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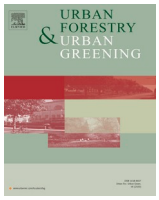

Original article

Enhancing liveability in urban-rural fringe areas: Integrating resident perspectives to community park planning and design in China

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ABSTRACT

Urban-rural fringe areas (URFAs) are transitional zones where rapid urban expansion intersects with rural landscapes, posing significant socio-environmental challenges. In China, this issue is particularly critical, with the urbanisation rate increasing from 17.9 % in 1978 to over 67 % in 2024, driving rapid land use transformation and reshaping the design and functionality of public spaces. Community parks (CPs) play a vital role in these areas in enhancing liveability and socio-ecological resilience. However, while policies increasingly emphasise the importance of green spaces, their quality and alignment with residents' needs remain underexplored. This study examines the role of CPs in Wuhan's URFAs by analysing park usage patterns, resident satisfaction, and functional design elements. Using structured questionnaire surveys (n = 452), the findings reveal that: (1) CPs within a 1,000-meter or 15-minute walking radius significantly enhance accessibility and utilisation; (2) resident satisfaction is influenced by infrastructure quality, particularly the availability of toilets, fitness equipment, and well-maintained facilities; and (3) CPs do not meet diverse community needs, highlighting a gap between quantity-based provision and quality-driven usability. This underscores the significance of prioritising functionality, inclusivity, and user-centred design. In response, this study advocates for a shift from a supply "quantity" driven approach towards a "quality" first planning approach, emphasising participatory design and people-centred approaches to optimise CP infrastructure. By providing empirical evidence, this research contributes to the discourse on urban liveability enhancement and offers insights for improving green space planning in rapidly urbanising regions.

1. Introduction

Rapid urbanisation and the outward expansion of urban regions have exacerbated ecological pressures and intensified socio-environmental challenges globally (Seifollahi-Aghmiuni et al., 2022). These issues are particularly evident in urban-rural fringe areas (URFAs)[1] - transitional zones where urban growth interfaces with rural landscapes, generating significant tension between urban development and ecosystem vulnerability (Wang et al., 2018). While urbanisation has been a key driver of global economic progress – facilitating housing provision, employment opportunities, and infrastructure development (Byomkesh et al., 2011; Ewing and Hamidi, 2015) - it has also led to extensive environmental degradation, biodiversity loss, and increasing social inequalities (Wang et al., 2024). These dynamics pose serious risks to urban sustainability and have negative impacts on public health and urban liveability (Fan et al., 2017).

Urban green spaces are widely recognised as essential components to address these challenges, offering a range of ecological and social benefits that support more resilient urban landscapes, with many studies, e.g., Artmann et al. (2017), highlighting their contributions to regulating microclimates, reducing air pollution, and promoting ecological connectivity. Beyond environmental functions, green spaces also promote

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[1] Urban-Rural Fringe Areas (URFA) are defined in this paper as "newly developed areas, the functions and perceptions of these suburban areas have been continuously reshaped through industrial development and transportation construction"(Wang, Mell, & Carter, 2024:618). URFAs are dynamic and continuously evolving as their functions and perceptions are reshaped by ongoing infrastructure construction, impacting the development of both their social structures and economies (Wang, Mell & Carter, 2024).

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mental and physical health, encourage social cohesion, and provide spaces for recreational (Grahn and Stigsdotter, 2003). These multi-functional benefits have established green spaces development as a central component of urban sustainability strategies (Kabisch et al., 2015), with international frameworks such as the United Nations Sustainable Development Goal (SDG) 15 advocating for the expansion and optimisation of urban green space to combat ecological degradation (Arora and Mishra, 2019).

Despite growing academic and policy attention, persistent global challenges remain concerning the provision, functionality, and responsiveness to residents' needs of green spaces (Kabisch et al., 2015; Guo and Mell, 2021). In many contexts, policy frameworks continue to prioritise quantitative indicators such as green space per capita (m^2 pp) or spatial coverage (m^2 / total%), while neglecting functional performance and experiential quality (Wu, 2015). For example, initiatives such as the Trust for Public Land Park Score in the United States (Jones and Morrell, 2021), the Accessible Natural Greenspace Standard in the United Kingdom (Handley et al., 2003), and the Urban Greening Guidelines in India (Town and Country planning Organisation Government of India, Ministry of Urban Development, 2014) offer benchmarks for green space provision, but lack specific guidance for the design and practical implementation of high-quality green space projects. While the adoption of ecological indicators such as the Normalised Difference Vegetation Index (NDVI) represents progress in assessing vegetation quality, these metrics often overlook crucial human-centred dimensions, such as safety, availability of amenities, diversity or user satisfaction and experiences (Donovan et al., 2022).

Empirical studies increasingly indicates that simply expanding the size of green spaces does not guarantee user satisfaction or optimal functionality. Instead, factors such as accessibility, environmental quality, and inclusive design significantly influence the effectiveness of green space in delivering *ecological* and *social* outcomes (Richardson et al., 2013; Jennings et al., 2017). This has prompted a discourse shift toward quality-oriented planning strategies that prioritise context-sensitive and demand-driven design principles (Schipperijn et al., 2010; Schrammeijer et al., 2021). In particular, the needs of vulnerable groups, such as the elderly and children, are often overlooked, contributing to low usage rates and underrealised benefits (Mu et al., 2020; Zhai et al., 2018). Such findings reinforce the importance of participatory planning and user-oriented approaches in the equitable delivery of equitable urban green space.

These challenges are particularly pronounced in URFAs, where rapid urban development is often guided by economic imperatives rather than ecological or social considerations. In China, government-led land conversion and infrastructure expansion have resulted in the widespread replacement of agricultural, forest and green spaces with residential and transport infrastructure. This has contributed to sharp declines in ecological quality and a growing marginalisation of green space provision in planning agendas (Mu et al., 2020; Zhai et al., 2018). Without coordinated planning strategies for green space provision, URFAs often exhibit fragmented spatial patterns leading to limited utilisation. For instance, research in Shanghai has shown that community parks (CPs) in URFAs often suffer from weak alignment in terms of design and resident needs (Cao et al., 2018). Similar patterns are observed globally, with planning for green space being fragmented in New Delhi's URFA (Kumar, 2015), and the limited consideration of residents' needs in European green space policies in Slovenia and Scotland (Žlender, 2021).

