THE IMPACT OF URBAN STREET CANYON MORPHOLOGY ON THE MICROCLIMATE ENVIRONMENT: THE CASE OF THE REPRESENTATIVE BUSINESS DISTRICTS IN SEOUL, KOREA (1091)

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Abstract. As urbanization progresses worldwide, high-density development emerges around major cities. Korea, with an 81.9% urbanization rate (2021), is no exception, especially in Seoul. The central and Gangnam districts have strong street canyon features due to complex land surfaces, urban morphology, and heavy transportation. These factors, combined with polluted traffic emissions, threaten urban residents' thermal and pollutant exposure. Understanding vulnerable areas in terms of microclimate and ventilation is vital for livability, sustainability, and resilience in urban planning. Using Ladybug & Dragonfly in Rhino's Grasshopper, we analyzed the correlation between street canyon morphology, microclimate, and the urban heat island index. The study focuses on the geometric characteristics of urban spaces, particularly high-rise buildings and roads forming street canyons, and their impact on microclimate(thermal comfort). The findings contribute to effective management, fostering sustainable urban forms and redeveloping street spaces with consideration for the microclimate environment.

Keywords: Urban Morphology, Urban Street Canyon, Microclimate Environment, Sustainable Urban Planning, UTCI Simulation.

1. Introduction

Today, more than half of the world's population lives in urban areas. This figure was only 30% in the 1950s, but it is expected to surpass two-thirds of the world's urban population by the 2050s. Since 2000, the urban population ratio in Korea has exceeded 80% and continues to increase. By 2050, it is projected that 90% of the population will reside in urban areas. In the case of Seoul, the capital of Korea, the population density was recorded at 15,650 persons per square kilometer in 2021. Within the context of high population density, urban development is occurring, accompanied by issues such as chaotic urban expansion, traffic congestion, environmental pollution, resource scarcity, and public health concerns. Moreover, this concentration of high population density leads to severe vulnerability to climate change.

Sustainable urban development has gained global consensus and a shared vision as a response to these issues. Nowadays, people expect sustainable urban spatial forms, including residential environments, to function in a more efficient manner and overcome climate vulnerability. Therefore, analyzing the environmental impacts based on the geometric characteristics of urban form and space is of great importance.

Seoul, as a representative city with high population density, possesses complex topography and urban form characteristics. In commercial and business areas, characteristics such as heavy transportation and strong street canyons emerge. These characteristics result from the high density of buildings and high floor area ratio, which are essential considerations for accommodating a high population within limited land, shaping a cityscape resembling a forest of buildings. As a fundamental geometric unit of urban form, the urban street canyon plays a crucial role in shaping the microclimate of central commercial and business areas. Urban street canyons, defined by various geometric parameters such as aspect ratio (H/W) and orientation, determine solar access, shading, wind conditions, and influence air and surface temperatures. Consequently, these microclimate conditions significantly affect outdoor thermal comfort indicators like the urban heat island (UHI) effect and the universal thermal climate index (UTCI). In recent decades, numerous studies have investigated the effects of urban canyon geometries, such as street aspect ratio and orientation, on the distribution patterns of microclimate parameters, including heat flux, air temperature, wind flow, and solar access, through field measurements or numerical simulations.

Urbanization is an inevitable process in human development. To create sustainable cities in the future, it is crucial to understand the characteristics of regions exhibiting climate vulnerability and address urban environmental issues related to microclimate phenomena such as UHI and UTCI. In this study, we aim to analyze the correlation between urban street canyon morphology and the microclimate environment by examining the geometrical characteristics of the central commercial and business areas in Seoul where the characteristics of urban street canyons are strongly pronounced (Central, Gangnam Business Districts). We will investigate the outdoor thermal comfort using microclimate simulations (Ladybug & Dragonfly in Parametric Rhinoceros plugins Grasshopper). Through this research, we seek to analyze the correlation between urban street canyon morphology and the microclimate environment, promoting effective and continuous management of urban spaces. The results can be applied to establishing sustainable urban forms and redevelopment of urban street spaces, taking into account the microclimate environment.

