Encounters within and beyond gates: Decoding co-presence patterns in Chinese housing estates through proximity-based social network analysis[1]

Abstract:

Housing developments naturally shape opportunities for people to encounter each other through their co-presence patterns, further determining their social vitality. Analysing co-presence patterns thus offers a promising evidence pathway from housing development design to its social effects. This study investigates whether China's gated and non-gated housing developments differ in their co-presence patterns, and if these differences are associated with their housing characteristics. The co-presence data were collected through walk-by observations at six paired gated and non-gated housing developments, and 120 co-presence networks were constructed using proximity-based social network analysis. Results indicated the non-gated estates had significantly higher levels of co-presence and social mixing, with smaller tendencies towards centralisation and clustering of social group types. Housing characteristics (e.g., enclosure degree, density, location, housing price) significantly correlated with co-presence attributes. However, after controlling for other socio-spatial factors, enclosure degree failed to explain the co-presence parameters significantly. These findings suggest that it is not the enclosure parameter alone that determines people's potential co-presence but the overall housing form. Simply dismantling the gates might not substantially change the way people use previously gated developments. This paper provides a fresh perspective on comprehending the social impacts of gated housing.

Keywords: co-presence pattern; proximity-based social network; housing developments; gated housing; behaviour mapping; social vitality

1. Introduction

While housing enclosures have existed for millennia, since the 1990s there has been unprecedented worldwide growth in 'gated communities' (Blakely & Snyder, 1997;

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Liao et al., 2018; Wu, 2005). A 'gated community' is a housing development enclosed by physical boundaries (e.g., walls, fences, high hedges) with controlled access to privatise space and amenities that would normally be open to the public (Atkinson & Flint, 2004; Blakely & Snyder, 1997; Blandy et al., 2003; Wang et al., 2021). In the Anglophone world the term was initially used to describe the walled or fenced housing developments in the United States. Yet, with its global prevalence, it has also been used to describe gated residential areas in China (e.g., Chiu-Shee et al., 2021; Dong et al., 2019; Han et al., 2020; Hu & He, 2024; Li et al., 2024; Sun & Webster, 2019; Wang et al., 2021). However, we argue that leaving aside historical, functional, and morphological differences between gated residential areas in China and the US (see Miao, 2003; Wu, 2005), the term *per se* lapses into architectural determinism by implying a causal link between physical boundaries ('gated') and social solidarities ('community'). Therefore, we refer to the cases studied here – Chinese residential developments with physical boundaries and guarded access – as '*gated housing estates*' (hereafter, GHEs).

China has possibly the longest history of gated living structures: ranging from courtyard housing for extended families in feudal times, to *danwei* (or work-unit) compounds in the socialist era for promoting production and constraining consumption, and to commodified units in contemporary China (Chiu-Shee et al., 2021; Li & Xie, 2023; Wu, 2005). GHEs have dominated China's housing market for decades (Miao, 2003; Wu, 2022): over 90% newly built housing estates being gated (Song & Liu, 2017), with roughly 300,000 compounds nationwide (Wu & Li, 2020), shaping a patchwork-like urban form known as enclave urbanism (Breitung, 2012; Douglass et al., 2013; He, 2013; Wissink, 2019) or borderland urbanism (Iossifova, 2015). This form of urbanism has been accused of causing 'cancers of urban life' (Miao, 2003), such as social exclusion, traffic congestion, high automobile dependency, and low infrastructure efficiency. Indeed, this strong metaphor may have real health outcomes, given the reduction in pedestrian movements and social encounters which are likely to have consequential health outcomes.

To address these problems, China's central government convened in December 2015 its first Central Urban Work Conference in 37 years, formulating new guidelines to create more harmonious, livable, and sustainable cities (Chiu-Shee et al., 2021;

Hamama & Liu, 2020). In February 2016, the State Council of China published new guidelines that prohibit the construction of new GHEs, gradually removing the gates of existing ones to allow public access (Renming, 2016). Since then, research on Chinese GHEs has burgeoned. These studies typically focus on topics such as neighbouring and sense of community (Deng, 2017; Li et al., 2025; Li et al., 2019; Lu et al., 2018), (perceived) safety (Sun & Webster, 2019; Wang et al., 2021; Zhang et al., 2020), pedestrian satisfaction (Dong et al., 2019), attitudes towards gating (Liao et al., 2018; Si et al., 2025), the logic and potential benefits of opening up gated areas, or 'ungating' (Hamama & Liu, 2020; Li et al., 2024; Lin et al., 2017; Liu, 2019; Sun et al., 2018; Wu et al., 2020), and, more recently, pandemic control (Hu & He, 2024; Jia & Morrison, 2025; Li et al., 2021).

Although these studies have discussed the impacts of Chinese GHEs using social research methods, there is a paucity of observational studies of social behaviour (Huang et al., 2018), particularly social interactions and encounters within such schemes. As Wissink (2019, p. 183) pointed out, 'We really do not know very much about the geography of social networks of enclave residents, or of encounters that do take place in meeting places.' This leaves an opportunity to compare Chinese GHEs and non-GHEs through the lens of the potential for the different layouts to create opportunities for encounter, by studying patterns of co-presence. Similarly, there are few studies that isolate the spatial constitution of these layout types.

This study intends to remedy these knowledge gaps by systematically comparing the co-presence patterns in GHEs and non-GHEs, and investigating how such patterns are influenced by housing forms. In doing so, it draws a conceptual distinction between *housing type* and *housing form*. Housing *type* refers to the governance or managerial category of an estate – namely whether it is gated or non-gated – typically reflecting management practices, access control, and development intentions. Housing *form*, by contrast, captures the physical and spatial characteristics of the built environment, including boundary design, street layout, density, ground-floor interface, and the structure of public space. While these two dimensions are often correlated, they are not identical: some GHEs may exhibit relatively open forms, while certain non-GHEs may retain spatially enclosed configurations. This distinction is essential, as it helps avoid over-attributing social outcomes to gating *per se*, when in fact they may be shaped by underlying spatial design.

Within this conceptual framing, co-presence serves as a key indicator for analysing the social potential of space. It describes the phenomenon of a group of people simultaneously and physically appearing in a common space (Lawrence et al., 2006; Maciel & Zampieri, 2020). Given the concerns that opening GHEs might damage community life, or introduce safety risks (Wu et al., 2018), this makes co-presence a vital concept, as it is a precondition for face-to-face social interactions and can provide natural surveillance to deter criminal behaviours (Hanson & Zako, 2007). Furthermore, the ungating directive seems to imply that the gated housing *type* or *enclosure itself* is the cause of 'urban diseases'; this demands an empirical assessment whether 'ungating' is likely to be an effective remedy, or indeed the most critical determinant for the social performance of housing.

Against this backdrop, this study addressed the following research questions:

- Q1: If and how do Chinese GHEs and non-GHEs significantly differ in their co-presence patterns (e.g., co-presence intensity or social mixing)?

- Q2: If and how do co-presence patterns correspond to the overall characteristics of housing estates (e.g., location, density, housing price, enclosure)?

- Q3: To what extent can enclosure explain co-presence patterns after controlling for other socio-spatial factors?

To answer the above research questions, we collected data on co-presence from twelve housing areas (i.e., six pairs of GHEs and Non-GHEs) in Wuhan, China, using a walk-by observation technique (Mehta, 2019) to observe people's patterns of behaviour within the streets and squares of the housing areas. In addition, we adapted proximity-based social network (PBSN) approaches (Spiegel et al., 2016) to construct and evaluate human co-presence networks. This quantitative method allowed us to further verify whether GHEs and non-GHEs statistically significantly differ in their co-presence networks and then test the impacts of estate features, particularly enclosure, through correlation and regression analyses.

This study distinguishes itself from the existing literature on 'gated communities' by shifting the focus from higher-level social outcomes (e.g., perceived safety, sense of community, social segregation) to an essential yet underexplored concept – co-presence. As co-presence is theoretically the precursor to these higher-level social outcomes, comparing co-presence patterns between Chinese GHEs and non-GHEs allows for a more precise consideration of the mechanisms underlying the social dynamics of GHEs in China. Additionally, this work provides rich empirical evidence on spatial usage patterns within the studied GHEs, addressing the current scarcity of observational studies in the 'gated community' literature. More importantly, our findings highlight the limitations of relying solely on binary housing classifications (gated or non-gated) as an indicator of social performance. The contributions of this research are discussed in greater length in Section 6.4.

2. Literature Review

2.1 Gated housing in China: history and social impacts

As mentioned above, China's gated housing has a long history – arguable the longest in the world (Pow, 2009). While in the feudal times, it was used to ensure social stability (Chen & Thwaites, 2018; Huang, 2006), during the socialist era (1949-1987), the housing form of work-unit (or 'dān wèi' in Mandarin) compound was created to promote productivity by integrating inhabited and working areas in close proximity, forming a 'production machine' (Song, 2013; Zhang & Chai, 2014). Typically, a state-owned enterprise or institute and residential dwellings were together enclosed by walls, along with other facilities such as hospitals, schools, canteens, and units of government (Xu & Yang, 2009; Zhang & Chai, 2014) with a clear demarcation from 'outsiders'.

Since the late 1980s there has been a shift towards commoditised housing estates (Wu, 2005). These 'sealed residential quarters' ('fēng bì xiǎo qū' in Mandarin) are equipped with shared amenities, varying from simple green space as a minimum, to a playground, clubhouse, school, or clinic (Miao, 2003; Pow, 2009). Fences and gates, therefore, become an efficient and prevalent design strategy to keep ‘free riders’ out (Breitung, 2012). Today, these types of modern GHEs have become dominant in China (Douglass et al., 2013), with approximately 80% of housing estates being gated (Miao, 2003).

Owing to this deep historical root of gated housing, this unique – yet globally controversial – housing form has been taken for granted in China, thus there is a scarcity of studies that look into their social impacts domestically have only developed since the abolition policy was announced in 2016, and are still relatively scarce (Liao et al., 2018). In addition to impacts on transportation (e.g., Han et al., 2020; Lin et al., 2017; Sun et al., 2018) and the Covid-19 pandemic (Li et al., 2021), other research interests focus on influences gated housing may exert on security and sociability.

Where sociability has been studied, the results are inconsistent. For example, Zhu et al. (2012)’s study in Guangzhou reported a weaker neighbourliness in GHEs than traditional neighbourhoods. Likewise, Forrest and Yip (2007) also witnessed noticeable decreases in neighbourly interactions, local intimacy, and mutual trust and assistance, as they moved from a traditional open neighbourhood to a work-unit compound, and to a commodified gated housing estate in Guangzhou. However, only five years later, Yip (2012)’s large-scale survey found a positive effect on the sense of community from gatedness, but this effect was overshadowed by that of other factors, such as personal and neighbourhood factors, and particularly the housing type.

More recently, a retrospective questionnaire survey of 197 residents who moved into GHEs from non-gated ones in Chongqing city showed significant decreases in both residents’ frequency of contacting other people and participating in local affairs, even after controlled the duration of residency (Deng, 2017). Nevertheless, Wu and Li (2020) surveyed 1781 households from five Chinese cities, and reported that homeowners from GHEs had a greater awareness of neighbourly interactions and sense of community than those from non-GHEs.

It is hence evident that the research findings of GHEs’ social effects in China remain inconsistent and inconclusive. A plausible explanation is the symbolic meaning of gatedness (Xu, 2009). Most existing literature has investigated gated residences from sociological and psychological perspectives (Farahani & Lozanovska, 2014). These studies commonly begin by identifying the gated housing estates, then choose the non-gated counterpart with similar socio-demographic features, and conclude by comparing survey results. Although they recognise the socio-demographic heterogeneity, these studies treated the 'gate' only as a symbolic feature for case selections. This might have unwittingly led to environmental determinism, given the expectation that the presence or absence of an enclosure would affect the housing areas' social performances. However, the actual circumstances are more complicated. For example, a recent study in China has pointed out that what is associated with the burglary rate is not the binary classification of 'gated' or 'non-gated', but the enclosure degree (Wang et al., 2021). This highlights the need to look beyond the housing types and pay attention to more detailed and essential spatial variances on the housing forms from architectural and urban design perspectives (Xu & Yang, 2008).

2.2 Co-presence pattern: an alternative way forward

Housing type is arguably less important than housing form because the former cannot directly determine the crime rates or social interactions, yet the latter can indirectly influence these social consequences by shaping the spatial usage pattern. For instance, the presence of a housing enclosure cannot itself force people to interact with each other; but the housing layout can shape patterns of pedestrian movement, thus increasing or decreasing the probability for encounters and interactions (Hillier, 1988). Therefore, for better understanding the social consequences of gated estates, we first need to understand how this housing form influences the co-presence pattern. As Hillier (1996, p. 142) states, '*the pattern of co-presence does result largely from design and its analysis therefore offers the most promising path from architecture to its social effects*'.

Co-presence is a critical sociological concept introduced by Erving Goffman who recognised the importance of the built environment on everyday life and social communication. Goffman (1963, p. 17) describes the concept of co-presence as a condition where *'persons must sense that they are close enough to be perceived in whatever they are doing, including their experiencing of others, and close enough to be perceived in this sensing of being perceived'*. This concept was then adopted by

Anthony Giddens (1984) to study social relations in public encounters in sociology, and meanwhile stressed by Bill Hillier and Julienne Hanson as an essential intervening variable to investigate the interrelation of space and society (Hillier, 1996).

According to space syntax theories, the spatial configuration of streets tends to naturally shape the co-presence (or co-absence) pattern, and this pattern further determines the positive (or negative) social performances of a place. Their studies of English social housing concluded that it is the overly complex and poorly structured layout that breaks down the natural co-presence pattern, with much lower rates of co-present people in planned social housing than in the surrounding streets (Hillier et al., 1993). Similar findings have been reported for Greece (Peponis et al., 1989) and Turkey (Can & Heath, 2015). Although the subject of these studies was not gated housing estates *per se*, they provide evidence that different housing forms may generate distinct co-presence patterns and thus different social consequences. This offers an alternative way to advance the study of gated housing estates through the lens of co-presence.

2.3 Spatial arrangement of housing estates and co-presence patterns

Previous studies have found a positive correlation between the spatial accessibility (i.e., centrality) and co-presence intensity both in urban (Askarizad & Safari, 2020; Shen et al., 2019; Stavroulaki et al., 2019) and residential areas (Can & Heath, 2015; Maciel & Zampieri, 2020; Yunitsyna et al., 2024). Moreover, whether space is constituted by building entrances (i.e., with doors directly opening onto the space) also affects the likelihood of being co-present (Hillier, 1996; Palaiologou, 2015). If a place is constituted by front doors, it is considered safer (van Nes & López, 2007) and provides greater opportunities for encounters and interactions when people are travelling to and from the buildings (Hanson & Zako, 2009).

Compared with mono-functional areas, mixed-use areas tend to attract more people (Özbil et al., 2011; Stavroulaki et al., 2019; Wu et al., 2018) and encourage socialising (Boessen et al., 2018; Mouratidis, 2018). While high density provides a greater opportunity for encounters and interactions (Boessen et al., 2018; Wu et al., 2018), notably, excessively high density might cause overcrowding, unwanted encounters, and social withdrawal (McCarthy & Saegert, 1978). Lastly, studies have found the use of common spaces in residential areas related to the presence of greenery. Both Coley et al. (1997) and Sullivan et al. (2004) have suggested that compared with barren places, spaces with trees and grass attracted more people and social activities.

