Exploring the potential of alley gardens in Seoul based on a study of Daegu

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Abstract. Seoul has experienced rapid economic growth and industrialization, and it has become the central city of South Korea. These densely populated urban spaces have undergone the urban heat island (UHI) phenomenon, wherein the temperature is higher than that of the surrounding areas. Green spaces constitute the primary response to this problem, yet Seoul has not yet taken measures to create small-scale green spaces, such as alley gardens. Therefore, this study analyses the case of alley gardens in Daegu and argues for the necessity of their introduction. Alley gardens in Daegu have proven effective in reducing heat and have influenced the residential satisfaction of residents in densely populated, old housing. After confirming that the concept of alley gardens can serve as a micro-urban planning tool to establish small-scale green spaces and alleviate the UHI effect in Seoul, we explored the target areas where alley gardens can be applied within Seoul. Through heat-related environmental indicators and social factor indicators, this study found that Mullae-dong is experiencing the UHI effect, and that the introduction of alley gardens would have a positive impact due to the concentration of small-scale, old residences. This paper establishes the rationale for applying alley gardens to Seoul, while also deriving the importance and implications for the dissemination and revitalization of micro-level urban environment policies.

1 Introduction

Industrialization and the centralization of economic and social functions have increased the density of cities. The relatively high temperatures in these urban areas are referred to as the Urban Heat Island (UHI) effect. The UHI phenomenon has a negative impact on the urban environment, leading to increased demand for cooling energy in the summer and intensifying air pollution and smog. The factors contributing to the UHI effect are mainly classified as the artificialization of land cover, an increase in artificial layouts, and changes in urban form, and the solutions include replacement of pavement materials, the creation of urban green spaces, and the establishment of wind paths [1].

Table 1. Factors of UHI

Factors	
Artificialization of land cover	1. Decrease in evapotranspiration effect due to decrease in greenery, water surface, farmland, and many other environmental areas. 2. Absorption of heat, decrease in heat storage, and decrease in reflectivity due to the increase of pavement, asphalt, concrete surfaces by buildings, and other components.
Increase in artificial layout	1. Arrangement in buildings 2. Arrangement by business activities such as factories 3. Arrangement of automobiles
Change in urban form	1. Weakening of winds due to changes in urban form 2. Reduction of large-scale green areas and water surfaces that cool the city

Seoul, the capital of South Korea, suffers from the UHI effect due to rapid industrialization, resulting in a low amount of green space per capita (excluding mountainous area), which stands at 5.8m^2. This figure is low compared to other cities. Consequently, the creation of urban green spaces has become a major issue in addressing the UHI effect [2]. Since it is difficult to create large green spaces in already developed urban areas, the concept of small green spaces is emerging as a solution. In particular, the original city center, developed early in the city’s history, is characterized by a large built-up area and high density, but it lacks sufficient green space. Parks and green spaces are scarce or outdated, and old buildings are densely concentrated, intensifying the severity of the UHI effect [1].

In order to create small-scale green spaces in areas with concentrated old buildings, the concept of alley gardens has gained attention. Alley gardens involve creating gardens by placing individual pots or flower beds in alleyways. In addition to the effectiveness of green space creation, alley gardens are considered a means for residents to enhance the aging alley environment and restore a sense of community [3]. However, among various small-scale green spaces, alley gardens lack legal status and a clear definition, resulting

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in few official implementations. Alley gardens can play a positive role in generating green spaces by utilizing underutilized urban areas, fostering stronger bonds among local residents through the creation process, and promoting a sense of psychological stability [4]. The alley garden created by the Seo-gu Office of Daegu Metropolitan City, which started in 2015, stands as a representative example and one of the few cases.

This paper analyzes the case of alley gardens in Daegu to extract the significance and implications of alley gardens. Additionally, it identifies areas in Seoul, where the UHI phenomenon is particularly severe, suitable for the implementation of alley gardens. The purpose of this paper is to propose the possibility of creating small-scale green spaces as a strategy for mitigating the urban heat island phenomenon.

