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Evaluating Green Space Design Alternatives Using Sustainable Thresholds: A Case Study of Bayti Residential Complex, Najaf, Iraq

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Abstract

This study evaluates green space design alternatives in the Bayti residential complex, Najaf, Iraq, using the concept of sustainable thresholds as a comprehensive planning and assessment tool. The research addresses the lack of integrated sustainability criteria in green space design within emerging urban environments, where climate adaptation, social inclusion, and economic resilience are often neglected. A descriptive-analytical methodology was adopted, incorporating ENVI-MET climate simulation and the LEED-ND v4.1 evaluation system. Three design alternatives were proposed to enhance thermal comfort, spatial equity, and local economic activation. The results revealed that the first alternative achieved the highest performance, significantly improving surface temperature distribution, social interaction, and access to services, while integrating economic functions through flexible green spaces. The study confirms that applying sustainable threshold indicators from the early stages of planning enhances decision-making and ensures better environmental, social, and economic outcomes. It recommends adopting threshold-based frameworks in residential green sector design and integrating simulation tools to align with climatic and contextual needs.

Keywords: *Green Sectors, Sustainable Thresholds, Urban Planning, Urban Design, Residential Complexes.*

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I. INTRODUCTION

Contemporary cities are increasingly confronted with compounded environmental and social challenges driven by rapid and unregulated urban expansion. This urban growth exerts immense pressure on infrastructure systems and open public spaces, often resulting in the degradation of urban environmental quality and diminished livability [1]. In this context, green spaces are not merely decorative amenities but essential infrastructure that contributes to environmental resilience, supports social interaction, and enhances psychological well-being [2]. Nonetheless, urban development patterns in many Middle Eastern cities, particularly in Iraq, continue to regard green spaces as ornamental luxuries rather than as integral components of sustainable urban planning [3, 4].

Despite the growing global discourse on sustainability, the concept of "sustainable thresholds" remains largely absent from urban planning practices, particularly in the design and development of green spaces. These thresholds encompassing ecological, social, economic, and ethical dimensions provide both quantitative and qualitative benchmarks necessary to ensure positive, measurable impacts across multiple urban systems [5, 6]. The lack of such integrated frameworks leads to green space designs that fall short in addressing the functional needs of diverse populations and fail to respond adequately to the socio-environmental dynamics of specific local contexts, including climate conditions, user behavior, and resource availability [7, 8].

This study aims to operationalize the concept of sustainable thresholds as a multi-dimensional planning and evaluation framework for green spaces. Through an in-depth analysis of the Bayit residential complex in Najaf, Iraq, the research seeks to develop, simulate, and assess alternative green space designs that optimize thermal comfort, ensure equitable access to services, and enhance both social integration and local economic vitality.

The significance of this research lies in its attempt to bridge the gap between theoretical sustainability principles and practical design implementation. By integrating advanced tools

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such as the ENVI-met climate simulation model and the LEED-ND v4.1 sustainability assessment framework, the study contributes a methodological blueprint for improving planning decisions in emerging urban environments. This integration supports the development of policy-relevant insights that align environmental performance with social equity and economic resilience in residential complexes [9, 10].

The theoretical underpinnings of this study draw upon a constellation of interdisciplinary concepts that extend beyond conventional green space design. First, the theory of behavioral ecology emphasizes how the spatial structure of urban environments influences patterns of human behavior, including mobility choices, social interaction, and place attachment [9]. Secondly, the principle of social justice in urban design calls for equitable access to ecological amenities such as clean air, inclusive participation, and economic opportunity, thereby reinforcing the moral imperative of integrating justice into spatial planning [11, 12].

The notion of urban resilience provides another critical perspective, framing green spaces as adaptive infrastructures that mitigate the effects of climate stressors such as extreme heat, water scarcity, and ecological disruption [13, 14]. In parallel, complex systems theory (CST) offers an epistemological foundation to understand green spaces not as isolated design features, but as dynamic socio-ecological systems shaped by interactions between users, climate patterns, and localized economic activities [15, 16].

Moreover, the framework of ethical sustainability asserts that urban design should not only pursue technical efficiency but also honor responsibilities toward future generations, biodiversity preservation, and existential values inherent in nature [17, 18]. Complementing these perspectives, the concept of sensory urbanism situates green spaces within the realm of human perception, focusing on sensory stimuli such as shade, airflow, and natural soundscapes that promote emotional and psychological well-being [19].

In alignment with these foundations, the concept of sustainable thresholds is operationalized through four primary dimensions:

- Ecological thresholds define the biological limits necessary to sustain vegetative and ecosystem functionality [20, 21].
- Social thresholds focus on inclusivity and participatory access to green spaces, ensuring visual and physical availability across different social groups [22].
- Economic thresholds pertain to the ability of green spaces to support job creation, local investment, and community skill-building [23].
- Ethical thresholds emphasize just access to environmental services for all age groups and social classes, reinforcing institutional responsibility [24].

These thresholds, as demonstrated in the literature, provide measurable criteria that can be integrated into comprehensive evaluation systems such as LEED-ND and BREEAM, offering robust planning tools to promote equitable and sustainable urban growth [25, 26].

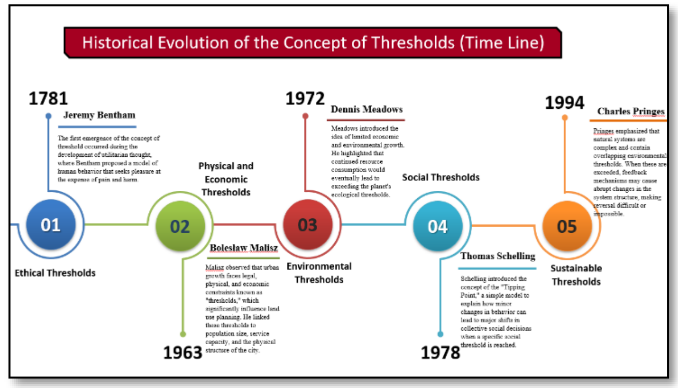

Fig. 1. Timeline illustrating the evolution of sustainable thresholds from ecological limits in the 1970s, through the integration of social justice in the 1990s, to formalization in global frameworks in the 2000s, and their application in urban planning tools and digital simulations in the 2010s and 2020s, Source: Author.

II. Methodology

This research adopts an analytical case study methodology centered on the “Bayti” residential complex, a newly developed urban project in Najaf Governorate, Iraq. The study aims to apply and test the concept of sustainable thresholds in the design and evaluation of green spaces within a context characterized by climatic challenges, limited ecological integration, and growing social needs. A descriptive-analytical approach was employed to critically examine the current planning structure and propose alternative design solutions that respond to both environmental conditions and urban development gaps. The methodology was supported by a combination of quantitative tools to ensure scientific rigor and replicability of the findings.

Primary data sources included detailed land use plans, population statistics, and the spatial distribution of green areas, which were complemented by field verification and updates to the original master plan of the complex. The analysis focused on identifying spatial deficits in green infrastructure and aligning interventions with national standards for per capita green space allocation. The use of Geographic Information Systems (GIS) facilitated the measurement of service coverage and access distances, while physical site observations were conducted to validate land availability and usage patterns.