2. Site description and climate characteristic

Description of Seoul

This study was conducted for typical summer conditions in Seoul, Republic of Korea. Seoul is characterized by a distinct four-season temperate climate, with hot and humid summers, where the average maximum temperature ranges around 34 degrees Celsius (Figure 1). As the impact of climate change and urban heat island (UHI) intensifies, Seoul has experienced an increasing number of heat wave events in recent years. In particular, in 2018, there were 31 days with temperatures exceeding 35°C, marking the highest number of such days on record. According to the "Korea Climate Change Assessment Report 2020," the number of heat wave days in Korea is projected to continue increasing due to rising temperatures. It is expected that by the late 21st century, an average of 35.5 heat wave days per year will be observed, with over 30% of summer days classified as heat wave days. Therefore, to minimize the effects of climate change and urban heat island, it is important to explore the impact of urban morphology on local thermal comfort and seek measures to mitigate these effects.

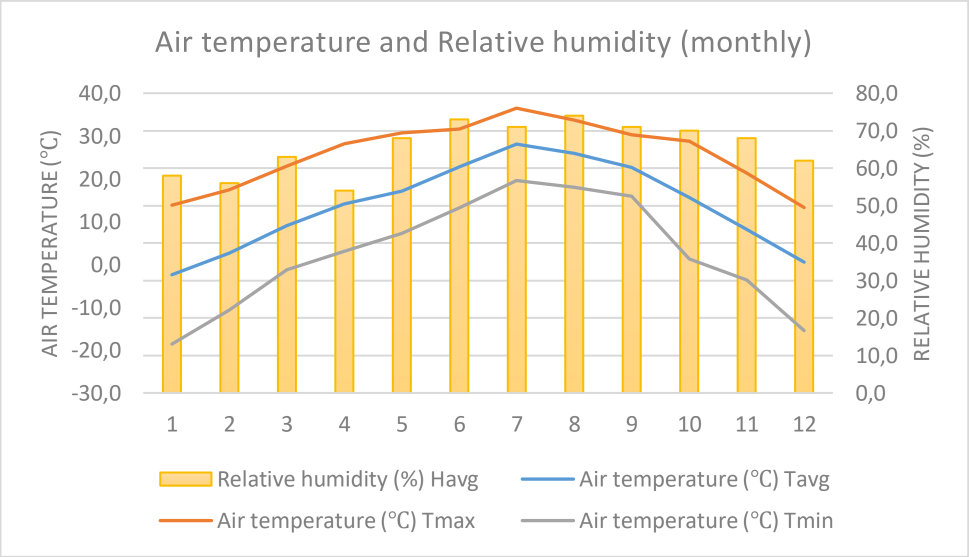

Figure 151. Air temperature and Relative humidity in Seoul

The study area focused on three central business and commercial districts with high population density during the day: Central, Gangnam Business Districts(Figure 2, 3). These areas exhibit a dense urban morphology with high buildings, highlighting the characteristics of Urban Street Canyons. By examining Figures 4 and 5, it is evident that the central commercial and business districts exhibit high values of daytime population density. The presence of a high population density in these densely populated areas is often associated with tall building heights and high plot ratios. Consequently, these characteristics increase the vulnerability to urban heat island effects, stagnant air pollution, and other aspects related to thermal comfort in the Urban Street Canyon.