2 Methodology

This study utilized literature research and spatial analysis with the Qgis 3.30 program. Initially, the case of alley gardens in Daegu was examined through literature sources, including previous studies and urban planning data. Subsequently, using three primary variables derived from prior research, this study identified areas within Seoul experiencing a severe UHI effect. The chosen variables for identifying UHI vulnerability were summer temperature and the Normalized Difference Vegetation Index (NDVI), both of which are environmental factors intuitively linked to UHI. In this case, the spatial scope is Seoul, with a temporal focus on the year 2022 and specifically the summer period from July 1 to August 31, during which the UHI effect is most prominent. Furthermore, by evaluating the ratio of old houses, an area characterized by a high concentration of housing was pinpointed as a target location. The next step involved assessing the potential of introducing alley gardens by calculating the heat reduction effect of small green spaces, as identified in prior studies, within the selected area.

1.1 Review the literature and set up variables

The majority of UHI vulnerability studies conducted in Korea have relied on temperature data and vegetation factors [1, 5, 6]. For temperature data, Automatic Weather System (AWS) temperature data was employed. The vegetation factor was determined by utilizing the Normalized Difference Vegetation Index (NDVI). The Korea Meteorological Administration operates an Automatic Weather System, which collects real-time weather information from approximately 510 locations across the nation. This network aids in bridging observational gaps, identifying local weather phenomena, and ensuring accurate weather data [7]. Temperature data (AWS data) for the period spanning July 1 to August 31, 2022, was acquired. The NDVI serves as a quantitative measure of vegetation density, encompassing factors such as vegetation distribution area and tree species. This index is generated by combining spectral band characteristics using the reflective properties of wavelength bands [8]. Among the various methods for calculating the vegetation index, NDV is the most widely employed. It leverages the stark contrast in reflectance between green plants in the visible and near-infrared regions, with Band4 and Band5 being used for calculation purposes in this study.

$$NDVI = (Band5)-(Band4)/(Band5)+(Band\ 4) \quad (1)$$

3 Case analysis of Daegu

Daegu Metropolitan City maintains an average annual temperature of 14.6℃, which is approximately 1.3℃ higher than the national average temperature of 13.3℃. The area of Bisan 2 and 3 dong, where the case of the alley garden is situated, was developed as a residential zone within a short timeframe during the rapid growth period of Daegu. Over time, as the industrial complexes in the vicinity that once attracted residents experienced stagnation, this region faced typical urban deterioration challenges, including population outmigration and the proliferation of neglected spaces. Situated in close proximity to the center of Daegu and significantly influenced by the waste heat generated by the industrial complex, this area's thermal environment was particularly susceptible [9]. Furthermore, the proportion of old buildings over 30 years old stood at 65.5%, which is approximately 1.65 times higher than the national average of 39.6%. This high percentage rendered the area more prone to the UHI effect [10].

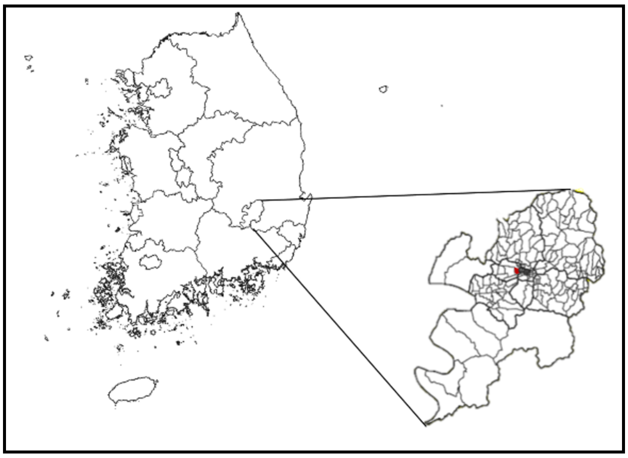

Fig. 1. Location in Bisan-dong, Seo-gu, Daegu

A study conducted by Kwon(2014), which analyzed the factors influencing the UHI effect in Daegu, identified greenery as having the most significant impact. In response, Daegu actively implemented greening projects, including the planting of 10 million street trees. Prior to 2015, greening projects were carried out individually, solely for the purpose of enhancing greenery. However, a shift occurred towards implementing these projects for multiple purposes, often in conjunction with urban regeneration. Recognizing the severity of the UHI effect in densely populated urban areas, the creation of participatory green spaces emerged as a positive measure. Alley gardens, initiated by the Seo-gu office in Daegu in 2015, numbered 36 by 2017 and 23 by 2020. These gardens were established through the efforts of local residents [9].