China, as one of the fastest urbanising and most populous countries globally exemplifies these challenges facing significant pressures in terms of green space development within URFAs (Wang and Mell, 2019). Since the 'Reform and Opening-Up' policy of 1978, the urbanisation rate has surged from 17.9 % to 66.2 % in 2023, and it is projected to reach 75 %-80 % by 2035 (He, 2022). URFAs have therefore become hotspots of both demographic expansion and ecological degradation. Moreover, according to Liu et al. (2021), the built-up area of 75 representative Chinese cities expanded dramatically from 3606.26 km^2 in the 1970s to 30,521.13 km^2 over the past five decades. Among them, the core cities within major metropolitan regions, such as Shenzhen and Guangzhou, experienced particularly rapid growth, with their urban footprint increasing from just 0.80 km^2 per year in the 1970s to 14.64 km^2 by 2013. During this process, URFAs have emerged as critical zones illustrating tensions between rapid urbanisation and ecological preservation. These regions, characterised by dynamic spatial patterns, dense populations, and concentrated socio-economic activities, face growing pressures to maintain ecological functionality and the avoidance of declining liveability (Wang et al., 2024). For example, in the Yellow River Delta, urban expansion led to the loss of approximately 33 % of wetland areas between 1980 and 2008 (Gong et al., 2010). The resulting wetland fragmentation weakened regional ecological functions and increased the risk of environmental hazards, i.e., flooding. Moreover, the mismatch between green space supply and demand has become increasingly prominent in URFAs. Guo et al. (2019) report that in Beijing a clear pattern of overuse is visible in CPs, where weekend visitor density exceeded 350 people per hectare. Despite acknowledging the insufficiency of facilities (as well as poor maintenance in these parks), many residents continued to visit during weekends and holidays. This underscores both the essential role of green spaces in daily life and the expectations of access to high-quality spaces to support liveability.

Wuhan, as one of China's megacities and a prominent example of rapidly urbanising regions, driven by the "Rise of Central China" initiative, has experienced significant urban expansion over the past two decades (Peng and Reilly, 2021). URFAs have served as the primary zones for development highlighting both the opportunities and challenges associated with green space construction in China (Zeng et al., 2015). Despite policy initiatives aimed at improving green space provision the persistent issues of low quality planning, design and delivery of green space remain evident. For instance, a 2000 government directive mandated the inclusion of CPs, a critical form of green space in URFAs, in all residential developments to meet the growing demand for accessible green spaces (Feng et al., 2019). However, it has been reported that these CPs often lack essential basic facilities, such as toilets, seating, and recreational amenities, resulting in low usage rates and resident dissatisfaction (Guo et al., 2019; Zhai et al., 2018). Moreover, current planning processes often lack public participation, resulting in a significant misalignment between the intended functions of CPs and the actual needs of residents (Mu et al., 2020). Many studies have emphasised that community residents, as key stakeholders, play a vital role in shaping socially responsive and liveable green spaces when their perspectives are integrated into planning practices (Boland & Zhu, 2012; Hoh et al., 2022). As Wang et al. (2025) illustrate incorporating both expert knowledge and residents' requirements during the planning stage helps bridge the gap between idealised designs and context-specific needs.

Existing research on green spaces in URFAs has though primarily focused on spatial distribution, quantitative supply metrics, and ecological outcomes (Žlender and Thompson, 2017). Limited attention has been given to how CPs in URFA address the needs of residents or how specific design attributes influence user satisfaction. The lack of empirical investigation into residents' preferences in the planning and design of CPs represents a significant gap in the knowledge required to inform contextually grounded green space development. To address this gap, this study investigates CP development in the URFAs of Wuhan by analysing resident perceptions and usage patterns. Specifically, the study aims to: (1) evaluate the current patterns of use and physical characteristics of CPs; (2) identify the key factors influencing resident satisfaction with park functions and amenities; and (3) determine which design elements most effectively align with user preferences. Employing a user-oriented evaluation framework, this research offers empirical evidence examining the relationship between park design and user experience. The findings contribute to the promotion of more inclusive and context-sensitive planning strategies for CPs, and provide actionable

insights for Wuhan and other cities seeking to promote green space development.

2. Materials and methods

2.1. Study area

This study focuses on three CPs located within URFAs of Wuhan, China. Wuhan, the capital of Hubei Province, has experienced rapid urbanisation since 1978, emerging as one of China's largest metropolitan areas. It covers approximately 8494 km^2, including 812 km^2 of urbanised zones (Peng and Reilly, 2021), and has a population exceeding 13 million, with a density of 1438 people/km^2 (Wuhan Municipal Government, 2022). Wuhan consists of 13 districts, seven in the urban core and six suburban districts (Zeng et al., 2015). From 2000–2020 Wuhan expanded from 209.99 km^2 to 812.39 km^2, an increase of 387 % (Peng and Reilly, 2021), and is considered typical of rural/urban land use change regions in China (Zeng et al., 2015). Rapid urban sprawl has increased environmental pressures, creating challenges for the delivery of sustainable development. In response, Wuhan's urban planning discourse has increasingly prioritised green space, especially within URFAs with the development of CPs considered as essential to balancing ecological sustainability with urban liveability (Jim and Chen, 2010; Middle et al., 2014).

To ensure representativeness the research screening all CPs located in URFAs of Wuhan for potential assessment. Based on multiple sources - including The Planning Map of the Green Space System in the Urban Master Plan of Wuhan (2010–2020), the Catalogue of Main Parks, and Baidu Map (a Chinese equivalent of Google Maps) - a total of 51 parks within Wuhan's URFAs were identified, including *urban parks, country parks*, and *community parks*. Combining the study's definition of CPs: *located in community/residential areas*; *the area of GS between 0.4 and 10hm*^{2}; *provides recreational and service facilities*; and the *main users are local residents*, seven parks were found to meet the inclusion criteria (Fig. 1). To enhance reliability an additional screening was performed using three criteria: *geographical location*, *construction period*, and

Fig. 1. The distribution of parks in URFAs in Wuhan (Adapted from *Wuhan Comprehensive Planning 2010–2020*, *Catalogue of Main Parks in Wuhan*, and *Baidu Map*).

development type. These criteria were designed to be representative and conducive to meaningful comparative analysis. The specific selection criteria included:

- *Geographic Location*: The parks are situated in URFAs at varying distances from the city centre. This criterion ensures geographic diversity, allowing the study to examine usage patterns and resident needs across different geographical and demographic contexts within URFAs.
- *Construction Period*: The three CPs were all constructed within the past decade and were influenced by Wuhan's comprehensive urban plan (2010–2020). This criterion ensures that the parks reflect contemporary urban planning policies and design trends, representing modern green spaces developed in the context of rapid urbanisation.
- *Development Type (New or Redeveloped)*: The selected CPs include both newly constructed parks and redeveloped parks. The newly built parks reflect expansion-driven green space development, while the redeveloped parks demonstrate the adaptation of existing parks to meet contemporary needs without significant expansion. This diversity provides insights into varied approaches to CP design and management, offering valuable reference points for cities undergoing similar urban transformations.

Three representative CPs were selected as the case study sites: Dangdai Sports Park, Wudong Park, and Xianghong Art Park as exhibited each of the criteria set our above (Fig. 2). The decision to focus on three CPs was considered both methodologically sound and practically feasible. First, this number enabled effective data collection and thorough on-site investigation and a balanced distribution of research efforts across multiple locations. Moreover, the selected parks were sufficient diverse in geographic setting, development background, and typology, providing a solid basis for comparative analysis. By examining these three selected CPs, this study aims to deepen the understanding CP multifunctionality in URFAs, residents' usage, satisfaction with existing CPs, and preferences for specific amenities within CPs.