Recently, Yang and Vaughan (2022b) compared the spatial signature of Chinese GHEs and non-GHEs, finding that the two differ significantly in their spatial accessibility, functional (land) use patterns, and movement interface (i.e., the potential for bringing different types of pedestrian movement together). It was argued that these configurational and morphological differences between GHEs and non-GHEs further led to different spatial logic of pedestrian distribution within and around the housing estates (Yang & Vaughan, 2022a). With these precedents above, it is then reasonable to hypothesise that GHEs and non-GHEs may demonstrate distinct co-presence patterns.

In summary, the literature review reveals a gap in the knowledge regarding the influence of housing forms and co-presence patterns. The following study is based on the premise that investigating co-presence patterns may provide empirical evidence of differences between the social impacts of GHEs and non-GHEs. Thus, the main objective of this paper is (i) to compare the co-presence pattern between China's GHEs and non-GHEs and (ii) to explore the relationship between co-presence patterns and housing characteristics. Bearing in mind that the binary of gated/ungated may be hiding nuances in these characteristics, we further take account of the amount of enclosure.

Theoretical proposition and hypotheses

The longstanding debate over the relationship between enclosure and co-presence – and by extension, social interaction and community cohesion – can be understood through two competing yet contrasting propositions: the *correspondence approach*, which posits that contemporary urban communities are structured tightly by clear territorial boundaries; and the *structured non-correspondence* approach, which argues that communities are structured loosely according to the spatial configuration of their neighbourhoods.

The *first* proposition argues that enclosure, through identifiable boundaries such as gates and fences, *corresponds directly* to enhanced spatial usage and localised social interactions within the defined territory. Rooted in human territoriality theory (Edney, 1974; Porteous, 1976; Taylor, 1988), this perspective posits that humans are territorial beings who assert control over space to satisfy both basic (e.g., security and privacy) and higher-level needs (e.g, group identity) (Gold, 1982; Rapoport, 1969). Consequently, this gives rise to the idea that physical enclosure can lead to enhanced safety, local solidarity, and frequent face-to-face encounters (Altman, 1975; Taylor, 1988), an idea that became prevalent in the late 20th century among architects and urbanists. The most well-known proponents are probably Clarence Perry for his 'neighbourhood unit' model (1929b) and Oscar Newman for his 'defensible space' theory (1972), later inventing the prototype of American 'gated communities' (Newman, 1996).

However, this territoriality-based correspondence proposition was criticised by urbanists for its architectural determinism and resulting pathological, patchwork-like urban morphology, with writers such as Jacobs (1961), Alexander (1965), and Lynch (1981) being the most well-known among them. In response, Hanson and Hillier (1987) challenged the deterministic link between territorial demarcation and community formation, and proposed a *structured non-correspondence approach*. They noted that while the built environment cannot directly dictate human behaviour and social life, it can be structured – in an integrated and permeable way – to generate a potential field of co-presence and encounter (Hillier et al., 1986; Hillier et al., 1993). Therefore, they argued, probably the only direct product of spatial design is co-presence; any other social outcome (e.g., social interaction, local solidarity) is not directly from space, but indirectly from culture (Hillier et al., 1986).

As reviewed in Section 2.3, empirical studies have demonstrated how spatial attributes – such as centrality (accessibility), ground-floor frontage conditions, land use mix, density, and greenery – influence everyday encounters in residential environments (e.g., Can & Heath, 2015; de Rooij & van Nes, 2015; van Nes & Rueb, 2009; Yunitsyna et al., 2024; Zerouati & Bellal, 2020). Building on this, recent comparative studies in Chinese context have also shown that GHEs and non-GHEs differ not only in access control and enclosure, but also in their internal street networks, embeddedness in wider areas, frontage permeability, land use patterns, and movement interface among different people (Yang & Vaughan, 2022a, 2022b). These differences suggest that enclosure may not be the sole or primary determinant of co-presence patterns.

Therefore, the present research supports the *structured non-correspondence* proposition that enclosure cannot guarantee greater co-presence patterns, but a more integrated and permeable spatial configuration (of non-GHEs) can encourage greater movement, thus more co-presence. Note that while the territory-based view has been widely critisised, numerous studies in 'gated community' literature have focused narrowly on enclosure/physical boundaries as the defining factor, unwittingly falling into the pitfall of architectural determinism (Xu & Yang, 2008).

Building upon the above theoretical framework, we proposed three hypotheses with regard to the relation between enclosure and co-presence patterns, to verify whether enclosure can determine (H1) and/or explain (H2, H3) co-presence patterns:

- H1: On average, GHEs will show significantly lower co-presence intensity and social mixing than non-GHEs, but higher centralisation. However, these differences will not be consistent across all comparative groups.

- H2: Co-presence patterns will be significantly correlated with enclosure, but also with other estate-level features, such as location, density, housing price, and greenery coverage.

- H3: After controlling for other socio-spatial factors, the net contribution of enclosure to explaining co-presence patterns will attenuate or become non-significant.

4. Materials and methods

Figure 1 illustrates the workflow of the methodology that contains four main steps. First, the co-presence data were collected from twelve housing areas (six pairs of gated and non-gated) and geocoded in a geographic information system (QGIS, version 3). Second, co-presence networks were generated and cleaned using proximity-based social network approaches. The data were imported into Gephi and Python for data visualisation, then analysed to detect differences between gated and non-gated cases and to verify how co-presence properties correlate with housing forms.

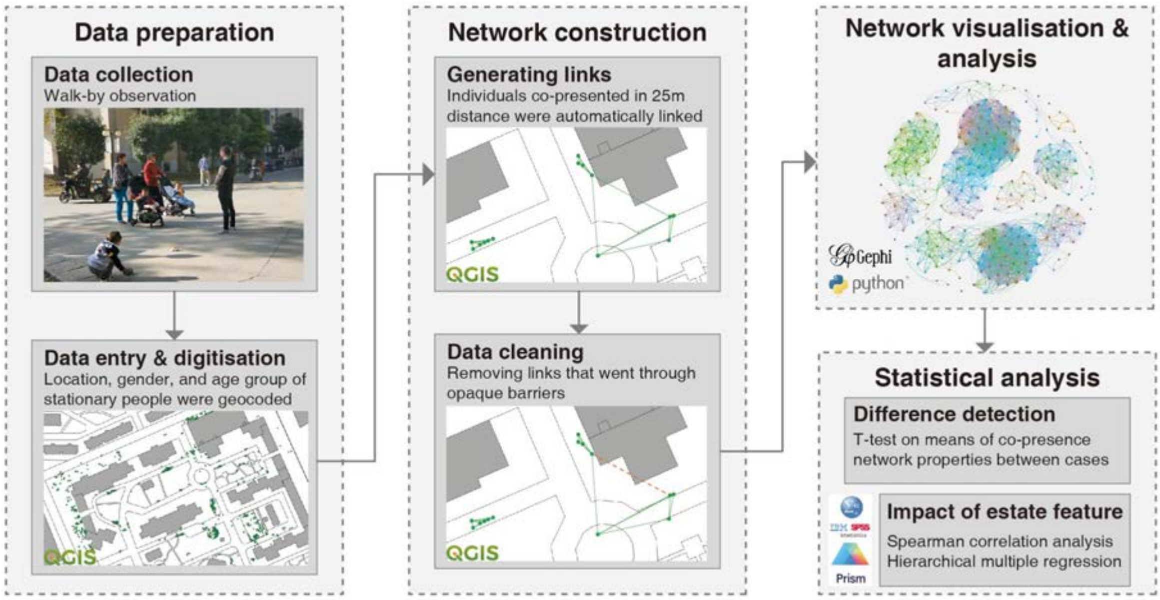


Figure 1. The workflow diagram illustrates the process of co-presence network construction and analysis.

4.1 Case studies

Case studies were carried out in Wuhan, China. Wuhan is a typical inland city that had accommodated nearly 2,000 gated estates by 2006, and more than half of the housing areas were gated by 2013 (Song, 2013), providing both abundant gated and non-gated samples for comparison. In line with definitions from previous studies (Atkinson & Flint, 2004; Blakely & Snyder, 1997; Blandy et al., 2003), we classified housing estates as gated if they have physical boundaries (e.g., fences, gates), or security guards, or any sign suggesting 'residents only'.

A total of twelve housing estates were selected, divided into six pairs of GHEs and non-GHEs (**Error! Reference source not found.**). Each pair of housing estates was selected for their close proximity to avoid any impact of geographical differences and are similarly comparable in plot size, housing price, and year of construction – the latter ensuring no cases were newer than five years aimed to ensure the population would have settled into local behavioural routines (Figure 3). Therefore, the sociodemographic features of the two housing estates in each group are deemed comparable.

Additionally, the selected housing estates pairs provided a contrast in spatial and morphological features, ensuring they represented the variation present in such housing types across urban China. Specifically, Groups 1, 2, and 3 are situated in the less densely populated peripheral urban areas developed after the 2000s, predominantly featuring gated superblocks. In contrast, Groups 4, 5, and 6 are located in the densely populated old city center, established before the 1970s, and dominated by small, non-gated residential areas (Fig. 3).

Group 1 contains two affordable housing estates: Huasheng and Zirun. While Huasheng lacks physical gates, its spatial configuration – comprising inward-facing residential clusters – creates a sense of enclosure, with extensive commercial functions integrated within the area. Zirun, on the other hand, is physically enclosed with walls, primarily residential in use, and features a hybrid street layout of grid and loop patterns.

Groups 2 and 4 contrast traditional open communities with modern gated commodity housing. Chang'er Community and Qingsong Community, built in the 1990s, are traditional open communities with mixed uses, compact layouts, and minimal landscaping. Sunshine Garden and Qianxi Garden, developed in the early 2000s, are gated, highly landscaped estates with monofunctional residential focus and commercial podiums at their edges.

In Group 3, Shiqiao Garden is a modern non-gated estate but features an inward-oriented layout, while Yisongting is a typical modern gated compounds with enclosed, highly landscaped designs. Both areas primarily serve residential purposes, with commercial podiums on the periphery.

In Group 5, Skyline II and Skyline III are part of the same real estate project but designed by different firms. Skyline II is a high-end gated estate with a large central garden for residents and is recognized as a 'garden-like estate' by the local authorities. Skyline III is a mixed-use complex combining commercial functions on the lower floors with residences above, aiming to create a more dynamic interaction with its surroundings.

Group 6 is a comparison between gated and semi-gated housing estates. Yongqingcheng is a densely populated and compact gated compound, with commercial podiums at its edges, leaving the interior exclusively residential. The Riverview, also awarded the ‘garden-like estate’ title, includes several gated residential clusters, with the space between the gated clusters shared with the public.

While the classification of estates in this study is based on governance and managerial characteristics, it is important to clarify how such forms came into being. In the Chinese context, most GHEs were intentionally designed as enclosed compounds by developers (in a top-down manner), rather than retrofitted from open forms. This reflects the wider, market-led production of GHEs during China’s housing reform and commodification of residential space (Wu & Li, 2020). The decision to develop GHEs is typically driven by market-oriented considerations, including the desire to provide stronger security, facilitate property management, create private green spaces, and increase real estate value (Pow, 2009; Wu, 2005, 2006; Zhou, 2016). This rationale is evident in all GHEs in our sample, such as Skyline II, Sunshine Garden, Qianxi Garden, where gating was a deliberate part of the design and branding strategy.

By contrast, the non-GHEs in this study originate from either earlier urban development models (e.g., open communities built around 1990s), or more recent efforts to promote openness and mixed-use vitality, as in the case of Skyline III. The latter, although developed by the same company as Skyline II, was intentionally planned by a different design team to adopt an open format that would activate street-level vitality. These examples show that gatedness in China is shaped more by development logic and market strategy than by post-hoc spatial adaptation, with planners and governance arragements interacting with developer-led enclosure decisions (Hamama & Liu, 2020; Liao et al., 2018). It is also worth noting that some residential areas originally designed as gated have, over time, become *de facto* open (gates left open or access relaxed due to management practices and policy guidance), resulting in ‘walled without gates’ or semi-enclosed conditions (Hamama & Liu, 2020; Yip, 2012).

Overall, the paired housing estates chosen in this study are comparable in their socio-economic characteristics (i.e., housing price, construction year, household density) but distinctly different in their housing forms (i.e., GSI, OSI, and greening rate). Additional detail on the case selection process has been previously published (reference was omitted for peer review).

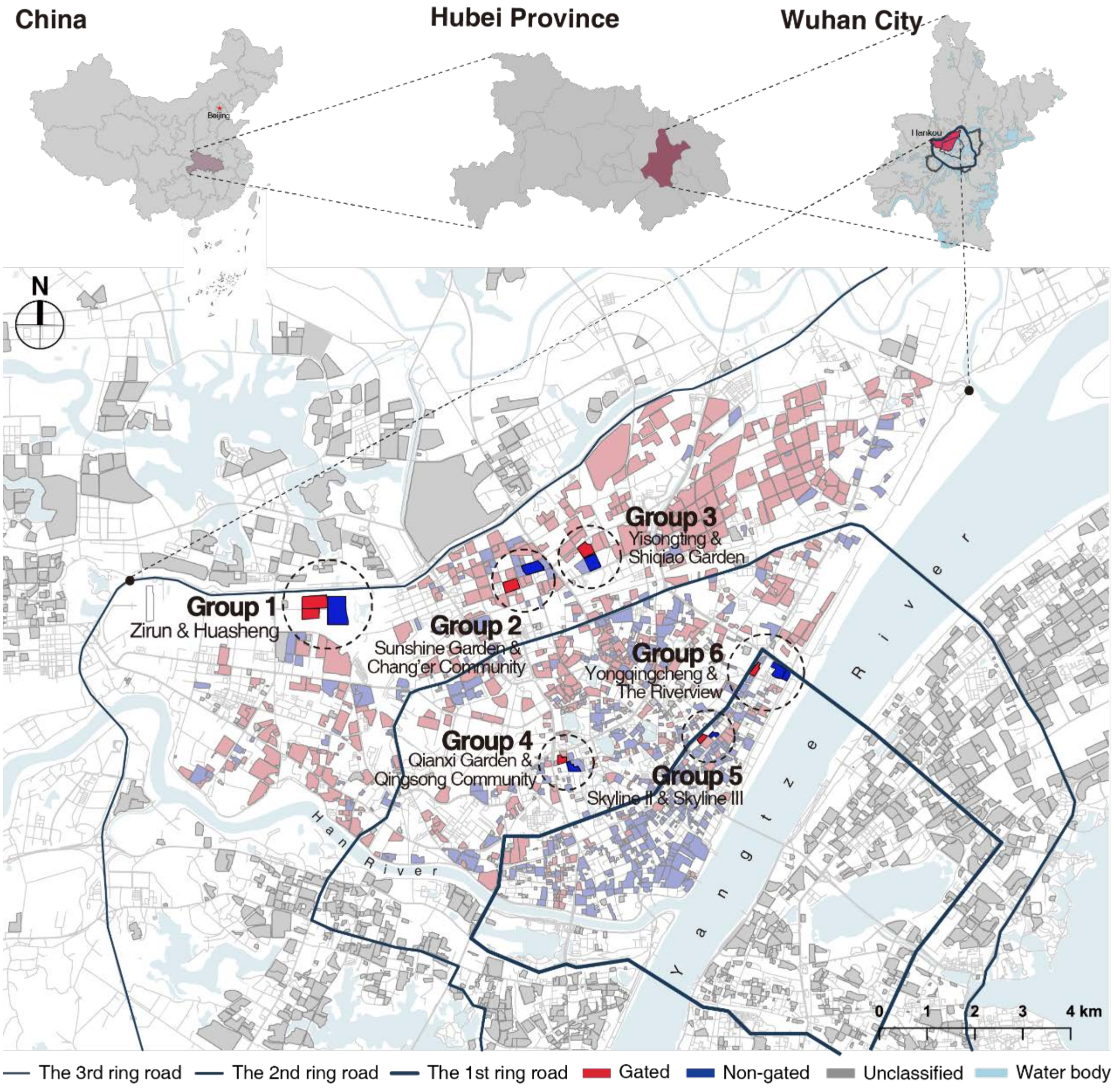


Figure 2. Geographic location of the research area, with 6 pairs of housing area groups classified into gated (in red) and non-gated (in blue). Mapping based on Baidu Street View imagery (http://map.baidu.com/).

