent	6.0
Very poor	4.5

The majority of residents (36.0%) rated their quality of life as "Average," followed by 30.5% who rated it as "Good." A significant portion (23.0%) rated it as "Poor," while only 6.0% considered it "Excellent."

4.2 Satisfaction with green spaces

Table 2 highlights residents' satisfaction with the availability and quality of green spaces in their neighborhood:

Table 2. Satisfaction with green spaces

Satisfaction with Green Spaces	Percentage (%)
Dissatisfied	31.0
Satisfied	27.5
Neutral	26.5
Very dissatisfied	10.0
Very satisfied	5.0

A large portion of residents (31.0%) expressed dissatisfaction with the green spaces in their area. However, 27.5% were satisfied, and 26.5% remained neutral. Only 5.0% were very satisfied.

4.3 Support for sustainable urban projects

The level of support for sustainable urban projects, such as increasing green spaces and adopting renewable energy solutions, is shown in Table 3.

Table 3. Support for sustainable projects

Support for Sustainable Urban Projects	Percentage (%)
Strongly agree	51.5
Agree	27.5
Neutral	15.0
Disagree	3.0
Strongly disagree	3.0

Over half of the respondents (51.5%) strongly agreed with the implementation of sustainable urban projects, while 27.5% agreed. Only a small percentage (3.0%) disagreed or strongly disagreed with the idea.

4.4 Challenges faced by residents

Residents reported multiple challenges in their daily urban life. However, the responses were quite diverse due to the variety of combinations of challenges mentioned by the respondents. The most frequently reported issues included lack of clean water, poor waste management, and public transportation issues. These challenges highlight critical infrastructure deficiencies in Dora.

Due to the wide range of combinations, a full table is not displayed here, but the top common challenges were:

- Traffic congestion, lack of public transportation, and poor air quality were reported by 1.5% of respondents.
- Lack of clean water and noise pollution were also significant concerns, each reported by 1.5% of the participants.
- The wide diversity of responses indicates that residents face multiple overlapping challenges, with no single challenge dominating the responses.

4.5 Perceived impact of air pollution on health

Table 4 shows the distribution of responses regarding the impact of air pollution on the health of residents:

Table 4. Impact of pollution on health

Air Pollution Effect on Health	Percentage (%)
Yes	54.5
No	25.5
Not sure	20.0

A majority (54.5%) of residents believed that air pollution affected their health, while 25.5% did not perceive any direct impact. A notable portion (20.0%) were uncertain about the effects.

4.6 Public transportation rating

The residents were also asked to evaluate the quality of public transportation in their area, as shown in Table 5.

Table 5. Public transport evaluation

Public Transport Rating	Percentage (%)
Average	43.0
Good	30.0
Poor	15.0
Very poor	6.0
Very good	6.0

Most respondents (43.0%) rated public transport as "Average," while 30.0% found it "Good." However, 15.0% rated it as "Poor," and a smaller percentage (6.0%) rated it as "Very poor" or "Very good."

4.7 Cross-tabulation results

4.7.1 Satisfaction with green spaces by age group

Table 6 shows the relationship between age group and satisfaction with green spaces. It highlights how different age groups perceive the availability and quality of green spaces in their area.

• Younger residents (30-39 years) show a higher satisfaction rate (32.14%) compared to older residents.

• Older residents (40-49 years) show the highest dissatisfaction (35.85%) and have a greater percentage of being very dissatisfied (11.32%).

4.7.2 Public transport rating by household size

The cross-tabulation between household size and public transport rating provides insights into how different household sizes rate public transportation (refer to Table 7).

• Smaller households (1-2 people) rated public transport more negatively, with 57.58% giving it an "Average" rating, and 15.15% rating it as "Poor."

• Larger households (more than 8 people) had the highest percentage of residents rating public transport as "Very poor" (17.65%).

4.7.3 Impact of air pollution on health by occupation (income proxy)

Table 8 shows how occupation (used as a proxy for income) affects residents' perceptions of air pollution's impact on health.

• Students reported the highest belief that air pollution impacts their health (65%), while self-employed residents were the most uncertain (37.50%).

• Unemployed residents had a relatively high rate of uncertainty as well (31.58%), with 47.37% acknowledging the health impact of air pollution.