2.2. Questionnaire

2.2.1. Questionnaire design and data collection

This study employed a structured questionnaire as the primary data collection instrument due to its advantage of capturing a large volume of standardised resident feedback. Compared with other approaches such as interviews or site-observation, structured questionnaires offer greater consistency in administration across multiple communities and facilitate comparative analysis. This method is particularly well-suited for examining general patterns and preferences in CPs use among residents living in URFAs. Moreover, the questionnaire method provides a time- and resource-efficient approach, enabling the collection of a broad and diverse sample while enhancing the representativeness and generalisability of the findings. Based on these methodological considerations, a structured questionnaire was developed to evaluate the current utilisation patterns of CPs, participant' satisfaction levels, their preferences, and needs regarding park features. The questionnaire comprised four sections (see S7):

- *Demographic Information*: This section collected respondents' basic demographic characteristics, such as gender and age, to facilitate grouping during data analysis and enhance the representativeness of the findings (McLafferty, 2003).
- *Open-ended Questions*: Open-ended questions, such as "What is your primary reason for visiting the park?" were included to gather qualitative insights into residents' motivations and to ease them into the survey before addressing specific park-related issues.
- *Satisfaction Assessment*: Residents' satisfaction with both macro-level attributes (e.g., overall landscape design) and micro-level features (e.

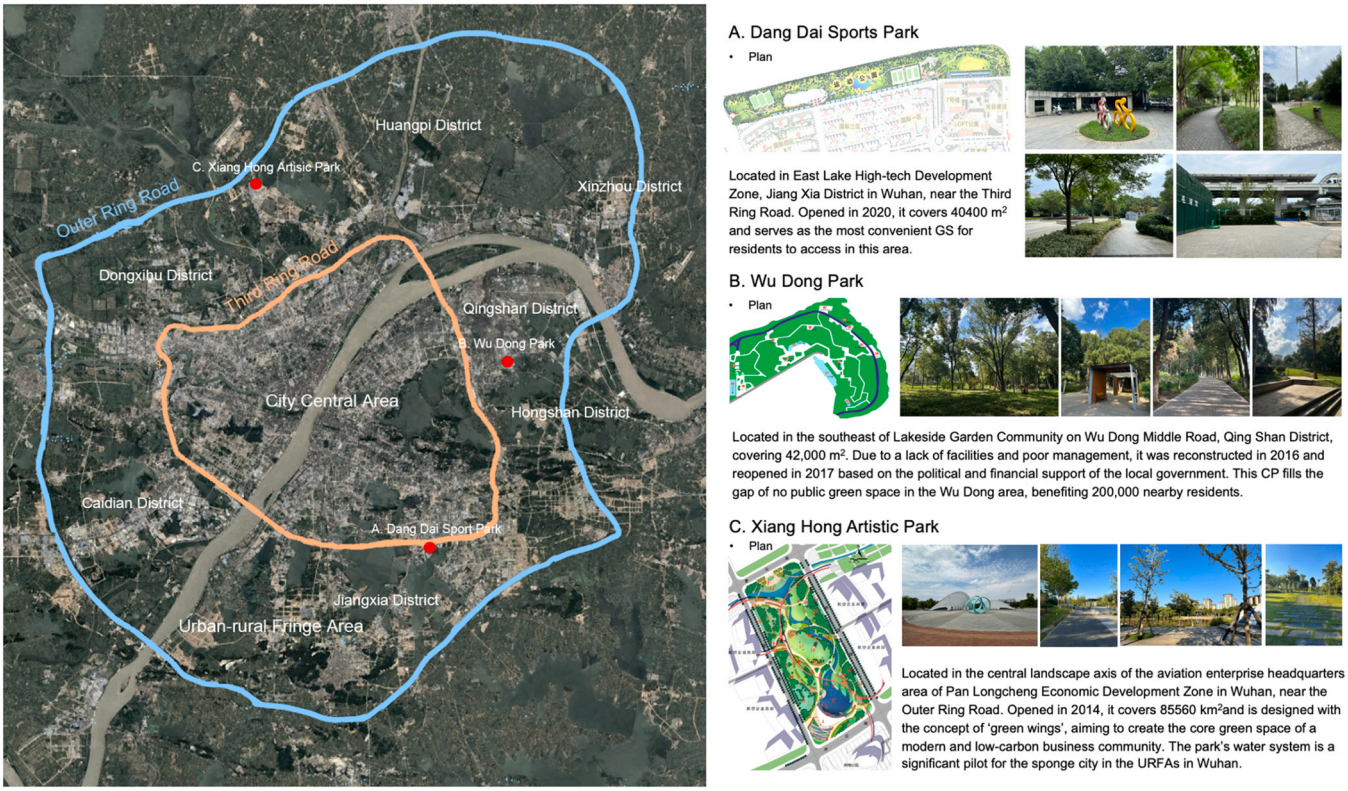

Fig. 2. Introduction of three selected CPs in URFAs in Wuhan (main map adapted from Google pro, all other images developed by the authors).

g., pathways and vegetation) was assessed using a five-point Likert scale (1 = very dissatisfied to 5 = very satisfied). This section provided quantitative measures of user experience and informed the identification of critical design elements to meet user needs.

- *Subjective Narrative Questions*: Open-ended narrative questions were included to provide respondents with an opportunity to share detailed feedback and suggestions for park improvement. These responses aimed to capture nuanced perspectives and potential areas for enhancement.

Ethical approval was granted by the University of Manchester's Ethics Committee before administration (Ethics application number: 2023–15304–26891; date of approval: 23/01/2023). Data collection ran from June-September 2023. A twin approach to surveying was adapted maximise sample diversity and ensure robust data collection. *Online surveys* were distributed via community WeChat groups, allowing participants to complete anonymous responses through the Qualtrics platform. This method aligns with approaches used in previous studies, such as Chen et al., (2024), who demonstrated the effectiveness of leveraging social media platforms for recruitment and collecting reliable data in community-based research contexts. *On-site surveys* were conducted in person by distributing printed questionnaires to visitors. Surveys were carried out across different times of the day (morning/afternoon/evening), and throughout the week to address variation in park usage patterns. A single researcher conducted the on-site questionnaire data collection on all three sites promoting a consistency of approach was achieved by ensuring that all questions and data was validated at the point of receipt. This supports greater reliability as there was minimal variation in the delivery of the surveys or the recording of responses. Both formats adhered to ethical standards, informed consent was obtained from all participants, and participation was voluntary. total, 452 valid responses were obtained, with distribution across the three CPs as follows: CP1 (182 responses), CP2 (140 responses), and CP3 (130 responses). Post-survey and during the data validation process no significant variation was identified in responses suggesting an internal reliability to the data.

2.3. Statistical analysis

All questionnaire data were analysed using SPSS V29 to examine patterns of park usage, residents' satisfaction, and the factors influencing satisfaction. The statistical analysis involved four main components: *descriptive analysis*, *correlation analysis*, *textual analysis*, and a *Generalized Linear Mixed Model (GLMM)*.

Descriptive statistics were employed to summarize respondent demographics and park usage behaviours, including visit frequency, travel modes, stay durations, and visit purposes. This analysis provided a baseline understanding of CP functionality and value to residents. This data supported the identification of trends in accessibility and usage patterns, such as the influence of proximity on visitation frequency. Correlation analysis was conducted to evaluate the relationships between specific park features (e.g., green coverage, water features, recreational facilities) and satisfaction levels. Survey items (Questions 12–26) were used to derive satisfaction scores, which were analysed alongside overall satisfaction ratings. The analysis measured the strength and direction of these associations, providing insight into how individual park attributes influenced user experiences. This process also identified areas where CPs require targeted improvements. Subjective responses from open-ended questions were analysed using textual analysis including sentiment analysis and keyword extraction. Positive and negative feedback were systematically categorised, and recurring themes/keywords were identified. This qualitative analysis complemented the quantitative findings by highlighting user preferences and potential areas for improvement.

