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Edible balcony landscapes as microscale urban green infrastructure for user needs and well-being in high-density housing

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Research Article

Keywords: urban green infrastructure, urban agriculture, edible balcony landscapes, user behaviour, well-being

Posted Date: June 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9597628/v1

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Additional Declarations: No competing interests reported.

Abstract

High-density urban environments often limit residents' regular access to nature, highlighting the need for alternative forms of urban green infrastructure. Edible balcony landscapes represent a promising microscale solution, yet their adoption remains constrained by technical and behavioural barriers. In this study, user needs and behavioural patterns in balcony-based urban agriculture were investigated through a mixed-methods approach that combined in-depth interviews (n = 12) and a Kano model-based survey (n = 206) conducted in Wuhan, China. The results reveal a hierarchical structure of user needs. Must-be attributes, such as maintenance simplicity, microclimate adaptability, and time efficiency, are essential for sustained engagement, whereas one-dimensional attributes, including ease of growth and food provision, directly influence user satisfaction. Attractive attributes—such as smart monitoring systems, modular planting configurations, and opportunities for social sharing—enhance the user experience and long-term participation. Furthermore, the findings reveal a behavioural lifecycle of edible balcony landscaping practices with four stages—design, implementation, maintenance, and sharing—highlighting the dynamic interactions among functional requirements, experiential values, and social motivations. These results suggest that edible balcony landscapes can function as microscale urban green infrastructure and deliver ecosystem services including local food provision, environmental regulation, and achievement of mental well-being benefits. This study contributes empirical evidence for user-driven urban agriculture in high-density housing and provides insights for designing accessible, low-maintenance green interventions to support sustainable and health-oriented urban living.

1. Introduction

With the acceleration in urbanization and decline in land resources, high-rise residential buildings have become the dominant housing type in many high-density cities since the 1970s (Wang and Ruan 2022). Wuhan, a central economic hub in China, exemplifies this trend, leading to both the quantity and height of super high-rise residential development (Li 2023), with nearly 10,000 such structures in its urban core (Xu et al. 2022). While this vertical urban form improves land use efficiency, it also intensifies residents' disconnection from nature, contributing to environmental stress, reduced well-being, and what are often described as "urban diseases".

In response, urban green infrastructure and nature-based solutions (NBSs) have gained increasing attention as strategies to reintegrate ecological functions into dense urban environments. Beyond large-scale parks and public green spaces, recent studies emphasize the importance of microscale and everyday green interventions embedded within residential environments. These small, distributed green elements can service ecosystemsvia microclimate regulation, food provision, and psychological restoration, particularly in contexts where access to conventional green space is limited.

Within this framework, edible landscapes have emerged as a promising approach that integrates ecological, social, and productive functions. The concept of edible landscaping traces back to Robert Kourik's 1970s work, Designing and Maintaining Your Edible Landscape Naturally, which advocates for

the chemical-free cultivation of vegetables, fruits, and ornamentals for multifunctional benefits (Kourik 2004). Subsequent studies have expanded its scope: Brown (2004) highlighted its contributions to food security and sustainability, whereas Luan et al. (2017) emphasized the integration of aesthetics and ecology. Moreover, edible landscapes have been shown to generate psychosocial benefits, including improved mental health and strengthened community relationships (Zhang 2021; Li 2022).

An edible landscape refers to the use of edible plant species as landscape materials, combining agricultural production with spatial design to create environments that are both ecologically functional and aesthetically meaningful (Luan et al. 2017). In urban contexts, edible landscapes can support small-scale food production while enhancing environmental quality and promoting well-being (Zhang 2021). The act of cultivation itself fosters a closer connection to nature, strengthens familial relationships, and encourages social interaction through shared experiences and outcomes (Li 2022; Fu 2022; Wu and Yan 2023).

In practice, edible landscapes have been widely explored in collective urban settings such as community gardens, campuses, and public green spaces. For example, the community edible garden of Wuhan Vanke Flower City has demonstrated the feasibility of integrating edible landscapes across multiple spatial scales, contributing to both food supply resilience and community cohesion (He et al. 2021). Similarly, the Clover Hall Community Garden Series in Shanghai highlights the role of public participation in shaping edible landscapes in high-density metropolitan contexts (Liu et al. 2017). Campus-based implementations further reveal strong links between edible landscapes and emotional attachment to place (Lin et al. 2022).

Despite these advances, a critical gap remains. Existing research has focused predominantly on collective or public environments, while the potential of private or semiprivate residential spaces—particularly high-rise balconies—remains underexplored. In high-density cities, balconies represent one of the few accessible interfaces between indoor living and the external environment. As transitional spaces, they offer unique opportunities for integrating microscale urban agriculture into everyday life. However, in practice, many residents rely on ad hoc potted planting because of technical constraints, limited knowledge, and a lack of systematic support.

Moreover, growing interest in home-based cultivation reflects a broader shift towards everyday urban agriculture, where food production is embedded within daily routines and domestic spaces. Understanding how residents engage with such practices requires not only spatial or ecological perspectives but also a user-centred analytical approach that captures behavioural motivations, experiential values, and practical constraints.

To address this gap, this study adopts the Kano model as an analytical framework to systematically examine users' needs in balcony-based edible landscape practices. The Kano model enables the classification of user requirements into different categories (e.g., must-be, one-dimensional, and attractive attributes), thereby revealing how different factors influence user satisfaction and engagement. By combining qualitative interviews with a structured questionnaire survey, this study

develops a mixed-method approach to identify key drivers of participation in microscale urban agriculture.

Furthermore, this research conceptualizes edible balcony landscapes as a form of microscale urban green infrastructure that is capable of servicing ecosystemsin multiple ways, including food provision, environmental regulation, and mental well-being benefits. By linking user behaviour with spatial and ecological functions, the study bridges the domains of urban agriculture, environmental psychology, and service-oriented design.

Therefore, the objectives of this study are threefold:

(1) to investigate the behavioural patterns and practical challenges of edible landscape cultivation in high-rise residential balconies;

(2) to identify and classify user needs using a Kano model-based analytical framework; and

(3) to explore how edible balcony landscapes can function as accessible and scalable green interventions in high-density urban environments.