Interpretation

• Younger residents (30-39 years) tend to be more satisfied with green spaces compared to older residents.

• Smaller households (1-2 people) express more dissatisfaction with public transport compared to larger households.

• Students are more likely to perceive air pollution as harmful to their health, while self-employed individuals show higher uncertainty regarding the impact.

Table 6. Green spaces satisfaction by age

Age Group	Dissatisfied (%)	Neutral (%)	Satisfied (%)	Very Dissatisfied (%)	Very Satisfied (%)
18-29 years	31.91	25.53	29.79	6.38	6.38
30-39 years	26.79	26.79	32.14	8.93	5.36
40-49 years	35.85	24.53	22.64	11.32	5.66
50 years and above	29.55	29.55	25.00	13.64	2.27

Table 7. Public transport by household size

Household Size	Average (%)	Good (%)	Poor (%)	Very Good (%)	Very Poor (%)
1-2 people	57.58	15.15	15.15	6.06	6.06
3-5 people	34.00	40.00	15.00	5.00	6.00
6-8 people	50.00	24.00	20.00	4.00	2.00
More than 8 people	47.06	17.65	0.00	17.65	17.65

Table 8. Pollution impact by occupation

Occupation	No (%)	Not Sure (%)	Yes (%)
Employed	26.17	18.69	55.14
Other	30.00	15.00	55.00
Retired	33.33	16.67	50.00
Self-employed	12.50	37.50	50.00
Student	25.00	10.00	65.00
Unemployed	21.05	31.58	47.37

4.8 Thematic analysis of stakeholder interviews

The qualitative data from stakeholder interviews was analyzed to identify common themes related to urban challenges, policy gaps, and opportunities for sustainable interventions. Below are the key themes, supported by relevant tables.

4.8.1 Pressing urban environmental challenges

Stakeholders highlighted several key environmental challenges facing Dora. Table 9 summarizes the most frequently mentioned challenges.

Air Pollution was the most frequently mentioned challenge, cited by 40% of stakeholders, followed by heat island effects (30%) and limited access to green spaces (20%).

Table 9. Pressing urban environmental challenges identified by stakeholders

Environmental Challenge	Frequency of Mention (%)
Air Pollution	40%
Heat Island Effect	30%
Limited Access to Green Spaces	20%
Water Scarcity and Poor Water Quality	10%

4.8.2 Barriers to sustainable development

Stakeholders identified several barriers that hinder sustainable urban development, summarized in Table 10.

Table 10. Barriers to sustainable development

Barrier	Frequency of Mention (%)
Lack of Funding	35%
Political Challenges and Resistance	25%
Inadequate Policies	20%
Poor Coordination Between Agencies	20%

Lack of funding was the most frequently cited barrier (35%), with political challenges (25%) and inadequate policies (20%) also being significant obstacles.

4.8.3 Opportunities for sustainable interventions

Stakeholders expressed optimism about the integration of natural systems into urban planning. Table 11 highlights the key opportunities for sustainable interventions.

Table 11. Opportunities for sustainable interventions

Natural Systems Intervention	Frequency of Mention (%)
Expanding Green Spaces	40%
Improved Water Management	30%
Sustainable Waste Management	20%
Renewable Energy Systems	10%

The most significant opportunity identified by stakeholders was expanding green spaces (40%), followed by improved water management (30%).

4.8.4 Policy and governance

Stakeholders recommended several policy changes to facilitate sustainable urban development, summarized in Table 12.

Table 12. Necessary policy changes for sustainability

Policy Recommendation	Frequency of Mention (%)
Clearer Regulations	35%
Increased Community Engagement	30%
Funding and Private Sector Involvement	20%
Better Coordination Between Agencies	15%

Clearer regulations (35%) and increased community engagement (30%) were seen as the most important steps to improve urban sustainability.

4.8.5 Vision for urban development

The stakeholders' vision for urban development in Dora over the next 10 years is outlined in Table 13.

Table 13. Vision for urban development in 10 years

Vision Theme	Frequency of Mention (%)
Greener and More Sustainable City	45%
Enhanced Air and Water Quality	25%
Balanced Urban Growth	20%
Improved Infrastructure with Green Solutions	10%

The majority of stakeholders (45%) envisioned a greener, more sustainable city over the next decade, with a significant focus on improving air and water quality (25%).