Figure 3. General profile of the studied housing estates. Figure-ground maps for six groups are displayed at the same scale for a better visual comparison. 'Enclosure degree ' refers to the observed extent of physical and managerial enclosure of each estate, based on aspects including boundaries,

signage, surveillance, and access control. For detailed measurement of 'enclosure degree', please see Section 4.3.2.

4.2 Data collection and processing

4.2.1 Co-presence data collection

Data on people's behaviour in the public realm of the housing areas, with a focus on patterns of co-presence, were collected from October to November 2019 using a walk-by observation technique. The first author walked along a predefined route at a constant speed while video recording until reaching all accessible spaces. This observation took place at each estate both on a weekday and a weekend. Each day contained five rounds: early morning (8am – 10am), mid-morning (10 am – 12 noon), lunchtime (12 noon – 2 pm), afternoon (2pm – 4pm), and dinnertime (4.30pm – 6.30pm). No observation was undertaken after dark when outdoor stationary activities are in theory largely influenced by the provision of artificial lighting, which is beyond the remit of the present study. Moreover, no observation took place on public holidays or days with special events or during extreme weather.

The behaviour data were then geocoded in the QGIS platform while reviewing the videos. Each person in the video was presented as a dot at the location of the layout map where their behaviour was first identified. The personal profile was also registered, including gender (men, women) and age group (children: aged up to 18; adults: aged 18-65; senior: over 65). The final dataset consisted of 14,331 stationary individuals observed at 12 selected housing estates.

4.2.2 Co-presence network construction

Subsequently, the collected data were used to construct co-presence networks through a proximity-based social network (PBSN) approach. In such network, entities (e.g., individuals, groups) are represented as 'nodes' (or 'vertices') (Haddadi et al., 2011); social associations (i.e., 'edges' or 'links') between two entities are created when they are within a predetermined spatial proximity (Spiegel et al., 2016). This fundamental structure allows a researcher to make comparisons within or across groups of entities (Faust & Skvoretz, 2002), provided that the networks are created with the same technique (Castles et al., 2014).

A key point for building a PBSN is to choose a distance threshold. In other words, what is a reasonable cut-off distance for people to be identified as co-present? The answer largely relies on the range within which individuals can directly perceive the co-presence of others (Haddadi et al., 2011). In his pioneering work *Life between Buildings* (1987), Jan Gehl – based on extensive fieldwork – concluded that people can clearly perceive other's facial expressions and emotions and generate meaningful interactions only when the distance between them reduced to 20 to 25 meters (also see Lawrence et al., 2006). Additionally, some psychological experiments on the effect of distance on facial recognition also reported similar results. Loftus and Harley (2005), for example, reported that the ability to identify familiar faces descends with increasing distance, losing recognition capability at approximately 25m. The 25 meters as a cut-off distance for facial recognition has also been verified in other well conducted experiments (e.g., Lampinen et al., 2014; Lin & Fotios, 2015; Rea et al., 2009).

Therefore, the above evidence collectively suggests that human vision constrains the ability to recognise other people's faces and behaviors to a distance of 25 meters, but not beyond. While other urban settings (such as highly crowded public squares) might reduce the possibility of recognizing people, the threshold of 25 meters was deemed the most suitable for our study – both because it is empirically validated, but also because housing estates are not as densely occupied as crowded squares. Consequently, the PBSNs were constructed using the following procedure (also see Figure 1). First, all geocoded points within 25 metres of each other were linked separately for each observation round to accurately reflect spatiotemporal co-presence patterns. Subsequently, all links which cross visual barriers (i.e., buildings and opaque fences) were removed. The cleaned data were then exported from QGIS as text files and finally imported into Gephi and Python (through a library named 'NetworkX') for network visualisation and analysis.

4.3 Measurement of variables

4.3.1 Measuring co-presence network characteristics

Since the research aim is to compare the overall characteristics of co-presence networks rather than specific individuals, this paper only considered sociocentric variables that account for the overall network structure (Cross & Parker, 2004). Due to the lack of precedents and exploratory nature of the current study, a somewhat exhaustive method was adopted when selecting relevant co-presence network measures. Consequently, nine network indicators were chosen, aiming to compare GHEs' and non-GHEs' co-presence patterns comprehensively.

Table 1 summarises the nine network attributes for measuring co-presence patterns and their meanings in the present study. The two most fundamental variables are *node count* and *edge count*, representing the total number of stationary individuals and their co-present connections, respectively. The *average degree* quantifies the average number of people each individual in the network co-presents with, providing insight into the general level of co-presence. *Graph density* (Tabassum et al., 2018) measures the proportion of connections present in a network relative to the total number of possible connections, reflecting the overall connectedness of the co-presence network. *Degree centralisation* (Freeman, 1978) assesses the centrality and inequality in co-presence among individuals, indicating whether co-presences are dominated by a few key individuals or places.

Table 1. Measurement of co-presence network

Variable	Formula and explanation		Implication in this study
Node Count	n = Total number of nodes		Indicates the total number of the stationary individuals observed
Edge Count	m = Total number of edges		Shows the total number of co-present connections between individuals
Average Degree	$\bar{k} = \frac{1}{n}\sum_{i=1}^{n} k_i$	k_i the degree of node i	Indicates the average number of people an individual is co-present with
Graph Density	$D = \frac{2m}{n(n-1)}$	m the number of edges n the number of nodes	Reflects the overall connectedness of co-presence networks, ranging between 0 (sparest) to 1 (densest)
Degree Centralisation	$C_D = \frac{\sum(C_D(v^*) - C_D(v))}{(n-1)(n-2)}$	$C_D(v)$ degree of node v $C_D(v^*)$ node with maximum degree n total number of nodes	Highlights the inequality in co-presence patterns. A high degree indicates a few key areas or individuals dominate the co-presence network
Co-presence Ratio	$R = \frac{n - n_{d(0)}}{n}$	$n_{d(0)}$ the total number of nodes with degree 0	Calculates the proportion of isolated individuals
Average Clustering Coefficient	$\bar{C}' = \frac{1}{1-\theta} C_i,$ $C_i = \frac{2L_i}{k_i(k_i - 1)}$	θ the proportion of nodes with less than two neighbours L_i the number of edges between the k_i neighbours of node i	Measures the degree of clustering. A higher coefficient suggests a more tightly knit or clustered co-presence structure
Connected Components	$C = \{C_i \mid \forall u, w \in C_i, u \sim w\}$	C_i represents a connected component of graph $u \sim w$ denotes that there exists a path between u and w	Reveals the number of separate groups or individuals of stationary people
Associativity Coefficient	$r = \frac{\sum_{ij} e_{ij} - \sum_i a_i b_i}{1 - \sum_i a_i b_i}$	e_{ij} fraction of edges connecting nodes of category i and j a_i fraction of edges from nodes of category i b_j faction of edges from nodes of category j	Measures the tendency for people to co-present with others who are similar in age and gender. Higher value suggests greater homophily. Positive value suggests homophily, and negative heterophily

The *co-presence ratio* and *connected components* (Tarjan, 1972) highlight levels of separated individuals and groups, respectively. The *average clustering coefficient* (Kaiser, 2008) reflects the tendency of individuals to form local clusters, while the *assortativity coefficient* (Newman, 2002) measures the degree of homophily in co-presence networks. In this study, social types were classified based on observable age (child, adult, senior) and gender (male, female) categories as recorded during behavioural mapping (see Section 4.2.1). Lower assortativity coefficient thus suggests a higher level of social mixing across different age and gender groups, indicating that individuals are more likely to be co-present with others who differ from themselves, rather than clustering with demographically similar peers.

4.3.2 Measuring estate characteristics

To explore how different estate characteristics affect co-presence patterns, this study distinguishes between housing type and housing form, both of which are operationalised in the analysis. As discussed in Introduction session, housing type refers to a binary classification of each estate as either gated or non-gated, based on its observed access control and regulatory status. Housing form, by contrast, refers to the measurable physical and spatial attributes of an estate's layout and design. In this study, only estate-level indicators of housing form – such as enclosure degree, density, greening rate) – were considered, corresponding to the network-level parameters of co-presence described in the previous section.

Enclosure degree, borrowed from Li et al. (2012), includes five aspects (see Table 2): physical boundaries, signs, manned surveillance, technological surveillance, and access control. To ensure replicability, the five components of the enclosure index were measured using structured on-site observation and standardised coding procedure.

Physical boundaries were assessed using GIS mapping based on street view imagery (https://map.baidu.com) and field verification. In QGIS, estate boundaries were digitised and classified into transparent (e.g., fences), non-transparent (e.g., walls), and commercial frontages (e.g., ground-floor shops). The length of each type was calculated as a proportion of the total perimeter, and estates were scored from 0 to 4 according to the share of different types of boundaries, following Table 2.

Signs aimed at deterring outsiders (e.g., ‘private estate’, ‘residents only’) were recorded through systematic scanning along all entrances and edge walls. Presence of any such signage was coded as 1; absence as 0. Manned surveillance was coded as 1 if any security guards or staffed booths were observed at estate gates during visit; otherwise, 0. Technological surveillance was similarly coded as 1 if visible CCTV cameras or electronic monitoring devices were observed; otherwise, 0. Access control was scored from 0 (completely open access) to 2 (fully restrict access), based on whether field surveyors could enter through visible gates across all observation rounds. All scoring was performed by two trained observers using a printed rubric based on Table 2, with inter-rater agreement checks conducted after observations.

The final enclosure degree was calculated as the sum of all five items, with the ‘access control’ given a weight of 2 and the other four components 1. The justification for a higher weight to access control is based on the understanding that it plays a fundamental role in the nature of GHEs. The essence of a GHE lies in its ability to restrict entry to non-residents. While physical boundaries, signs, and surveillance provide important role in security, it is access control – which directly enforces limits on entry – that most distinctly defines a GHE. This approach has been previously published (reference was omitted for double-blind peer review).

Table 2. Measurement of enclosure degree, modified based on Li et al., 2012.

Item	Description	Score
Physical boundaries	Boundaries to define the territory of the compound, such as walls, gates, hedges.	0 = no physical boundaries 1 = some transparent boundaries (less than 50%) 2 = some non-transparent boundaries (less than 50%) 3 = surrounded by transparent boundaries or shops plus non-transparent boundaries 4= surrounded by non-transparent boundaries
Signs	Signs used to deter outsiders, e.g., 'show your ID', 'private housing areas', 'residents only'.	0 = no signs 1 = presence of signs
Manned surveillance	Whether the area is equipped with security patrollers or guard booths	0 = no manned surveillance 1 = presence of manned surveillance
Technological surveillance	Whether technological surveillance is in use, such as cameras.	0 = no technological surveillance 1 = presence of technological surveillance
Access control	Whether outsiders are restricted to entry	0 = anyone can enter the whole area 1 = the guard decide whether to check; or outsiders have free access to only certain areas 2 = outsiders cannot enter without permission

Density. This variable reflects the construction intensity of an area. Four density parameters were calculated. Floor Space Index (FSI) is the ratio of total floor area and plot area, measuring the intensity of the estate. Ground Space Index (GSI) is the ratio of total built-up area on the ground floor and plot area, measuring ground-level compactness. Open Space Index (OSI) is the ratio of open space and total floor area, measuring spaciousness and pressure on the non-built space. These three indexes measure housing areas' construction intensity and morphology (Berghauser Pont & Haupt, 2009). The fourth property is household density as the ratio between total number of households and the plot area. All data for plot size, building area, and household number were obtained in 2019 from estate-level profiles on the LIANJIA website (https://bj.lianjia.com/), the largest real estate brokerage firm in China.

Greening rate measures the ratio of total green area and plot area. A previous study suggested a positive correlation between greenery and the number of static activities observed in residential areas (Sullivan et al., 2004). Accordingly, it is hypothesised that a higher greening rate might lead to a higher co-presence level among residents. The greening rate data was also collected from LIANJIA website accessed in 2019, and cross-checked with on-site observations and satellite imagery.

Other Characteristics. Other characteristics of housing estates – including the construction year, location (city centre or inner suburb), and housing price – might also impact how people co-present in the space. For example, due to the lack of mobility, residents (especially the elderly and children) from a suburban area are arguably more localised and thus more likely to spend time in their outdoor residential areas (Kuo et al., 1998). Additionally, compared with low-income areas (indicated by housing price) where residents more rely on local mutual help, high-income people were detected sparser contacts (Wissink & Hazelzet, 2016). These data were also collected from the LIANJIA website in 2019.

4.4 Statistical approaches

4.4.1 Statistical approaches for difference detection

Statistical analyses were conducted using IBM SPSS version 26. We first tested if GHEs and non-GHEs statistically differ in their means of co-presence attributes. (e.g., node count, edge count, average degree) through independent samples *t*-tests. There were two levels of analyses: group level and pair level. Adhering to the conventional approach in the 'gated community' literature , all twelve housing estates from six pairs were first classified into a gated and a non-gated group to make a general comparison across cases. To verify the consistency of the general result, pair-by-pair comparisons were subsequently performed.

The unit of analysis for the *t*-tests was the co-presence network (i.e., a graph with a minimum of two nodes linked by one edge) of each individual observation round, rather than the housing estates as a whole. Specifically, the analysis compared co-presence patterns between GHEs and non-GHEs by investigating data from 10 rounds of observation conducted in each estate (5 rounds on a weekday and 5 on weekend, see Figure 5 – Figure 10). Each observation round captured a co-presence network, which was then treated as separate data points in analyses, rather than averaging across rounds, allowing for a more nuanced examination of how co-presence patterns vary over time.