By doing so, this study aims to contribute to the growing discourse on urban green infrastructure by foregrounding the role of everyday, user-driven practices in shaping more sustainable and health-oriented urban living.

2. Methods

A mixed-methods research design was adopted in this study that integrated qualitative interviews and quantitative survey analysis to examine users' behaviour and preferences in edible balcony landscape practices. This approach enables methodological triangulation and increases the robustness and validity of the findings by combining in-depth experiential insights with structured empirical data. This study was conducted in accordance with the Declaration of Helsinki and approved by Art and Design Ethics Committee of Wuhan Polytechnic University. Informed consent was obtained from all participants, and all the data were anonymised prior to analysis to ensure confidentiality.

2.1 Field visits

The interview data were analysed using thematic analysis, allowing recurring patterns and key themes related to user behaviour, preferences, and challenges to be systematically identified.

“Qualitative research is the study of subjective things, and it is a great way to show your stakeholders first-hand how your customers feel" (Su 2018). The purpose of this qualitative study is to explore in detail not only the experiences of residents who plant edible gardens on the balconies of high-rise residences but also their expectations of and needs regarding edible landscapes. A snowball sampling strategy was employed to recruit 12 participants in Wuhan with extensive experience in edible balcony landscaping

practices.The sample size is consistent with established qualitative research standards, where depth of insight is prioritized over statistical representativeness (Marshall 1996; Crouch and McKenzie 2006).

Following the specific protocol, we first obtained initial recommendations from Wuhan's edible landscape community and identified three veteran growers who met the study criteria. Second, we conducted lateral recruitment where these initial contacts, guided by our research requirements, referred to additional qualified candidates. Participation was confirmed through both telephone consultations and face-to-face meetings. Finally, all the participants signed informed consent forms that provided details of the research objectives, data utilization protocols, and confidentiality provisions, with vegetable seed packets provided to show appreciation.

The interviews were conducted in a quiet environment, with a focus on interaction during the interview process to ensure that each interviewee could fully express his or her own opinions. The duration was limited to approximately 45 minutes, and the entire interview was recorded and then transcribed for analysis. All participants signed informed consent forms explicitly acknowledging their right to withdraw from the study at any time. We implemented anonymization protocols in which all personally identifiable information was either removed or encrypted, with each participant assigned unique codes (LS1–LS12) for data tracking purposes.

In accordance with the analysis of the current domestic and international literature on edible landscapes, the main interview points were divided into five categories: behavioural motivation, operational management, aesthetic perception, technological application and social interaction. Thus, the interviews covered the original intention of planting, the planting process, and the harvest results, with the aim of helping us comprehensively analyse the opportunities and challenges of constructing edible landscapes on urban high-rise residential balconies. The specific interview points are shown in Table 1.

Table 1
Interview points

Category	Interview Points
Behavioural Motivation	A1Temporal patterns & motivations
	A2 Psychosocial benefits
	A3 Dietary diversity expectations
Operational Management	B1 Spatial allocation & crop selection
	B2 Maintenance convenience
	B3 Technical feasibility gap analysis
	B4 Microclimate adaptation strategies
	B5 Time investment and knowledge acquisition
Aesthetic Perception	C1 Morphological preferences
	C2 Chromatic composition preferences
	C3 Olfactory satisfaction
Technological Application	D1 Modular container configurations
	D2 Substrate selection determinants
	D3 IoT(Internet of Things) adoption rate
Social Interaction	E1 Knowledge dissemination behaviours
	E2 Produce distribution patterns

To ensure the accuracy and reliability of the study and comprehensively verify the data, the authors used triangulation mutual verification, personnel checking, and peer testing. During the analysis phase, we first transcribed and categorized the interview recordings and then encoded and clustered the data according to the questionnaire structure. The focus of this paper is the needs, preferences, behaviours and methods of the respondents regarding balcony planting, as well as the service strategies designed for these needs and behaviours.

2.2 Questionnaire Based on the Kano Model

The Kano model was adopted as an analytical framework to classify user needs on the basis of their impact on satisfaction and dissatisfaction. This approach is particularly suitable for identifying differentiated user requirements and prioritising design and intervention strategies.

Through the analysis of the data from our field investigations, a total of 102 factors were summarized, and 20 corresponding factors were ultimately determined through cluster screening, as shown in

Table 2. The four main stages of a user's planting of edible landscapes, namely, design, implementation, maintenance, and sharing, were summarized.

Table 2
Classification of factors

Category	Factor
Behavioural Motivation	A1 Daily food provision
	A2 Microclimate Regulation
	A3 Increases in Dietary Diversity
Operational Management	B1 Space Utilization Efficiency
	B2 Extended Harvest Duration
	B3 Maintenance Simplicity
	B4 Ease of Growth
	B5 Spatial Flexibility
	B6 Time Investment (≤ 0.5h/Day)
Aesthetic Perception	C1 Plant Morphology Preference
	C2 Chromatic Diversity
	C3 Olfactory Pleasantness
Technological Application	D1 Modular Planter Systems
	D2 Soilless Cultivation
	D3 Smart Monitoring Systems
	D4 Cultivation Decision Support
	D5 Supplemental Lighting
Social Interaction	E1 Experience Sharing
	E2 Harvest Sharing
	E3 Plant Material Exchange

To further assess the attributes of user needs in the process of planting edible landscapes in a wider population, we designed a questionnaire employing the Kano model to classify these 20 factors. Each identified factor was operationalised through paired functional and dysfunctional questions in accordance with the standard Kano questionnaire design. The participants could select one of five response options (e.g., very satisfied, satisfied, neutral, dissatisfied, or very dissatisfied). We subsequently analysed the survey data using the Kano evaluation matrix (Table 3), which cross-

references responses to functional and dysfunctional questions to generate categorical classifications for each attribute.