To evaluate the environmental performance of the proposed design alternatives, the ENVI-met simulation software was used to model microclimatic variables, including air temperature, humidity, and wind flow, for both summer and winter scenarios. Simulations were carried out for the current conditions and for each of the three design proposals, allowing for a comparative assessment of thermal comfort. Parallel to this, the LEED-ND v4.1 rating system was employed to assess sustainability performance based on five dimensions: smart location and linkage, neighborhood pattern and design, green infrastructure and buildings, innovation, and regional priorities. This dual evaluation approach ensured that both environmental behavior and broader sustainability indicators were accounted for.

Three design alternatives were developed using vacant land within the residential complex, particularly in areas designated for public or municipal functions. Each alternative was designed to enhance ecological functionality, social interaction, and economic activation. The proposals were assessed using a comprehensive matrix that integrated ENVI-met simulation outputs with LEED-ND scoring criteria. The analysis revealed that the first alternative achieved the highest degree of balance among environmental, social, and economic thresholds, particularly in reducing surface temperature, improving equitable access to services, and supporting small-scale economic activities. These findings highlight the practical value of using sustainable thresholds as an operational tool in guiding context-sensitive urban design.

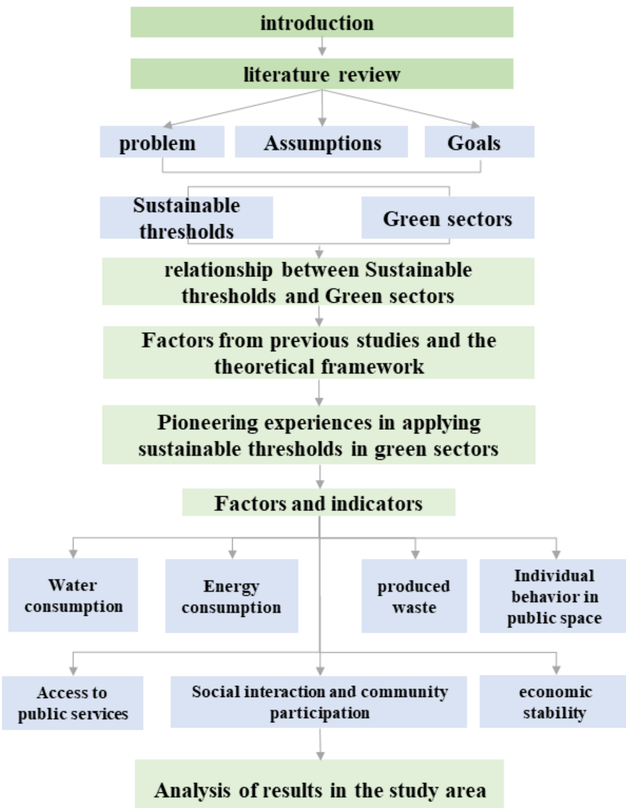

Fig. 2. Research methodology framework illustrating the integration of ENVI-met simulation, LEED-ND assessment, and spatial analysis for evaluating green space design alternatives in the Bayti residential complex, Source: Author.

III. Comparative Global

A. Hammarby Sjöstad Project – Stockholm, Sweden

Hammarby Sjöstad is one of the most prominent projects to apply the "Integrated Ecological Neighborhood" model in urban design. The project integrates water, energy, and waste management systems within a single neighborhood unit, and utilizes green spaces as green infrastructure elements that perform environmental functions, not just aesthetic ones. The design also relies on careful distribution of green spaces to connect residents to daily activities and promote active mobility [27].

B. The Vauban Project – Freiburg, Germany

The Vauban Project in Germany is a model of community governance and sustainable design at the neighborhood level. The project combines the principles of energy independence, reliance on non-motorized transportation, and the equitable distribution of open spaces. The distribution of green spaces is based on the principle of spatial accessibility for all ages and abilities, while incorporating community agricultural programs to support the local economy [28].

C. The Augustenborg Project – Malmö, Sweden.

This is a comprehensive redesign of a former industrial neighborhood into an ecological neighborhood using multifunctional green interventions. The project relied on open stormwater management systems, increased plant diversity, and the use of green roofs to reduce the heat island effect. Residents were also involved in the design of green spaces, enhancing participation and social cohesion [29, 30].

The previous case studies represent an important practical reference that can be used to guide design decisions for green spaces within the "Bity" residential complex, especially in an emerging urban environment. By analyzing these experiences, the following conclusions can be drawn:

The Hammarby Sjöstad experience confirms the importance of functionally integrating green spaces into environmental infrastructure, particularly with regard to water and energy management. This can be used in the design of green spaces within the complex as effective tools for mitigating climate impact.The Vauban experience highlights the need to involve the local community in decision-making, while designing green spaces to be inclusive and integrated for all age groups and social groups. This intersects with the social and ethical thresholds adopted in this research. Augustenborg emphasized the importance of intelligent use of small spaces and open spaces, with a focus on multifunctionality and surface water control, which enhances the climate resilience of residential complexes and supports the urban resilience index [31, 32].

Based on the above, it can be concluded that these international case studies offer practical evidence that aligns with the theoretical foundations of sustainable thresholds and reinforces the validity of the approach adopted in this research by integrating environmental, social, and economic indicators into the evaluation and design of green spaces, According to Table 1.

IV. Case Study

The “Bayti” residential complex in Najaf Governorate was selected as the case study for this research due to its strategic relevance as a recently developed residential project that exemplifies common planning challenges in emerging Iraqi urban environments. Its large scale, standardized layout, and incomplete integration of ecological design principles make it a suitable model for examining the application of sustainable threshold indicators in green space design. A notable planning deficiency in the existing scheme lies in the insufficient allocation of green areas, with a recorded per capita green space provision of only 6 m², significantly below the Iraqi national standard of 9 m² per person.

TABLE I. INDICATORS OF THE CONCEPT OF SUSTAINABLE THRESHOLDS RELATED TO GREEN SECTORS.

Indicator	Description	Measurement method	Standard
Water consumption	Refers to the efficient use of water, improvement of water quality, conservation of water resources, water recycling, and desalination of brackish water.	Data from relevant authorities	Per capita water share: 250 liters/person/day
Energy consumption	The extent of reliance on renewable energy sources and reducing energy waste through the use of smart and natural lighting systems.	Data from relevant authorities	12.5 kWh/residential unit/day
produced waste	It aims to reduce the amount of waste produced and improve recycling, reuse, and waste disposal in healthy and environmentally friendly ways.	Data from relevant authorities	1.3 kg/person/day
Individual behavior in public space	It measures the extent to which changes in urban fabric affect individual behavior.	Field monitoring and questionnaire form	The extent to which urban fabric changes affect individual behavior
Access to public services	Refers to the spatial distribution of green spaces and areas and ensuring equal access to them by all individuals according to approved access standards.	Within the GIS	Residential district services 200 meters, residential neighborhood services 400 meters, sector services 1600 meters
Social interaction and community participation	Measuring the social interaction and community participation achieved by green spaces. The more participants, the better.	Interim Monitoring and Survey Form	The more participants, the better.
economic stability	Individual satisfaction with the availability of job opportunities reflects the Green Zone's ability to provide a stable economic environment.	Survey form	Individuals' satisfaction with the availability of job opportunities reflects the urban center's ability to provide a stable economic environmet.

This case study was not limited to assessing the current situation but aimed primarily at formulating and testing alternative green space designs based on measurable sustainability criteria. The selection of “Bayti” was also informed by the opportunity to work with an unbuilt portion of land within the master plan, which allows for realistic interventions and simulation-based design testing. The study, therefore, bridges analysis and design by identifying existing gaps and proposing context-sensitive solutions grounded in scientific assessment tools.