The independent *t*-test typically assumes: (i) independence of observations, (ii) normality of data, and (iii) homogeneity of variance between groups. We have taken the following approaches to ensure that these assumptions are met. First, while data from multiple rounds were collected from the same estate, the minimum one-hour interval between rounds helps to mitigate potential correlations between observations, supporting the assumption of independence. To handle the assumption of normality and equal variance, we adopted a bootstrapped *t*-test approach (20,000 iterations, 95% confidence intervals), which resamples the observed data with replacement to generate an empirical distribution of the sample mean difference between the two groups. This resampling process provides robust estimates of the confidence intervals and significance levels without relying on the normality or equal variance assumptions (LaFlair et al., 2015).

4.4.2 Statistical approaches for correlation and interpretability

The second aim of statistical analyses was to examine if and how the co-presence parameters correlate with and can be explained by the characteristics of housing estates, particularly the enclosure. The unit of analysis was also the co-presence network of each individual observation round, reflecting the temporal variance of the co-presnce patterns. This analysis contained two stages. Due to the skewed data distribution, the associations between all possible pairs of variables was first computed using nonparametric Spearman rank correlation (Spearman's rho), which is less sensitive to normality and outliers.

To further examine the effect of enclosure on co-presence patterns while controlling other variables, the two-stage hierarchical multiple linear regressions (Blockwise Entry) were employed. Location, FSI, GSI, OSI, household density, housing price, construction year, and greening rate were forced at step one to be controlled, and enclosure degree was entered at step two. All dependent variables were normalised through conversion to natural logarithms to achieve the data normality requirement for regressions. Additionally, all independent variables with different measurement units (e.g., year, ratio, price) were normalised by min-max scaling, resulting in a common scale with values between 0 and 1, corresponding to the dummy variable of location (coded as '0' =inner suburb, '1' =city centre). Note that, all independent variables passed the multicollinearity diagnoses, and the highest variance inflation factor (VIF) was 7.963, less than 10, indicating no severe multicollinearity issue.

Table 3. Descriptive statistics of co-presence network raw data, summarising key network parameters across all estates (120 networks), non-gated housing estates (60 networks), and gated housing estates (60 networks).

Variable	Dataset	obs	Mean	Std. Dev.	Min	Max	Sum
Node count	All estates	120	118.942	132.179	6.000	654.000	14313.000
	Non-GHEs	60	173.467	157.053	6.000	654.000	10408.000
	GHEs	60	65.083	67.823	6.000	275.000	3905.000
Edge count	All estates	120	1104.408	2540.991	1.000	16618.000	132529.000
	Non-GHEs	60	1911.917	3386.299	1.000	16618.000	114715.000
	GHEs	60	296.900	479.005	1.000	2005.000	17814.000
Avg. degree	All estates	120	8.991	9.769	0.333	52.497	1078.904
	Non-GHEs	60	12.187	12.056	0.333	52.497	731.220
	GHEs	60	5.795	5.135	0.333	30.370	347.684
Graph density	All estates	120	0.098	0.053	0.028	0.334	11.730
	Non-GHEs	60	0.083	0.044	0.028	0.243	4.985
	GHEs	60	0.112	0.058	0.035	0.334	6.745
Co-presence ratio	All estates	120	0.890	0.108	0.333	1.000	106.752
	Non-GHEs	60	0.916	0.099	0.454	1.000	54.938
	GHEs	60	0.864	0.112	0.333	1.000	51.814
Centralisation	All estates	120	0.137	0.055	0.043	0.288	16.410
	Non-GHEs	60	0.127	0.050	0.043	0.239	7.641
	GHEs	60	0.146	0.059	0.044	0.288	8.770
Adjusted avg. clustering coef.	All estates	120	1.295	0.603	0.818	4.333	152.850
	Non-GHEs	60	1.159	0.448	0.818	3.667	68.394
	GHEs	60	1.432	0.704	0.900	4.333	84.458
Assortativity coef.	All estates	120	0.153	0.211	− 0.524	1.000	18.180
	Non-GHEs	60	0.151	0.201	− 0.524	1.000	8.900
	GHEs	60	0.155	0.223	− 0.171	1.000	9.283
Connected components	All estates	120	18.840	12.750	5.000	51.000	2261.000
	Non-GHEs	60	22.250	12.780	5.000	51.000	1335.000
	GHEs	60	15.430	11.870	5.000	48.000	926.000

5. Results

5.1 Comparing structural characteristics of co-presence network

This section compares co-presence patterns between GHEs and non-GHEs. All twelve housing estates were first divided into gated and non-gated groups to overall compare the co-presence attributes. Subsequently, to verify the consistency of the overall findings, pair-by-pair comparisons were conducted between the estates.

Table 4 summarises the results of bootstrapped independent samples *t*-tests on co-presence variables between the gated and non-gated groups. Notably, the non-gated group displayed significantly higher means than the gated group on nodes count (count of stationary people, p <.000) and edges count (count of co-present links, p =.015), reflecting a greater number of stationary people, actively co-present and higher level of spatial utilisation. The non-gated group also demonstrated significantly higher average degree (the average number of people one co-presents with, p =.001) and co-presence ratio (the percentage of non-isolated people, p =.005), suggesting that individuals in non-GHEs are more likely to co-present with many other people, leading to reduced isolation and a more interconnected social fabric. These differences can be seen from Figure 4 as an example and from the co-presence networks of all studied housing estates (Figure 5 – Figure 10).

Table 4. Bootstrapped independent samples t-tests (20,000 iterations, 95% confidence intervals) show differences between gated and non-gated cases on social network parameters.

	Type	Mean	Std. Deviation	Mean difference	Std. Error	*t*	*p*
Node count	Non-gated	173.47	157.053	108.383	21.978	4.931	0.000
	Gated	65.08	67.823				
Edge count	Non-gated	1911.92	3386.299	1615.017	438.684	3.681	0.015
	Gated	296.90	479.005				
Avg. degree	Non-gated	12.18700	12.055795	6.392	1.678	3.809	0.001
	Gated	5.79473	5.135113				
Co-presence ratio	Non-gated	0.91563	0.098651	0.052	0.019	2.737	0.005
	Gated	0.86357	0.111760				
Graph density	Non-gated	0.08308	0.043537	-0.029	0.009	-3.222	0.003
	Gated	0.11242	0.058012				
Centralisation	Non-gated	0.12735	0.049744	-0.019	0.010	-1.900	0.065
	Gated	0.14616	0.059414				
Adjusted avg. clustering coef.	Non-gated	1.15922	0.447919	-0.272	0.107	-2.542	0.019
	Gated	1.43149	0.703873				
Assortativity coef.	Non-gated	0.15085	0.201058	-0.004	0.038	-0.105	0.925
	Gated	0.15472	0.098651				
Connected components	Non-gated	22.25	12.777	6.817	2.223	3.066	0.002
	Gated	15.43	11.870				

Figure 4. Typical scenes of the two comparative housing estates in Group 2, showcasing the open spaces where the most stationary people gathered. The scenes on the left (Sunshine Garden, gated) have much fewer stationary people and fewer co-presences than the scenes on the right (Chang'er Community, non-gated).

However, the gated group (M =.11242) surprisingly demonstrated denser co-presence graphs than the non-gated group (M =.08308), p =.003. This finding is intriguing as it challenges the common perception that GHEs, often criticised for fostering social isolation and reduce interactions, actually demonstrated a higher network density for co-presence. However, this finding needs to be treated with caution, as network density is closely related to network size, which will be elaborated in the Discussion section.

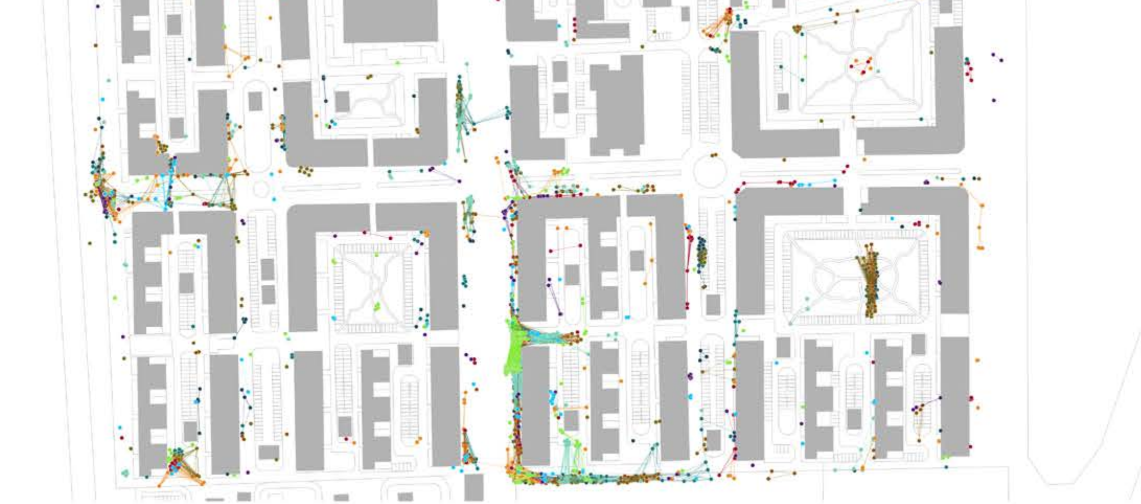
The difference in density further led to a significantly higher number of connected components in the non-gated group than the gated one, suggesting there are more separated clusters and individuals in the non-GHEs. This result suggests that the co-presence networks in non-GHEs are usually more fragmented, with a larger number of separated clusters and isolated individuals. This fragmentation reflects the more dispersed and unstructured spatial layouts typically found in non-GHEs, where encounters may occur across various scattered spaces rather than being concentrated in centralized nodes (also see below). While this may reduce the intensity of localised interactions, it likely to be fostering a more diverse pattern of co-presence, accommodating a broader range of users.

Turning to the adjusted average clustering coefficient, the value for GHEs and non-GHEs groups was 1.431 and 1.159, respectively. Both values are greater than 1, indicating the tendency of clustering in both housing types; however, this tendency was statistically stronger in the gated ones. This point can also be seen from the network graphs (Figure 5 - Figure 10). In GHEs, stationary individuals tended to cluster around centralised leisure areas such as gardens or squares, or in peripheral zones enclosed behind internal walls. In contrast, non-GHEs showed a more dispersed contribution of co-presence, often aligned with linear pedestrain paths or semi-public street edges. These visual patterns reflect the spatial logic of the two housing types: while non-GHEs typically integrate with the surrounding street network, encouraging movement and incidental encounters, GHEs tend to internalise social life within enclosed, purposefully designed communal spaces.

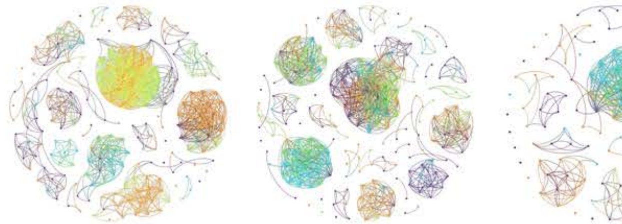
This phenomenon was further confirmed through the centralisation degree of gated (M = .14616) and non-gated settings (M = .12735), suggesting that the co-present individuals in the former are significantly more centralised. While one may argue that the higher clustering and centralisation in GHEs supports localised social cohesion, it may limit broader social mixing, whereas the more dispersed patterns in non-GHEs highlight a trade-off between strong localised ties and greater inclusivity and diversity in social encounters.

As for the assortativity, both groups showed a positive coefficient, suggesting both gated and non-gated groups have a mixed social pattern. However, the non-gated group showed a slightly lower average assortativity coefficient, suggesting a more heterogeneous pattern of co-presence based on age and gender. This implies that non-gated housing estates facilitate greater demographic diversity in their co-presence patterns, with individuals encountering more evenly across different age groups and genders. In contrast, co-presence in gated estates tend to occur more frequently among individuals with similar demographic characteristics, possibly influenced by the controlled and localised nature of their open spaces.

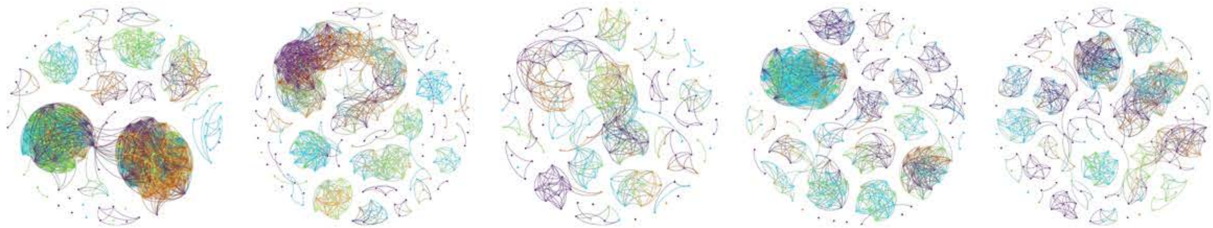
Figure 11 demonstrates the results of independent samples t-tests for each pair. Overall, the finding was consistent with the conclusion above. Among all six pairs, the non-gated estates displayed higher node counts, higher edge counts, and higher co-presence ratio in four pairs, with three statistically significant. Likewise, four pairs showed a greater average degree for the non-gated cases, but only two were statistically significant. Conversely, the gated estates had greater graph density and centralisation in five pairs and greater adjusted average clustering coefficient in four pairs, yet only statistically significant for one pair.