Table 3

Kano evaluation matrix[1]

		Dysfunctional (negative)				
		Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Functional (positive)	Very satisfied	Q	A	A	A	O
	Satisfied	R	I	I	I	M
	Neutral	R	I	I	I	M
	Dissatisfied	R	I	I	I	M
	Very dissatisfied	R	R	R	R	Q

[1]Must-be attribute (M), one-dimensional attribute (O), attractive attribute (A), and indifferent attribute (I), reverse attribute (R), and questionable result (Q).

By categorizing each factor into one of four attribute categories, namely, must-be attribute (M), one-dimensional attribute (O), attractive attribute (A), and indifferent attribute (I), we can better understand the needs and expectations of users for balcony planting. In the classification process, we made judgements on the basis of the satisfaction index (SI) and the dissatisfaction index (DSI) of each factor according to the satisfaction coefficient proposed by Timko (1993). The SI indicates the level of user satisfaction with the factor, whereas the DSI reflects the level of user dissatisfaction when the factor is not met. By comparing the two indices, we could determine the extent to which each factor contributes to user satisfaction and identify the extent to which different factors affect user satisfaction. This analytical approach enables the identification of critical factors influencing user engagement and provides a structured basis for interpreting behavioural drivers in urban agricultural practices.

$$\mathrm{SI} = \frac{\mathrm{A} + \mathrm{O}}{\mathrm{A} + \mathrm{O} + \mathrm{M} + \mathrm{I}}$$

$$\mathrm{DSI} = \frac{\mathrm{M} + \mathrm{O}}{\mathrm{A} + \mathrm{O} + \mathrm{M} + \mathrm{I}}$$

We distributed the questionnaire through online planting community groups and rigorously screened the participants to ensure that they were experienced balcony gardeners. A total of 230 questionnaires were distributed; 230 were recovered, and a total of 206 valid questionnaires were included, for an effective response rate of 89.5%.The sample size provides sufficient statistical reliability for identifying general patterns of user preference and behaviour.

3. Results

3.1Findings

3.1.1 A four-stage behavioural lifecycle of balcony edible landscape practices

On the basis of user feedback, the process of edible plant cultivation on balconies can be conceptualized as a four-stage behavioural lifecycle consisting of design, implementation, maintenance, and sharing (Fig. 1).

The design stage represents the cognitive entry point, where users formulate planting strategies by balancing functional considerations (e.g., spatial efficiency and cost) with aesthetic preferences. The implementation stage translates these plans into practice, during which users navigate the tension between environmental constraints and operational feasibility through iterative adjustments.

The maintenance stage reflects a process of experiential learning and knowledge accumulation. Users gradually shift from reactive problem-solving to proactive management, indicating increasing levels of engagement and competence. The sharing stage extends individual practices into the social domain, where users exchange knowledge, distribute produce, and derive social recognition.

Taken together, these stages constitute a dynamic behavioural lifecycle, demonstrating that edible balcony landscaping practices evolve from individual experimentation to socially embedded activities. This lifecycle highlights the interplay among functional requirements, experiential learning, and social interaction in sustaining user engagement.

3.1.2 Classification of user needs based on Kano analysis

The Kano model was applied to classify 20 identified factors according to their impact on user satisfaction (Table 4; Fig. 2). The results reveal a clear hierarchical structure of user needs across four categories: must-be (M), one-dimensional (O), attractive (A), and indifferent (I) attributes.

Table 4
Classification of factors

Category	Factor	SI	DSI	Attribute Category
Behavioural Motivation	A1 Daily food provision	0.523	0.528	O
	A2 Microclimate Regulation	0.438	0.315	M
	A3 Increases in Dietary Diversity	0.710	0.068	A
Operational Management	B1 Space Utilization Efficiency	0.462	0.204	I
	B2 Extended Harvest Duration	0.260	0.313	M
	B3 Maintenance Simplicity	0.401	0.395	M
	B4 Ease of Growth	0.674	0.658	O
	B5 Spatial Flexibility	0.552	0.169	A
	B6 Time Investment (≤ 0.5h/Day)	0.333	0.222	M
Aesthetic Perception	C1 Plant Morphology Preference	0.503	0.399	O
	C2 Chromatic Diversity	0.563	0.086	A
	C3 Olfactory Pleasantness	0.796	0.087	A
Technological Application	D1 Modular Planter Systems	0.567	0.129	A
	D2 Soilless Cultivation	0.415	0.094	I
	D3 Smart Monitoring Systems	0.625	0.101	A
	D4 Cultivation Decision Support	0.756	0.134	A
	D5 Supplemental Lighting	0.478	0.083	I
Social Interaction	E1 Experience Sharing	0.252	0.148	I
	E2 Harvest Sharing	0.518	0.079	A
	E3 Plant Material Exchange	0.411	0.114	I

Must-be attributes—including microclimate regulation, maintenance simplicity, extended harvest duration, time investment (≤ 0.5 h/day), and plant morphology—represent fundamental conditions for user acceptance. The absence of these attributes leads to significant dissatisfaction, indicating that these attributes form the baseline requirements for participation in edible balcony landscaping practices.

One-dimensional attributes, such as ease of growth and daily food provision, have a direct linear relationship with user satisfaction. Improvements in these factors proportionally enhance the user experience, suggesting that they are key performance drivers influencing continued engagement.

Attractiveness attributes—including dietary diversity, spatial flexibility, chromatic diversity, olfactory pleasantness, modular planter systems, smart monitoring systems, decision support, and harvest sharing—do not constitute basic expectations but significantly increase user satisfaction when present. These attributes contribute primarily to experiential enrichment and long-term user retention.

Indifferent attributes, such as space utilization efficiency, soilless cultivation, supplemental lighting, experience sharing, and plant material exchange, have a limited influence on overall satisfaction, suggesting that they are not primary determinants of user behaviour in this context.

Overall, the findings indicate that user engagement in edible balcony landscapes is driven by a combination of baseline functional requirements (must-be attributes), performance-related factors (one-dimensional attributes), and experiential enhancements (attractive attributes).

3.1.3 Priority structure of user requirements

Scatter plot analysis (Fig. 2) performed on the basis ofthe satisfaction (SI) and dissatisfaction (DSI) indices, further illustrates the relative importance of different factors.