4.8.6 Top recommendations for sustainable development

Stakeholders provided key recommendations for achieving sustainable urban development, summarized in Table 14.

Table 14. Top recommendations for sustainable urban development

Recommendation	Frequency of Mention (%)
Enhance Public Transportation	30%
Focus on Water Conservation	25%
Promote Renewable Energy	20%
Invest in Green Spaces	15%
Improve Waste Management	10%

The top recommendation from stakeholders was to enhance public transportation (30%), followed by a focus on water conservation (25%).

5. DISCUSSION

The factor analysis conducted on both resident and stakeholder survey data reveals several important insights into urban sustainability and life quality improvements in the Dora area. The extracted factors provide a framework for understanding how various elements, such as green spaces, air quality, and sustainable initiatives, impact both residents' and stakeholders' perceptions of urban development.

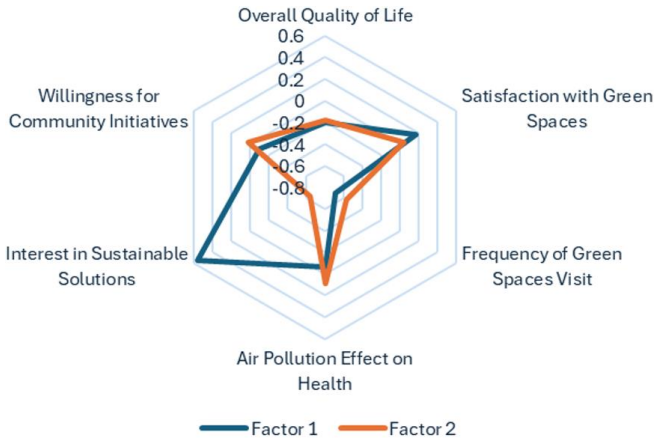

Figure 2. Resident survey factor loadings

Table 15. Resident survey factor loadings

Variable	Factor 1	Factor 2
Overall Quality of Life	-0.199	-0.181
Satisfaction with Green Spaces	0.169	0.037
Frequency of Green Spaces Visit	-0.696	-0.569
Air Pollution Effect on Health	-0.061	0.086
Interest in Sustainable Solutions	0.556	-0.633
Willingness for Community Initiatives	-0.098	0.024

5.1 Resident survey insights

The factor analysis of the resident survey identified two major factors influencing their perception of life quality (Table 15 and Figure 2).

Factor 1 (Environmental Satisfaction and Initiative

Support): This factor is strongly influenced by variables such as satisfaction with green spaces (0.169), interest in sustainable solutions (0.556), and willingness to participate in community initiatives (-0.098). These results indicate that residents who report higher levels of satisfaction with green spaces and support sustainable solutions tend to rate their quality of life more positively. However, the negative loading on the frequency of green space visits (-0.696) suggests that access to these spaces might be limited, despite the strong support for environmental initiatives.

Factor 2 (Air Quality and Life Satisfaction): The second factor significantly reflects concerns about air quality and its impact on overall life satisfaction. The negative loading on the perceived effect of air pollution on health (-0.061) and general life satisfaction indicates that residents who feel more affected by air pollution tend to rate their lives less favorably. This highlights that addressing air quality issues would have a substantial positive effect on residents' overall well-being.

5.2 Stakeholder survey insights

For the stakeholder survey, two main factors were identified, driving their perception of urban sustainability (Table 16 and Figure 3).