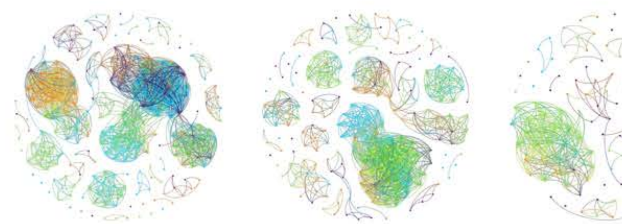
	WKDY 8:00-10:00	**WKDY 10:00-12:00**	**WKDY 12:00-14:00**	**WKDY 14:00-16:00**	**WKDY 16:30-18:30**
Nodes count	178	131	113	122	254
Edges count	1,825	393	177	261	1,118
Avg. degree	20.506	6	3.133	4.279	8.803
Graph density	0.116	0.046	0.028	0.035	0.035
Centralisation	0.231	0.109	0.071	0.073	0.064
Adj.avg.clustering	1.123	1.248	1.536	1.183	1.109
Assortativity coef.	-0.015	0.214	0.352	0.363	0.192
Co-presence ratio	0.888	0.855	0.841	0.893	0.925
Connected components	36	38	43	34	51



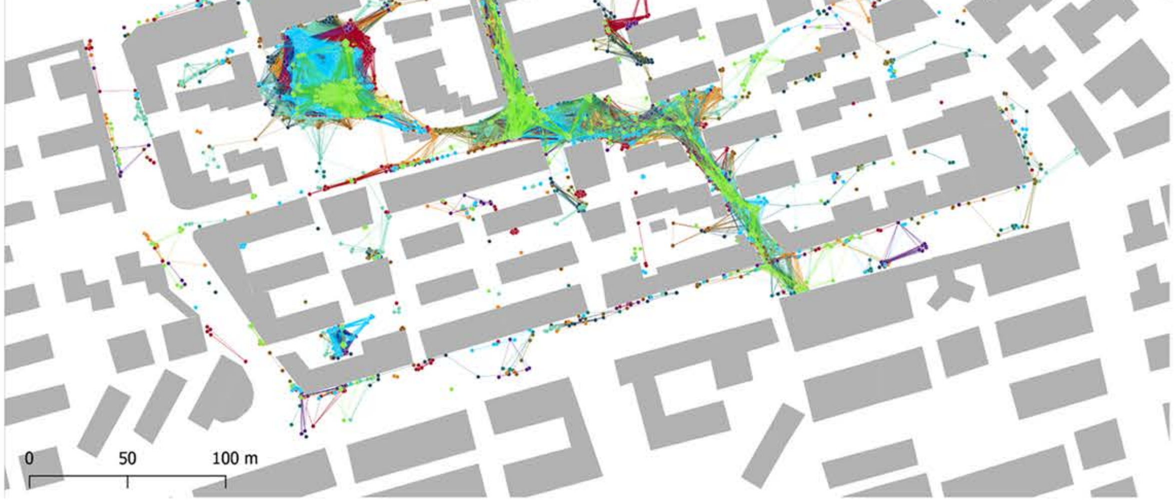
	WKDY 8:00-10:00	**WKDY 10:00-12:00**	**WKDY 12:**
Nodes count	227	223	
Edges count	1,327	1,279	
Avg. degree	11.692	10.979	
Graph density	0.052	0.047	
Centralisation	0.099	0.119	
Adj.avg.clustering	0.984	1.169	
Assortativity coef.	0.148	0.107	
Co-presence ratio	0.943	0.951	
Connected components	33	46	



	WKND 8:00-10:00	**WKND 10:00-12:00**	**WKND 12:00-14:00**	**WKND 14:00-16:00**	**WKND 16:30-18:30**
Nodes count	221	267	188	239	242
Edges count	2,303	1,371	553	1,364	949
Avg. degree	20.842	10.270	5.883	11.414	7.843
Graph density	0.095	0.039	0.031	0.048	0.033
Centralisation	0.129	0.101	0.082	0.113	0.063
Adj.avg.clustering	1.021	1.068	1.078	1.077	1.002
Assortativity coef.	0.063	0.192	0.186	0.131	0.123
Co-presence ratio	0.923	0.940	0.920	0.937	0.942



	WKND 8:00-10:00	**WKND 10:00-12:00**	**WKND 12:**
Nodes count	260	235	
Edges count	1,880	1,317	
Avg. degree	14.462	11.209	
Graph density	0.056	0.048	
Centralisation	0.119	0.124	
Adj.avg.clustering	1.072	1.044	
Assortativity coef.	0.156	0.111	
Co-presence ratio	0.931	0.923	



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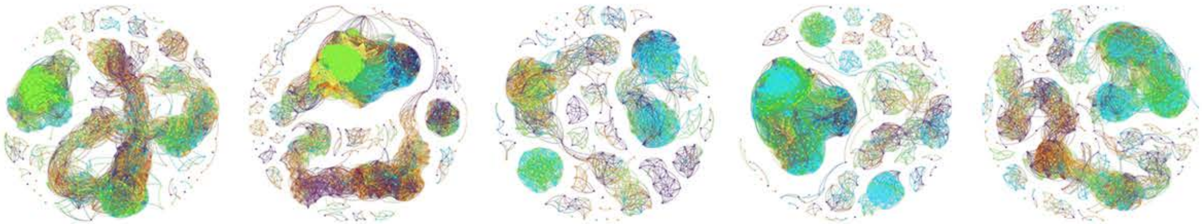
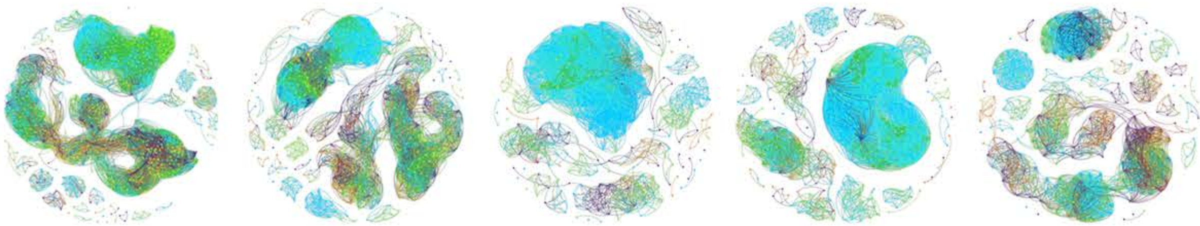
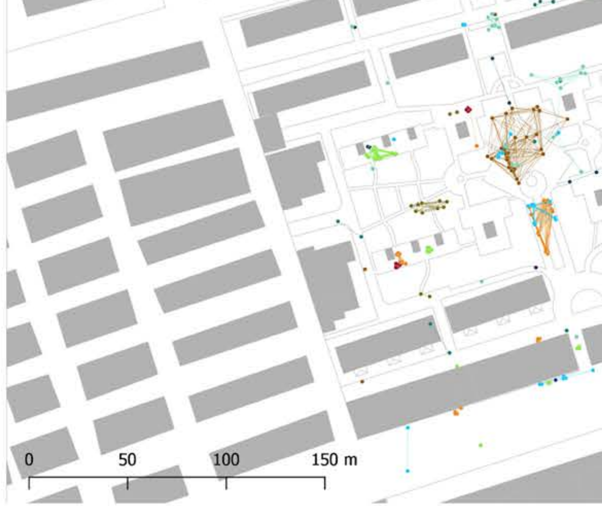


	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12:00-14:00	WKDY 14:00-16:00	WKDY 16:30-18:30
Nodes count	485	576	344	465	483
Edges count	7,600	15,119	2,899	8,431	5,939
Avg. degree	31.340	52.497	16.855	36.262	24.592
Graph density	0.065	0.091	0.049	0.078	0.051
Centralisation	0.095	0.208	0.080	0.203	0.113
Adj.avg.clustering	0.886	0.862	0.934	0.890	0.868
Assortativity coef.	0.082	0.095	0.119	0.029	0.069
Co-presence ratio	0.967	0.988	0.962	0.983	0.981
Connected components	38	36	35	35	33



	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12:00-14:00	WKND 14:00-16:00	WKND 16:30-18:30
Nodes count	654	501	334	392	360
Edges count	16,618	8,639	5,229	6,870	3,582
Avg. degree	50.820	34.487	31.311	35.051	19.900
Graph density	0.078	0.069	0.094	0.090	0.055
Centralisation	0.122	0.168	0.232	0.213	0.076
Adj.avg.clustering	0.866	0.884	0.895	0.894	0.942
Assortativity coef.	0.051	0.113	0.114	0.073	0.090
Co-presence ratio	0.988	0.974	0.955	0.972	0.972



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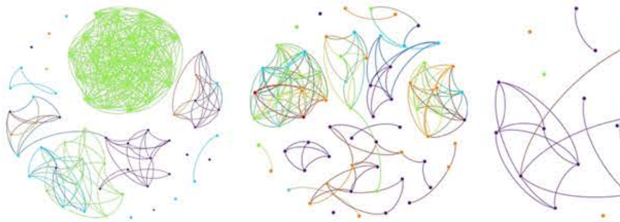
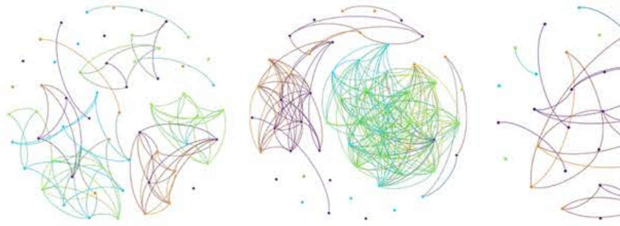
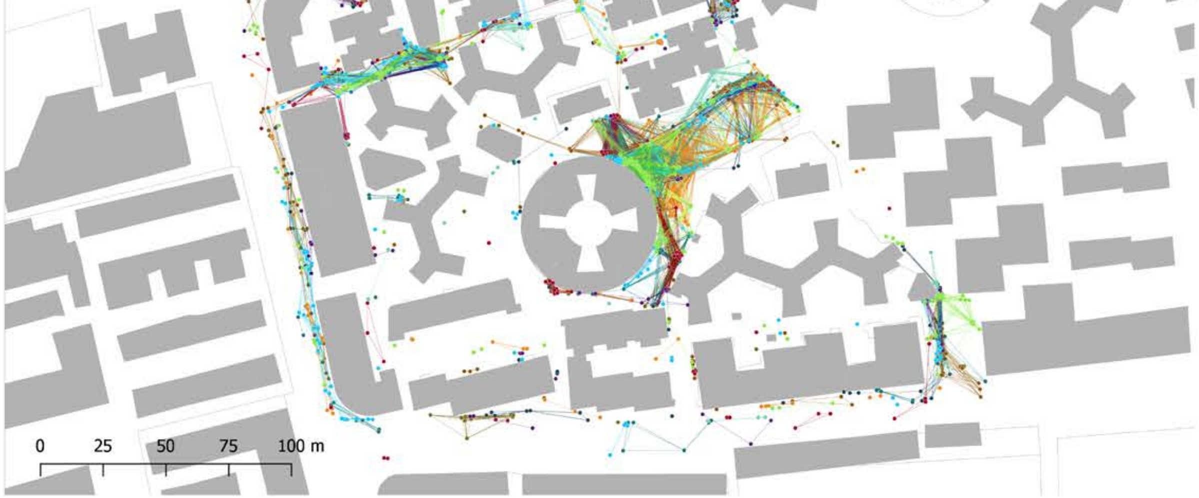
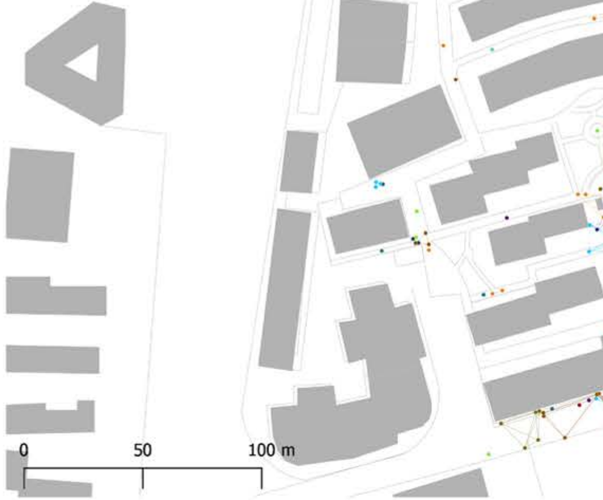


	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12:0
Nodes count	72	67	
Edges count	346	161	
Avg. degree	9.611	4.806	
Graph density	0.135	0.073	
Centralisation	0.179	0.097	
Adj.avg.clustering	1.154	1.214	
Assortativity coef.	0.674	0.083	
Co-presence ratio	0.875	0.940	
Connected components	17	17	



	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12:0
Nodes count	60	56	
Edges count	94	248	
Avg. degree	3.133	8.857	
Graph density	0.053	0.161	
Centralisation	0.068	0.267	
Adj.avg.clustering	1.228	1.177	
Assortativity coef.	0.339	0.121	
Co-presence ratio	0.833	0.821	





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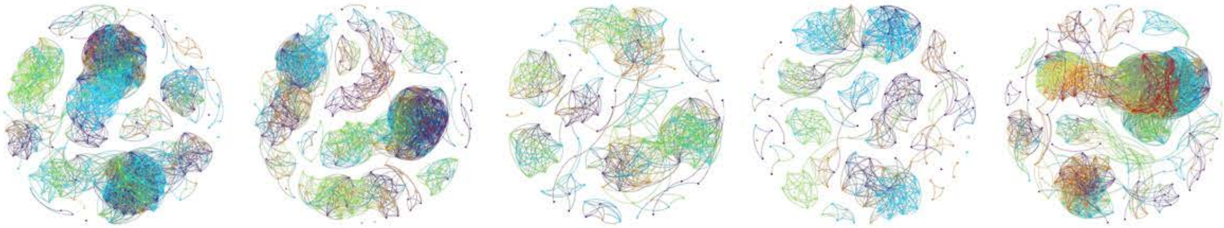
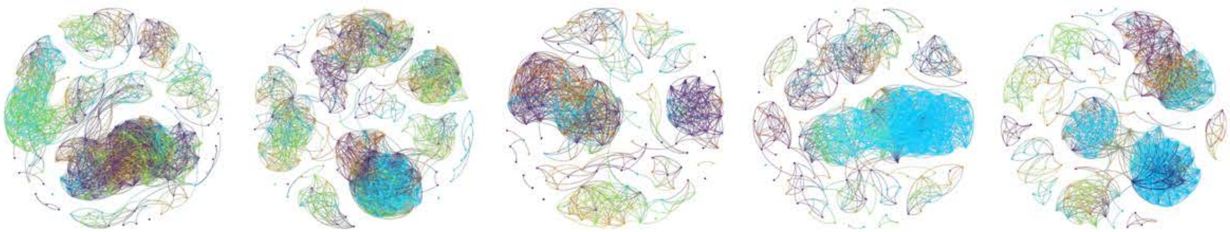
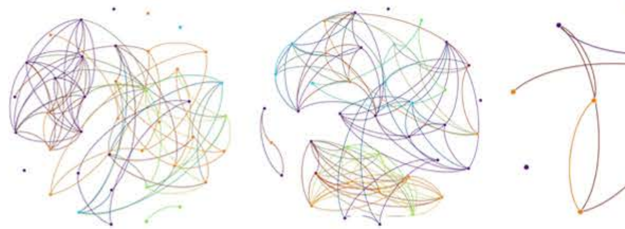


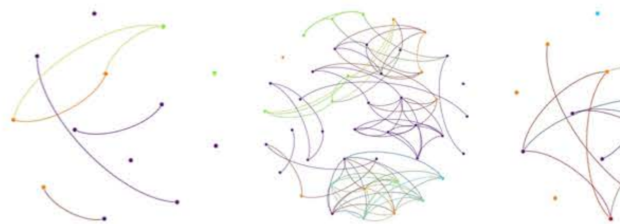
	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12:00-14:00	WKDY 14:00-16:00	WKDY 16:30-18:30
Nodes count	251	280	158	190	264
Edges count	2,576	2,395	780	824	3,010
Avg. degree	20.526	17.107	9.873	8.674	22.803
Graph density	0.082	0.061	0.063	0.046	0.087
Centralisation	0.103	0.108	0.136	0.087	0.181
Adj.avg.clustering	0.900	0.881	0.958	0.970	0.881
Assortativity coef.	0.061	0.086	0.037	0.265	0.082
Co-presence ratio	0.984	0.978	0.981	0.963	0.996
Connected components	17	21	17	23	15



	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12:00-14:00	WKND 14:00-16:00	WKND 16:30-18:30
Nodes count	234	238	179	208	209
Edges count	2,271	2,204	1,089	1,638	1,612
Avg. degree	19.410	18.521	12.168	15.75	15.426
Graph density	0.083	0.078	0.068	0.076	0.074
Centralisation	0.141	0.125	0.158	0.152	0.095
Adj.avg.clustering	0.866	0.884	0.818	0.909	0.924
Assortativity coef.	0.085	0.067	0.085	0.223	0.178