To examine how individual visitor traits and park related factors influence perceived satisfaction with green spaces, we used a Generalized Linear Mixed Model (GLMM) with the GENLIN procedure in IBM SPSS Statistics (version 18.0). This approach examined the hierarchical structure of date and the subjective nature of satisfaction as a perceived outcome on benefits from a visit to park. The dependent variable was the total satisfaction score, a continuous measure of visitors' subjective assessment of their park experience. this was a sum of 15 variables: *1) size; 2) layout; 3) sport facilities; 4) theme of the park; 5) landscape design; 6) plants; 7) guiding signs; 8) entrance; 9) footpaths; 10) art facilities; 11) convenient facilities; 12) cleanliness; 13) management and maintenance; 14) light availability; 15) security*. Each respondent (N = 452) rated these 15 variables on a 1–5 scale, with 1 indicating the lowest satisfaction and 5 indicating the highest. Responses for 15 variables were subsequently added to calculate a total satisfaction score for one respondent.

As satisfaction varies based on personal traits and environmental factors, GLMMs are well-suited for modeling both fixed effects (systematic influences) and random effects (unobserved individual differences) on the assessment of each respondent's satisfaction and the factors that may influence it.

The fixed effects explanatory variables used were: 1) park ID (categorical: 1, 2, 3); 2) occupation (categorical); 3) main reason for visiting the park (13 categorical variables); 4) frequency of visit (categorical); 5) duration of stay (categorical). The Serial Number of respondents was included as a random effect in the GLMM to account for individual variability among respondents. This allowed the model to control for unobserved heterogeneity in satisfaction scores while testing the impact of response bias or heterogeneity in sociodemographic factors that could not be explained by the fixed effects, which are mentioned above (Acharya et al., 2021; Fox et al., 2019). This approach allowed the identification of significant predictors of satisfaction while accounting for individual variations. Before modeling, multicollinearity among all explanatory variables using Spearman's rank correlation coefficient was checked (See S6). As per Dormann et al. (2013), pairs with correlation coefficients of $|\rho| \geq 0.0.5$ were considered collinear; in such cases, only one variable from each pair was included to reduce redundancy and improve interpretability.

A GLMM with a normal distribution and identity link function was specified, fitting for the continuous nature of target variable. Parameters were estimated via maximum likelihood. Model fit was evaluated with the Akaike Information Criterion (AIC), and fixed effects significance was tested with Wald chi- square at $\alpha = 0.05$. This analytical framework allowed a thorough exploration of park characteristics and individual factors influencing satisfaction, while controlling for multicollinearity and individual variability. GLMM was used in the past, for example, to understand the perceptions of tourists on cultural ecosystem services in an alpine region to map and improve management of specific landscape locations (Zoderer et al., 2016).

3. Results

3.1. Respondents' profiles

A total of 452 valid responses were collected from users of three CPs in URFAs of Wuhan: 215 were male (47.6 %) and 237 were female (52.4 %). Most respondents (over 75 %) resided within the communities where these parks are located. The largest age group among respondents was 26–40 years, with a balanced distribution across other age categories. The majority of participants reported being employed, while fewer respondents identified as students, retirees, or public servants (Table 1).

3.2. Usage patterns of CPs in URFAs in Wuhan

Approximately 70 % of respondents lived within 1000 m of the three CPs, with 84 % residing within 2000 m (see Table 2). Visitor frequency declined as distance increased, although a slight increase was noted

Table 1
Demographic information of respondents of three CPs in URFAs (n denotes the number of respondents).

	CP1		CP2		CP3	
	N	%	N	%	N	%
Are you a resident of the community?						
Yes	140	76.90 %	108	77.10 %	106	81.50 %
No	42	23.10 %	32	22.90 %	24	18.50 %
Are you?						
Work nearby (with 2 km/15 mins walk)	108	59.30 %	50	35.70 %	57	43.80 %
Study nearby (with 2 km/15 mins walk)	9	4.90 %	6	4.30 %	14	10.80 %
Visitor	39	21.40 %	82	58.60 %	47	36.20 %
Other	26	14.30 %	2	1.40 %	12	9.20 %
Sex						
Male	81	44.50 %	69	49.30 %	65	50.00 %
Female	101	55.50 %	71	50.70 %	65	50.00 %
Age						
18–25	27	14.80 %	40	28.60 %	18	13.80 %
26–40	106	58.20 %	32	22.90 %	61	46.90 %
41–55	34	18.70 %	32	22.90 %	34	26.20 %
⩾ 56	15	8.20 %	36	25.70 %	17	13.10 %
Occupation						
Employee	98	53.80 %	60	42.90 %	66	50.80 %
Public servant	13	7.10 %	4	2.90 %	9	6.90 %
Student	14	7.70 %	29	20.70 %	13	10.00 %
Retiree	13	7.10 %	37	26.40 %	15	11.80 %
Others	44	24.20 %	10	7.10 %	27	20.80 %

Table 2
Usage patterns of respondents of three CPs in URFAs (n denotes the number of respondents).

Category	CP1		CP2		CP3	
	N	%	N	%	N	%
Distance between home and CPs						
0–500 m	128	70.32 %	52	37.14 %	9	6.92 %
500–1000 m	8	4.40 %	54	38.57 %	58	44.62 %
1000-2000m	27	14.84 %	11	7.86 %	34	26.15 %
2000-3000m	2	1.10 %	1	0.71 %	15	11.54 %
> 3000 m	17	9.34 %	14	10.00 %	4	3.08
unknown	/	/	9		7	/
Main mode of transport to visit CPs						
Walking	138	76.00 %	100	71.00 %	78	60.00 %
Cycling	13	7.00 %	10	7.00 %	10	8.00 %
Motorbike	12	7.00 %	3	2.00 %	12	9.00 %
Car	7	4.00 %	11	8.00 %	11	8.00 %
Bus	10	5.00 %	7	5.00 %	4	3.00 %
Taxi	/	/	2	1.00 %	/	/
Other	2	1.00 %	7	5.00 %	12	15.00 %
Travelling time to visit CPs						
Within 15 mins	136	75.00 %	97	70.00 %	86	66.00 %
15–30 mins	41	23.00 %	25	18.00 %	34	26.00 %
More than 30 mins	5	3.00 %	18	13.00 %	10	8.00 %
Frequency to visit CPs						
Daily	75	41.00 %	76	54.00 %	72	55.00 %
Weekly	39	39.00 %	24	24.00 %	23	23.00 %
Monthly	8	4.00 %	1	1.00 %	5	4.00 %
Occasionally	47	26.00 %	35	25.00 %	26	20.00 %
Rarely	13	7.00 %	4	3.00 %	4	3.00 %
Duration of stay in CPs						
Only passing by	25	13.74 %	11	7.86 %	5	3.85 %
Under 30 mins	65	35.71 %	42	30.00 %	21	16.15 %
30–60 mins	80	43.96 %	54	38.58 %	65	50.00 %
More than 60 mins	12	6.59 %	33	23.57 %	39	30.00 %

beyond 3000 m. Additionally, most visitors (approximately 70 %) accessed the CPs by walking, with 81 % reporting a walking time of < 15 min. This finding suggested that a 1000-meter or 15-minute walking radius could serve as an effective service boundary for CPs.