Factors located in the first quadrant (one-dimensional attributes), namely, ease of growth and daily food provision, emerge as the most critical drivers of user satisfaction. These factors directly address practical needs and strongly influence users' willingness to participate.

The second quadrant (attractive attributes) includes features that enhance the overall experience, such as sensory qualities (colour and smell), technological support (smart monitoring and decision systems), and social interaction (harvest sharing). While not essential, these features significantly increase user satisfaction and engagement.

The fourth quadrant (must-be attributes) highlights essential conditions that users take for granted. Failure to meet these requirements—such as maintenance simplicity or microclimate adaptability—results in substantial dissatisfaction, underscoring their foundational role.

In contrast, factors in the third quadrant (indifferent attributes) have a minimal effect on user satisfaction and may therefore be deprioritized in resource allocation.

These results suggest that effective interventions in edible balcony landscape design should prioritize must-be and one-dimensional attributes to ensure usability and satisfaction while selectively integrating attractiveness attributes to enhance the user experience and long-term engagement.

These findings provide empirical evidence for understanding how microscale urban agricultural practices can be sustained in high-density residential environments.

3.2 Optimization strategy

Combined with the results of the user data analysis in the abovementioned five dimensions—basic substance, operability, aesthetic feelings, material selection, and social sharing—a design service strategy for the four stages of edible landscape planting for users is further proposed below.

3.2.1 Increasing practicality through user participation: A design strategy for edible landscape solutions

Through the analysis of user research, we identified residents' core requirements for edible landscape design, including key dimensions such as vegetable/fruit variety selection, yield expectations, and labour input. From the analysis of the content from interviews with twelve users and the results from the Kano questionnaires, we proposed a cocreation design model for implementation during the design phase. This approach actively involves users in developing edible landscape solutions through consultations and iterative feedback and integrates their suggestions and actual needs into planting plans. The aim is to increase both the practicality and the adaptability of the design solutions while strengthening residents' sense of participation and engagement in balcony-based gardening projects.

3.2.2 Bridging convenience and community through digital planting platforms

Considering user demand for convenient operation and professional guidance, a digital platform was established to provide users with personalized planting suggestions, answers to questions, and online communication forums. Through this platform, combined with real-time data from sensors such as humidity and light sensors, as well as artificial intelligence-assisted diagnosis functions, users can obtain dynamically adjusted planting plans and reduce maintenance requirements. Additionally, users can record their planting process, share photos of their results, and even participate in community planting competitions through the platform, thereby establishing an organic connection between convenience and social interaction and stimulating users' enthusiasm for planting.

3.2.3 Intelligent container systems for adaptive urban planting

Through Kano model analysis, spatial flexibility, modular planter systems, smart monitoring systems, and cultivation decision support are identified as attractive product features. This is addressed by designing lightweight and movable planting containers that are integrated with intelligent irrigation and nutrient control systems, enabling users to not only adjust layouts but also flexibly switch planting varieties on the basis of seasonal changes and user needs. The modular design maintains an expansion interface so that the planting plan can be continuously upgraded, and the intelligent operation and maintenance system greatly reduces the user burden in daily planting through automatic management and real-time feedback.

3.2.4 From Soil to Society: A Collaborative Model for Community Greening

To meet the needs of users in the material and social dimensions, we constructed a multiparty collaborative support network and cooperated with horticultural experts, social enterprises, nonprofit organizations and local governments to provide users with a variety of online training, professional consultation and material sharing services. Through activities such as the “Balcony Harvest Festival” and “Plant-Sharing Meeting”, we aim to enrich the lives of neighbourhoods and promote the dissemination of planting knowledge and the construction of community culture. The purpose of this collaborative model is to enhance the social aspect of planting in balconies and help users gain a sense of belonging and accomplishment through green planting.

3.3 Design practice

3.3.1 User engagement service framework

On the basis of the four stages of user behaviour (design, implementation, maintenance, and sharing) and the classification of key factors, a service framework was developed to support edible balcony landscape practices. This framework integrates user participation, digital support, and modular planting systems to respond to the user needs identified. Rather than representing a fixed solution, it serves as a conceptual model that links user requirements with practical implementation strategies.

3.3.2 Modular planting units

To translate user needs into practical applications, a modular planting unit is proposed as a supporting solution for edible balcony landscapes in high-density environments. The modular approach enables flexible spatial configurations, allowing users to adapt planting layouts to different balcony sizes, light conditions, and seasonal requirements.

The system emphasizes ease of use and maintenance, aligning with key must-be attributes identified in the Kano analysis, such as maintenance simplicity and time efficiency. In addition, its adaptability reflects attractiveness attributes, including spatial flexibility and modularity, which enhanced user satisfaction and engagement.

Rather than focusing on technical complexity, the modular concept highlights the importance of accessible and scalable design strategies that lower barriers to participation in urban agriculture. As such, it serves as an example of how user-driven insights can inform the development of microscale green infrastructure interventions in high-density residential contexts.

3.3.3 Digital support for user engagement in balcony edible landscape practices

In addition to physical planting solutions, a digital support system is conceptualized to facilitate user engagement throughout the cultivation process. The system is designed to provide basic guidance, environmental feedback, and opportunities for knowledge sharing, thereby supporting users across the four identified stages: design, implementation, maintenance, and sharing.

This digital component corresponds to several attractiveness attributes identified in the Kano analysis, including cultivation decision support and smart monitoring. By offering accessible information and lightweight interaction mechanisms, it reduces the knowledge barrier for novice users while supporting more experienced participants in optimizing their practices.

Importantly, the system also enables social interaction through experience and harvest sharing, reinforcing the role of community dynamics in sustaining long-term engagement. Rather than representing a fully developed technological solution, this framework illustrates how digital tools can complement microscale urban agriculture by enhancing usability, learning, and participation.