Geographic Information Systems (GIS) were employed to analyze the spatial distribution and service coverage of green spaces, distinguishing between public and semi-public typologies. Based on this spatial assessment, a strategic reallocation was proposed by utilizing available vacant land designated for municipal use within the complex to bridge the gap between actual and required green space per capita.

Three alternative design proposals were developed for the target site, each incorporating different spatial configurations and functions. These were then modeled using ENVI-met software to simulate microclimatic conditions, including temperature, wind flow, and relative humidity, in both summer and winter scenarios. The purpose was to assess thermal comfort performance at a granular level and compare it against the baseline conditions of the site. Concurrently, the alternatives were evaluated using the LEED-ND v4.1 system, applying five main categories of indicators: smart location and linkage, neighborhood pattern and design, green infrastructure and buildings, innovation, and regional priority. This dual evaluation combining environmental simulation and sustainability scoring provided a robust basis for determining which alternative most effectively satisfied the environmental, social, and economic dimensions of sustainable thresholds.

The Bayti Residential Complex is one of the pioneering residential complexes recently built in Najaf Governorate. This residential complex has a significant impact on solving the housing problem facing hundreds of Iraqi families in Najaf, specifically, and Iraq in general. Construction of the project commenced in June 2009, and the project delivery period was scheduled for 2011. The land was handed over to the investor free of charge. Instead, the state and the investor relied on financial loans obtained from banksz Architects, designers, and consultants were employed to ensure the project met international standards According to Figure 3.

Fig. 3. Master plan of the Bayti residential complex in Najaf, Iraq, showing the distribution of land uses, including residential zones (A, B, C, VIP), educational and commercial areas, and the initially allocated green spaces. This plan serves as the spatial foundation for analyzing green space deficiencies and informing the development of sustainable design alternatives.

The total area of the complex is 486,054 m2, equivalent to 48 hectares. The number of residential units, as per the master plan, is 1,274. The complex is divided into four residential unit categories: A, B, C, and VIP. The complex is bordered to the north by the holy Karbala, to the south by the Milad neighborhood, to the east by the Najaf-Karbala Road, and to the west by the Najaf Sea. Distribution of uses and their percentage of the total area of the complex: The residential use rate in the complex reached 55%. The educational usage rate is 3.2%. The commercial usage rate reached 1.4%. The percentage of green spaces reached 7.5% of the total area of the complex, According to Figure 4.

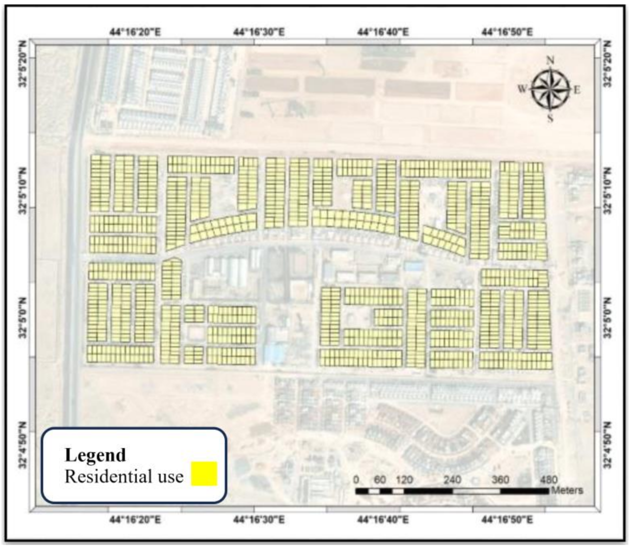

Fig. 4. Land use distribution within the Bayti residential complex, illustrating the spatial proportions of residential (55%), educational (3.2%), commercial (1.4%), and green spaces (7.5%) across a total area of 486,054 m². The complex is bordered by Karbala to the north, Milad neighborhood to the south, Najaf-Karbala Road to the east, and Najaf Sea to the west, Source: Author by GIS.

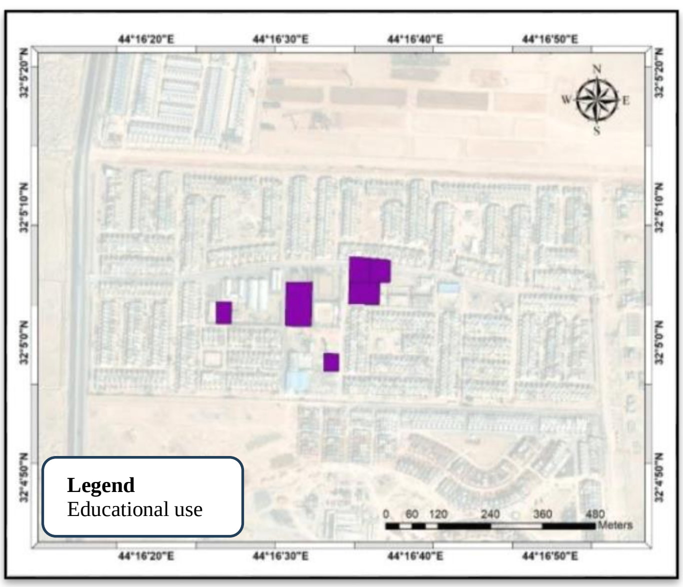

Fig. 5. Spatial distribution of educational land use within the Bayti residential complex, highlighting designated zones allocated for schools and related facilities, which represent 3.2% of the total project area according to the approved master plan, Source: Author by GIS.

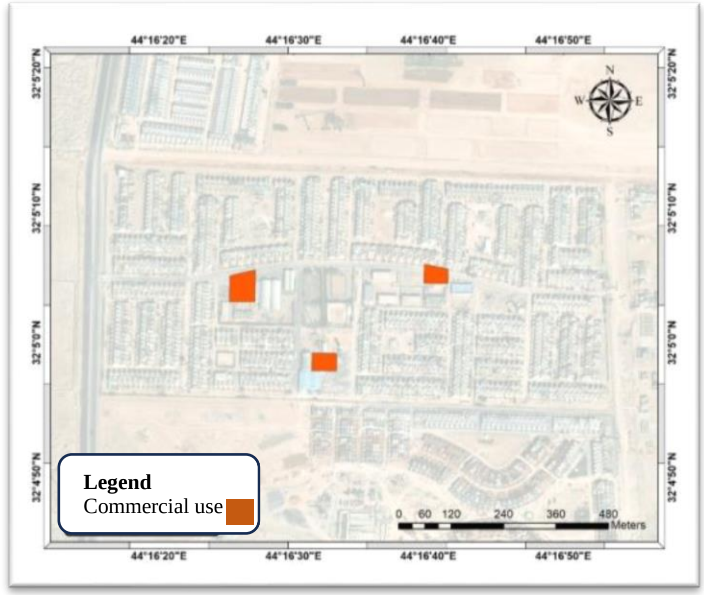

Fig. 6. Commercial land use distribution in the Bayti residential complex, showing the designated areas for markets and retail services, which occupy 1.4% of the total site area as per the master plan, Source: Author by GIS.