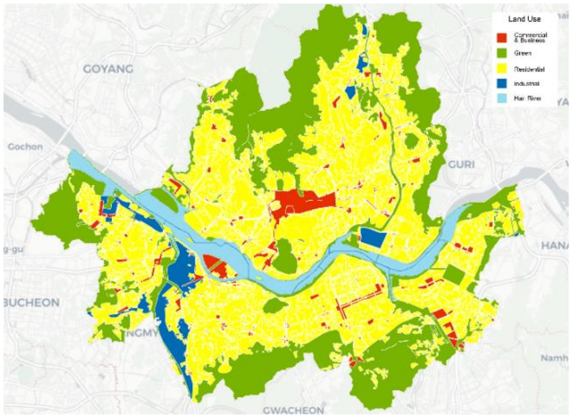

Figure 2. Land Use Plan in Seoul, Republic of Korea

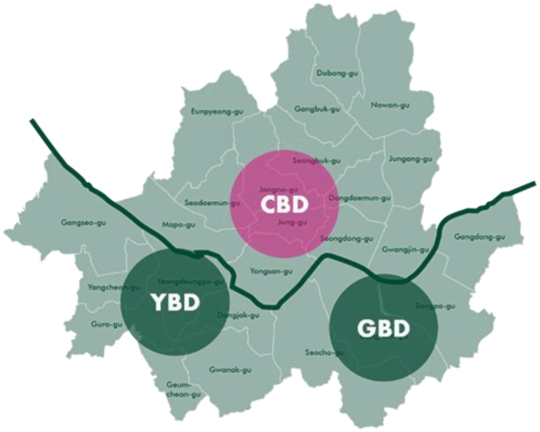

Figure 3. Three representative business districts in Seoul

Figure 4. Business and commercial districts in Seoul

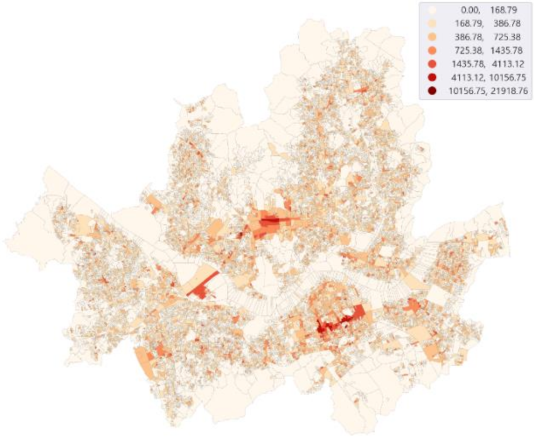

Figure 5. Weekly Living Population Density(pop/km2) in Seoul

Geometrical characteristic of urban street canyon

In the central business district of Jongro-gu in Seoul(Figure 6-left), the urban street canyon exhibits unique characteristics in terms of population density, building floor area ratio, and environmental aspects, with a notable feature being the presence of the Cheonggyecheon Stream. Firstly, the population density in the central business district of Jongro-gu is relatively high. As a prominent commercial and administrative hub, the district attracts a large number of residents, workers, and tourists. The area is bustling with activity, leading to a dense concentration of people and contributing to a vibrant urban atmosphere. Secondly, the building floor area ratio in the central business district is also significant. Tall office buildings, commercial complexes, and government institutions dominate the skyline, showcasing the efficient utilization of available land and the vertical growth of the district. The high building floor area ratio indicates the intensive use of space for commercial and administrative purposes. Furthermore, the environmental aspect in the urban street canyon of Jongro-gu's central business district is notable due to the presence of the Cheonggyecheon Stream. The Cheonggyecheon Stream is a restored waterway that runs through the heart of the district, providing a refreshing and natural element within the urban environment. The stream offers a serene escape from the bustling cityscape and serves as a recreational and cultural space for residents and visitors. The combination of high population density, a significant building floor area ratio, and the presence of the Cheonggyecheon Stream influences the district's environment. The stream contributes to the enhancement of the urban landscape, providing ecological benefits, promoting biodiversity, and improving air quality. It also offers a cooling effect, mitigating the urban heat island effect and enhancing the overall microclimate in the area. Considering the complex dynamics of the urban street canyon in Jongro-gu's central business district, it is essential to strike a balance between urban development and environmental sustainability. This can be achieved through the implementation of green infrastructure, such as parks and green spaces, the promotion of sustainable transportation options, and the continuous preservation and enhancement of the Cheonggyecheon Stream as a valuable natural asset in the district.

In the Gangnam business district of Gangnam-gu in Seoul(Figure 6-mid), the urban street canyon exhibits distinct characteristics in terms of population density and building floor area ratio. The area is known for its vibrant commercial activities and high concentration of businesses and offices. Firstly, the population density in the Gangnam business district is notably high. The district attracts a significant number of residents, workers, and visitors due to its bustling nature and prominent economic activities. The population density is intensified by the presence of numerous commercial establishments, entertainment venues, and transportation hubs, contributing to a dense urban environment. Secondly, the building floor area ratio in the Gangnam business district is generally high. The district features a vertical urban landscape with tall buildings and a substantial utilization of available land for construction purposes. The high building floor area ratio reflects the efficient use of space and the presence of towering structures that define the district's skyline. The combination of high population density and a high building floor area ratio in the urban street canyon of Gangnam-gu's business district contributes to various effects. The concentration of people and buildings intensifies the urban heat island effect, exacerbating heat retention and temperature rise within the district. It may also result in reduced air circulation and increased pollution levels, affecting the overall microclimate and thermal comfort in the area. Considering the dense urban morphology and the challenges posed by the high population density and building floor area ratio, it is crucial to implement appropriate urban planning strategies. These strategies should focus on promoting sustainable development, enhancing green spaces, improving pedestrian infrastructure, and implementing measures to mitigate the adverse effects of the urban street canyon on local climate, air quality, and the well-being of residents and visitors.