4. Discussion

Urbanization-driven spatial constraints in high-density cities have intensified the demand for accessible and integrated forms of urban green infrastructure. While previous studies have focused primarily on large-scale or community-level edible landscapes, this study focuses on the domestic scale, demonstrating that high-rise residential balconies can function as microscale urban green infrastructure. By embedding food production within everyday living spaces, edible balcony landscapes provide a complementary pathway for servicing ecosystems in environments where conventional green space is limited.

4.1 Balcony edible landscapes as micro-scale urban green infrastructure

This study extends the existing research on edible landscapes by conceptualizing balcony-based cultivation as a distributed and user-driven form of urban greening. Unlike traditional green infrastructure, which is typically planned and implemented at the city or community level, edible balcony landscapes are decentralized, highly personalized, and embedded in daily life. Despite their small spatial footprint, the cumulative effect of such microscale interventions can be significant, particularly in high-density cities with extensive high-rise housing.

Consistent with the findings of previous studies (Luan et al. 2017; Wu and Yan 2023), our findings confirm that edible landscapes integrate ecological, aesthetic, and productive functions. However, this study further demonstrates that their effectiveness depends on aligning design and service provision with user needs. The identification of must-be attributes—such as maintenance simplicity, microclimate adaptability, and time efficiency—reveals that basic functional reliability is a prerequisite for sustained

engagement. Without these conditions, participation in cultivation in the balcony remains fragile and discontinuous.

Moreover, one-dimensional attributes (e.g., ease of growth and food provision) and attractiveness attributes (e.g., smart monitoring systems and modular configurations) play critical roles in enhancing user satisfaction and long-term commitment. This layered structure of user needs suggests that the performance of microscale urban green infrastructure is determined not only by ecological factors but also by user experience and behavioural compatibility. Therefore, integrating user-centred perspectives into urban greening strategies is essential for maximizing the effectiveness of such interventions.

4.2 Behavioural mechanisms and the everyday practice of urban agriculture

A key contribution of this study is the identification of a four-stage behavioural lifecycle—design, implementation, maintenance, and sharing—which captures the dynamic evolution of user engagement in edible balcony landscaping practices. These findings advance existing research by framing urban agriculture not only as a spatial or ecological intervention but also as an ongoing socio-behavioural process embedded in everyday life.

The results reveal that user engagement is driven by a combination of functional necessity, experiential value, and social interaction. During the design and implementation stages, users are motivated primarily by practical considerations such as space constraints, crop selection, and ease of operation. In the maintenance stage, continuous interaction with plants fosters experiential learning and emotional attachment, which aligns with previous findings on the psychological benefits of edible landscapes (Zhang 2021; Li 2022). The sharing stage further extends individual practices into social domains and reinforces motivation through community interaction and knowledge exchange.

These findings resonate with broader discussions on everyday urbanism and the role of routine practices in shaping urban environments. By embedding cultivation activities within daily life, edible balcony landscapes transform passive residential spaces into active sites of production, learning, and social engagement. This perspective highlights the importance of considering behavioural dynamics in the design and evaluation of urban green infrastructure.

4.3 Implications for well-being and ecosystem services

The results of this study reinforce the multifunctional value of edible landscapes, particularly in terms of their contribution to human well-being. Consistent with prior research (Lin et al. 2022; Wu and Yan 2023), cultivation in the balcony provides not only access to fresh food but also opportunities for stress relief, emotional regulation, and social interaction. The act of planting, nurturing, and harvesting creates a cyclical experience that fosters a sense of achievement and connection to nature, which is especially valuable in high-rise living environments characterized by limited natural contact.

From an ecosystem services perspective, edible balcony landscapes can deliver multiple benefits, including microclimate regulation, biodiversity support, and local food production. Although each individual balcony represents a small-scale intervention, their cumulative impact across dense urban environments can contribute to broader ecological functions. Importantly, the results of this study suggest that the realization of these benefits depends on the accessibility and usability of cultivation systems. Ecosystem services at the microscale are mediated by user participation and engagement rather than being determined solely by physical design.

4.4 Implications for urban policy and design practice

The findings of this study have important implications for urban policy and design strategies in high-density cities. First, they highlight the potential of incorporating balcony-based edible landscapes into urban greening policies as a low-cost and scalable complement to traditional green infrastructure. In contexts where land availability is limited, promoting microscale interventions within residential environments can significantly increase the overall green capacity of cities.

Second, the results underscore the importance of user-centred design in supporting urban agricultural initiatives. Rather than focusing exclusively on spatial or technological solutions, policymakers and designers should prioritize accessibility, ease of maintenance, and adaptability to diverse user needs. This aligns with the growing recognition that the successful implementation of nature-based solutions requires not only ecological effectiveness but also social acceptance and usability.

Third, the integration of digital technologies and service systems, as explored in this study, offers new opportunities for enhancing user engagement and lowering barriers to participation. By providing real-time feedback, personalized guidance, and platforms for social interaction, such systems can strengthen the connection between residents and their cultivation practices, thereby improving the sustainability of urban agricultural initiatives.

5. Conclusion

This study investigated the potential of edible balcony landscapes as a form of microscale urban green infrastructure in high-density cities using a mixed-methods approach that combines qualitative interviews and a Kano model-based survey. The findings reveal a structured hierarchy of user needs, in which must-be attributes (e.g., maintenance simplicity and environmental adaptability) form the foundation for participation, whereas one-dimensional attributes (e.g., ease of growth and food provision) directly influence user satisfaction. Attractiveness attributes, including flexibility and opportunities for social interaction, further enhance long-term engagement.

In addition, this study identifies a four-stage behavioural lifecycle—design, implementation, maintenance, and sharing—and reveals that participation in balcony-based urban agriculture is not a static activity but an evolving process shaped by functional, experiential, and social factors. These findings demonstrate

that user behaviour plays a central role in determining the effectiveness and sustainability of microscale green interventions.

From the perspective of urban green infrastructure, edible balcony landscapes represent a distributed and accessible form of nature-based solution that can deliver multiple ecosystem services, including local food provision, environmental regulation, and achievement of mental well-being benefits. In high-density urban contexts where conventional green space is limited, such microscale interventions offer a complementary pathway for enhancing urban resilience and liveability.

