Precise Establishment of Community Micro-gardens through Data Empowerment:

Environmental Physical Examination Driven by Mobile Measurement and Plant Response Strategies

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Abstract During the process of urbanization, community environments encounter challenges such as data disconnection and the underutilization of small and micro spaces. The establishment of "complete communities" necessitates the implementation of refined governance strategies. This research develops a path for the precise establishment of community micro-gardens driven by mobile measurement. It involves the collection of environmental data via mobile devices equipped with various types of sensors, the generation of visualization maps that are adjusted for spatio-temporal synchronization, and the identification of environmental paint points, including areas of excessive temperature exposure and zones with elevated noise levels. Based on the aforementioned considerations, various plant allocation strategies have been proposed for distinct areas. For instance, the implementation of a composite shade and cooling vegetation system is recommended for regions experiencing high temperatures, while a triple protection structure is suggested for areas affected by odor contamination. The efficacy of these strategies is demonstrated through a case study of the micro-garden transformation in the Dongjie Community of Wulituo Street, Shijingshan, Beijing. The study presents operational technical pathways and plant response solutions aimed at facilitating data-driven governance of community micro-environments.

Keywords Data empowerment, Mobile measurement, Community micro-garden, Environmental physical examination

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China is undergoing a significant and extensive process of urbanization, which has resulted in an increasingly complex spatial structure of communities and a highly heterogeneous population composition. In light of these transformations, the limitations of the traditional model of community governance have become increasingly apparent. On the one hand, the rapid urban expansion and population agglomeration have led to increasingly prominent community environmental issues. These challenges encompass, but are not limited to, heightened environmental pollution, the shrinking of ecological spaces, conflicts arising from the underutilization of public spaces, and a deficiency in service facilities[1]. According to the survey results of the *Guidelines for the Construction of Complete Residential Communities* released by the Ministry of Housing and Urban-Rural Development, over 60% of the nation's older communities experience a deficiency in public activity space and a fragmentation of green areas. This situation has led to a significant disparity between residents' demand for outdoor recreational space and the community's capacity to provide such amenities[2]. On the other hand, the complexity of group structure and spatial structure within small town communities have presented novel challenges to the traditional model of community governance[3].

In contemporary community environmental governance, two primary pain points persist: data disconnection and the underutilization of small and micro spaces, which significantly hinder the enhancement of governance effectiveness. Traditional approaches to community environmental governance frequently depend on manual empirical judgment and passive qualitative analysis, lacking the backing of systematic, dynamic, and precise environmental data. In Zhoubai Street of Qianjiang District, there existed more than 20 illegal dumping sites for construction waste along the urban-rural fringe, primarily attributable to gaps in supervision. Urban management officials were unable to monitor remote areas in real time, resulting in a delay of over 48 h in addressing these illegal activities. The disconnection of data presents significant challenges in aligning environmental monitoring data with the actual needs of the community and spatial enhancements. Consequently, residents often lack a scientific foundation for their involvement in community environmental management. This issue is particularly evident in the management and maintenance

Column introduction

The City Observer column focuses on the establishment of community micro-gardens, with a particular emphasis on addressing the challenge of numerous underutilized plots and other small spaces within high-density urban environments. This article has effectively verified the feasibility and effectiveness of environmental physical examination driven by mobile measurement and targeted plant response strategies in addressing environmental issues in community micro spaces and activating spatial vitality, thereby offering a replicable model for the refined environmental governance of complete communities.

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of micro-gardens in old communities, where latent risks—such as plant wilting and soil degradation—are typically addressed only when they become visibly apparent. This reactive approach, exacerbated by the absence of sensor deployment, frequently results in missed opportunities for timely intervention. In high-density urban environments, numerous unused plots of land and various small and micro spaces exist within communities. These areas frequently remain inactive due to insufficient planning, management, and effective utilization. Consequently, their ecological functions, social interaction potential, and aesthetic values are not fully realized, which can detrimentally impact the overall community environment. Specific manifestations of these areas include unused and abandoned spaces that exhibit a lack of popularity and vitality; insufficient greenery or inappropriate plant configurations that provide minimal ecological benefits; and an absence of suitable facilities for recreation and social interaction, which does not adequately address the diverse needs of residents. Urban micro-renewal, characterized as a progressive transformation approach involving "small repairs", is emerging as a new trend aimed at revitalizing these spaces[4].