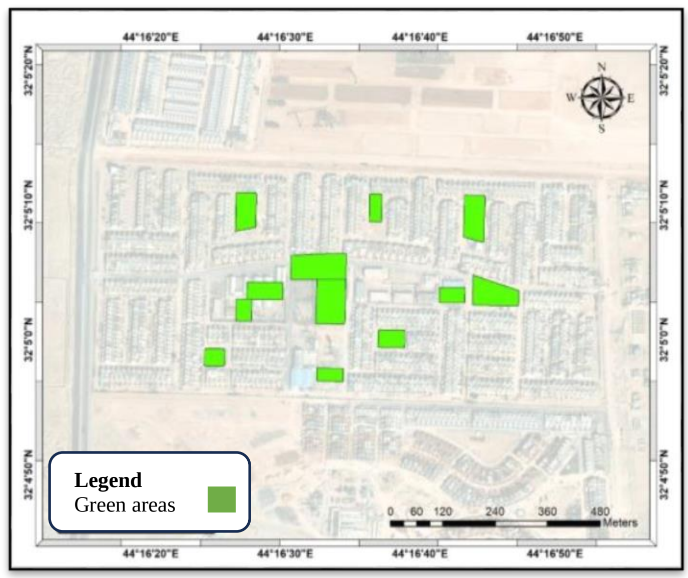

Fig. 7. Distribution of green areas within the Bayti residential complex, illustrating the location and extent of existing public and semi-public green spaces, which account for 7.5% of the total site area, prior to implementing the proposed design alternatives, Source: Author by GIS.

An evaluation of green space service coverage within the Bayti residential complex indicates that, while the spatial distribution of green areas adequately covers the entire site, the per capita share falls short of national standards. Specifically, the actual provision prior to intervention was 6 m² per person, compared to the Iraqi standard of 9 m² per person as set in 2018. To address this gap, a strategy was developed to increase the green area coverage by utilizing designated municipal land located centrally within the complex, adjacent to the main neighborhood park.

Following this intervention, the total green space increased to 46,778 m², accounting for approximately 9.6% of the overall site area. The updated provision ensures that the green space now meets the standard per capita requirement and is capable of serving the entire residential population, as demonstrated in Table 2.

TABLE II. POPULATION CALCULATION AND GREEN SPACE ADEQUACY BASED ON IRAQI PER CAPITA STANDARDS, BEFORE AND AFTER COMPENSATORY PLANNING IN THE BAYTI RESIDENTIAL COMPLEX.

Parameter	Value
Number of housing units	1,274
Average household size	6
Total population	7,644
Available green space after compensation (m²)	46,778
Iraqi standard per capita share (m²)	6
Calculated served population	7,796

Source: Authors based on Iraqi standards for green spaces

It is evident that the green spaces within the Bayti residential complex suffer from neglect, both in terms of maintenance and functional integration, limiting their effectiveness as active components of the urban environment, see Figure 8.

Fig. 8. Existing green spaces in the Bayti residential complex, highlighting areas of spatial coverage and evident signs of neglect in landscape quality and usability, Source: Author.

V. DESIGN ALTERNATIVES

A. *First alternative:*

The planning concept of the first alternative is centered on activating the interface between the neighborhood park and the adjacent commercial center, transforming this junction into a vibrant socio-economic node. The proposal aims to economically empower local residents by integrating micro-business opportunities directly within the green space. Specifically, the design introduces a cluster of small kiosks along the edge of the park facing the mall, offering goods and services such as fast food, children's toys, and daily necessities to park visitors. This spatial strategy not only encourages informal commerce but also strengthens the functional link between the commercial and recreational zones.

The main entrance to the park is repositioned adjacent to the existing neighborhood parking area, facilitating accessibility and increasing footfall through the economic activity corridor. This sequence reinforces user engagement with the green space upon entry, while embedding behavioral cues that promote local consumption. To preserve spatial hierarchy and minimize noise overlap, activity zones are carefully distributed: play areas for children and resting zones for the elderly are placed along the quieter periphery, whereas a central public plaza is allocated for social gatherings and unprogrammed community interactions.

This alternative responds strongly to economic and social sustainability thresholds by offering inclusive access, supporting small-scale entrepreneurship, and promoting shared public experiences. Its layout is designed to stimulate local economic circulation while maintaining the environmental and social functionality of the green space.

Figure 9 illustrates the spatial configuration of the first design alternative, emphasizing the integration between the commercial center and the park. The layout includes designated zones for sales kiosks near the entrance (b), a central Islamic monument as a visual and cultural landmark (c), shaded sitting areas distributed throughout (d), dedicated children's play zones along the quieter edges (e), pedestrian paths with visual discontinuities for safety (f), and a central water feature (g) to enhance microclimate and visual appeal.

Fig. 9. Spatial layout of the first design alternative, showing key elements such as commercial kiosks (b), a central Islamic monument (c), shaded sitting areas (d), children's playgrounds (e), pedestrian crossings (f), and a central water body (g), all organized to activate the interface between the park and the adjacent commercial zone, Source: Authors, using SketchUp, Lumion.

B. *The second alternative*

The second design alternative adopts a spatial strategy focused on mitigating the acoustic and visual impact of the adjacent commercial center by introducing a semi-buffered layout. Rather than full isolation, the design proposes a graduated transition between the commercial edge and the park's core, thereby maintaining accessibility while protecting the recreational environment from noise pollution. The central organizing element of this alternative is a large social interaction plaza, which acts as the heart of the park and is surrounded by zones dedicated to children's play and elderly seating, ensuring inclusivity and comfort across age groups.

A key feature of this layout is the creation of axial movement corridors that visually and physically connect peripheral activity zones to the central plaza. These axes are intentionally designed to foster interaction and wayfinding, encouraging continuous engagement with the space. The design explicitly targets social and ethical sustainability thresholds, aiming to cultivate a sense of belonging and community cohesion among residents. By offering multiple access points and avoiding hierarchical spatial divisions, the park reinforces the principles of non-discrimination and universal accessibility.

The proposed layout encourages behavioral stewardship through spatial legibility and shared ownership, making it more likely that users will feel responsible for maintaining and respecting the park. As such, this alternative emphasizes inclusivity, equity in use, and psychological attachment to place core components of socially sustainable public space design.

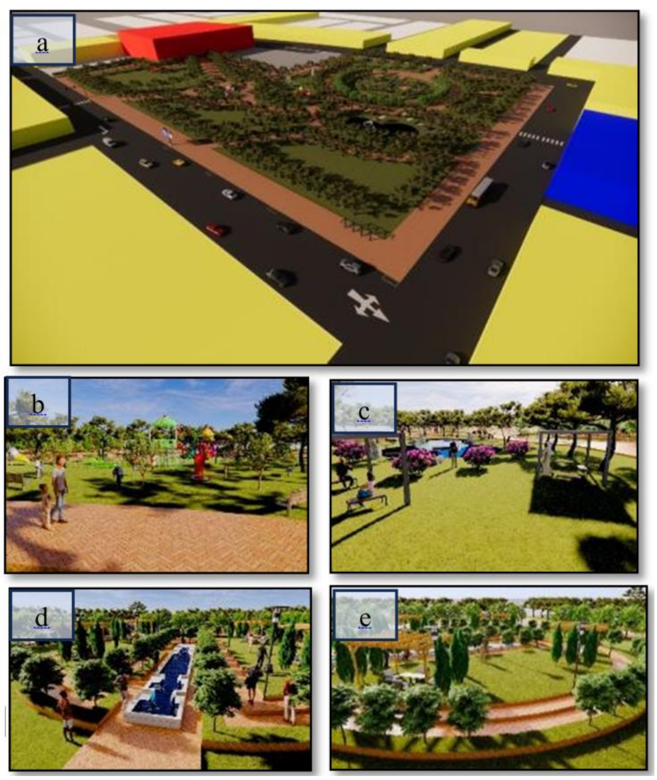

Fig. 10. Spatial layout of the second design alternative, showing key elements such as entertainment areas (b), seating benches and umbrellas (c), a central water body (d), and shading trees along pedestrian paths (e), all organized to enhance social interaction and environmental comfort, Source: Authors, using SketchUp, Lumion.