The results also have practical implications for urban policy and design. Promoting low-maintenance, user-friendly, and adaptable planting systems can lower barriers to participation and support wider adoption of household-level urban agriculture. More broadly, integrating residential-scale green practices into urban greening strategies may contribute to more inclusive and sustainable urban environments.

Overall, this study contributes to the understanding of how regular, user-driven practices can support urban sustainability goals. Linking user needs, behavioural dynamics, and ecological functions provides a framework for rethinking the role of domestic spaces in the development of future urban green infrastructure.

6. Limitations

By focusing on the domestic scale, this study addresses a gap in existing urban agriculture research, which has predominantly examined community gardens and public green spaces. The findings suggest that future research should pay greater attention to the role of private and semiprivate spaces in shaping urban ecological systems.

Further studies could expand this research in several directions. First, comparative analyses across different climatic and cultural contexts would help evaluate the generalizability of the findings. Second, longitudinal studies could provide deeper insights into how user engagement evolves over time and how sustained participation influences both well-being and environmental outcomes. Third, integrating objective environmental data (e.g., microclimate measurements or biodiversity indicators) with user-based data could enhance the understanding of the interaction between ecological performance and human behaviour.

Overall, this study contributes to the growing discourse on urban green infrastructure by demonstrating that microscale, user-driven practices can play a significant role in advancing sustainable and health-oriented urban living. By bridging spatial, ecological, and behavioural perspectives, it provides a more holistic understanding of how everyday environments can be transformed into productive and restorative landscapes.

Declarations

Ethical approval and consent to participate

The study was approved by Art and Design Ethics Committee (AD-HW2024/01/03.17)of Wuhan Polytechnic University, School of Art and Design. Informed consent was obtained from all participants. All personal identifiers were removed prior to analysis. The authors declare no competing interests relevant to this study.

Consent to publication

We conceal the names of all interviewees in the publication.

Informed Consent

Informed consent was obtained from all participants. All personal identifiers were removed prior to analysis.

Competing interests

The authors declare no conflict of interest.

Clinical trial number

Not applicable.

Funding

This research was funded by the Humanities and Social Sciences Research Project of Hubei Provincial Department of Education (No. 22Q101).

Author Contribution

Conceptualization, W.W. and D.Y.; methodology, W.W.; investigation, D.Y. and H.S.; data analysis, W.W. and D.Y.; writing, W.W. and D.Y.; funding acquisition, W.W. All authors have read and agreed to the published version of the manuscript.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