In response to these challenges, the national government has introduced the concept of developing "complete communities". In December 2021, the General Office of the Ministry of Housing and Urban-Rural Development released the *Guidelines for the Construction of Complete Residential Communities*. This initiative aims to deliver more targeted and refined services to residents within the community, thereby fostering the establishment of a comprehensive residential environment that is safe, healthy, well-equipped, and effectively managed. The fundamental objective of constructing "complete communities" is to prioritize the improvement of the quality of the human environment while addressing the aspirations of individuals for an enhanced quality of life.

The construction of "complete communities" has necessitated enhanced standards for the refinement and scientific level to community environmental management. This underscores the importance of accurately identifying specific issues within community environments and implementing targeted, contextually appropriate improvement strategies. The key to achieving this goal lies in the acquisition of timely, accurate, and comprehensive environmental data support[5]. Consequently, the utilization of modern information technology, particularly data collection and analysis, to enhance the refined governance of community environments has emerged as a significant issue within the context of "complete community" construction.

This study aims to develop a pathway for the renovation of community micro-gardens, emphasizing the utilization of mobile measurement data. It addresses key components such as data collection, problem diagnosis, and plant interventions. Additionally, the study proposes a universal plant allocation strategy that aligns with environmental data responses. The specific objectives of the project are as follows: to identify the key environmental influences at the micro-garden scale, including light distribution, microclimate temperature, and humidity; to validate the applicability and accuracy of mobile measurement technology in complex community environments; to establish an evaluation system for assessing the impacts of environmental factors; to diagnose core issues such as the heat island effect, inadequate ventilation, and elevated levels of hazardous gases through spatial analysis and data mining; and to propose plant allocation strategies that address environmental stresses, ultimately developing a data-driven optimization scheme that can be adapted to various communities.

1 Environmental physical examination of communities driven by mobile measurement

1.1 Data acquisition technology

1.1.1 Mobile sensor devices and monitoring capability sets. The mobile measurement system facilitates data acquisition and analysis through the coordinated operation of the hardware component, processing unit, and visualization interface. The hardware component employs portable devices to incorporate various types of sensors, including those for greenhouse gases (e.g., carbon dioxide), noise levels, solar radiation, air temperature, relative humidity, wind speed, and particulate matter ($PM_{2.5}$/PM_{10}), along with other monitoring modules. These devices can be flexibly installed in vehicles, handheld devices, or cycling equipment (e.g., electric cars and bicycles), making them suitable for a diverse array of mobile scenarios, such as walking and cycling. The device operates on a lithium battery and records data at 5-min intervals. This data is transmitted to the software platform via WiFi and is also stored on an SD card, facilitating real-time dynamic data monitoring (Fig.1).

This integrated design addresses the limitations associated with traditional fixed-point sensor installations, which are often constrained by site-specific factors and high maintenance costs. For instance, in the Beijing Baita Temple area, fixed-point sensors are dependent on the installation of electrical boxes within the existing infrastructure. This reliance leads to inadequate data coverage and accuracy, as well as a lack of real-time feedback, thereby diminishing their effectiveness in early warning and alerting systems. In contrast, mobile devices have the capability to access and monitor previously overlooked areas within the community, effectively addressing these monitoring blind spots.