Proximity was strongly correlated with visit frequency: approximately 50 % of respondents visited CPs daily, and an additional 19 % visited one to three times weekly. Travel time further influenced these patterns, with those residents who lived closer to CPs visiting more frequently. Detailed tables on proximity, visitation frequency, travel time, and transportation mode are provided in the supplementary materials (S1, S2, S3, and S4). Approximately 62 % of visitors spent 30–60 min per visit, reflecting the role of CPs in supporting mid-length leisure activities. Quantitative analysis for proximity, travel mode, visit frequency, and stay duration is summarised in Table 2.

3.3. Residents' preferences and areas for improvements

3.3.1. Visiting patterns and motivations: highlighting CP's vital role in resident's life

The analysis of visitation patterns indicates that CPs served as significant public greenspaces for residents' routines. Across all sites, "evening" emerged as the most preferred time for visits followed by "morning". However, there were differences in morning attendance among the parks: CP2 attracted the highest proportion of morning visitors (42 % of respondents), while CP1 and CP3 had lower morning attendance, with 9 % and 21 %, respectively. CP1 visitors tended to visit "when free," while weekends were more popular for CP3 visitors, suggesting distinct usage patterns likely related to residents' schedules and park-specific amenities (S5).

The main motivations for visiting CPs reflect their appeal as multifunctional and social spaces. "Taking a walk" (333 respondents), "seeking peace and quiet" (295 respondents), and "getting fresh air" (279 respondents) were frequently cited highlighting the role of CP in providing relaxation and contact with nature. Other motivations included visiting playgrounds, enjoying natural scenery, picnicking, and socialising with friends and family were also reported. Differences in usage emerged between parks. CP1 recorded the highest number of playground users and was more frequently used for sports compared to CP2 and CP3 (see Fig. 3).

3.3.2. Attitudes toward CP features: positive aspects and opportunities for improvement

Open-ended responses showed that residents generally held favourable views toward CPs, particularly appreciating the landscape, open space, and tranquillity these parks provided. Respondents highlighted the importance of the natural environment for residents' well-being, specifically mentioning landscape features as key attractions. Simultaneously, specific aspects for improvement were also identified, primarily park facilities and site maintenance. Residents frequently mentioned the need for more convenience facilities, e.g., toilets, improved lighting, and enhanced maintenance. In CP1, while sports facilities received positive feedback, many respondents suggested adding fitness equipment suited to older people, indicating a need to accommodate various age groups more effectively. CP2 received criticism regarding cleanliness, children's play facilities, and water features, with concerns about Yanxi Lake, which was reported to have issues with odours and pollution. CP3 respondents highlighted the need for improved lighting and general maintenance. These responses suggest gaps between existing facilities and user expectations, especially regarding diverse recreational facilities and CP maintenance.

3.4. Factors influencing satisfaction

3.4.1. Correlation analysis between current CP facilities and resident satisfaction

The correlation analysis revealed significant positive associations between CP facilities and overall resident satisfaction (Table 3).

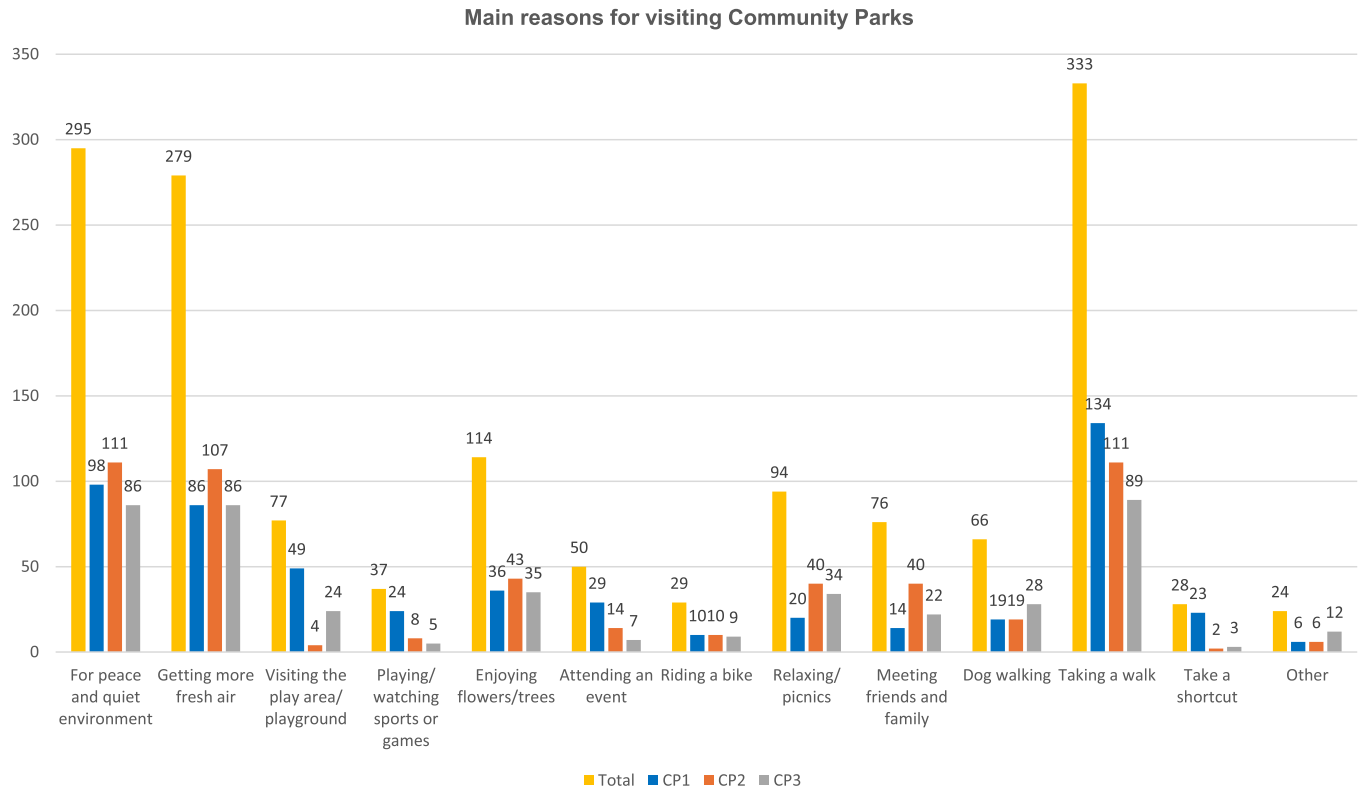

Fig. 3. Respondents' Main reasons for visiting these three CPs.

Table 3
Correlation analysis between current park facilities and park satisfaction.