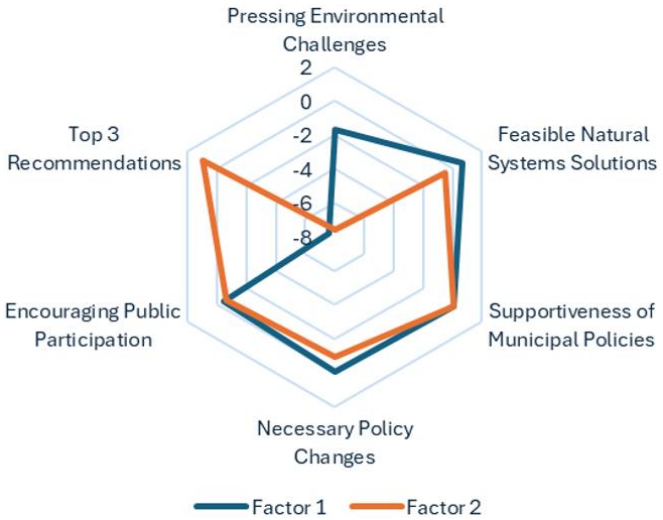

Figure 3. Stakeholder survey factor loadings

Table 16. Stakeholder survey factor loadings

Variable	Factor 1	Factor 2
Pressing Environmental Challenges	-1.692	-7.570
Feasible Natural Systems Solutions	0.671	-0.540
Supportiveness of Municipal Policies	0.119	0.109
Necessary Policy Changes	-0.042	-0.955
Encouraging Public Participation	-0.448	-0.618
Top 3 Recommendations	-7.610	0.986

Factor 1 (Environmental Challenges and Feasible Solutions): This factor shows the alignment between pressing urban environmental challenges and the feasibility of natural systems-based solutions. The strong negative loading on environmental challenges (-1.692) suggests that stakeholders who recognize more significant challenges are also more likely to support practical solutions such as expanding green spaces (0.671). This factor reflects stakeholders' desire to address critical environmental issues through sustainable solutions, particularly in areas such as water management and green space development.

Factor 2 (Public Participation and Policy Support): This factor is dominated by variables related to public participation and support for municipal policies. The positive loading on policy support (0.119) and the negative loading on public participation (-0.448) suggest that stakeholders who support municipal policies also advocate for greater public engagement in urban planning. The results imply that for sustainable solutions to be successfully implemented, stronger coordination between policy frameworks and community involvement is required.

5.3 Interpretation of factor analysis results

The factor analysis results identified several key factors influencing residents' and stakeholders' perceptions of life quality and urban sustainability in the Dora Municipality. From the survey data, two main factors were highlighted as significant drivers of satisfaction and support for sustainable urban interventions.

Factor 1: Environmental Satisfaction and Support for Sustainable Initiatives

It is high marked by variables as satisfaction with green spaces or interest in solutions for sustainable issues. Their analysis shows that residents who were more satisfied with green spaces also report a better evaluation of their overall life quality. Yet, in the factor analysis results was detected a low negative loading on visits to green spaces frequency signaling that even though environment is supported some residents seem not have access to those amenities. This could be a result of insufficient access to green space in these same neighborhoods, highlighting the potential mismatch between residents' attitudes toward sustainability and their ability to live it.

Factor 2: Air Quality and Overall Life Satisfaction

This reflects the high correlation of air quality with the overall life satisfaction. The findings indicate that those residents who believe air pollution is harmful to health are also less satisfied with their life as a whole. It again highlights an important issue; air quality in Dora remains poor forcing citizens to live miserable lives, and unless the political class puts their foot down on this matter life will not improve for residents.

By relating these elements to the urban context of Dora, we get a better understanding about environmental impacts on residents quality-of-life related to green spaces and air quality. The reasons mentioned above do provide a clear frame for both policymaking and urban planning, as the measurements give ground to concentrate on better access to green spaces in particular and improving air quality overall which is key for sustainable development within cities.

5.4 Implications

The findings from both the resident and stakeholder surveys emphasize the importance of integrating environmental improvements with active public participation. Residents' quality of life is closely tied to environmental factors such as access to green spaces and air quality, while stakeholders see the potential of natural systems and policy changes to address these challenges. The alignment between both groups around sustainable solutions, such as green space development and public engagement, indicates a clear pathway for urban planners to pursue.

5.5 Conclusions supported by the tables

Factor analysis reveals the critical importance of access to green spaces and air quality as central elements in improving residents' quality of life, as highlighted in Table 15.

From the stakeholders' perspective, feasible natural system solutions like green space expansion and water management are at the forefront of sustainable development, as shown in Table 16.

These factors provide a solid foundation for policymakers and urban planners to prioritize green space development, air quality improvements, and enhanced public participation to create a more sustainable and livable urban environment in Dora.