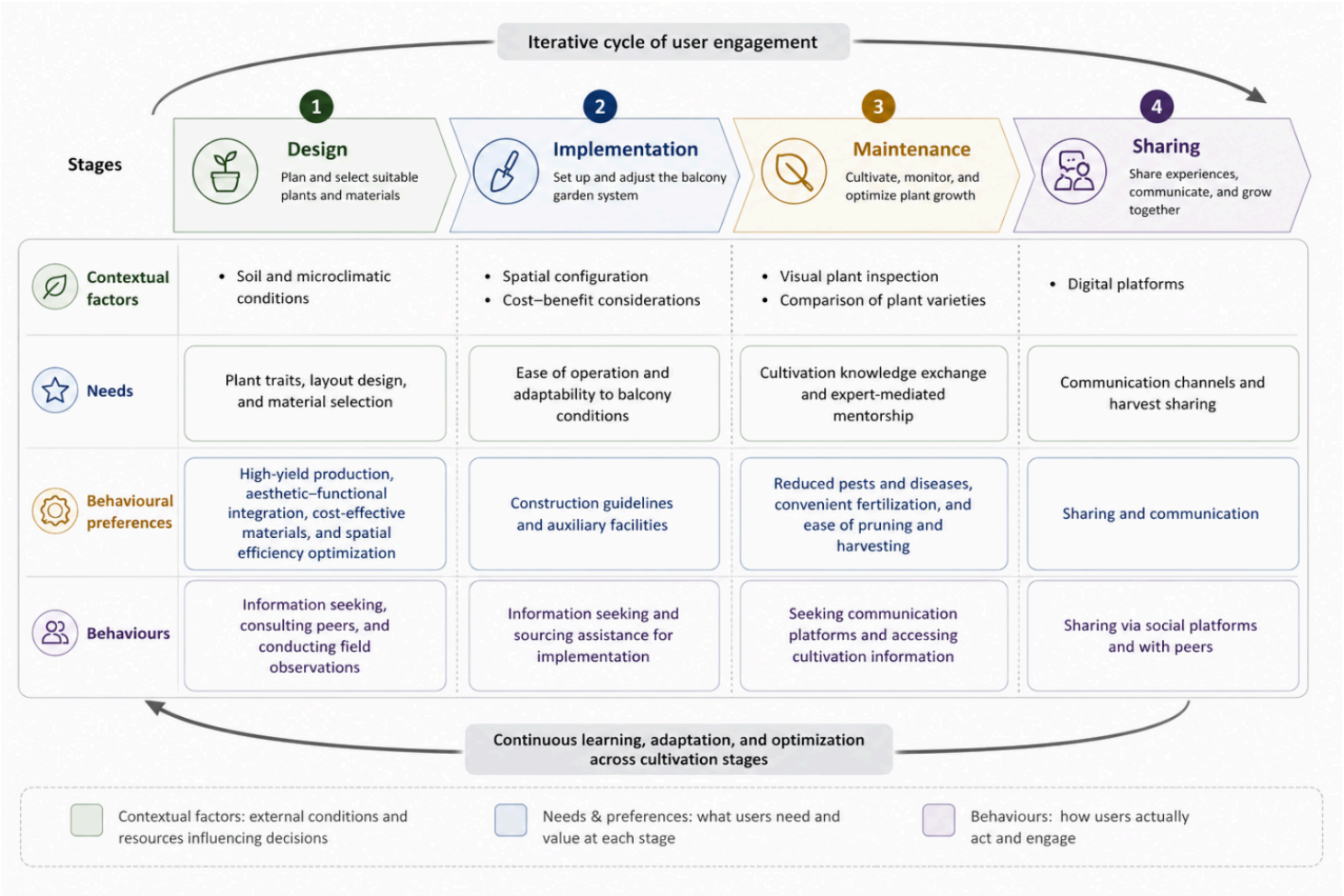


Figure 1

The four stages of user planting of edible plants

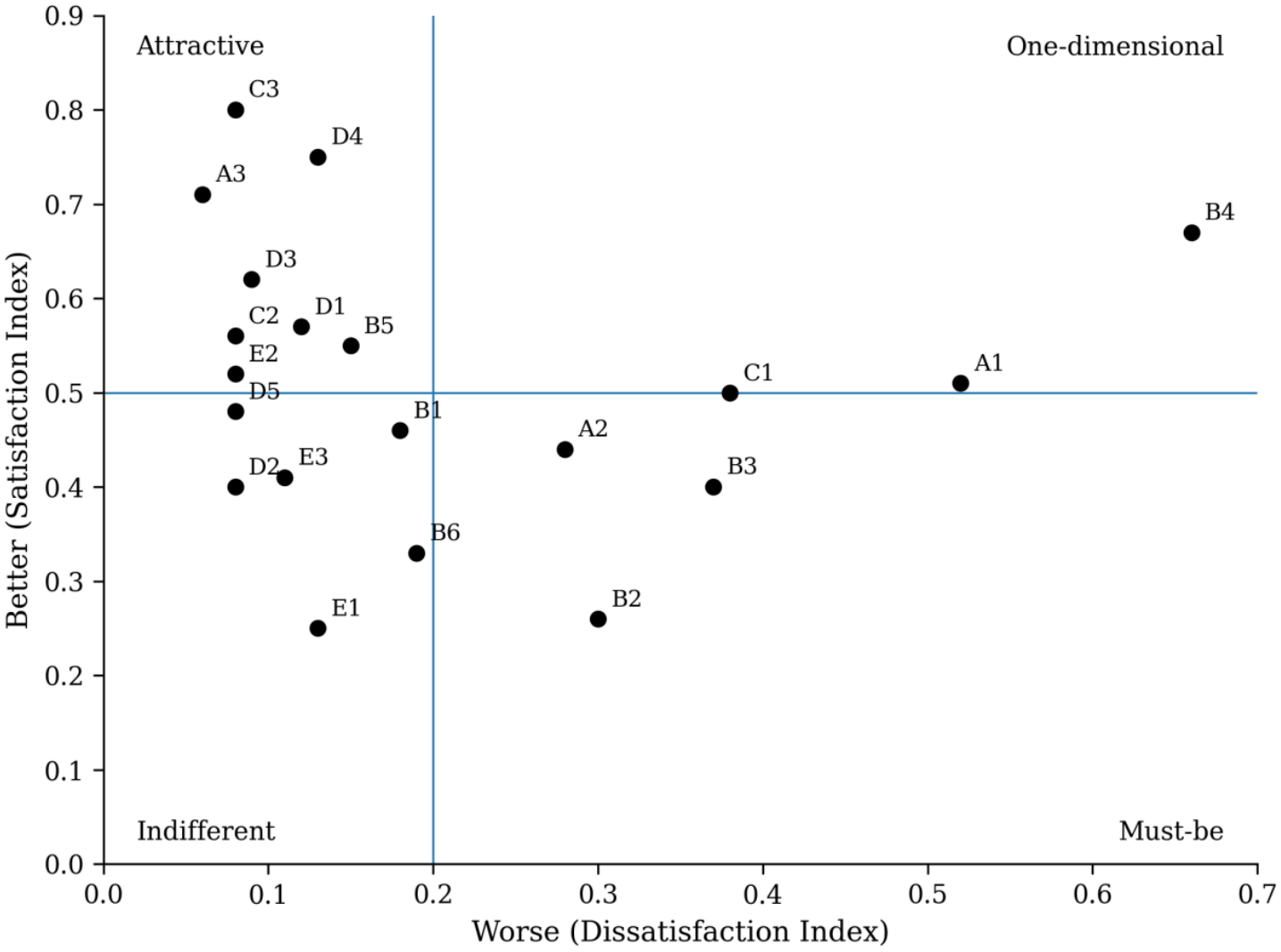


Figure 2

Scatter diagram

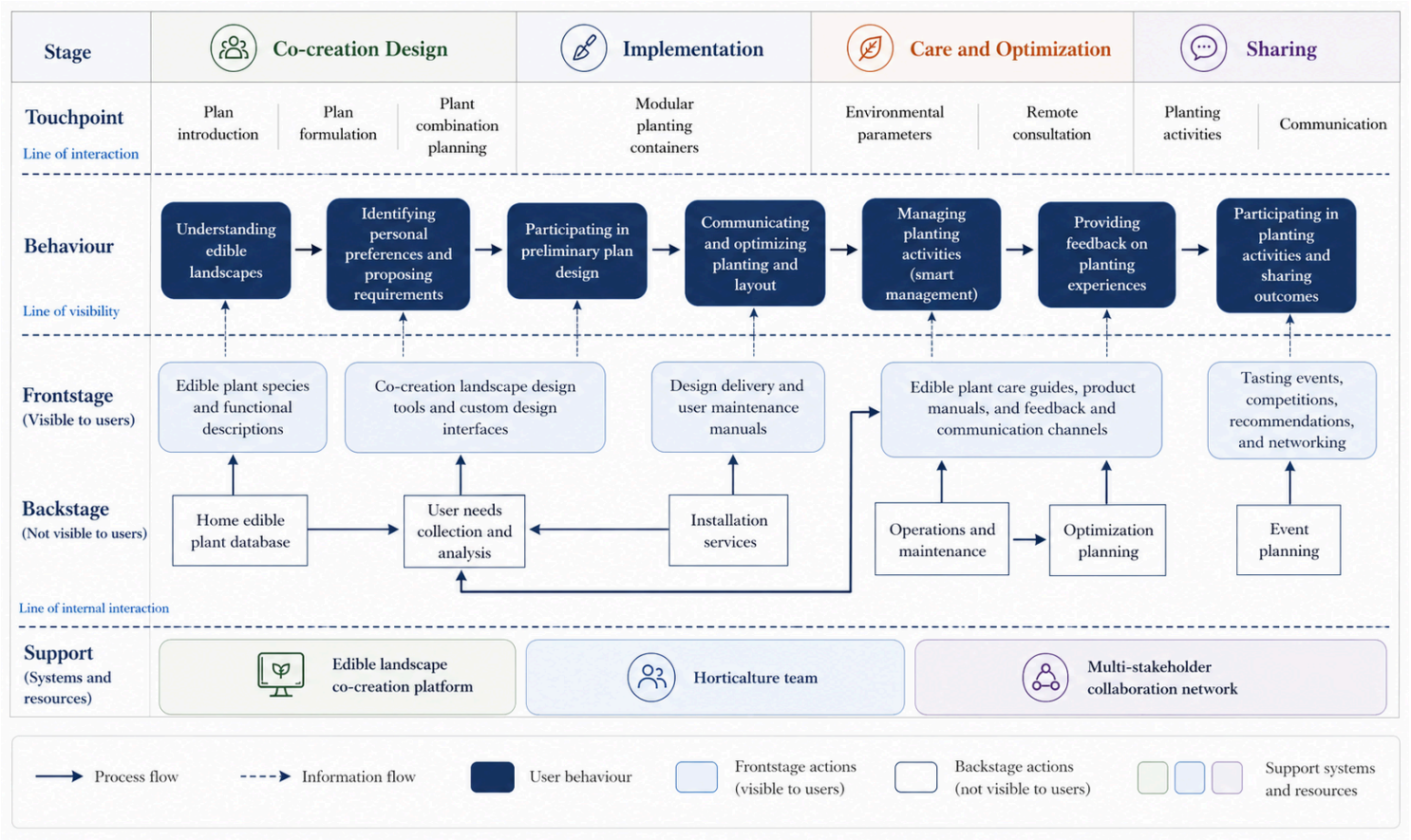