1.1.2 Advantages of dynamic data collection. The primary advantage of dynamic collection lies in its enhanced spatial and temporal resolution, as well as its flexible adaptability. Mobile measurements facilitate the generation of a comprehensive visual map for spatial and temporal environmental analysis every 2 h, in contrast to traditional fixed-point monitoring. In community environments, the technology can effectively tackle issues related to the deactivation of public spaces and the fragmentation of green areas in old communities. Additionally, it can identify environmental pain points, such as areas exposed to excessive heat and regions affected by high levels of noise, through the use of mobile monitoring systems. The Shuangjing community in Beijing previously monitored temperature, humidity, and other indicators using equipment installed in city management vehicles. However, the accuracy of these measurements was compromised due to uncorrected data. The current system addresses these inaccuracies by employing a residual Auto-Regressive model to correct the spatial and temporal synchronization of mobile data. This approach standardizes the data to a reference moment, thereby enhancing the comparability of measurements across different time periods and locations.

1.1.3 Data visualization. The corrected data are utilized to create spatial visualization maps for each monitoring indicator via the visual interface of the ArcGIS cloud platform. This approach effectively illustrates the spatial distribution of each indicator using varying color gradients. For instance, in an air temperature heat map, regions depicted in red signify areas of high-temperature exposure, while blue regions indicate zones of low temperature. In a noise heat map, darker colors correspond to more severe levels of noise pollution. This form of visualization converts abstract data into a spatial representation, thereby enabling the swift identification of problematic areas.

1.2 Technology application process and diagnosis of environmental issues

1.2.1 Application process. The mobile device can be utilized to facilitate urban renewal projects and refined governance. For the purposes of community renewal and transformation, personnel can traverse the entire community by either walking or riding while carrying the device. This enables the rapid scanning of unused plots, street areas, and other small micro spaces for the collection of environmental data. Subsequently, the visualized data map generated from the monitoring data can identify and locate hidden sources of pollution, areas of ecological vulnerability, as well as regions with elevated temperatures and noise levels. This information can then inform the diagnosis of regional environmental issues and the development of plant configuration design strategies aimed at optimizing the community environment.

1.2.2 Data-driven identification of environmental issues. The system utilizes corrected dynamic data to identify various types of environmental issues through the application of spatial analysis algorithms.

High Temperature Exposure Zone: The analysis of the measured data indicates that when the air temperature surpasses 35 °C and the intensity of solar radiation exceeds 500 W/m², it is possible to identify public spaces within the community that are deficient in shade. This assessment integrates building shadow analysis with community green coverage data.

Noise Exceedance Zone: According to China's current *Acoustic Environment Quality Standards* (GB 3096−2008), thresholds of 55 dB during the daytime and 45 dB at night can be utilized as thresholds, in conjunction with the positioning of sound sources (e.g., traffic arteries, commercial outlets), to identify noise pollution hotspots and determine spatial locations that require noise reduction buffers.

Low Wind Speed Zone: When the local wind speed in a community consistently falls below 1 m/s, the air diffusion capacity decreases significantly. This reduction can lead to the accumulation of pollutants in the near-surface layer, resulting in concentrations of $PM_{2.5}$ and NO_2 that are 2−2.5 times higher than those in neighboring, well-ventilated areas. Additionally, CO emitted from idling motor vehicles is more likely to accumulate in low wind speed zones[6]. Consequently, areas that require the construction of wind-conducting green corridors can be identified.

2 Micro-gardens as a spatial medium for data response

2.1 Pinpointing problem points

The data obtained from the sensors are utilized in conjunction with ArcGIS to produce spatial heat maps depicting temperature, carbon monoxide, methane, and other variables. These heat maps are overlaid on community maps, thereby identifying regions with elevated temperatures and higher levels of pollution. This process facilitates the selection of micro-garden sites based on the insights derived from the generated heat maps, such as areas adjacent to high-temperature zones, proximity to waste disposal stations, underutilized corner plots, etc. Appropriate solutions should be implemented to address various problem areas. In regions characterized by high temperatures, the strategic planting of tall trees is recommended to provide shade. Conversely, in areas with elevated pollution levels, the cultivation of edible plants should be temporarily avoided. Instead, priority should be given to the planting of non-edible varieties that possess a greater capacity for adsorption.