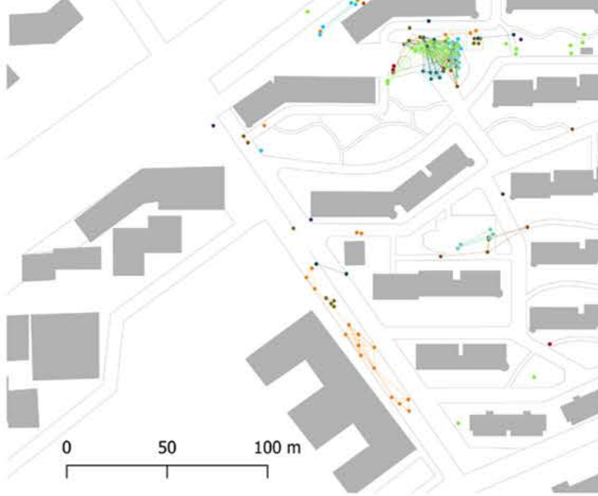


	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12
Nodes count	40	41	
Edges count	88	116	
Avg. degree	4.400	5.659	
Graph density	0.113	0.141	
Centralisation	0.205	0.114	
Adj.avg.clustering	1.200	0.988	
Assortativity coef.	0.196	0.151	
Co-presence ratio	0.875	0.951	
Connected components	11	7	



	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12
Nodes count	13	45	
Edges count	6	88	
Avg. degree	0.923	3.911	
Graph density	0.077	0.089	
Centralisation	0.106	0.097	
Adj.avg.clustering	4.333	1.073	
Assortativity coef.	0.200	0.195	

WKDY 8:00-10:00 · WKDY 10:00-12:00 · WKDY 12:00-14:00 · WKDY 14:00-16:00 · WKDY 16:30-18:30
WKND 8:00-10:00 · WKND 10:00-12:00 · WKND 12:00-14:00 · WKND 14:00-16:00 · WKND 16:30-18:30

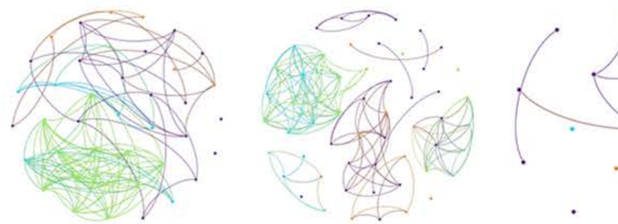


WKDY 8:00-10:00 · WKDY 10:00-12:00 · WKDY 12
WKND 8:00-10:00 · WKND 10:00-12:00 · WKND 12

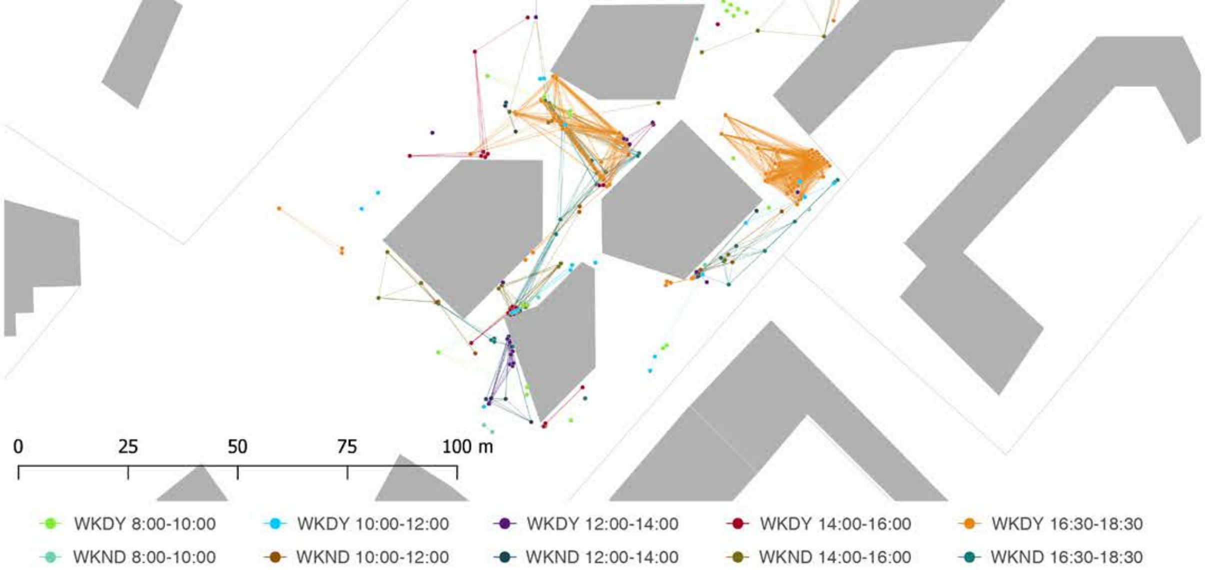
	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12:00-14:00	WKDY 14:00-16:00	WKDY 16:30-18:30
Nodes count	98	129	66	94	103
Edges count	268	496	95	194	250
Avg. degree	5.469	7.690	2.879	4.128	4.854
Graph density	0.056	0.060	0.044	0.044	0.048
Centralisation	0.090	0.106	0.049	0.042	0.061
Adj.avg.clustering	1.081	0.989	1.160	1.046	1.057
Assortativity coef.	0.254	0.147	0.175	0.221	0.299
Co-presence ratio	0.928	0.961	0.864	0.936	0.98
Connected components	22	20	21	20	19

	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12:00-14:00	WKND 14:00-16:00	WKND 16:30-18:30
Nodes count	109	137	59	97	134
Edges count	305	686	100	245	431
Avg. degree	5.596	10.015	3.39	5.052	6.433
Graph density	0.052	0.074	0.058	0.053	0.048
Centralisation	0.060	0.127	0.082	0.116	0.119
Adj.avg.clustering	0.992	1.076	1.137	1.093	0.958
Assortativity coef.	0.200	0.134	0.105	0.336	0.208
Co-presence ratio	0.927	0.912	0.915	0.917	0.970

	WKDY 8:00-10:00	WKDY 10:00-12:00
Nodes count	41	25
Edges count	151	34
Avg. degree	7.366	2.720
Graph density	0.184	0.113
Centralisation	0.253	0.148
Adj.avg.clustering	1.216	1.115
Assortativity coef.	0.161	-0.001
Co-presence ratio	0.878	0.920
Connected components	11	8



	WKND 8:00-10:00	WKND 10:00-12:00
Nodes count	40	56
Edges count	122	141
Avg. degree	6.1	5.036
Graph density	0.156	0.092
Centralisation	0.186	0.131
Adj.avg.clustering	1.088	1.214
Assortativity coef.	0.556	0.281
Co-presence ratio	0.925	0.928



WKDY 8:00-10:00

Nodes count	20
Edges count	29
Avg. degree	2.900
Graph density	0.153
Centralisation	0.123
Adj.avg.clustering	1.275
Assortativity coef.	0.492
Co-presence ratio	0.950
Connected components	6

WKDY 10:00-12:00

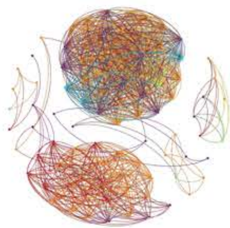
Nodes count	26
Edges count	32
Avg. degree	2.462
Graph density	0.098
Centralisation	0.067
Adj.avg.clustering	1.091
Assortativity coef.	-0.098
Co-presence ratio	0.923
Connected components	8

WKDY 12:00-14:00

Nodes count	21
Edges count	36
Avg. degree	3.429
Graph density	0.171
Centralisation	0.197
Adj.avg.clustering	1.750
Assortativity coef.	0.166
Co-presence ratio	0.762
Connected components	9

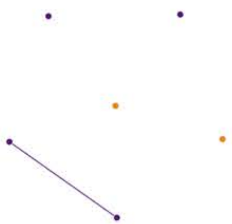
WKDY 14:00-16:00

Nodes count	31
Edges count	65
Avg. degree	4.194
Graph density	0.140
Centralisation	0.136
Adj.avg.clustering	0.995
Assortativity coef.	0.184
Co-presence ratio	0.968
Connected components	7



WKDY 16:30-18:30

Nodes count	91
Edges count	997
Avg. degree	21.912
Graph density	0.243
Modularity	0.160
Adj.avg.clustering	0.966
Assortativity coef.	0.053
Co-presence ratio	0.989
Connected components	8



WKND 8:00-10:00

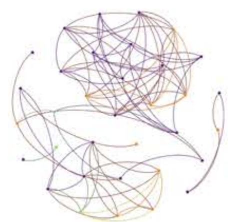
Nodes count	6
Edges count	1
Avg. degree	0.333
Graph density	0.067
Centralisation	0.200
Adj.avg.clustering	-
Assortativity coef.	-

WKND 10:00-12:00

Nodes count	20
Edges count	28
Avg. degree	2.800
Graph density	0.147
Centralisation	0.129
Adj.avg.clustering	0.971
Assortativity coef.	-0.024

WKND 12:00-14:00

Nodes count	23
Edges count	48
Avg. degree	4.174
Graph density	0.190
Centralisation	0.091
Adj.avg.clustering	1.000
Assortativity coef.	0.097

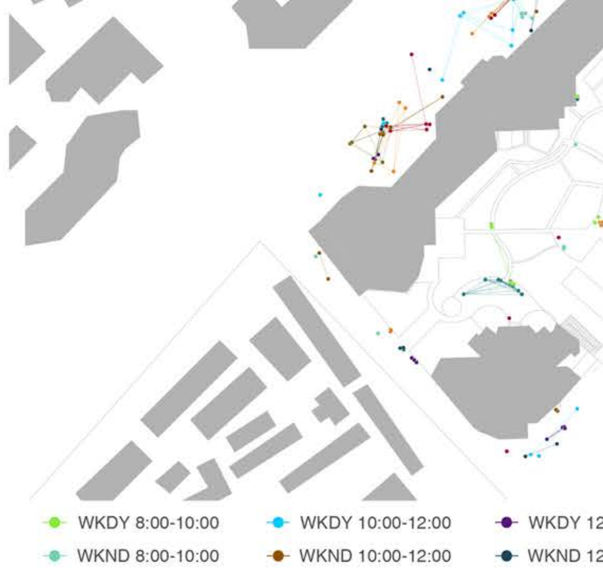


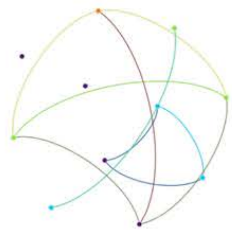
WKND 14:00-16:00

Nodes count	34
Edges count	85
Avg. degree	5.000
Graph density	0.152
Centralisation	0.096
Adj.avg.clustering	0.934
Assortativity coef.	-0.005

WKND 16:30-18:30

Nodes count	41
Edges count	142
Avg. degree	6.927
Graph density	0.173
Centralisation	0.238
Adj.avg.clustering	0.975
Assortativity coef.	0.012





WKDY 8:00-10:00

Nodes count	11
Edges count	10
Avg. degree	1.818
Graph density	0.182
Centralisation	0.144
Adj.avg.clustering	1.571
Assortativity coef.	-0.096
Co-presence ratio	0.818
Connected components	5

WKDY 10:00-12:00

Nodes count	24
Edges count	30
Avg. degree	2.500
Graph density	0.109
Centralisation	0.166
Adj.avg.clustering	1.229
Assortativity coef.	0.208
Co-presence ratio	0.833
Connected components	9

WKDY 12

Nodes count
Edges count
Avg. degree
Graph density
Centralisation
Adj.avg.cluste
Assortativity c
Co-presence
Connected co
onents

WKND 8:00-10:00

Nodes count	24
Edges count	35
Avg. degree	2.917
Graph density	0.127
Centralisation	0.099
Adj.avg.clustering	1.362
Assortativity coef.	0.187

WKND 10:00-12:00

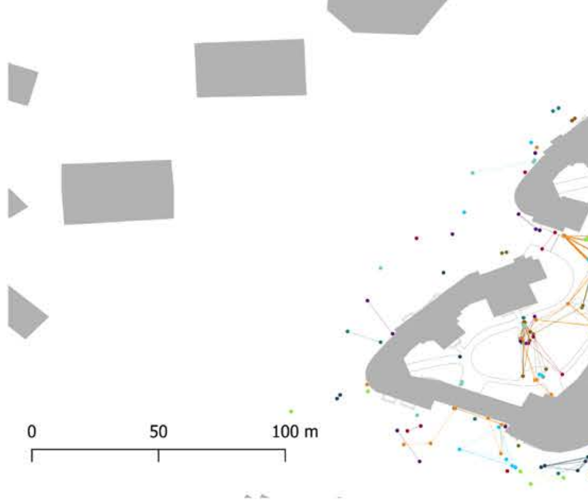
Nodes count	19
Edges count	18
Avg. degree	1.895
Graph density	0.105
Centralisation	0.193
Adj.avg.clustering	2.85
Assortativity coef.	-0.111

WKND 12

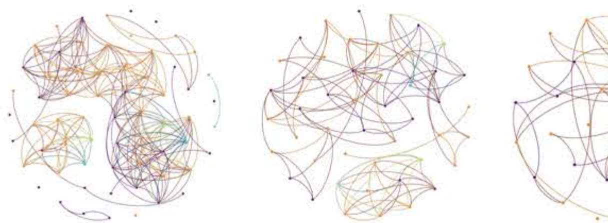
Nodes count
Edges count
Avg. degree
Graph density
Centralisation
Adj.avg.cluste
Assortativity c

	WKDY 8:00-10:00	WKDY 10:00-12:00	WKDY 12:00-14:00	WKDY 14:00-16:00	WKDY 16:30-18:30
Nodes count	17	11	34	18	44
Edges count	12	4	38	15	66
Avg. degree	1.412	0.727	2.235	1.667	3
Graph density	0.088	0.073	0.068	0.098	0.070
Centralisation	0.112	0.155	0.121	0.154	0.146
Adj.avg.clustering	2.198	3.667	1.557	2.110	1.635
Assortativity coef.	0.619	0.000	-0.104	0.524	-0.524
Co-presence ratio	0.706	0.454	0.853	0.722	0.750
Connected components	9	8	14	9	19

	WKND 8:00-10:00	WKND 10:00-12:00	WKND 12:00-14:00	WKND 14:00-16:00	WKND 16:30-18:30
Node number	33	61	25	27	39
Edge number	58	170	32	42	106
Avg. degree	3.515	5.574	2.560	3.111	5.436
Graph density	0.110	0.093	0.107	0.120	0.143
Centralisation	0.149	0.145	0.201	0.120	0.210
Adj.avg.clustering	1.486	1.183	1.484	1.421	1.750
Assortativity coef.	0.459	0.085	1.000	-0.001	0.081