Fig. 2. Location of alley gardens in Bisan 2,3 dong and pictures

Subsequently, the area of Bisan 2 and 3 dong (158,074 m^2) in Seo-gu, Daegu, where the alley garden was located, was designated as an urban revitalization zone in 2018 [10]. In addition to alley gardens, small-scale green spaces such as village gardens and small parks were created in the area. These attempts aimed to cultivate a pleasant environment, with the newly established parks and green spaces serving as gathering spots for residents and visitor. These spaces fostered diverse community activities, contributing positive values not only in terms of the environment but also in the social sphere [1]. Moreover, the alley gardens in Bisan 2 and 3 dong, Seou-gu, Daegu, were created through the voluntary participation of residents and are regarded as a precedent in that they increased the initiative of residents and the sustainability of the project, which is often lacking in existing public projects. The alley gardens have effectively become amenities for the neighborhood. A study by Kwon (2017), involving a survey of residents, indicated that this project generated a perceived reduction in heat for residents. In addition to temperature reduction, aesthetic cooling effects emerged due to the introduction of green spaces. Positive outcomes included an improved settlement environment, positive shifts in residents' perception, and a decrease in neighborhood anxiety factors.

In summary, alley gardens fulfil a dual role. They not only serve as greening initiatives to enhance the thermal environment but also function as means of repurposing aging or neglected urban spaces. This revitalizes underdeveloped areas, infusing them with newfound vibrancy. The case of alley gardens has consequently introduced a new avenue as a solution to combat the UHI effect [9].

4 Case analysis of Seoul

The average annual temperature in Seoul is approximately 12.89℃, indicating an increase from the past average of 12.2℃. As a consequence of Seoul's ongoing development, both its population and building density have surged, naturally giving rise to the UHI phenomenon. Seoul is one of the major cities facing the UHI in Korea, prompting us to explore the viability of introducing alley gardens in this highly developed metropolis. Employing the average monthly summer temperature and the Normalized Difference Vegetation Index (NDVI), used in previous studies to identify the causes of UHI, we have pinpointed the most severely affected gu(autonomous region) among Seoul's 25 autonomous regions. Subsequently, we identified the dong(town) exhibiting the highest concentration of older buildings, determined by examining construction years within each dong.

First, we used the summer average temperature data from the Automatic Weather System (AWS) located in Seoul to identify regions experiencing elevated temperatures. Upon scrutinizing the average temperature figures for July and August of 2022, the overall Seoul's mean stood at 21.3℃. Notably, Gwanak-gu recorded the lowest temperature of 19.8℃, while Yeongdeungpo-gu registered the highest at 22.4℃. The deviation was relatively modest, but it was apparent that the southwestern segment of Seoul exhibited higher temperatures compared to other areas.

Table 2. Summary table of Seoul summer average temperature

District	Summer average temperature (℃)
Seoul	**21.3 (average)**
Gangnam	21.7
Gangdong	21.2
Gangbuk	21.7
Gangseo	21.7
Gwanak	**19.8 (lowest)**
Gwangjin	21.2
Guro	21.5
Geumcheon	22
Namhyeon	19.9
Nowon	20.4
Dobong	21.3
Dongdaemun	21.5
Mapo	21.7

Seodaemun	20.3
Seocho	21.6
Seongdong	23
Seongbuk	20.4
Songpa	21.7
Yangcheon	**22. 4 (highest)**
Yeongdeungpo	**22.4 (highest)**
Yongsan	21.9
Eungpyeong	20.4
Junggu	20
Jungrang	21.8
Han-river	22.1
Memorial center (Dongjak)	21.6