6. RECOMMENDATIONS

Based on the research findings, which highlight the challenges of urban sustainability and the importance of integrating natural systems into urban planning, the following recommendations are proposed to enhance urban life quality and environmental sustainability:

• Air quality must be improved by expanding parks, urban forestry and green roofs which also alleviate the heat island effect of cities. Green infrastructure must be an integral part of the urban fabric, and constructed in a strategic manner to ensure that all residents have access; particularly those living in underserved communities. Increasing areas of green space can also foster mental health and allow residents in cities to engage regularly with the environment.

• Cities must also utilize water management techniques that mimic natural cycles of precipitation, infiltration and storage. Rainwater harvesting, permeable surfaces and urban wetlands can contribute to efficient storm water management, less flooding as well as impacting positively the quality of lakes/reservoirs. Not only do these systems help to protect the environment but they strengthen climate change resilience of cities, reducing risks associated with events of extreme weather.

• In order to decrease traffic congestion, reduce GHG emissions and improve urban air quality Cities should give priority attention for sustainable transportation systems like intelligent public transit as well as non- polluting types of mobility (walking & cycling). Natural system principles (including green corridors for pedestrians and cyclists) may further embed nature into cities transportation infrastructure.

• Thus, cities should move away from traditional models of waste management to more sustainable systems that prioritize reducing (the first and most important R) landfill-bound trash, while increasing recycling rates and developing processes for composting organic materials. Based on nature's cycling processes, these waste-to-resource systems can drastically reduce the use of landfills and emissions while also moving toward a much needed resource efficiency.

• Sustainable urban planning will be best achieved when local communities are actively involved in this process. Undertake education campaigns to build awareness and promote community engagement in green infrastructure, transportation improvements, utility resource management Also, it is important that we consult local inhabitants while planning urban and when making a final decision so the solution meets their requirements.

• Urban intelligence: Real-time environmental monitoring (of air quality, water consumption and energy use) in cities with Idatalabs. As such systems come online, they will allow urban planning that is far more adaptable and adjustable, making for cities than can continuously reshape themselves as circumstances evolve. Optimized resource allocation and long-term sustainability are achieved with natural system simulation in combination of data-driven models.

7. CONCLUSION

The findings confirm that natural systems should be included in future urban planning so as to improve quality and livability in an increasingly complex environment of rapid urbanization, loss of biodiversity and damage from climate change. The study involves a novel approach to urban intelligence (i.e., the capacity of cities as systems to respond and adapt over time, in order to improve their functioning) focusing on how we could simulate natural ecosystems within them. At its heart, this research argues that cities too (like ecosystems) possess a balance and resilience through which they can be sustainable in their functioning — supporting the health of both people and planet.

For better understanding, it reveals the major challenges encountered by urban ecosystem such as inconsistent urban growth or habitat expansion, absence of weak infrastructure development that provides suitable green space and pollution. Trying Times: Traditional urban planning models mostly reactive and separate from natural systems have been shown time by attempting to deal with these challenges. This study addresses this major gap by suggesting that a new urban planning paradigm grounded on the fundamentals of natural systems, highlighting resource efficiency, resilience and connectivity.

Results show that when these natural systems are simulated and incorporated into urban design they can notably improve environmental outcomes including air quality, water quality and the reduction of the urban heat island. Additionally, ensuring access to green space or enhancing human health and quality of life broadly are other ways these systems might increase social equity. It also supports adaptive urban planning by using simulated natural systems, which helps cities manage resources more efficiently while limiting emissions and sustainability in the promotion of sustainable urban mobility.

This research offers insight to other cities by demonstrating more effectively the process of incorporating natural systems through detailed case studies and models. The results highlight the need for employing adaptive water management measures, broadening green infrastructure and providing knowledge-based urban intelligence to create cities more sustainable and resilient. These solutions are environmentally sound and economically viable, providing an affordable way to implement sustainable urban development.

In summary, the approach related to integrating natural systems into Urban Intelligence provides a massive shift in thinking about urban planning. Cities can become so much more sustainable, adaptable, and livable by following the efficiency and resilience of ecosystems. We provide a holistic model that combines ecological underpinnings with some of the technological advancements also being used in smart cities, thus this research contributes to broader discussions on urban sustainably. The report requires collective action by policy-makers, urban planners and communities to plan for sustainable city development that is responsive to the

combined goals of environmental conservation and social equity; cities that are geared up against modern day problems as well equipped enough with what they will face in future.

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