2.2 Ecological functional design of plant planting

2.2.1 High-temperature and strong radiation zone. Many regions characterized by elevated temperatures and intense solar radiation consist predominantly of extensive paved squares. In terms of ecological restoration, this paper proposes a strategy that involves the coordinated development of a composite system for shading and cooling vegetation, alongside the integration of edible landscapes. At the level of plant configuration, a three-tiered vertical structure is established. The arborous layer comprises drought-resistant and pollution-tolerant tree species, including *Sophora japonica* and *Populus tomentosa*, which are planted at intervals of 5−8 m to establish a continuous canopy. The vine layer incorporates climbing plants, including *Parthenocissus tricuspidata* and *Wisteria sinensis*, to offer shade for the facade. The area beneath the forest can be complemented with shade-tolerant shrubs such as *Buxus megistophylla* and *Sorbaria sorbifolia*, which contribute to a reduction in surface temperature through the establishment of a multi-layered canopy structure. Furthermore, the edible landscape will be innovatively integrated. The upper layer will feature native fruit trees with crowns measuring 6−8 m, while the middle layer will incorporate plant pergolas to create three-dimensional shading effects. In the lower layer, shade-tolerant edible plants, such as *Perilla frutescens* and *Mentha canadensis*, will be cultivated, thereby establishing a composite community that serves both ecological and production functions[7].

2.2.2 Odor-contaminated area. The areas affected by odor pollution within the community are primarily located in proximity to the waste disposal station. To address the control of pollution sources, a tripartite protective structure has been implemented. The arborous layer consists of *Platycladus orientalis* and *Juniperus chinensis*, which together create an evergreen barrier that is not only aromatic but also possesses properties for sterilization, pest control, and deodorization, thereby inhibiting pathogenic microorganisms present in the atmosphere[8]. The shrub layer features *Hibiscus syriacus* and *Forsythia suspensa*, which are effective in absorbing odoriferous particles and enhancing air quality. Additionally, the herbaceous layer includes *M. canadensis* and *Artemisia argyi*, whose volatile compounds can neutralize malodorous gases, such as hydrogen sulfide.

The regions within the community that experience heightened levels of odor pollution are frequently situated in proximity to waste disposal stations. There is a pressing need for environmental restoration and enhancements in public health. It is recommended to establish a system of aromatic and antibacterial plant communities to address these issues. In terms of arborous layers, *P. orientalis* and *J. chinensis* can establish an evergreen barrier. The aromatic properties they possess are both pleasant and fragrant, and they exhibit functions such as sterilization, pest control, and deodorization, which can effectively inhibit pathogenic microorganisms present in the atmosphere[9]. The shrub layer may be populated with *H. syriacus* and *F. suspensa*, both of which possess the ability to absorb odoriferous particles, thereby contributing to air purification. Additionally, the ground cover layer can be cultivated with *M. canadensis* and *A. argyi*, as the compounds they release have the potential to neutralize unpleasant gases, including hydrogen sulfide. The concentrated cultivation of aromatic plants in the downwind areas adjacent to locations with significant odor emissions, such as waste disposal stations, can effectively reduce the concentration of gaseous pollutants while simultaneously providing the benefits of aromatherapy[10].

2.2.3 Noise zone. Noise-affected areas are primarily located adjacent to traffic arteries and active public squares. There is an urgent need for the optimization of the acoustic environment in these regions. This paper summarizes design strategies for a vegetation system aimed at noise reduction and sound insulation. In the arborous layer, indigenous tree species such as *Pinus bungeana* and *Koelreuteria paniculata* may be selected. These species exhibit relatively dense branches and foliage, with a rough leaf surface that contributes to effective sound insulation.

When cultivated in clusters, they can establish continuous windbreaks and forests that mitigate noise pollution. The shrub layer consists of cold-resistant and shade-tolerant species, including *B. megistophylla* and *Kerria japonica*, which occupies the understory of the forest, thereby contributing to the establishment of a dense sound barrier at the base layer. The ground cover layer may be established with shade-tolerant native herbaceous plants, including *Iris tectorum*, *Hosta plantaginea*, and *Iris lactea*. These herbaceous species can provide concealed habitats for small organisms while simultaneously improving the absorption of surface sound waves.