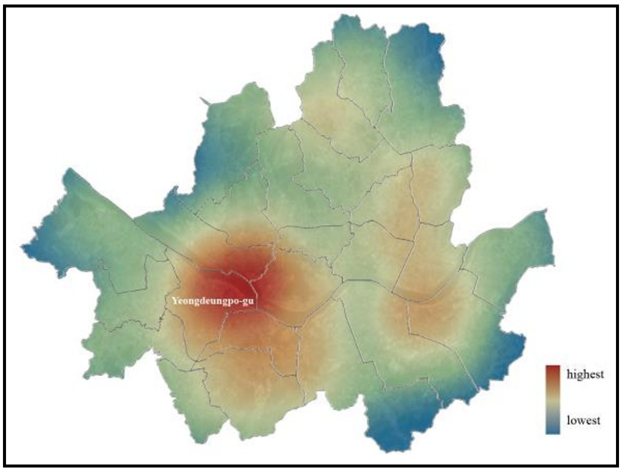

Fig. 3. Seoul Summer Average Temperature Heat Map

Proceeding, we examined Seoul's NDVI, utilizing an NDVI image of South Korea that resulted from processing Landsat satellite image from NASA. This index gauges the presence or absence of green vegetation and was derived from 2019 Landsat8 data. Operating within a range of -1.0 to 1.0, Seoul's average NDVI scored at 0.25, with a peak of 0.5 and a nadir of -0.1.

Table 3. Summary table of NDVI

Key	Data
Mean	0.25282528286033
Maximum	0.5030529499054
Minimum	-0.11807061731815
Statistics_stddev	0.10279691429342

Given the mountains encircling Seoul's periphery, discernible trends revealed higher values to the north and south, while heavily urbanized regions registered lower values. As Seoul boasts diverse mountains, gus with substantial mountainous terrain exhibited elevated NDVI values. Conversely, Yeongdeungpo-gu, endowed with fewer mountains, returned one of the lower values, notably exhibiting a negative outcome.

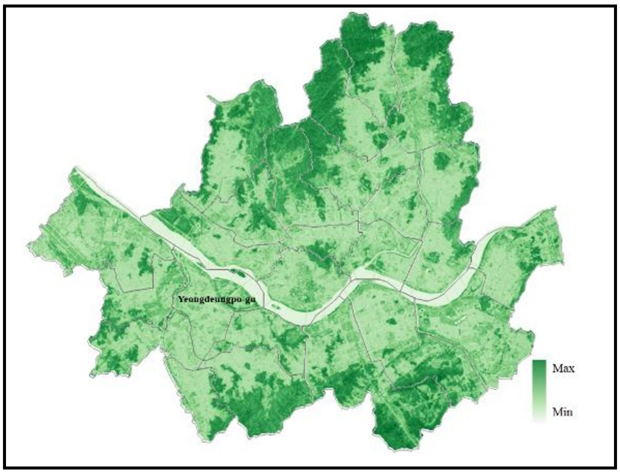

Fig. 4. Seoul NDVI Map

According to the average summer temperature and the NDVI, areas displaying the highest average temperature and lowest NDVI tended to correspond. Outskirts, characterized by mountains, forests, and relatively lower building density, displayed relatively favorable results across both indicators, implying heightened susceptibility to severe UHI effects. Particularly noteworthy, Yeongdeungpo-gu, which yielded negative outcomes for both indicators, emerged as environmentally vulnerable, struggling to cope with UHI. Being an early-developed area and a long-standing industrial hub, Yeongdeungpo-gu suffers from inadequate green space. Compounded by a high concentration of old buildings, UHI's impact is accentuated [1], necessitating an intervention. As noted in the Introduction, Seoul's densely developed urban fabric complicates UHI mitigation through extensive green space creation.