Figure 10 illustrates the spatial configuration of the second design alternative, emphasizing its focus on creating an interactive, inclusive space. The layout incorporates entertainment zones (b), seating areas with shaded benches (c), a central water feature (d), and tree-lined paths (e) to enhance comfort and foster social engagement among park visitors.

C. The second alternative

The third design alternative focuses on educational integration and environmental sustainability by utilizing the park area adjacent to the school zone located on the eastern side of the residential complex. This proposal is based on a dual-function approach. The first function includes the creation of recreational and sports spaces aimed at providing students with opportunities for physical activity, leisure, and psychological restoration during and after school hours. The second function introduces outdoor learning environments through the installation of seating areas and canopies, enabling students to engage in educational activities within a natural setting that supports concentration and sensory engagement.

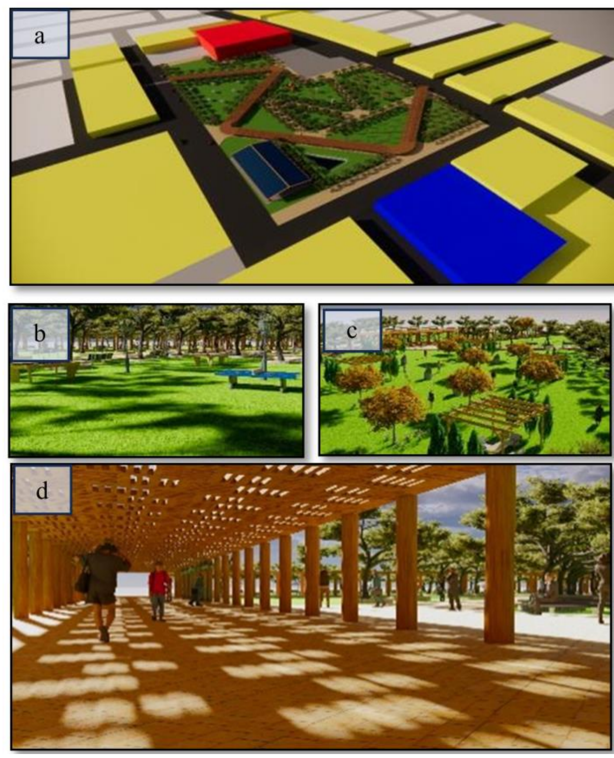

Fig. 11. Spatial configuration of the third design alternative, highlighting educational and ecological features such as motion-sensitive lighting (b), shaded seating areas (c), and covered pedestrian walkways (d), supporting both student activities and environmental sustainability, Source: Authors, using SketchUp, Lumion.

In addition to its educational orientation, the design incorporates a visually articulated entrance sequence through deliberate refractions in the movement axes. This spatial composition enables progressive visibility of different zones including social interaction spaces, children's play areas, and rest zones for the elderly thus enhancing user navigation and spatial legibility. The environmental dimension is addressed through the incorporation of solar panels placed at the far end of the park, supporting off-grid lighting solutions powered by motion-sensitive fixtures. This not only reduces reliance on conventional energy sources but also aligns with broader ecological thresholds related to energy efficiency and carbon reduction.

As illustrated in Figure 11, the third alternative includes key elements such as motion-sensitive lighting (b), shaded seating areas with umbrellas (c), and pedestrian walkway ceilings (d), all arranged to serve both educational and communal functions while maintaining climate responsiveness and spatial harmony. This design effectively addresses environmental, ethical, and educational sustainability goals by integrating multifunctional infrastructure and promoting responsible energy use.

VI. Simulation And Thermal Comfort Analysis

To evaluate the baseline climatic conditions within the Bayti residential complex, a thermal comfort simulation was conducted using the ENVI-met model. The analysis focused on the peak summer scenario, specifically on July 11, 2024—identified by the Iraqi Meteorological Organization as the hottest day of the year. Simulation data were captured between 2:00 p.m. and 4:00 p.m., aligning with the peak period of solar exposure and thermal stress.

The ENVI-met outputs revealed elevated surface temperatures throughout the study area, particularly in zones with minimal vegetation and high asphalt coverage. Wind speed was generally low, and relative humidity remained within typical summer thresholds for central Iraq. These conditions contributed to a significant decline in outdoor thermal comfort, particularly in areas lacking tree cover or shaded structures. The findings confirm that, under existing conditions, the current green space layout does not provide sufficient climatic mitigation, thus reinforcing the necessity of strategic redesign interventions based on sustainable thresholds.

Figure 12 presents the baseline environmental analysis for the study area. Subfigure (a) delineates the spatial extent of the Bayti residential complex and its land use configuration. Subfigure (b) displays the ENVI-met simulation results for summer, highlighting critical heat accumulation zones, particularly in areas lacking vegetation. Subfigure (c) shows the corresponding winter simulation, indicating improved thermal comfort but with persistent cold spots in shaded, wind-exposed areas. These visualizations provide a comparative understanding of the microclimatic challenges under current conditions and support the rationale for proposed green design interventions.

Having established the climatic shortcomings of the existing layout, particularly in terms of thermal discomfort during peak summer periods, the next section presents a detailed environmental simulation of the proposed green space design alternatives. Each alternative is evaluated using ENVI-met to assess its potential for improving microclimatic conditions and achieving thermal comfort in both summer and winter scenarios.