Figure 3

User engagement service framework



Figure 4

Planting containers prototype design

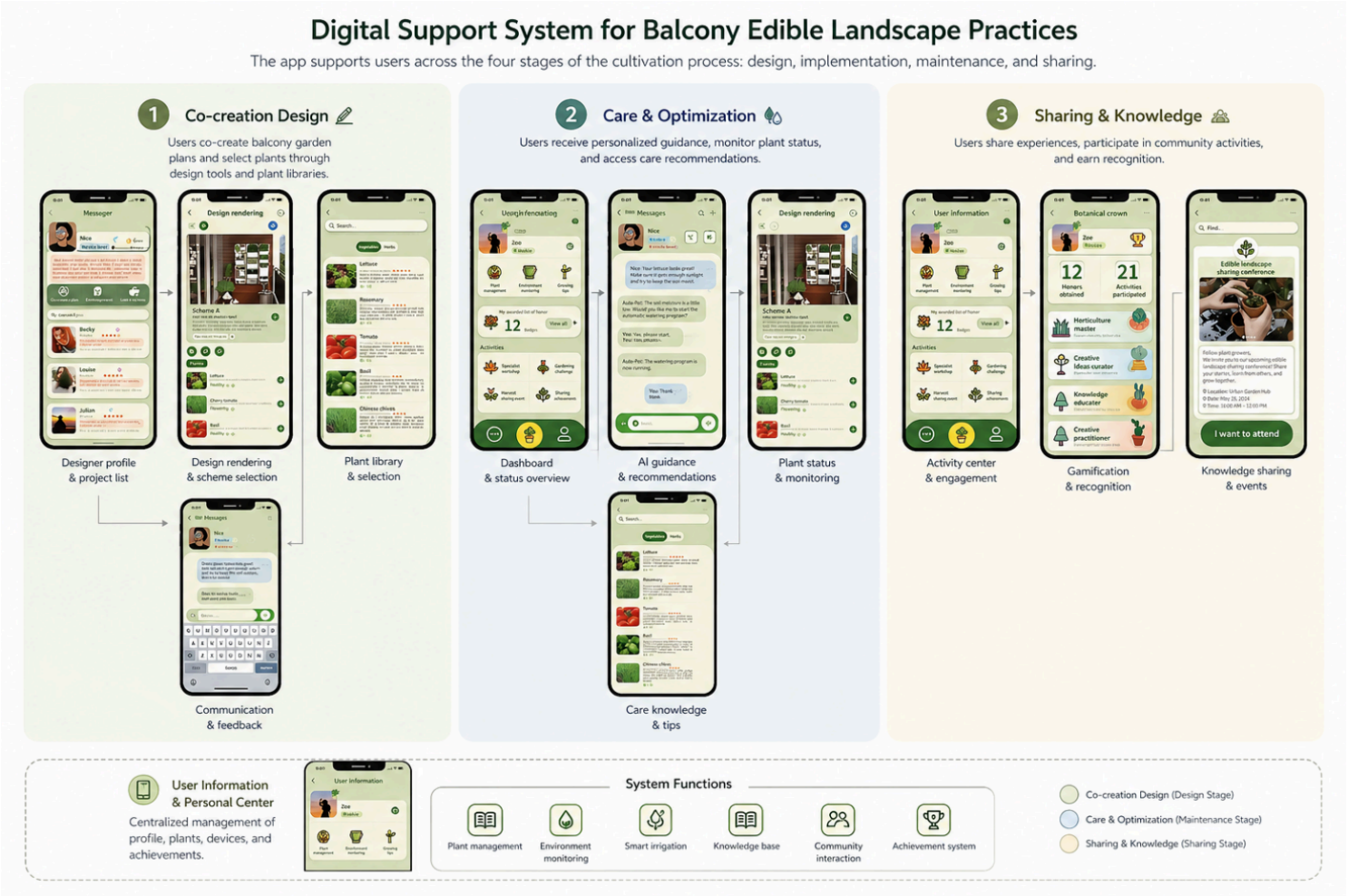


Figure 5

Digital support

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