The urban street canyon in the central business district near the Cheonggyecheon Stream exhibits distinctive characteristics in terms of population density and building floor area ratio(Figure 7). The central business district near the Cheonggyecheon Stream is known for its high population density. The area attracts a large number of residents, commuters, and tourists due to its strategic location and vibrant urban environment. The population density in this district is typically higher compared to other areas in Seoul. The concentration of people contributes to the lively atmosphere and bustling activity, making it a vibrant hub of economic and social interactions. The central business district near the Cheonggyecheon Stream is characterized by high building floor area ratios. The district is densely developed, with tall buildings and a mix of commercial, residential, and office spaces. The utilization of land is maximized, and buildings often have multiple floors and compact footprints to accommodate the high demand for space in this prime location. The vertical expansion of buildings helps accommodate the growing population and meet the requirements of various businesses and organizations. Together, the high population density and building floor area ratio in the central business district near the Cheonggyecheon Stream create a unique urban street canyon. The tall buildings and compact urban form contribute to the formation of narrow street corridors, enhancing the canyon-like effect. This urban configuration can influence the microclimate, creating localized airflows, shading patterns, and temperature variations within the street canyon. Additionally, the presence of the Cheonggyecheon Stream adds an environmental element, providing a natural feature and promoting a more pleasant and cooler microclimate in the area. Overall, the combination of high population density, dense building development, and the presence of the Cheonggyecheon Stream characterizes the urban street canyon in the central business district near the Cheonggyecheon Stream, creating a dynamic and vibrant urban environment.

Figure 6. Urban Street Canyon in each business district

(Left: Central Business District, Right: Gangnam Business District)

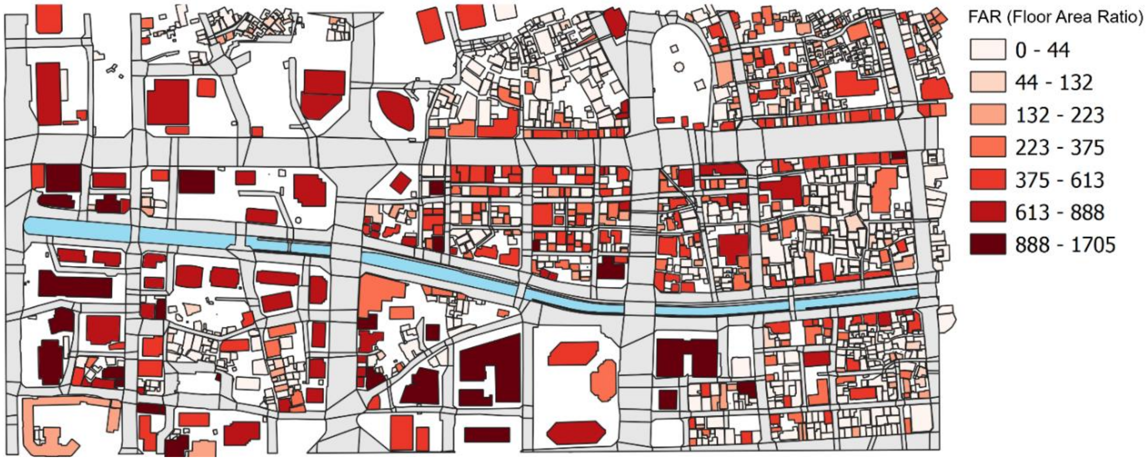

Figure 7. Building Floor Area Ratio Diagram in CBD(Central Business District in Jongro-gu)

The Gangnam business district(Figure 8) features a long continuous urban street canyon that can be described from the perspectives of population density, building floor area ratio, and surrounding environment. The Gangnam business district is known for its high population density. It attracts a significant number of residents, workers, and visitors due to its prominence as a commercial and financial hub. The area is densely populated, with a mix of residential, commercial, and office spaces. The high population density contributes to the district's energetic atmosphere, vibrant street life, and diverse cultural offerings. The building floor area ratio in the Gangnam business district is relatively high. The district boasts tall and modern buildings that make efficient use of limited land space. The buildings often have multiple floors, maximizing the utilization of available land and accommodating the demand for commercial and office spaces. The high building floor area ratio in Gangnam reflects the district's status as a prestigious and sought-after location for businesses and organizations. The surrounding environment of the urban street canyon in Gangnam is characterized by a mix of urban elements and amenities. The district is well-developed with modern infrastructure, wide roads, and pedestrian-friendly areas. Surrounding the urban street canyon, you can find a variety of amenities, including luxury retail stores, restaurants, cafes, entertainment venues, and cultural institutions. The district's well-maintained public spaces, such as parks and plazas, provide opportunities for relaxation and social interaction. Moreover, the Gangnam business district is situated in close proximity to the scenic Han River, which adds to the district's appeal. The river serves as a recreational area and offers beautiful views, creating a more pleasant environment for residents, workers, and visitors. The presence of green spaces, trees, and landscaping efforts further enhances the overall ambiance of the urban street canyon in Gangnam. In summary, the long continuous urban street canyon in the Gangnam business district is characterized by high population density, a significant building floor area ratio, and a vibrant surrounding environment. The combination of these factors creates a lively and dynamic atmosphere, attracting people from various walks of life and contributing to the district's reputation as a bustling economic and cultural center.