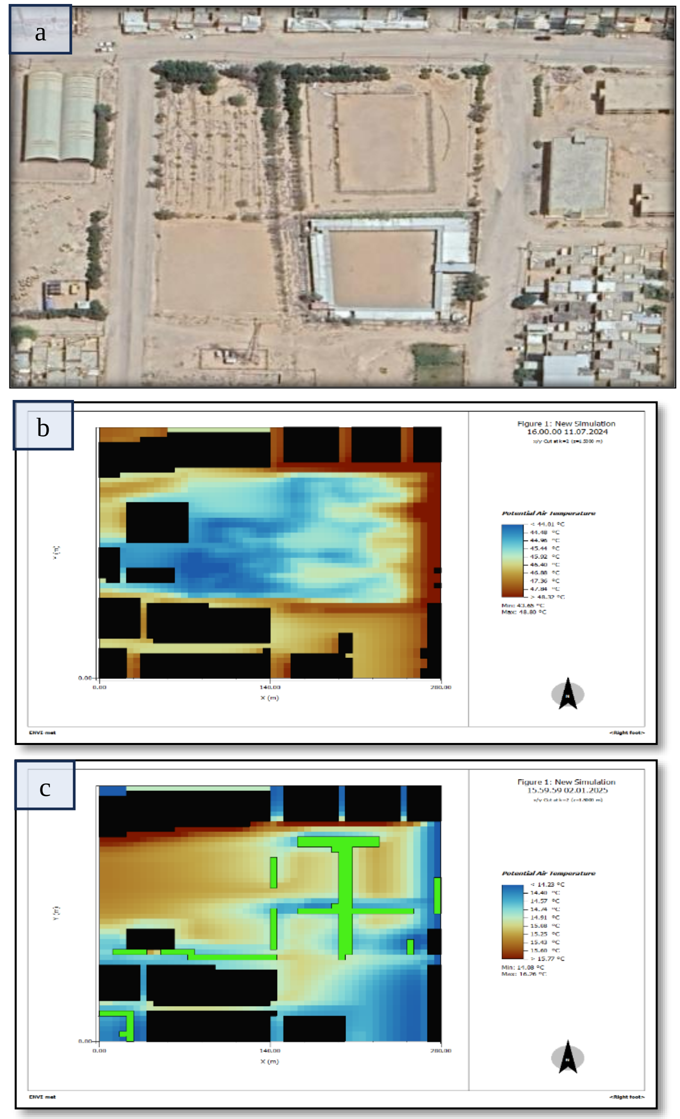

Fig. 12. Existing environmental conditions in the Bayti residential complex: (a) study area boundaries and land use layout, (b) simulated surface temperature distribution during peak summer hours using ENVI-met (July 11, 2024, 2–4 p.m.), and (c) simulated temperature distribution during a representative winter day. Source: Generated by authors using ENVI-met software (v5).

A. ENVI-met Simulation: First Design Alternative

The first design alternative was evaluated using ENVI-met simulations to measure its effectiveness in mitigating thermal stress during both summer and winter conditions. The simulation parameters remained consistent with the baseline analysis, with data collected on July 11, 2024, from 2:00 p.m. to 4:00 p.m., representing peak climatic stress conditions.

During summer, the simulation results revealed a noticeable reduction in surface temperatures across the park's core zone, particularly in areas adjacent to the commercial edge where shade structures, water features, and increased vegetative cover were introduced. The integration of economic kiosks and shaded plazas not only supported activity concentration but also contributed to moderating thermal hotspots through increased evapotranspiration and wind corridor design. This outcome reflects a clear improvement over the existing condition, aligning with the environmental thresholds for thermal comfort. In winter, the simulation indicated relatively moderate conditions with slight cold zones forming around heavily shaded areas. However, the spatial configuration preserved sufficient solar exposure in key gathering spaces, supporting usability throughout the year. Overall, the first alternative demonstrated the highest performance in terms of thermal comfort, particularly due to its combination of dense vegetation, diversified surface materials, and the presence of water elements.

Figure 13 illustrates the ENVI-met simulation results for the first design alternative. Subfigure (a) presents the average surface temperature distribution during summer, showing clear reductions in heat accumulation across shaded and vegetated zones. Subfigure (b) displays the winter scenario, revealing stable thermal conditions with minimal discomfort zones and effective sunlight access in core activity areas.

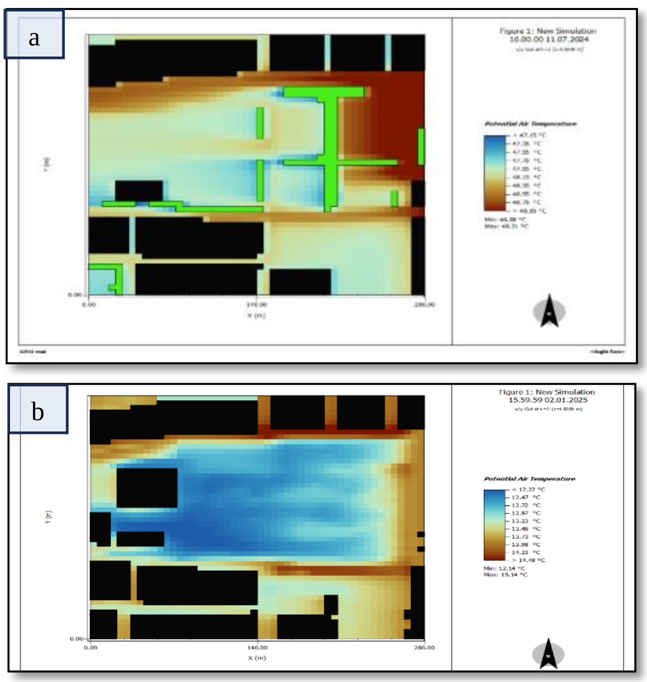

Fig. 13. ENVI-met simulation results for the first design alternative: (a) surface temperature distribution during summer (July 11, 2024, 2–4 p.m.), and (b) winter scenario illustrating thermal behavior across shaded and open areas. Source: Generated by authors using ENVI-met software (v5).

B. *ENVI-met Simulation: Second Design Alternative*

The second design alternative was assessed using ENVI-met simulations under the same climatic parameters applied in the baseline and first alternative analyses. Simulations were conducted on July 11, 2024, between 2:00 p.m. and 4:00 p.m., to evaluate the thermal performance of the spatial configuration during summer and winter conditions.

In the summer scenario, the results showed a moderate improvement in surface temperature distribution compared to the existing condition, though slightly less effective than the first alternative. The semi-buffering of the commercial zone through vegetative and spatial transitions contributed to reducing heat exposure along the park's edges. Central areas benefited from increased shading due to tree cover and seating elements, while the open interaction zones remained warmer due to limited overhead structures. Overall, the thermal comfort levels were acceptable but slightly lower in performance compared to the more densely vegetated first design. During winter, the configuration provided a balanced distribution of sunlight and shade, maintaining usability across the park. However, the more centralized activity layout and increased wind exposure in open corridors resulted in cooler localized areas, particularly along the axial paths. Nevertheless, the spatial design preserved solar access for key functions such as seating and play areas, supporting seasonal adaptability.

Figure 14 displays the ENVI-met simulation results for the second design alternative. Subfigure (a) illustrates surface temperature variation during peak summer hours, highlighting thermal moderation along vegetated boundaries. Subfigure (b) presents the winter simulation, revealing a generally stable thermal profile with minor cold spots in exposed circulation paths.

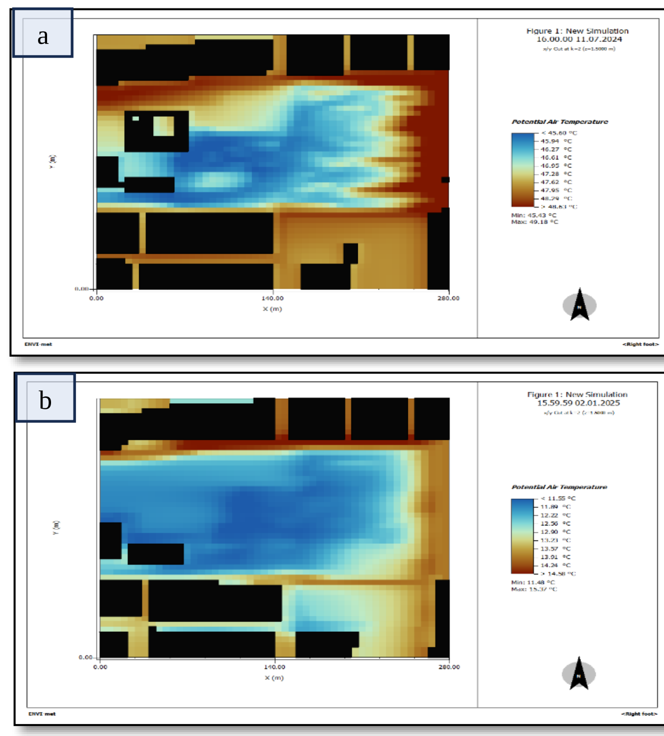

Fig. 14. ENVI-met simulation results for the second design alternative: (a) surface temperature distribution during summer (July 11, 2024, 2–4 p.m.), and (b) winter scenario showing thermal performance across central and peripheral park zones. Source: Generated by authors using ENVI-met software (v5).