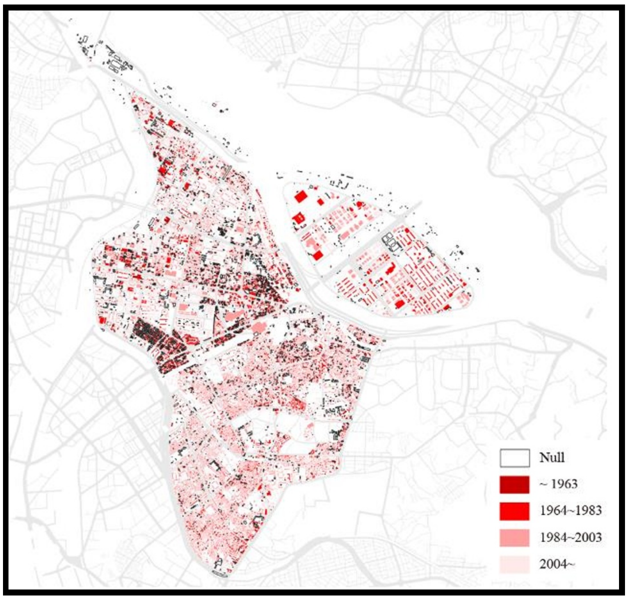

Fig. 5. Age of buildings in Yeongdeungpo-gu

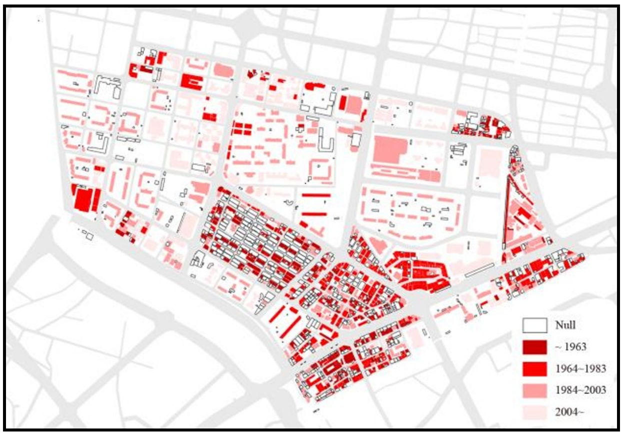

Fig. 6. Age of buildings in Mullae-dong

To identify UHI-vulnerable zones within Yeongdeungpo-gu, we scrutinized the completion years of 27,617 buildings in the area. After excluding 5,950 missing values, we categorized the remaining 21,667 buildings: 1,011 were constructed before 1963, constituting approximately 4.6%; 4,792 were built between 1964 and 1983, accounting for 22%; 12,355 were erected from 1984 to 2003, representing 57%; and 3,509 were constructed after 2004, making up about 17%. In densely populated Mullae-dong, 23% of buildings predate 1963, 35% were built between 1964 and 1983, 28% were constructed between 1984 and 2003, and 13% emerged after 2004.

Table 4. the year of completion buildings and proportion in Yeongdeungpo-gu and Mullae-dong

Year	Number of buildings (Ratio)	
	Yeongdeungpo-gu	**Mullae-dong**
~1963	1,011(4.7%)	262(23%)
1964~1983	4,792(22.1%)	406(35.8%)
1984~2003	12,355(57%)	318(28%)
2004~2023	3,509(16.2%)	150(13.2%)
Total	21,667	1,136

This is the highest percentage of old buildings in Yeongdeungpo-gu. Coupled with the characteristic of narrow lots densely packed with numerous structures, this area is anticipated to be UHI-vulnerable. Consequently, we identified Mullae-dong as an appropriate location for introducing alley gardens.

5 Mullae-dong and alley gardens

This chapter elucidates the potential and effects of alley gardens in Mullae-dong, the previously selected neighborhood. From both environmental and social standpoints, alley gardens stand poised to make a positive impact on Mullae-dong. Specifically, we have designated Mullae-dong—a locale characterized by a high concentration of old buildings without apartments and large-scale structures—as our primary focus.

Fig. 7. Maps and aerial of main target area
Source: NGII homepage

From an environmental perspective, the creation of urban forests akin to alley gardens can yield temperature reductions. A study by Kim (2011) employed the an econometric approach to evaluate the urban heat island mitigation effect of urban forests. The study incorporated variables encompassing meteorological, urban, and forest elements, utilizing average summer temperature as the dependent variable. The model demonstrated a commendable explanatory power of 0.85, confirming the effectiveness of urban forests in lowering average temperatures. Notably, the study determined that augmenting urban forest area per capita by 1m2 results in a 1.15℃ reduction in midday summer temperatures within metropolitan city areas [11].

As of 2020, there were 23 alley gardens in Daegu, with an average size of 15m^2, totalling about 345m^2, and we applied this to Mullae-dong. The total population of Mullae-dong is 32,202, but to find the population of the target area with a high concentration of elderly residences, we checked the number of households living in apartments, offices, and other large residential buildings in Mullae-dong. Within this count of 8,328 households and 32 apartments, the average household size of 2.3 individuals was calculated using the Korea National Indicator System's household headcount indicator. Accordingly, it was estimated that around 19,154 individuals lived in the excluded area. When a Mullae-dong alley garden, similar in size to the Daegu case, is introduced to the target area, the urban forest per capita increases by approximately 0.02m2, subsequently leading to a summer midday temperature decrease of about 0.023℃. The potential positive impact could be further amplified if wider alley gardens are feasible, considering that Mullae-dong's alleyways span 15 meters in width and 3 meters in breadth, with an average length of approximately 220 meters.