Table Correlation Analysis											
	Total area	Green area	Water area	Path area	Square area	Parking space	Basketball court	Exhibition hall	Sculpture	Toilet	Shops
Size	**0.330****	**0.330****	**0.380****	0.064	**0.330****	**0.305****	**0.141****	**0.380****	**0.141****	**0.218****	**0.141****
Layout	**0.279****	**0.279****	**0.282****	**0.109***	**0.279****	**0.193****	0.049	**0.282****	0.049	**0.214****	0.049
Sport facilities	0.009	0.009	0.063	−0.072	0.009	**0.096***	**0.099***	0.063	**0.099***	−0.035	**0.099***
Theme	**0.255****	**0.255****	**0.290****	0.055	**0.255****	**0.229****	**0.102***	**0.290****	**0.102***	**0.171****	**0.102***
Landscape design	**0.304****	**0.304****	**0.350****	0.059	**0.304****	**0.281****	**0.130****	**0.350****	**0.130****	**0.200****	**0.130****
Plants	**0.229****	**0.229****	**0.265****	0.043	**0.229****	**0.214****	**0.100***	**0.265****	**0.100***	**0.150****	**0.100***
Guide signs	**0.188****	**0.188****	**0.190****	0.074	**0.188****	**0.129****	0.032	**0.190****	0.032	**0.145****	0.032
entrance	**0.299****	**0.299****	**0.340****	0.064	**0.299****	**0.269****	**0.120***	**0.340****	**0.120***	**0.201****	**0.120***
Footpath	**0.302****	**0.302****	**0.331****	0.082	**0.302****	**0.251****	**0.099***	**0.331****	**0.099***	**0.212****	**0.099***
Art facilities	**0.175****	**0.175****	**0.217****	0.013	**0.175****	**0.187****	**0.102***	**0.217****	**0.102***	**0.104***	**0.102***
Convenient facilities	**0.199****	**0.199****	**0.153****	**0.146****	**0.199****	0.056	−0.053	**0.153****	−0.053	**0.191****	−0.053
Clean	**0.267****	**0.267****	**0.289****	0.076	**0.267****	**0.217****	0.082	**0.289****	0.082	**0.190****	0.082
Management	**0.136****	**0.136****	**0.165****	0.014	**0.136****	**0.140****	0.074	**0.165****	0.074	0.083	0.074
Light	−0.049	−0.049	**−0.136****	**0.101***	−0.049	**−0.178****	−0.163**	−0.136**	−0.163**	0.029	-,0.63**
Safety	**−0.109***	**−0.109***	**-,099***	−0.057	**−0.109***	−0.057	0.000	−0.099*	0.000	−0.092	0.000
Total satisfaction score	**0.246****	**0.246****	**0.265****	0.074	**0.246****	**0.196****	0.072	**0.265****	0.072	**0.177****	0.072

**. Very significant: Correlation is significant at the 0.01 level (2-tailed).
*. Significant: Correlation is significant at the 0.05 level (2-tailed).

Specifically, green spaces, water features, public realm (squares and park areas), exhibition halls, and toilets demonstrated the strongest positive correlations with overall satisfaction, indicating that those quality aspects played a crucial role in enhancing user experiences (emphasised in Table 3). Further analysis showed that CP size, including total area, green and water spaces, roads, squares, and parking spaces, was positively correlated with satisfaction in various aspects including size, layout, theme, landscape, plants, guide signs, entrances, footpaths, convenient facilities, cleanliness, and management (as presented in bold, following the order from top to bottom as listed in the Table 3). This suggests that larger CPs with well-designed spaces and supporting amenities contribute positively to user satisfaction by meeting diverse recreational and aesthetic needs. However, there was also a negative correlation between the size of CP areas and user satisfaction regarding lighting and safety (as emphasised in bold in Table 3), indicating that the spatial extent of CP increases, concerns related to lighting and security should become more pronounced.

Table 4
Results of GLMM analysis. Impact of park characteristics, frequency and duration of visit, and demographic profile on total satisfaction of visitors (N = 452).

Fixed Coefficients						
					95 % Confidence Interval	
Explanatory Variables	Estimate	Std. Error	t	P-Value	Lower	Upper
Intercept	3915	0,0833	46,996	**< 0.05**	3752	4079
CP1	−0118	0,0270	−4385	**< 0.05**	−0171	−0065
CP2	−0095	0,0285	−3316	**< 0.05**	−0151	−0038
CP3	0b					
Employee	−0099	0,0296	−3334	**< 0.05**	**−0157**	−0041
Public servant	−0067	0,0528	−1269	0205	−0171	0037
Student	−0076	0,0419	−1821	0069	−0159	0006
Retiree	−0069	0,0406	−1698	0090	−0149	0011
Other	0b					
Everyday	0122	0,0622	1965	0050	−0.001	0244
Weekly	0133	0,0652	2040	**< 0.05**	0005	0261
Monthly	0065	0,0886	0738	0461	−0109	0240
Occasionally	0132	0,0623	2123	**< 0.05**	0010	0255
Rarely	0b					
Only passing by	−0072	0,0493	−1452	0147	−0168	0025
Under 30 mins	−0117	0,0344	−3415	< 0.05	−0185	−0050
30–60 mins	−0096	0,0304	−3146	< 0.05	−0155	−0036
More than 60 mins	0b					
Play area (no)	0058	0,0312	1876	0061	−0003	0120
Play area (yes)	0b					
Meeting friends (no)	0087	0,0317	2756	**< 0.05**	0025	0150
Meeting friends (yes)	0b					
Dog walking (no)	0059	0,0329	1801	0072	−0005	0124
Dog walking (yes)	0b					

Probability distribution: Normal;
a. Target: Satisfaction Total Score; b. This coefficient is set to zero because it is redundant.

3.4.2. Impact of socio-demographic and park use patterns on visitors' satisfaction

The GLMM analysis identified key socio-demographic and park-use patterns that influenced visitor satisfaction across the three CP sites, with notable variations among the parks themselves (Table 4). Overall, CP3 received higher satisfaction scores compared to CP1 and CP2, suggesting that specific features/amenities in this park meet visitors' expectations more effectively and enhance their experience.

Occupation emerged as a significant factor in satisfaction outcomes. Employees, public servants, students, and retirees all reported significantly lower satisfaction scores compared to the reference category, "Other," with employees showing the largest discrepancy. This suggests that satisfaction may be influenced by the expectations or experiences associated with different occupational backgrounds. The frequency of park visits was positively correlated with satisfaction. Respondents who visited daily, weekly, or occasionally reported significantly higher satisfaction scores than those visiting rarely. Additionally, visit duration influenced satisfaction: visitors who spent under 30 min or between 30 and 60 min in the park reported significantly lower satisfaction than those who stayed over 60 min.

The purpose of park visits also impacted satisfaction scores. Those who visited for purposes other than meeting friends or dog walking reported significantly higher satisfaction than individuals who engaged in these activities. This finding implies that socialising and dog-walking might bring specific expectations that affect users' overall satisfaction, as presented in Table 4. Furthermore, the analysis found that the random effect, represented by the serial number of respondents, did not significantly impact satisfaction scores (Estimate = 0.004, Standard Error = 0.004, Z value = 1.102, p = 0.270). This result affirms the independence of respondent selection in the study, indicating that individual variations in the sample did not affect the overall findings.