C. *ENVI-met Simulation: Third Design Alternative*

The third design alternative was evaluated using ENVI-met under identical simulation parameters used in previous analyses, with measurements conducted on July 11, 2024, from 2:00 p.m. to 4:00 p.m. The objective was to assess the alternative's ability to regulate thermal comfort in both summer and winter conditions, especially in the context of educational and environmental functions integrated into the spatial layout.

During the summer simulation, the results indicated localized improvements in thermal comfort, particularly in areas near the educational canopy structures and vegetated walkways. The use of covered seating and pedestrian corridors provided partial shading and airflow regulation, contributing to a moderate reduction in surface temperature. However, due to the more open layout and lower vegetation density compared to the first alternative, heat accumulation persisted in some exposed zones. The inclusion of a water feature and solar-sensitive lighting had minimal direct impact on thermal conditions but contributed to overall environmental quality. In winter, the design performed relatively well, with open zones near the school edges receiving ample solar exposure, maintaining warmth during peak daylight hours. Shaded zones remained cooler but usable, and the orientation of pedestrian paths ensured passive solar gain in key circulation and seating areas. The layout's adaptability across seasons, particularly its balance between exposure and shading, supports its alignment with sustainable environmental thresholds.

Figure 15 presents the ENVI-met simulation outputs for the third design alternative. Subfigure (a) illustrates summer surface temperature patterns, with notable thermal relief in shaded educational zones and along vegetated paths. Subfigure (b) shows the winter scenario, where sunlight accessibility and moderate cooling were observed across both educational and social use areas.

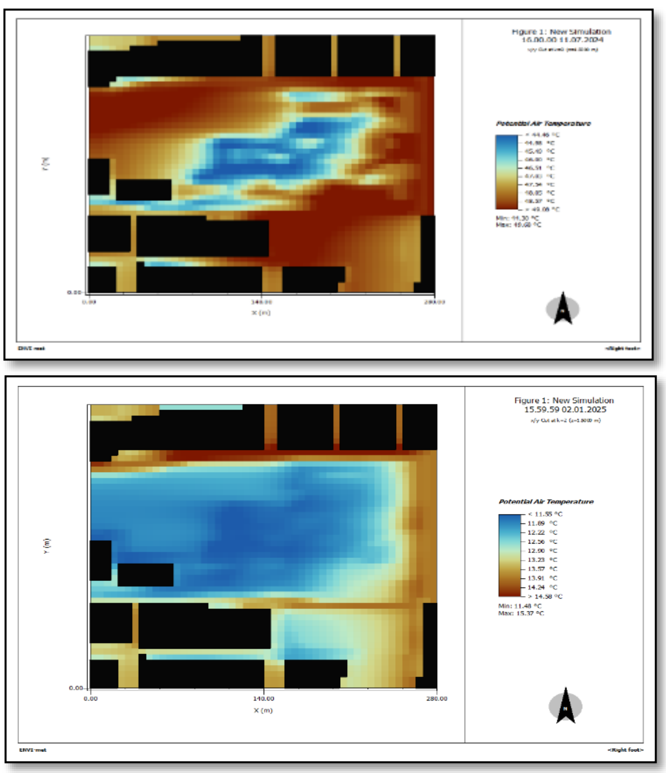

Fig. 15. ENVI-met simulation results for the third design alternative: (a) surface temperature distribution during summer (July 11, 2024, 2–4 p.m.), and (b) winter scenario reflecting thermal conditions in educational, recreational, and circulation zones. Source: Generated by authors using ENVI-met software (v5).

VII. Using The LEED-Nd System To Design Design Alternatives

To complement the ENVI-met environmental simulation results, the LEED for Neighborhood Development (LEED-ND v4.1) framework was adopted to provide a comprehensive sustainability assessment of the three proposed design alternatives. LEED-ND is an internationally recognized system that evaluates neighborhood-scale developments based on integrative criteria spanning environmental performance, spatial planning, social equity, and innovation. In this study, five core categories were selected: Smart Location & Linkage (SLL), Neighborhood Pattern & Design (NPD), Green Infrastructure & Buildings (GIB), Innovation (IN), and Regional Priority (RP). Each alternative was evaluated using a combination of spatial analysis, simulation outputs, and expert assessment, and the results are presented in Tables 3, 4, and 5. Table 3 shows the LEED-ND scores for the first alternative, which demonstrated strong performance in GIB and NPD due to its integration of kiosks, shaded gathering spaces, and compact pedestrian networks. Table 4 outlines the evaluation of the second alternative, which scored moderately across categories, with a particular emphasis on spatial equity and diversified access. Table 5 details the third alternative's performance, highlighting its innovative use of educational spaces and solar energy features, which contributed positively to the IN and RP categories. These evaluations serve as a structured basis for identifying the most context-appropriate and sustainability-oriented design solution.

TABLE III. First Alternative Evaluation

Main category	**Indicators (headings)**	**Indicator type**	**Number of possible points**
1. Smart Location & Linkage	Site selection, proximity to services, environmental protection, transport connectivity	Prerequisite + Points	28 points
- Smart location and land use	Credit	Up to 10 points	7
- Protection of the environment and sensitive areas	Prerequisite + Credit	1 condition + up to 2 points	3
- Proximity to public transportation	Credit	Up to 7 points	6
- Connecting to the surrounding community	Credit	Up to 3 points	1
- Reducing impacts on natural sites	Credit	Up to 3 points	2
2. Neighborhood Pattern and Design	Density, walkability, mix of uses, accessibility, universal design	Prerequisite + Points	44 points
- Density and condensation	Credit	Up to 2 points	1
- Walkability and comfort for pedestrians	Prerequisite + Credit	1 condition + up to 6 points	4
- Mixed uses	Credit	Up to 5 points	4
- Easy access to public spaces	Credit	Up to 2 points	2
- Contextually responsive architectural design	Credit	Up to 4 points	2
- Urban fabric and network distribution	Credit	Up to 4 points	3
- Reducing	Credit	Up to 7 points	3

dependence on cars			
- Participatory planning practices	Credit	Up to 1 point	1
3. Green Infrastructure & Buildings	Energy, Water, Materials, Green Buildings	Prerequisite + Points	31 points
- Certified green buildings	Prerequisite + Credit	1 condition + up to 5 points	1
- Use of renewable energy	Credit	Up to 3 points	2
- Water use efficiency	Credit	Up to 5 points	3
- Rainwater management	Prerequisite + Credit	1 condition + up to 4 points	3
- Sustainable materials and waste reduction	Credit	Up to 4 points	3
-Indoor air quality and health practices	Credit	Up to 2 points	2
4. Awareness and Innovation	Innovative solutions, exceptional performance, active participation	Points only	6 points
- Innovation in design or processes	Credit	Up to 5 points	3
- Relying on a LEED AP ND certified design team	Credit	1 point	0
Total = 55 point (silver)			

Source: Authors' compilation based on LEED for Neighborhood Development (v4.1) framework.