Mullae-dong, despite being an industrial zone within Yeongdeungpo-gu, has undergone significant change. Originally a congregation of factories, the area transformed with the influx of artists into vacant factory spaces, evolving into a diverse commerce and residential amalgam. Conversations revolving around harmonious coexistence between residents, merchants, and businesses ensued, as did discussions about regenerating old buildings. While implementation proved challenging, alley gardens—materializing through the voluntary engagement of residents, merchants, and businesses—yield synergistic cooperative participation. This framework fosters active exchange and communication [12]. Positive shifts are anticipated on the consciousness level, especially in domains where new development is implausible. In such instances, residents crafting their own spaces can foster an affection for their surroundings, thereby enhancing the settlement environment and attracting increased visitors [9].

6 Conclusions

This paper scrutinized the Daegu alley garden case, drawing insights from preceding research and literature data. It extracted implications from both environmental and social viewpoints. In order to argue the necessity of applying alley gardens, which have the effect of not only reducing temperature but also strengthening community and improving the aesthetics of urban space, to Seoul, where the urban heat island effect is serious, we selected the area most in need of applying alley gardens in Seoul. Using the average summer temperature and NDVI, derived from previous studies, we confirmed that Yeongdeungpo-gu is vulnerable to the UHI, and found that the proportion of old buildings in Mullae-dong is the highest. Therefore, we targeted the place with the highest concentration of old buildings in Mullae-dong as a target area and derived the expected heat reduction effect using the equation of previous studies, and suggested the possibility of creating small green spaces as a way to mitigate the UHI by stating that alley gardens can play a profound role even in the social background and situation of Mullae-dong.

Similar to this study, Cho (2019) identified vulnerable areas in Seoul based on physical environmental variables and population and socioeconomic variables. They also found that Yeongdeungpo-gu, an area with a high concentration of industrial uses in the past, was concentrated in heat islands [5]. Unlike prior research including Cho's study, which identified vulnerable areas in Seoul as a whole, this study looked at the target area in more detail and explored the possibility of a solution called alley gardens through the equation derived from the previous study. Despite these findings, certain limitations exist in terms of data acquisition and methodology. This paper's reliance on previous studies necessitates follow-up research that employs simulations—such as ENVI-MET—to generate concrete alley garden figures for the target area. Furthermore, given that safety concerns impede rooftop and wall greening within densely populated Mullae-dong, where old buildings dominate, a future study should propose diverse small-scale green spaces in alternative target zones.

Nevertheless, the significance of this study lies in its advocacy for micro-level strategies as a countermeasure to the UHI effect in already developed cities. We further emphasize the need for policy and institutional support for small-scale green spaces. Korea's top laws related to urban greenery include the Act on the Planning and Use of Land, the Building Act, and the Act on Urban Parks and Green spaces [13]. However, the Act on the Planning and Utilization of National Land merely outlines the concept of urban greenery as urban infrastructure. Meanwhile, the Building Act and the Act on Urban Parks and Green Spaces stipulate the area ratios for large urban greenery and the planning of expansive parks and green spaces. Consequently, a dearth of legal frameworks and planning methods for employing small-scale urban green spaces as UHI countermeasures persists on a micro spatial scale. Few studies offer evidence-backed proposals for the small-scale green spaces with heat island mitigation efficacy [14]. Hence, there is a distinct need for policy support geared toward small-scale green spaces. In addition, Furthermore, given that climate phenomena like heat waves and heat islands pose increasingly frequent and intense threats to citizens' lives, long-term solutions that enhance citizens' experiences are imperative. Alley gardens, which are created and maintained by citizens themselves, can serve as a long-term solution to the heat island phenomenon. Daegu has installed flower beds and benches at 24 project sites through a project cost of 120 million won, with the initial cost accounting for the majority of the project cost. The alley garden project, which is classified into two main types of costs, such as creating green spaces such as trees and flowering plants, paving and managing the floor, and installing convenience facilities such as benches, is a representative small-scale green space creation project, which has the advantage of costing less than the maintenance cost of large-scale green spaces after creation and can affect the lives of citizens more closely.

Therefore, it is evident that there exists a pressing need to engage in proactive discussions and introduce micro-level measures capable of addressing the Urban Heat Island (UHI) effect while simultaneously yielding positive social impacts within local communities.

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