	WKDY 8:00-10:00	WKDY 10:00-12:00
Nodes count	55	48
Edges count	189	91
Avg. degree	6.873	3.792
Graph density	0.127	0.081
Centralisation	0.137	0.071
Adj.avg.clustering	1.083	1.102
Assortativity coef.	0.161	-0.001
Co-presence ratio	0.964	0.937
Connected components	11	13



	WKND 8:00-10:00	WKND 10:00-12:00
Node number	64	47
Edge number	241	105
Avg. degree	7.531	4.468
Graph density	0.120	0.097
Centralisation	0.204	0.082
Adj.avg.clustering	1.135	0.954
Assortativity coef.	0.556	0.281

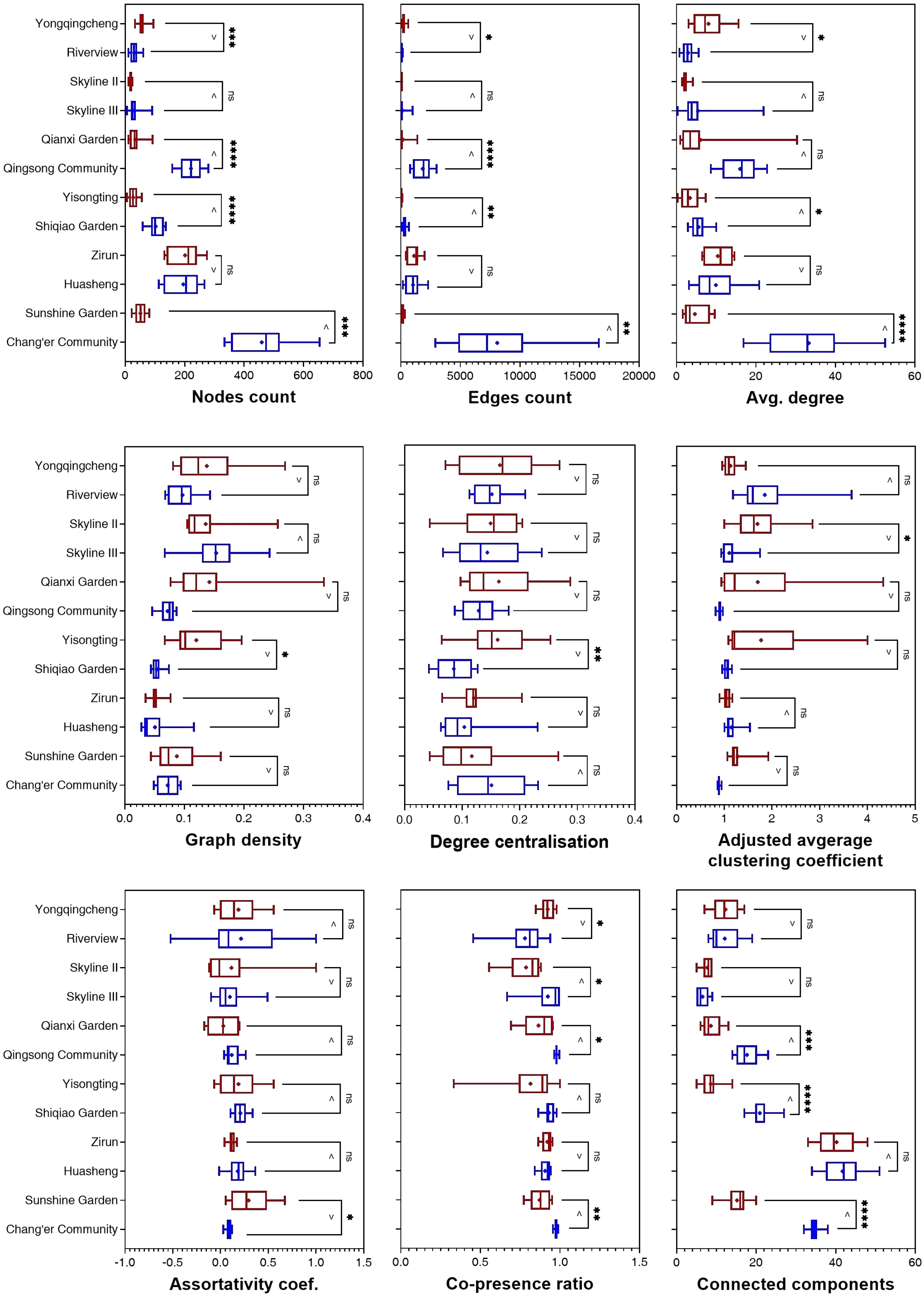


Figure 11. Box and Whisker plots display the data distribution of nine co-presence network parameters, grouped by housing areas for comparison. The blue colour indicates non-GHEs, and red is GHEs.

Bootstrapped independent samples t-test results are reported, where **** refers to significance at 0.0001 level, *** at 0.001 level, ** at 0.01 level, * at 0.05 level, and 'ns' for non-significant results.

5.2 Correlation between co-presence network properties and housing characteristics

This section focuses on the impact of the housing characteristics on the co-presence parameters. It starts with Spearman correlation analysis to unveil the association between housing characteristics and co-presence parameters. It then reports the result of hierarchical multiple linear regressions, where other variables are controlled, to reveal the effect of enclosure.

5.2.1 Spearman correlation

The housing estates characteristics and co-presence parameters were significantly yet weakly correlated (Figure 12). The housing type (i.e., gated or non-gated) significantly and positively correlated to the overall co-presence level (node count, edge count, average degree, and co-presence ratio), and was negatively associated with graph density, degree of centralisation and clustering coefficient. However, compared with the binary 'type', correlations of enclosure degree demonstrated remarkably higher coefficients towards co-presence variables.

Regarding the four density parameters, the co-presence parameters barely correlated to Floor Space Index (FSI) and Open Space Index (OSI). However, Ground Space Index (GSI) and household density were positively associated with node counts, edge counts, average density, and co-presence ratio. These findings imply that a higher level of co-presence among people require a more compact layout and higher population density, but not necessarily more open spaces.

Housing price was significantly correlated to all co-presence variables, suggesting that people in more expensive estates had a sparse co-presence structure but a strong tendency of centralisation and clustering. Meanwhile, the more peripheral housing estates displayed a denser co-presence network but weaker centralisation structure compared with those closer to the city centre. Furthermore, construction year significantly (though weakly) correlated with node counts, edge counts, average degree, co-presence ratio, and adjusted average clustering coefficient. These results imply that older residential areas tend to have denser and more evenly distributed co-presence patterns.

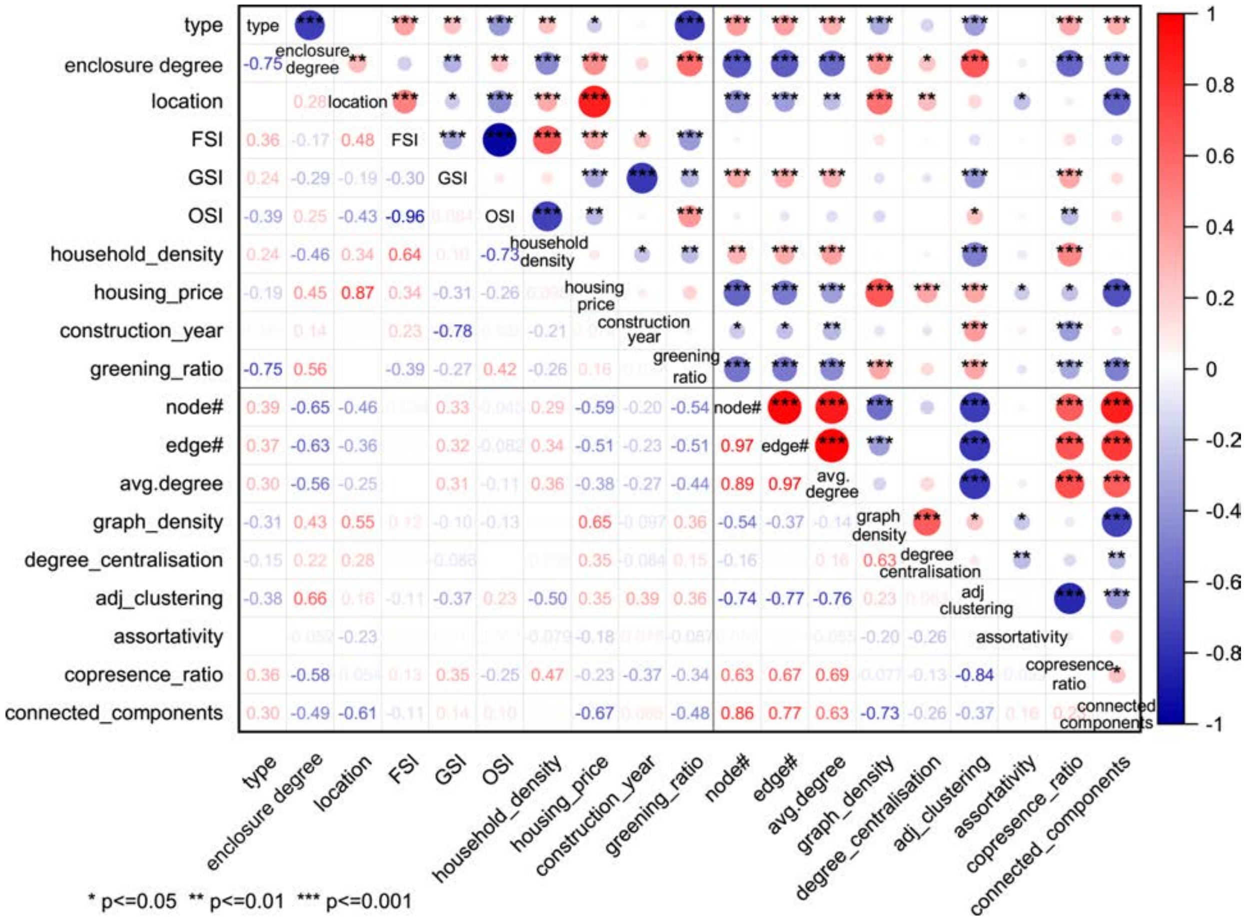


Figure 12. Spearman correlation matrix of all variables, computed in OriginPro® 2021 software. Note: 'type' was coded as '0'-gated, '1'-non-gated; 'location' was coded as '0'-inner suburb, '1'-city centre.

Strikingly, only housing price and location significantly correlated to assortativity. This result suggested that people with lower incomes living in the urban periphery are more likely to co-present with others unlike themselves than their richer counterparts in the city.

5.2.2 Hierarchical multiple linear regression

Hierarchical multiple linear regressions were performed to test the explanatory power of enclosure degree on co-presence whilst controlling other socio-spatial variables. The results were summarised in Table 5 – Table 7. Note that all control variables were pre-tested in stepwise regression models to reduce multicollinearity, and only significant ones were entered into the hierarchical regression models. Overall, the final models significantly explained about one third to one half the variation in most co-presence network attributes, excepting centralisation degree and assortativity (only accounting for one tenth the variation).

What stands out in the tables is that the enclosure degree was non-significant in all final models except the one for assortativity. Furthermore, in most cases, the enclosure degree had the smallest effect size (standard coefficient) when comparing to other variables. Moreover, adding enclosure degree into the model hardly improved variance prediction of nine co-presence variables with the highest ΔR^2 of .044, and the ΔF was not significant in all final models except the one for assortativity coefficient. This evidence suggests that after controlling other socio-spatial factors, the enclosure degree was not essential for shaping the co-presence pattern among people in their housing areas.

Table 5. Summary of hierarchical multiple regression analyses predicting nodes count, edges count, and average degree.

	Node count		Edge count		Average degree	
	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Control variables						
Location	–0.815 **	–0.816 **	–1.442 *	–1.441 *	–0.571	–0.571
Ground Space Index	–1.446 **	–1.450 **	–2.541 **	–2.537 **	–0.963 *	–0.966 *
Open Space Index	–0.640	–0.645	–1.020	–1.016	–0.375	–0.378
Household density	0.393	0.394	0.922	0.921	0.653	0.653
Housing price	–1.515 **	–1.525 *	–1.871	–1.862	–0.558	–0.564
Construction year	–1.816 ***	–1.821 ***	–3.619 ***	–3.614 ***	–1.632 ***	–1.634 ***
Greening ratio	–1.651 ***	–1.663 ***	–2.909 ***	–2.898 ***	–1.137 ***	–1.144 **
Independent variable						
Enclosure degree		0.015		–0.104		0.009
R^2	0.665	0.665	0.594	0.594	0.473	0.473
R^2 adjusted	0.644	0.641	0.568	0.564	0.440	0.435
ΔR^2		0.000		0.000		0.000
ΔF	31.815 ***	0.003	23.371 ***	0.001	14.376 ***	0.001

Note: Figures shown are standardised coefficients (beta). ΔR2: change in variance. *p<.05, **p<.01, ***p<.001.

Table 6. Summary of hierarchical multiple regression analyses predicting graph density, co-presence ratio, and centralisation.

	Graph density	Co-presence ratio	Degree centralisation

	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Control variables						
Location	0.237	0.238	0.010	0.010	0.067	0.065
Ground Space Index	0.623 *	0.632 *	–0.038	–0.037	–0.134	–0.163
Open Space Index	0.186	0.197	–0.082	–0.080	0.475	0.440
Household density	0.334	0.332	0.062	0.061	0.177	0.184
Housing price	0.860 **	0.879 *	–0.189	–0.186	0.489	0.423
Construction year	0.237	0.247	–0.061	–0.060	–0.309	–0.342
Greening ratio	0.680 ***	0.705 ***	–0.117 *	–0.114	–0.128	–0.211
Independent variable						
Enclosure degree		–0.031		–0.004		0.105
R^2	0.431	0.431	0.254	0.254	0.113	0.113
R^2 adjusted	0.395	0.390	0.207	0.200	0.058	0.052
ΔR^2		0.000		0.000		0.002
ΔF	12.101 ***	0.033	5.442 ***	0.005	2.041	0.276

Note: Figures shown are standardised coefficients (beta). ΔR2: change in variance. *p<.05, **p<.01, ***p<.001.

Table 7. Summary of hierarchical multiple regression analyses predicting adjusted average clustering coefficient, assortativity, and connected components.

	Adj. avg. clustering coefficient		Assortativity coefficient		Connected components	
	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Control variables						
Location	0.098	0.094	–0.428	–0.379	–0.768 ***	–0.773 ***
Ground Space Index	0.195	0.153	0.677	0.431	–0.747 **	–0.821 **
Open Space Index	0.172	0.122	0.402	0.134	–0.257	–0.345
Household density	–0.284	–0.274	0.340	0.323	–0.044	–0.026
Housing price	0.386	0.295	1.359	0.730	–0.541	–0.707
Construction year	0.227	0.177	0.909 *	0.565	–0.538 *	–0.621 *
Greening ratio	0.279 **	0.162	0.188	–0.562	–0.964 ***	–1.173 ***
Independent variable						
Enclosure degree		0.148		0.888 *		0.264
R^2	0.395	0.404	0.146	0.190	0.582	0.589
R^2 adjusted	0.357	0.360	0.077	0.115	0.556	0.560
ΔR^2		0.009		0.044		0.007
ΔF	10.265 ***	1.658	2.117 *	4.721 *	22.271 ***	1.942

Note: Figures shown are standardised coefficients (beta). ΔR2: change in variance. *p<.05, **p<.01, ***p<.001.