TABLE IV. SECOND ALTERNATIVE EVALUATION

Main category	Indicators (headings)	Indicator type	Number of possible points
1. Smart Location & Linkage	Site selection, proximity to services, environmental protection, transport connectivity	Prerequisite + Points	28 points
- Smart location and land use	Credit	Up to 10 points	7
- Protection of the environment and sensitive areas	Prerequisite + Credit	1 condition + up to 2 points	2
- Proximity to public transportation	Credit	Up to 7 points	6
- Connecting to the surrounding community	Credit	Up to 3 points	2
- Reducing impacts on natural sites	Credit	Up to 3 points	2
2. Neighborhood Pattern and Design	Density, walkability, mix of uses, accessibility, universal design	Prerequisite + Points	44 points
- Density and condensation	Credit	Up to 2 points	1
- Walkability and comfort for pedestrians	Prerequisite + Credit	1 condition + up to 6 points	3
- Mixed uses	Credit	Up to 5 points	1
- Easy access to public spaces	Credit	Up to 2 points	2
- Contextually responsive architectural design	Credit	Up to 4 points	2
- Urban fabric and network distribution	Credit	Up to 4 points	2
- Reducing dependence on cars	Credit	Up to 7 points	1
- Participatory planning practices	Credit	Up to 1 point	1
3. Green Infrastructure & Buildings	Energy, Water, Materials, Green Buildings	Prerequisite + Points	31 points
- Certified green buildings	Prerequisite + Credit	1 condition + up to 5 points	1
- Use of renewable energy	Credit	Up to 3 points	2
- Water use efficiency	Credit	Up to 5 points	2
- Rainwater management	Prerequisite + Credit	1 condition + up to 4 points	1
- Sustainable materials and waste reduction	Credit	Up to 4 points	3
-Indoor air quality and health practices	Credit	Up to 2 points	2
4. Awareness and Innovation	Innovative solutions, exceptional performance, active participation	Points only	6 points
- Innovation in design or processes	Credit	Up to 5 points	2
- Relying on a LEED AP ND certified design team	Credit	1 point	0
Total = 44 point (Certified)			

Source: Authors' compilation based on LEED for Neighborhood Development (v4.1) framework.

TABLE V. THIRD ALTERNATIVE EVALUATION

Main category	Indicators (headings)	Indicator type	Number of possible points
1. Smart Location & Linkage	Site selection, proximity to services, environmental protection, transport connectivity	Prerequisite + Points	28 points
- Smart location and land use	Credit	Up to 10 points	7
- Protection of the environment and sensitive areas	Prerequisite + Credit	1 condition + up to 2 points	2
- Proximity to public transportation	Credit	Up to 7 points	6
- Connecting to the surrounding community	Credit	Up to 3 points	3
- Reducing impacts on natural sites	Credit	Up to 3 points	2
2. Neighborhood Pattern and Design	Density, walkability, mix of uses, accessibility,	Prerequisite + Points	44 points

	universal design		
- Density and condensation	Credit	Up to 2 points	2
- Walkability and comfort for pedestrians	Prerequisite + Credit	1 condition + up to 6 points	4
- Mixed uses	Credit	Up to 5 points	2
- Easy access to public spaces	Credit	Up to 2 points	2
- Contextually responsive architectural design	Credit	Up to 4 points	2
- Urban fabric and network distribution	Credit	Up to 4 points	2
- Reducing dependence on cars	Credit	Up to 7 points	2
- Participatory planning practices	Credit	Up to 1 points	1
3. Green Infrastructure & Buildings	Energy, Water, Materials, Green Buildings	Prerequisite + Points	31 points
- Certified green buildings	Prerequisite + Credit	1 condition + up to 5 points	1
- Use of renewable energy	Credit	Up to 3 points	2
- Water use efficiency	Credit	Up to 5 points	2
- Rainwater management	Prerequisite + Credit	1 condition + up to 4 points	2
- Sustainable materials and waste reduction	Credit	Up to 4 points	3
-Indoor air quality and health practices	Credit	Up to 2 points	2
4. Awareness and Innovation	Innovative solutions, exceptional performance, active participation	Points only	6 points
- Innovation in design or processes	Credit	Up to 5 points	4
- Relying on a LEED AP ND certified design team	Credit	1 point	0
Total = 52 point (silver)			

Source: Authors' compilation based on LEED for Neighborhood Development (v4.1) framework.

VIII. Results And Discussion

The results of the applied analysis for the Bayti residential complex confirm the efficacy of integrating sustainable threshold indicators within the early stages of green space planning. By aligning environmental, social, and economic dimensions, the proposed alternatives achieved notable improvements in both spatial performance and user experience. Climate simulations using the ENVI-met model demonstrated that all three design alternatives enhanced thermal comfort relative to the baseline condition. However, the first alternative exhibited superior performance in mitigating surface temperature during peak summer periods and increasing shade coverage across activity zones. This outcome indicates that the design exceeded the environmental threshold associated with urban thermal regulation.

On the social dimension, the first alternative proved more effective in promoting inclusivity and active public engagement. Its spatial layout, which features accessible walkways, open plazas, and age-inclusive recreational areas, fostered greater potential for social interaction, thus enhancing the social equity index. Additionally, the incorporation of multiple entry points and balanced distribution of functions encouraged behavioral attachment and a sense of community ownership.

From an economic standpoint, the first alternative introduced a functional model for leveraging green spaces as hubs of local economic activity. By allocating space for micro-enterprises, kiosks, and market stalls adjacent to the commercial edge, the design created opportunities for job generation and informal commerce. This integration elevated its score on the local economic empowerment index, reflecting its potential to support small-scale economic resilience.

When aggregated within a composite evaluation matrix combining ENVI-met results and LEED-ND scores, the first design alternative achieved the highest cumulative score across all categories. This comprehensive performance validates its selection as the most suitable and sustainable solution among the proposed options. The findings underscore the critical importance of adopting sustainability thresholds not as post-design evaluations but as guiding principles in the formative stages of urban design. This approach not only ensures functional and climatic adaptability but also strengthens long-term social equity and economic viability in emerging urban contexts.

IX. Conclusion

This study examined the role of sustainable thresholds in planning urban green spaces within emerging residential environments, using the Bayti residential complex in Najaf as a case study. The research employed a multi-dimensional analytical approach combining spatial analysis, climate simulation (ENVI-met), and sustainability evaluation (LEED-ND v4.1) to assess the performance of three design alternatives. The findings confirmed that the absence of integrated environmental, social, and economic benchmarks in conventional planning leads to suboptimal outcomes, particularly in contexts subject to climate stress and rapid urban growth.

Among the proposed alternatives, the first design option emerged as the most effective in achieving thermal comfort, social inclusivity, and local economic activation. Its performance surpassed both environmental and socio-economic thresholds, demonstrating the practical value of embedding these criteria from the earliest stages of design. Compared to the baseline, the simulation results revealed substantial reductions in surface temperature and improved spatial usability. Moreover, the LEED-ND evaluation highlighted the first alternative's alignment with international sustainability standards, particularly in categories related to urban pattern, innovation, and green infrastructure.

The study emphasizes that applying threshold-based sustainability frameworks enables urban designers and planners to move beyond aesthetic or formal solutions, and toward evidence-based, equitable, and resilient design strategies. Such integration is essential not only to enhance microclimatic performance and spatial functionality but also to promote long-term social justice and economic sustainability in rapidly transforming cities. Future urban development projects, especially in Middle Eastern contexts, would benefit from institutionalizing sustainable thresholds as formal planning tools to guide green space design and management.

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