Figure 8. Building Floor Area Ratio Diagram in GBD (Gangnam Business District in Gangnam-gu)

3. Methodology

Ladybug and Dragonfly are parametric plugins for Rhinoceros and Grasshopper that are widely used for analyzing microclimatic conditions and environmental effects in urban areas. Here is a description of the methodology of Ladybug and Dragonfly:

Ladybug: Ladybug is a plugin that provides various weather data analysis tools for environmental simulation. It allows users to import weather data from different sources and analyze parameters such as temperature, humidity, wind speed, and solar radiation.

Importing Weather Data: Ladybug allows users to import weather data from local weather stations or global weather datasets. This data includes hourly or daily values of temperature, humidity, wind speed, solar radiation, and other relevant climatic parameters.

Solar Analysis: Ladybug enables the calculation of solar radiation and shadow analysis for specific locations and times. It helps evaluate the availability of sunlight and shading patterns in urban environments, which is crucial for understanding the microclimatic conditions and energy performance of buildings.

Outdoor Comfort Analysis: Ladybug includes tools to assess outdoor thermal comfort using indices such as the Universal Thermal Climate Index (UTCI). It helps analyze the thermal stress on humans and evaluate the effectiveness of urban design strategies in providing comfortable outdoor environments.

Dragonfly: Dragonfly is a plugin that extends the capabilities of Ladybug and focuses on urban-scale environmental analysis. It allows users to simulate and evaluate the urban heat island effect, energy consumption, and other environmental factors.

Urban Heat Island Analysis: Dragonfly enables the assessment of the urban heat island (UHI) effect, which refers to the temperature difference between urban areas and their surrounding rural regions. It helps identify areas with higher UHI intensity and evaluate the impact of urban form, materials, and vegetation on temperature distribution.

Environmental Impact Analysis: Dragonfly supports the evaluation of various environmental factors, including daylighting, natural ventilation, and acoustic performance. It helps assess the impact of urban design decisions on these factors and optimize the design for better environmental outcomes.

By utilizing the powerful capabilities of Ladybug and Dragonfly, we conducted extensive microclimate and environmental analyses in the three bustling business districts of Seoul: the Central Business District, Gangnam Business District, and Yeouido Business District. Our simulations focused on assessing the urban heat island effect, evaluating outdoor thermal comfort using the Universal Thermal Climate Index (UTCI), analyzing daylight availability, and considering various other crucial environmental aspects. Through our rigorous analysis, we aim to uncover the intricate correlation between the morphology of urban street canyons and the microclimate environment. This comprehensive study provides valuable insights for urban planners and policymakers, enabling them to make informed decisions to enhance the sustainability, livability, and resilience of these dynamic urban areas.

4. Analysis Results

Through the simulation of thermal comfort considering the urban heat island effect using the Grasshopper plugins Ladybug & Dragonfly, notable differences were observed between the left and right sides of the Central Business District (CBD) (Figure 10). Interestingly, despite the prevalence of high-rise buildings with high floor area ratios on the left side (Figure 7), the thermal comfort indicators were relatively better compared to the right side. This can be attributed to the fact that although there are many large-scale buildings with high floor area ratios on the left side, the spacing between buildings is not densely packed, leading to a decrease in the influence of the urban heat island effect. On the contrary, the right side exhibited a trend of relatively lower thermal comfort indicators, even if the buildings were not particularly tall or spacious. This is due to the dense arrangement of buildings with narrow spacing between them, which enhances the urban heat island effect.