6. Discussion and conclusions

6.1 Divergent co-presence patterns in gated and non-gated housing estates

In this study, we first conducted a binary comparison of the co-presence parameters between gated and non-gated types, adhering to the conventional approach in the 'gated community' literature (Table 4). Overall, our analysis revealed that the GHEs exhibited a significantly lower intensity of co-presence than the non-GHEs. Specifically, the co-presence networks in GHEs showed significantly lower values in nodes count (count of stationary people), edges count (count of co-present links), average degree (the average number of people one co-presents with), and co-presence ratio (the percentage of non-isolated people). These findings collectively suggest that GHEs might hinder urban vitality and sociability, corroborating previous criticisms (Blandy et al., 2003; Deng, 2017; Dong et al., 2019; Miao, 2003; Wu et al., 2018).

Interestingly, despite the lower intensity of co-presence, we observed a higher network density in the GHEs compared to the non-GHEs. This initially counterintuitive finding can be explained by the larger network size of the non-GHEs. It has been well established that the number of potential connections grows quadratically with the number of nodes (Newman, 2018); therefore, as networks grow larger, they tend to become less dense (Wasserman & Faust, 1994). In our case, stationary activities in the GHEs were scarce and gated housing estates typically have a large open space at the geometric centre (Cheshmehzangi, 2018; Xu & Yang, 2008) in the form of a 'hollow heart' (see Figure 5 to Figure 10), where mutual visibility is maximised to generate a high density value. Conversely, the non-GHEs accommodated more stationary individuals outdoors, and their layouts were more linear and street-based, resulting in buildings obstructing visual links, leading to a lower network density.

Additionally, we found a slightly higher assortativity coefficient for the gated group, indicating a more homogeneous pattern of co-presence. In other words, the residents of gated areas tend to co-present with others of same age and gender, which, however, might not be entirely intentional. During working hours the outdoor spaces were predominantly occupied by senior women and young mothers (see Figure 6 as an illustrative example), consistent with findings from Wu et al. (2014) who studied four Chinese GHEs in Xiamen and reported that the primary users of outdoor spaces in the GHEs were children, housewives and retirees.

Furthermore, our analyses also revealed that co-present people from the non-GHEs were more evenly distributed, whilst those in the GHEs displayed a greater tendency of clustering and centralisation. These distribution features can be closely related to place safety. The high tendency of clustering and centralisation of the GHEs, while creating a few bustling hubs, can leave many other areas relatively deserted as 'blind spots' that are more vulnerable to potential crimes and anti-social behaviours, due to the lack of 'eyes on the street' (Carmona, 2019; Jacobs, 1961; Van Asten et al., 2023). This is particularly problematic during working hours, as there is also a lack of natural surveillance from residents of nearby buildings. The role of natural surveillance in deterring offenders has been supported by numerous previous studies. A most recent study, for instance, reported that the presence of people was strongly correlated with the number of robberies (Vidal-Domper et al., 2024).

All in all, our comparisons of co-presence networks suggested that the non-GHEs tend to show a higher level of co-presence and social mixing and a lower tendency of centralisation and clustering, but these conclusions were not universally applicable across all study cases. This implies that not all estates of the same kind shape the co-presence pattern in the same way, which is in line with a statement from Kostenwein (2021), namely that it is not useful to discuss GHEs in an aggregated manner because they can influence how people use and perceive the place differently. This inconsistency highlights that simply classifying estates into gated or non-gated group cannot fully explain their co-presence patterns, and that there are other factors are equally – if not more – important (as discussed below).

6.2 Explanations of co-presence patterns at housing estate level

Indeed, our correlation analyses illustrated that the co-presence parameters were less associated with binary housing type than they were with the enclosure degree of housing estates, corresponding to a similar argument by Wang et al. (2021) that the degree of entry control is a more efficient variable than housing type in explaining the social performances (burglary rates in their case) of the place.

Meanwhile, we found that other spatial and social features of overall estate can simultaneously influence how people co-present at housing estates (Figure 12). For example, the co-presence network parameters were more correlated with GSI (Ground Space Index) , but hardly with FSI (Floor Space Index) and OSI (Open Space Index). These findings echo the idea that high lot coverage and reasonable population density are important for creating a lively city (Gehl, 2013; Montgomery, 1998; Wu et al., 2018; Ye et al., 2017), and that more open spaces do not necessarily guarantee more outdoor activities in housing estates (Wu et al., 2014).

Additionally, we found the location and price of housing estates were correlated with co-presence structures. Specifically, housing estates located in city centre with high housing prices had a sparse co-presence pattern, probably because residents have a wider ambit of activity. This is in line with earlier research on the Bangkok gated field, where researchers noticed that residents of high-end estates had fewer contacts inside the compounds, but they did have a thriving social life outside the area (Wissink & Hazelzet, 2016). We also found that older residential areas tend to have denser and more evenly distributed co-presence network, echoing a prevalent notion that older residential areas are often more vibrant (Merlino, 2011). In China, such housing estates have higher rates of occupancy by senior citizens, who are arguably more dependent on their locality for daily needs and have more time to spend in their residential areas.

6.3 Ungating is not the panacea

Although both housing type and enclosure degree significantly correlated with co-presence patterns, and the latter was a stronger predictor, even the enclosure degree became non-significant after controlling for other social and spatial factors (e.g., location, housing price, OSI) , with only an additional 1% explanation of the variance on average in all hierarchical regression models (see Table 5 – Table 7). This outcome implies that 'gated or not' or even enclosure degree alone may not be the culprit for the loss of vitality as is commonly claimed. This finding is in line with studies of gated areas in Shanghai (Yip, 2012) and Guangzhou (Li et al., 2012), where the researchers found that the impact of enclosure on the sense of community was minimal – and overshadowed by other spatial and personal factors.

Based on findings above, we therefore argue that simply demolishing gates and physical boundaries may not necessarily encourage spatial usage, nor stimulate co-presence. This research can be seen as an alarm bell for China's ongoing housing reform, highlighting the need for policy-makers and designers pay attention to the most likely influential spatial attributes, rather physical boundaries *per se*. These attributes may include the layout of estates, the interface between buildings and open spaces, the provision of amenities, as they have been evidenced to facilitate outdoor activities and therefore, co-presence (e.g., de Rooij & van Nes, 2015; Ewing & Handy, 2009; Kim & Kim, 2022; Mehta, 2019; van Nes & Rueb, 2009). For example, Yang and Vaughan (2022a) evidenced the ways that internal streets are interconnected and are embedded in their wider neighbourhood can shape not only flows of pedestrian movement but also distribution of non-residential functions (e.g., shops and restaurants), with consequential more opportunities for people to co-present and interactions when they walk on the street and conduct function-based activities such as shopping.

The factors and attributes discussed above are inherently more influential than enclosure alone in shaping co-presnce patterns due to their broader and more direct impacts on how spaces are used and perceived. While enclosure primarily dictates access and boundary conditions, its influence is often indirect – mediated by the broader context of the built environment and social dynamics. Factors that directly affect the spatial quality, usability, and inclusiveness of open spaces inherently play a more pivotal role in shaping co-presence patterns, as they govern not just who can access a space but also how people interact within it. Enclosure, by contrast, serves as a structural framework, influencing the potential for interaction rather than the actual social dynamics that emerge. This distinction highlights the need to consider enclosure as one component within a broader network of interrelated factors driving social and spatial behaviors.

6.4 Contributions and implications

This research makes significant contributions to the theoretical understanding of the social impacts of GHEs, offers feasible methodological frameworks to quantitatively compare co-presence patterns, and provides practical implications for urban planning and policy-making, particularly for the ungating housing reforms taking place in China. Although the primary goal of the reforms was to facilitate urban permeability and ease traffic congestion, enhancing co-presence in outdoor spaces at housing estates is equally critical, as it directly influences the vitality, sociability, and inclusiveness or urban communities. A successful city should be a city for people, not one for vehicles.

Interpreting the network results in spatial and managerial terms helps clarify what kinds of social life different estate forms tend to support. Higher node and edge counts and a higher average degree – more often found in non-GHEs – indicate broader outdoor use and a greater likelihood of incidental encounters across the layouts, namely a more distributed and inclusive social field. By contrast, higher density, clustering, and centralisation – more often found in GHEs – signal internally cohesive but spatially concentrated co-presence, typically organised around designed leisure nodes. These signatures imply that open, street-facing forms tend to faciliate social mixing and permeability (lower assortativity), whereas enclosed forms tend to strengthen local bonding within a smaller set of focal places. Designers and managers should therefore work backwards from desired social outcomes: when mixing and permeability are priorities, walkable linear links, active ground-floor interfaces, and small-grain amenities can convert movement into dwell; when community bonding is prioritised, a supervised 'one-main-multiple-secondary' node structure can avoid single-point crowding while maintaining cohesion.

Specifically, while co-presence has been recognised as a key concept for vibrant communities (Horgan et al., 2022; Legeby, 2013) and GHEs have long been blamed for community decline (Chiu-Shee et al., 2021; Hamama & Liu, 2020), few studies have investigated the social influences of GHEs through the lens of co-presence patterns. To our knowledge, this is the first study that quantitatively compared co-presence patterns between GHEs and non-GHEs. This research offers not only valuable empirical evidence on spatial utilization that has been missing in 'gated community' literature, but also a fresh perspective to help better understand urban social dynamics in China. Additionally, it has developed a novel comparative framework for analysing co-presence patterns through proximity-based social network approaches. This methodology can be replicated to investigate co-presence patterns in diverse geographic and socio-economic contexts.

Furthermore, co-presence patterns at GHEs and non-GHEs were compared in both aggregated classifications and case-by-case fashions, highlighting the variability within same estate types and emphasizing the importance of context-specific analyses over aggregated classifications – also relevant for future research in this domain.

This study also has strong practical implications, particularly in the policy of ungating housing reform in China. After its first announcement in 2016, this reform had progressed very slowly due to strong public resistance till late 2019 (Chiu-Shee et al., 2021). Since the global outbreak of COVID-19 in early 2020, owing to the critical role gating has played in lockdown enforcement to prevent virus transmission, we have even witnessed an intensification and preference for gated housing, both in China (Fu, 2023; Hu & He, 2024; Shen et al., 2023) and abroad (Asfour, 2022). Thus, it can be said that the Chinese policy of ungating is now almost redundant. However, we argue that although housing environments need to be resilient for managing future public health crisis, doing so in the form of GHEs may come at the expense of losing community sociability and urban vitality, as has been shown in this study.

We suggest that future strategies for housing planning and urban design should consider steps beyond simply removing physical barriers. Instead, they should focus on creating spatial layouts that support both resilience and sociability. For example, redesigning open spaces within gated estates to include multifunctional areas that serve both residents and external visitors can mitigate against social segregation and enhance co-presence. Furthermore, increasing accessibility through additional pedestrian pathways that link interior spaces to the surroundings streets would improve natural flows of movement into and around housing areas, while mixed-use developments would have the advantage of enhancing interaction opportunities, so long as there are adequate safeguards for health and safety. Additionally, policy incentives that encourage developers to implement such design approaches, such as subsidies for creating semi-public spaces or mixed-use properties at the edges of housing areas, can also help retain social vibrancy while maintaining functional resilience. These proposed measures provide a balanced path forward, addressing both community vibrancy and the evolving demands of public health – both protection against future epidemics, as well as encouraging active use of the urban realm.

6.5 Limitations and future recommendations

Given its exploratory nature, this research had some limitations. However, we believe these limitations do not invalidate the findings. First, like other PBSN studies, this method considered individuals within a visible distance as co-present; however, it does not necessarily mean they actually saw or were aware of each other. Therefore, the networks analysed through this research can only reflect hypothetical co-presenc rather than actual ones. Future studies might capture actual rather than hypothetical co-presence between people, which can be achieved (with the necessary ethical considerations) by using technologies such as wearable devices to verify whether individuals actually see each other.

Additionally, the co-presence networks in this study did not measure co-presence between people walking past each other, though this method is arguably sufficiently robust for the purpose of measuring co-presence variability since stationary activities are more reflective of the design quality of places, indicating a willingness to stay. Future research might include not only stationary individuals but also those walking past each other to provide a comprehensive view of co-presence patterns in housing areas.

Furthermore, this study tackled the co-presence as a ‘static snapshot’, yet the duration of co-presence may also be an important parameter. Future studies might further explore the temporal dimension of co-presence patterns by tracking the duration of co-presence over time, to understand how the use of space evolves throughout the day, week, or season, and how it impacts community life. In addition, while this study only investigated the impacts of socio-spatial features at estate level onto co-presence patterns, further micro analysis could examine how spatial configuration of individual streets or open spaces within estates actually affect the distribution of outdoor activities and the co-presence between the users. Coupled with qualitative research into people’s motivations for spending time in the public realm, such analysis might shed light on individual responses to the environment – though this is clearly beyond the scope of the current study.

As mentioned in the methods section, while the 25-meters distance is considered an appropriate threshold for defining co-presence in residential areas, it may not be universally applicable, particularly in dense urban areas (e.g., commercial districts, shopping malls, transport hubs) that experience high levels of crowding and/or movement. In such environments, the effective co-presence distance for meaningful social interactions may be shorter than 25 meters. Future research could then explore the variation in effective proximity thresholds by examining different urban settings.

Moreover, an important conceptual limitation concerns the causal interpretation of gatedness and spatial design. While this study treats gatedness as an explanatory factor affecting co-presence network structures, it is important to acknowledge that in some contexts, the decision to gate may itself by influenced by the underlying design of open spaces. However, in the Chinese context – and specifically in all estates examined here – gatedness was not an outcome of spatial design but a top-down decision made during the development stage, driven by management convenience, market positioning, and branding strategy (Hu & He, 2024; Liao et al., 2018; Pow, 2009; Wu & Li, 2020). Spatial design elements such as walls, entrances, and internal layouts were implemented to support, rather than determine, this decision. Nevertheless, the close interdependence between design and gating highlights the need for future research to disentangle their respective effects on spatial and social outcomes.

Finally, as the impacts of GEHs are context-specific, the generalisability of our findings on the influence of enclosure on co-presence patterns should be approached with caution. This study focused on gated estates in China, where the development of GHEs is not predominantly driven by security concerns but rather by preferences for privacy, order, and exclusivity. Our findings therefore suggest that enclosure alone does not significantly determine co-presence patterns. It is plausible to consider whether in socio-cultural settings with high levels of crime, such as in South Africa and parts of Latin America, the dynamics observed here may differ. GHEs are often primarily preferred for their relative safety in some parts of the world. Consequently, residents and even outsiders may prefer using the internal spaces of GHEs, which could lead to higher co-presence levels within these estates. This contrasts with the Chinese context, where public parks and green spaces are generally well-maintained and heavily utilized, reducing reliance on privatized spaces within GHEs. These differences highlight the need for further research into how enclosure influences co-presence patterns in varying sociocultural and institutional contexts. Future studies could explore how factors such as safety, governance, and cultural preferences shape the use of open spaces within GHEs, providing a more nuanced understanding of their social and spatial impacts globally.

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