2.2.4 High-concentration contaminated area. High levels of pollution within the community are primarily associated with roadways frequented by vehicles. The exhaust emissions from vehicles are significant contributors to the release of harmful gases and other environmental issues. The implementation of multifunctional treatment strategies can be realized through the optimization of plant configurations and spatial structures. In the arborous layer, a combination of *Ailanthus altissima* and *Fraxinus chinensis* has been selected for planting. *A. altissima* serves the purpose of absorbing sulfur dioxide, whereas *F. chinensis* contributes to an increased capacity for carbon sequestration. Together, these species establish a mechanism that facilitates the synergistic degradation of gaseous pollutants. In the shrub layer, species with anti-pollution properties, such as *Ligustrum × vicaryi* and *Prunus triloba*, may be incorporated. For the herb layer, Iris tectorum can be chosen to improve its dust retention capabilities.

3 Practical case of the micro-garden renovation in Dongjie Community

3.1 Community overview and diagnosis of environmental pain points

The location of the micro-garden construction project is situated within a rectangular flower bed on the southern side of Building 2, Zhanqian Railway Community, Dongjie Community, Wulituo Street, Shijingshan District, Beijing (Fig. 2). The site is situated in proximity to a roadway, resulting in the presence of vehicular noise, exhaust emissions, and indiscriminate parking in the vicinity. Although a limited number of trees and a small quantity of shrubs remain on the site, the green space exhibits areas of bare soil and the seedlings appear disorganized, lacking both vibrancy and stratification. Additionally, residents have planted vegetable seedling boxes around the flower beds.

3.2 Design concept of the micro-garden scheme

The renovation of the micro-garden in Dongjie Community features *Salvia nemorosa* as the predominant plant species, complemented by *Hydrangea macrophylla*, *Rosa chinensis*, and various other flowering plants, thereby establishing a shade-tolerant garden that exhibits a dynamic visual effect. The design guides the natural growth of plants through the implementation of artificial frameworks. By leveraging the color variations and the morphological balance of the flower bed, it establishes an ecological model that exemplifies the "harmonious coexistence of artificial intervention and natural growth" (Fig.3).

The fundamental design employs a "ribbon-shaped flower bed" layout characterized by several key elements: linear spatial guidance, wherein the broad leaves of *H. plantaginea* extend along the narrow plot to create a verdant visual corridor; a morphological hierarchy combination, which contrasts the rounded flower clusters of *H. macrophylla* with the elongated flower spikes of *S. nemorosa*, thereby highlighting variations in height; and a three-season color palette, in which the golden foliage of *L. vicaryi* and *Sedum lineare* persists through spring, summer, and autumn, offering a consistent warm color backdrop.

The seasonal landscape is characterized by a succession of three types of foundational plants. During the spring, the drooping yellow flowers of *F. suspensa* create a chromatic resonance with the purple flowers of *I. tectorum* in the intermediate layer. In the summer, the blue-pink inflorescences of *H. macrophylla* become the focal point, contrasting vividly with the yellow foliage of *L. vicaryi*. In the autumn, the leaves of *L. vicaryi* transit to an orange-yellow hue, establishing a harmonious color palette alongside the blooming *R. chinensis*. In winter, the golden branches of *L. vicaryi* and the brown stems of *F. suspensa* create a structural framework that highlights the aesthetic appeal of winter forms.

The fundamental design principle centers on documenting seasonal variations through the use of plants. *F. suspensa* signifies the conclusion of spring, *H. macrophylla* embodies the vibrancy of summer, and *L. vicaryi* preserves the autumnal scenery. This approach ultimately fosters a sustainable landscape characterized by "blooming across three seasons and structural appreciation during winter", making micro-garden serve as a valuable venue for nature observation and ecological education in the community.