4. Discussion

4.1. Significance of community parks in enhancing residents' well-being

As a vital component of urban green spaces provision, CPs play a crucial role in enhancing social cohesion, recreational opportunities and public health. While large green spaces, such as urban parks, are widely recognised for their contributions to a city's image and are linked city urban sustainable development discussions, CPs distinguish themselves by offering more immediate services and connections to nature for urban residents (Luo and Fu, 2016). These unique characteristics make CPs as essential assets in addressing urban challenges, including mental health issues and social equities, particularly in densely populated environments (Jim and Chen, 2010). However, existing literature, e.g., Dempsey and Burton, 2012, demonstrates that the functionality and value of CPs are influenced by a range of factors including geographic distribution, accessibility, quality of design, and integration with local contexts. These factors not only affect the frequency and diversity of park usage but also directly impact user satisfaction and the subsequent realisation of a given park's multifunctional potential (Guo et al., 2019). For instance, shorter travel distances or higher accessibility are associated with increased usage, and well-designed parks with high-quality facilities improve user experiences and better address the diverse needs of local communities (Zolfaghari and Choi, 2023). These insights underscore the importance of considering these factors in the planning of CPs to maximise their social and ecological benefits.

The findings in this study demonstrate the significance of CPs in urban settings, e.g., approximately 70 % of respondents reported visiting CPs daily or several times a week to engage in physical activity. This high frequency of use shows the key role of CPs as accessible urban green spaces supporting quality of life for residents. These findings are consistent with previous studies, such as Feng et al. (2019), which emphasise the multifunctionality of CPs in providing accessible and natural environments that foster both individual and communal well-being. CPs thus serve as critical nodes within urban landscapes, distinguished from other types of green spaces by their location in residential areas. This proximity allows for direct and frequent interaction with urban nature, providing social benefits to residents, particularly those with limited mobility or cognitive impairments (Cao, 2018; Alves et al., 2008). As Artmann et al. (2017) highlight, CPs support physical activity, encourage social interactions, and offer restorative environments, making them indispensable for maintaining the mental and physical health of urban residents. Similar observations emerged from this study. Despite variations in the specific features valued by residents across the three CP cases, respondents consistently recognised the significance of these spaces in providing opportunities for relaxation and connection with nature in their daily lives. Moreover, as shown in Fig. 3, the diverse purposes for which respondents reported visiting CPs highlight the multi-functional value of these spaces. These functions not only contribute to meeting individual needs but also foster social cohesion and improve urban liveability (Zhao et al., 2024). These findings align with policy objectives outlined in the urban spatial planning documents of Wuhan, e.g., Master Plan of Wuhan Territorial Space 2021–2035), which prioritise the development of CPs to enhance social cohesion, improve public well-being, and support sustainable urban development. CPs are therefore instrumental in advancing broader societal goals, including urban sustainability and liveability. Beyond their immediate benefits to individual users, CPs play a key role in creating resilient, inclusive, and sustainable urban environments, reinforcing their importance in contemporary urban planning.

4.2. Design considerations for community parks: accessibility, functionality, and cultural relevance

Although CPs play a crucial role in enhancing urban well-being, significant challenges persist in their design and management, particularly in URFAs, limiting their potential to meet the diverse needs of users effectively.

Evidence from Wuhan identifies a significant correlation between the proximity of CPs and their visitation frequency, travel time, and modes of transport. This finding aligns with previous studies including Liu and Xiao (2021) who highlighted that shorter walking times significantly enhance visitation frequency and user satisfaction. Similarly, Wood et al. (2017) demonstrated that nearby parks not only attract more visitors but also effectively promote residents' participation in physical activities and other recreational pursuits, contributing to improved physical and mental well-being. Moreover, the empirical findings of this study reinforce the critical role of proximity in promoting park usage. As mentioned, 70 % of users surveyed live within 1000 m of the three studied CPs of which 70 % accessed CPs by walking (with 81 % reporting walking times of 15 min or less). These results provide not only robust evidence to support the recommendation of a '1000-meter or 15-minute walking radius' as an effective service boundary for CPs, but also provide actionable guidance for future site selection. While this recommendation aligns with globally recognised proximity-based standards discussed above (e.g., ANGSt in the UK, the Urban Greening Guidelines in India, and Park Score in the US), the findings of this study emphasise the need to go beyond spatial/quantitively targets. Specifically, while such standards prioritise measurable distance thresholds to ensure accessibility, they often lack guidance on functional design to support use. This gap underscores the importance of balancing spatial accessibility with considerations such as park quality, functional diversity, and contextual adaptability. Proximity alone cannot guarantee equitable or meaningful access if facility design and service provision do not align with the needs and preferences of the surrounding community.

Meanwhile, this raises a broader issue concerning the alignment of park functionality and residents' requirements. We found that approximately 70 % of respondents visited CPs frequently (daily or several times a week), with the majority staying for 30–60 min, and only a small proportion extending visiting beyond this duration. While duration of stay shows the role of CPs in providing accessible spaces for activities such as walking and relaxation, the limited duration of visits also reflects the unfulfilled potential for current CPs to serve as multifunctional spaces that support deeper social interactions or a wider range of recreational activities. Moreover, respondent feedback highlighted specific barriers to extended use including insufficient amenities such as toilets and recreational facilities, and poor park maintenance. These issues particularly affected families and older people who often require more user-friendly environments to engage in longer visits. Therefore, these findings support the need for a critical reflection on whether current CP facilities and designs adequately support extended or more diverse forms of engagement. Through a detailed quantitative analysis of visitation patterns, durations, and user needs, this study identified a misalignment between existing park facilities and residents' expectations. Current designs and amenities were found to be insufficient across CP in Wuhan to meet diverse user demands, thereby limiting the social potential of these spaces. These findings align with observations from previous studies that demonstrated that inadequate facilities can significantly reduce user satisfaction and staying duration in urban parks (Nasution et al., 2025). Consequently, this research highlights the need for improved strategic thinking in CP design to enhance essential amenities and addressing maintenance issues. By engaging with this process future CP development will be better able to contribute to increasing the usability and appeal of these spaces and maximise their value to promote social well-being.

Additionally, the study revealed variations in usage patterns and satisfaction levels among different CPs, e.g., CP1's sports facilities attracted younger users, while CP3 was more popular among families seeking weekend activities, indicating specific park facilities hold a key role in influencing the demographic profile of park users and the activities they undertake. This aligns with Li et al. (2023), who emphasised the impact of distinct park features, such as design themes and internal amenities, play a significant role in shaping use and resident satisfaction with parks. Furthermore, this study incorporates users' feedback on the targeted demands for specific amenities: older generations expressed requirements for fitness equipment for daily exercises and health needs, while families highlighted the importance of child-friendly amenities, including safe play zones and shaded seating for caregivers. These insights underscore the necessity of designing parks that accommodate the diverse needs of various user groups, thereby enhancing user satisfaction and engagement.