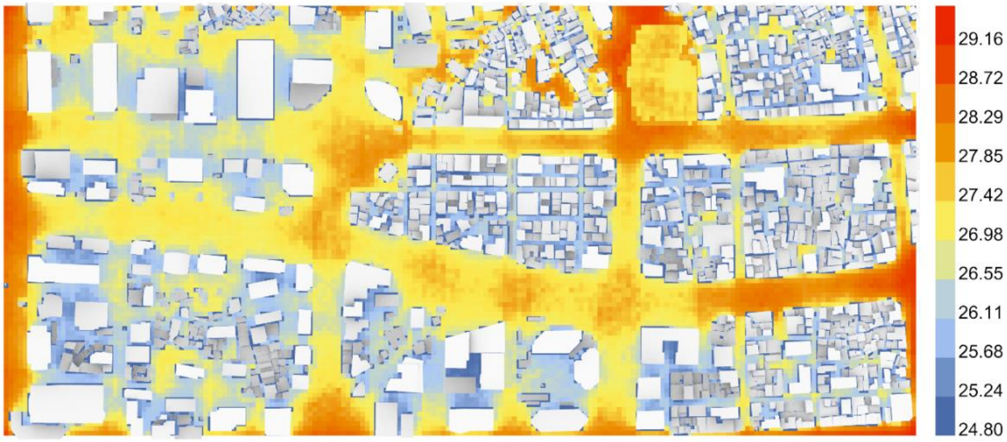

Figure 9. CBD_UTCI (Universial Temperature Climate Index) considering UHI (Urban Heat Island)

In the case of GBD (Gangnam Business District) (Figure 11), the urban street canyon showcases distinct features of intensive high-density development. Notably, the urban heat island effect becomes apparent within the dense forest of towering buildings. It is intriguing to observe that the areas experiencing the heat island effect coincide with regions characterized by taller structures, larger building sizes, and higher population density(Figure 8). This correlation suggests that the physical attributes of the built environment play a significant role in shaping the microclimate dynamics. The prevalence of tall buildings and increased population density contribute to the formation of localized heat islands, resulting in thermal discomfort and potential environmental challenges. Understanding these patterns and their implications is crucial for implementing effective urban design strategies that mitigate the adverse effects of the heat island phenomenon, ensuring a more sustainable and comfortable living environment for residents and visitors alike.

Figure 10. GBD_UTCI(Universial Temperature Climate Index) considering UHI(Urban Heat Island)

5. Discussion

The research highlights the global trend of increasing urbanization, with more than half of the world's population currently living in urban areas. Korea's urban population has exceeded 80% since 2000, and it is projected to reach 90% by 2050. Seoul, the capital of Korea, has a high population density, leading to various urban challenges such as chaotic urban expansion, traffic congestion, environmental pollution, resource scarcity, and public health concerns. The concentration of high population density also makes cities more vulnerable to climate change. In response to these issues, sustainable urban development has gained global consensus. The study aims to analyze the correlation between urban street canyon morphology and the microclimate environment in Seoul's central commercial and business areas. The characteristics of urban street canyons, such as aspect ratio and orientation, significantly affect microclimate conditions, including urban heat island (UHI) effect and thermal comfort. Seoul's climate is characterized by hot and humid summers, with an increasing number of heat wave events due to climate change and urban heat island effect.

The study focuses on two central business and commercial districts with high population density: Central and Gangnam Business Districts. These areas exhibit dense urban morphology and unique characteristics of urban street canyons. The urban street canyon in Jongro-gu's central business district is characterized by high population density, a significant building floor area ratio, and the presence of the Cheonggyecheon Stream. The combination of these factors influences the microclimate, providing ecological benefits, improving air quality, and mitigating the urban heat island effect. The Gangnam business district also has a high population density and building floor area ratio. It features a long continuous urban street canyon with a vibrant surrounding environment. The district's well-developed infrastructure, amenities, and proximity to the Han River enhance the overall ambiance.

Through thermal comfort simulations, the research reveals notable differences in thermal comfort indicators between the left and right sides of the Central Business District. Despite the prevalence of high-rise buildings on the left side, the spacing between buildings reduces the urban heat island effect compared to the densely arranged buildings on the right side. In the case of the Gangnam Business District, the dense forest of tall buildings contributes to the urban heat island effect. Areas experiencing the heat island effect coincide with regions characterized by taller structures, larger building sizes, and higher population density. Understanding these patterns is crucial for implementing effective urban design strategies to mitigate the adverse effects of the heat island phenomenon and create a more sustainable and comfortable living environment.

Overall, the research emphasizes the importance of analyzing the correlation between urban street canyon morphology and the microclimate environment to promote effective urban management, sustainable urban forms, and redevelopment of urban street spaces while considering the microclimate environment.

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