3.3 Plant intervention program

In the development of community micro-gardens, the construction of composite plant communities should adhere to the principle of ecological niche complementarity. The waxy leaf surface of *L. vicaryi* serves as an effective interface for dust trapping. The volatile compounds emitted by *F. suspensa* facilitate the degradation of odors through chemical adsorption. The broad-leaf morphology of *I. tectorum* integrates the functions of sound wave reflection and dust interception, thereby underscoring the distinct ecological advantages associated with individual plant species. The integration of ground cover and mid-level vegetation can yield a variety of benefits. The broadleaf layers of *H. macrophylla*, *H. plantaginea*, and *Matteuccia struthiopteris* create a medium- and low-frequency sound barrier. In contrast, *S. lineare* and *Sedum polytrichoides* are densely structured to diminish the reflection of surface sound waves, thereby constituting a stereo attenuation system. The aromatic volatile compounds produced by *S. nemorosa* establish an odor degradation network in conjunction with *F. suspensa*. Additionally, the root systems of *Ophiopogon japonicus* and *Potentilla chinensis* contribute to soil stabilization, dust suppression, and the prevention of secondary diffusion of particulate matter. The high transpiration rates of *Astilbe chinensis* facilitate the wet deposition of aerosols, while the evergreen ground cover provides an insulating substrate that regulates surface heat radiation (Fig.4).

This scientific combination of plants can effectively mitigate the issues of noise, dust, odor, and exhaust pollution resulting from traffic. Additionally, it significantly enhances the aesthetic appeal of the landscape and improves the regional microclimate, thereby contributing to the creation of a healthier and more comfortable living environment.

3.4 Actual evaluation and effectiveness after renovation

Through the ongoing monitoring of the micro-garden renovation in the Dongjie Community, coupled with feedback surveys from residents, this data-driven precise establishment model has yielded significant outcomes. In proximity to vehicular traffic routes, the composite vegetation system comprising *L. vicaryi*, *F. suspensa*, and other plant species demonstrates significant efficacy in mitigating traffic noise and reducing dust deposition. The strategic aggregation of *F. suspensa* contributes to the neutralization of localized odors and enhances overall sensory comfort. The integration of shade-tolerant shrubs with a plentiful ground cover significantly lowers surface temperatures. During the hot summer months, the modified area creates a cooler and more enjoyable recreational micro-environment in comparison to the surrounding hard-paved surfaces. The combination of plant species contributes to a high survival rate. The inclusion of diverse species such as *H. macrophylla*, *H. plantaginea*, *M. struthiopteris*, and *A.chinensis* significantly enhances spatial layering and seasonal color variations. This transformation converts the previously chaotic and barren green space into a focal point of the community, integrating both ecological functions and ornamental value. Residents express a high level of satisfaction with the renovated micro-gardens, generally perceiving that these enhancements have effectively beautified the environment, improved local air quality, created a more comfortable space for outdoor activities, and fostered a greater sense of community belonging.

This practical case has effectively verified the feasibility and effectiveness of environmental physical examination driven by mobile measurement and targeted plant response strategies in addressing environmental issues in community micro spaces and activating spatial vitality, thereby offering a replicable model for the refined environmental governance of complete communities.

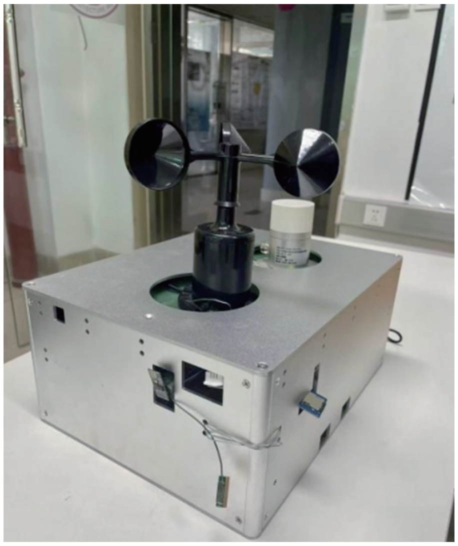

Fig.1 Portable equipment for mobile measurements

Fig.2 Current status of the site

Fig.3 Micro-garden design plane

Fig.4 Real scene after renovation

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