Local environmental and social factors significantly shape park usage, underscoring the importance of context-sensitive planning and management strategies. As highlighted above CP2 was specifically criticised for poor cleanliness and unpleasant odours from its water features, reflecting the need for management plans to address localised challenges. Previous research by Li et al. (2021) also highlighted the value of community-led approaches in urban green space design but note that they often lack detailed strategies or practical frameworks for implementation. Moreover, Tosi et al. (2023) advocate for resident-centred design frameworks, emphasising the importance of integrating user feedback to inform and refine planning and management processes. Similar trends are evident in global praxis reflecting a growing emphasis on inclusive and tailored design approaches. For instance, the 'Make Space for Girls' initiative in the United Kingdom exemplifies this shift by focusing on the inclusion of underrepresented demographic groups, such as teenage girls, in the planning and design of public spaces. This initiative highlights the importance of engaging specific user groups to ensure that designs address their unique needs and preferences, moving beyond conventional, aesthetically driven, or universally applied models of park planning. These examples demonstrate the growing recognition of the need to balance universal design principles with context-specific adaptations, ensuring public spaces remain functional, inclusive, and relevant.

Meanwhile, evidence from Wuhan also highlights the need to contextualise park use within broader socio-cultural context. For instance, temporal and spatial variations in park usage patterns emphasise the importance of culturally sensitive and context-specific design strategies. For example we identified 'evenings' as the peak visitation time, reflecting cultural practices in China, where post-dinner walks are a popular activity which is widely regarded as beneficial for health (Song et al., 2014). This highlights the need for targeted design improvements, such as enhanced lighting to increase safety and usability during evening hours. This contrasts with findings in other regions, for instance, Birenboim et al. (2013) observed morning and midday peak usage in European parks, while Dinda and Ghosh (2021) reported afternoon peaks in Indian parks due to climatic and cultural preferences. These differences highlight the significance of aligning park designs to local cultural and social contexts to maximise functionality and user satisfaction. The design of CPs in China's URFAs should therefore prioritise cultural practices and the specific needs of local residents, rather than merely replicating Western design aesthetics or focusing on superficial visual appeal. Critiques of current practices have highlighted that some park designs overly emphasise "Western aesthetics" while neglecting the

complexities of local socio-cultural contexts, such as the spatiotemporal patterns of residents' daily activities and their functional needs. These design approaches not only limit the practical usability of parks but also undermine their potential to enhance community cohesion and social engagement. By adopting localised design strategies rooted in place-specific characteristics and user needs, CPs can better address diverse requirements while delivering broader socio-cultural benefits. Therefore, this study emphasises that the planning and design of CPs should not focus on proximity, but also incorporate considerations of facility quality, service provision, and cultural adaptability to maximise the multifunctional value of parks and optimise their social and ecological benefits.

Balancing standardised design principles with localised customisation remains a significant challenge in CP planning. While benchmarks such as the widely referenced 15-minute walking radius, as exemplified by the *Standard for Urban Residential Area Planning and Design (GB 50180–2018)*, offer a valuable framework for improving accessibility, they must be adapted to address the specific needs and preferences of local communities. As previous studies suggest (Currie, 2017), a universal design standard may provide an initial structure, but it is insufficient to accommodate the demographic, cultural, and environmental diversity inherent in urban areas. Thus, to address these limitations, evidence from Wuhan suggests that a mixed approach is necessary - one that combines the consistency of universal frameworks with the flexibility of locally tailored solutions. This approach ensures that CPs are not only accessible and inclusive but also reflective of their unique local contexts and residents' needs which can be shape the construction of multi-functional green spaces. By integrating socio-cultural and environmental considerations alongside residents' specific preferences within the planning process, CPs can more effectively fulfil their role of supporting enhanced community liveability.

This study therefore provides valuable insights into the planning and design of CPs and green spaces, particularly for URFAs undergoing rapid urbanisation. The findings highlight a shift from a 'quantity-oriented' to a 'quality-oriented' approach, underscoring the need for policymakers to prioritise design, accessibility, and facility enhancement over mere coverage metrics (increased m^2 green space). This perspective aligns with previous research, such as Guo and Mell (2021), which emphasises the integration of quality considerations into green space planning. However, the paper acknowledges that its finding may be constrained by its geographically specific focus on CPs in Wuhan's URFAs. Although it offers critical insights into local conditions this may limit the generalisability to other cultural and socioeconomic contexts although this is not necessarily in large urban areas in China. Second, the study primarily centres on residents' perspectives, while insufficiently addressing the views of other critical stakeholders, such as urban planners, policymakers, and green space managers. These stakeholders play a crucial role in translating user needs into actionable policies and implementable designs. Therefore, future research should explore collaborative mechanisms that enable the effective translation of residents' needs into policy and design process. Although there is a growing body of literature on co-creation and participatory planning the integration of user-centred and stakeholder-driven approaches to CP development in URFA remains under-explored. In practice, there is still a lack of systematic mechanisms for incorporating diverse actors into green space governance. Consequently, future research should prioritise collaborative frameworks that engage diverse stakeholders, facilitating the co-creation of parks that are both responsive to local needs and aligned with broader urban sustainability goals. Furthermore, although questionnaire surveys offer clear advantages in collecting large-scale standardised data, they also impose limitations on uncovering residents' deeper experiences and emotional connections with CPs. Subtle behavioural motivations and nuanced user preferences may therefore be overlooked. To address this, future research should consider incorporating qualitative methods, such as semi-structured interviews, within a mixed-methods framework. This would allow for a more nuanced understanding of how residents in URFAs use CPs, perceive their benefits, and articulate their personal and social meanings.

Despite these limitations, the study has significant implications for urban planning and landscape design. Identifying a 1000-meter or 15-minute walking radius as an effective service boundary for CPs provides a practical framework for improving accessibility. This empirical evidence offers actionable guidance for policymakers and urban planners to align existing theoretical studies on accessibility with a useable metric for future development. However, accessibility alone is insufficient to ensure sustained user engagement. The findings emphasise the importance of integrating proximity with diverse facilities, effective management, and local socio-cultural context to create multifunctional CPs. Moreover, user feedback highlighted their needs and preferences such as the need for more recreational amenities offering guidance for enhancing the inclusivity of CPs. Thus, integrating residents' needs is essential in maximising CPs' value to improve social well-being, particularly in URFAs where diverse demographics and spatial dynamics demand context-specific consideration. By addressing these needs CPs can be planned to more effectively meet individual and community liveability goals.

5. Conclusion

This study provides an in-depth analysis of the usage patterns, resident preferences, and functional alignment of CPs in URFAs in Wuhan, revealing critical shortcomings in current CP planning practices while proposing actionable strategies to address these gaps. The findings emphasise that simply increasing the quantity of green spaces is insufficient to meet the diverse needs of residents. Instead, the study advocates for a shift from quantity-focused to quality-focused green space planning, emphasising functional design, accessibility, local contextual factors, and the incorporation of user preferences into the planning process. Through an analysis of empirical evidence generated from CP users in Wuhan, this research contributes to the growing discourse on green space planning in rapidly urbanising contexts. The study offers actionable insights and practical guidance for designing CPs that are not only responsive to local needs but also aligned with broader social well-being objectives. The findings underline the importance of integrating residents' needs and socio-cultural considerations into green space planning, aiming to enhance both user satisfaction and maximise green space multifunctional benefits to promote urban liveability.

CRediT authorship contribution statement

Ke Wang: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ian Mell:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis. **Somidh Saha:** Writing – review & editing, Formal analysis, Data curation.

Intellectual Property

There are no impediments no impediments to publication, including the timing of publication, with respect to intellectual property.

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We confirm that this manuscript is original and has not been published or submitted elsewhere. Additionally, we declare no conflicts of interest associated with this research.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.129055.

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