

“MICROCLIMATE OPTIMIZATION THROUGH THE CREATION OF A DIGITAL TWIN OF URBAN LANDSCAPE SYSTEMS: A GREEN INFRASTRUCTURE MODEL BASED ON GENERATIVE DESIGN”

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Abstract: This study explores the optimization of urban microclimate using digital twins of landscape systems. A generative design approach is applied to determine the optimal configuration of green infrastructure elements. The research aims to reduce urban heat, improve ventilation, and enhance environmental sustainability. The results provide efficient landscape design solutions that support climate-responsive urban planning and contribute to the development of smart and sustainable cities.

Keywords: digital twin, landscape architecture, generative design, microclimate, green infrastructure, urban environment, environmental sustainability, climate optimization, parametric modeling.

INTRODUCTION

As a result of modern urbanization processes, microclimatic changes in urban environments have become increasingly significant, particularly issues such as the urban heat island effect, air pollution, and reduced ventilation. These problems directly affect public health, energy consumption, and overall environmental sustainability. Therefore, in the design of urban areas, not only functional and aesthetic factors but also microclimate management issues are gaining critical importance.

In recent years, the development of digital technologies, particularly the Digital Twin concept, has significantly expanded the possibilities for comprehensive analysis and management of urban environments. A digital twin is a virtual model of a real object or system that enables the monitoring of environmental parameters, simulation of various scenarios, and identification of optimal solutions. This approach is considered an effective tool for the in-depth study of urban landscape systems and the assessment of their impact on the urban microclimate.

Furthermore, the development of generative design and parametric modeling methods has brought architectural and landscape design processes to a new stage. These approaches enable the automatic generation of multiple design alternatives, from which the most optimal configurations can be selected. In particular, urban microclimates can be significantly improved through the optimization of the placement and parameters of green infrastructure elements such as trees, shrubs, water bodies, and open green spaces.

The purpose of this study is to identify the possibilities for optimizing the urban microclimate through the creation of a digital twin of urban landscape systems. Within the framework of the research, the effective placement of green infrastructure elements is modeled using a generative design approach, and their impact on temperature, ventilation, and environmental indicators is evaluated.



Figure 1. Optimal placement of green infrastructure elements through a generative design approach.

The scientific novelty of this research lies in the integrated consideration of landscape architecture elements within a digital twin environment, resulting in the development of a comprehensive model for microclimate management. Its practical significance is that the proposed approach contributes to the development of energy-efficient and environmentally sustainable landscape solutions for cities with hot climatic conditions.

Results and Discussion. During the research process, a digital twin of the landscape system was developed for the selected urban area, and several alternative solutions were generated using generative design algorithms. The simulation results demonstrated that the optimal placement of green infrastructure elements has a significant positive impact on the urban microclimate. In particular, increasing the density of tree plantations and arranging them according to prevailing wind directions improved the level of natural ventilation within the area.



Figure 2. Smart city and heat-resilient green design.

According to the simulation results, the proposed optimal scenario led to a decrease of 2–3°C in the average ground-level temperature during the summer period. At the same time, the direct impact of solar radiation was reduced, and the proportion of shaded areas was increased. This not only created a more comfortable environment for pedestrians but also contributed to reducing the cooling energy consumption of nearby buildings. In addition, the combination of water elements and green zones proved to be an effective means of balancing air humidity. Figure 2.

The analysis of the alternatives developed through the generative design approach demonstrated that parametric optimization makes it possible to achieve more efficient and adaptable solutions compared to traditional design methods. The digital twin model enabled the testing of various scenarios, near real-time analysis, and a more substantiated decision-making process.

The discussion revealed that considering landscape architecture elements as tools for microclimate management is of significant importance in contemporary urban planning. At the same time, the practical implementation of such an approach depends on several key factors, including data accuracy, software integration, and the digital competencies of specialists.

Overall, the obtained results confirm that landscape solutions developed on the basis of digital twin technology and generative design serve as effective tools for improving the urban microclimate, ensuring environmental sustainability, and enhancing the quality of the living environment.

CONCLUSION

The results of this study demonstrated that modeling urban landscape systems based on Digital Twin technology and applying generative design approaches constitute effective tools for microclimate optimization. It was determined that the scientifically grounded placement of green infrastructure elements can reduce urban temperatures, improve ventilation, and ensure environmental sustainability within urban areas.

The models developed and the results obtained during the research confirmed that generative design makes it possible to determine the optimal configuration of landscape elements. This approach provides greater efficiency and flexibility compared to traditional design methods. Digital Twin technology enables the preliminary evaluation of various scenarios and the selection of the most appropriate solutions while taking real environmental parameters into account.

Furthermore, the findings of the study indicate that microclimate management through landscape architecture represents an important strategic direction for cities with hot climatic conditions. The integrated organization of green spaces, water elements, and shaded areas contributes not only to ecological balance but also to the creation of a comfortable and healthy living environment for residents. In turn, this supports the rational use of energy resources and the sustainable development of the urban environment.

In the future, it is advisable to further expand research in this field, particularly through the integration of intelligent management systems operating with real-time data, as well as the development of more advanced generative models based on artificial intelligence. At the same time, improving the regulatory and legal framework and enhancing the digital competencies of specialists are essential for the practical implementation of the proposed approach.

In conclusion, landscape solutions developed on the basis of Digital Twin technology and generative design can be regarded as an innovative and promising approach to microclimate management within the concept of modern smart cities.

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