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RESEARCH ARTICLE

A graphical method of presenting property rights, building types, and residential behaviors: A case study of Xiaoxihu historic area, Nanjing

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Abstract One of the main reasons for the decline of urban historic areas in China is the co-existence of multiple property rights. It also deeply affects conservation and regeneration practice. This paper aims to propose a graphical method that illustrates the association between property rights, space, and resident behavior. Based on typological maps and justified graphs, a three-step method was proposed to visualize the relationships between these three elements. The final graph and quantitative data were used to observe the evolution of the courtyard building from a diachronic perspective, as well as to compare the residential behavior in different types from a synchronic perspective. The results show that following the subdivision of property rights, the building layout become more diverse due to various illegal additions, while the residential behavior within different building types tends to be consistent. Moreover, the study observed the traditional Chinese courtyard buildings' adaptability. The findings contribute to understand the evolution of Chinese urban historic areas and internal motivation, and provide guidance for the conservation and regeneration practice.
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1. Introduction

The complex coexistence of multiple property rights is one of the important characteristics of most Chinese urban historic areas. Since 1949, with the rapidly increasing urban population, the transformation of the land system from private to public ownership, and the socialist reform of private housing, many urban private lands and buildings have been subdivided. Many households live together in one plot or even one building, and property rights of different natures, such as those to public houses and private houses, coexist. Some scholars have highlighted that high densities of property rights, and the complex relationship between different property rights are some of the main internal causes of the decline of Chinese historic areas (Zhang et al., 2006). The former leads to continuous illegal construction due to the insufficient useable area, which deteriorates the living environment and destroys the traditional texture; the latter causes unclear responsibilities and lack of motivation or funds to maintain the house. In the conservation and regeneration practice, property rights are also ignored in favor of a focus on the issue of physical space. This makes it difficult to implement the practice process in a sustainable manner, and may even trigger social conflicts during implementation process.

Property rights have different definitions in different fields, such as law and economics (Barzel, 1989; Demsetz, 1967; Alchian, 1965; Alchian and Demsetz, 1973). The property rights examined in the urban planning and architecture research mainly relate to real property, including land property and housing property. The two are the same in many cases; however, in other cases, they form an inclusive relationship, that is, the same land property contain several housing properties. In essence, property rights cover three aspects: the land, the person or group, and the connection of ownership between them, sometimes called a "holding" (Kropf, 2018; Linklater, 2013). In historic areas, these three aspects are specifically manifested as physical space, residential behavior, and property rights; their boundaries are sometimes clear and unified, although more often, they are very vague and chaotic. This causes difficulties in the residential historic areas' recognition and regeneration design; however, academic research has not paid enough attention to this situation.

This study takes Nanjing's Xiaoxihu, a typical case of Chinese historic area and home to high density of property rights and complex property relations, as its research object and undertakes historical research, status survey, graphical drawings, and correlation analysis. The study's purpose is to establish a graphical presentation method of the relationship between space, behavior, and property rights, and, thereafter, explain the influence of changes in property rights on the physical space forms' and residential behaviors' evolution. Furthermore, it aims to provide guidance for conservation and regeneration design practice of historic areas in the context of the coexistence of multiple property rights.

2. Property rights in Chinese historic areas

The research on property rights in historic areas has mainly focused on the field of typo-morphology. Property rights are often mentioned as a hidden attribute of plots but rarely go deep to the architectural level. Among Conzen's (1969) three plan elements, "plot" refers to a piece of land defined by property rights boundary, representing a property holding. The term *lotto edificato* (built lot) was used to express the same concept by Cannigia (1979), who believed that the related area (courtyard) and area occupied by the building comprises of a lot and is a module that constitutes part of the urban fabric. Kropf (2018) analyzed the relationship between plot boundaries, property rights boundaries, and human behavior and proposed that plot, as property and an element of control, is rooted in human behavior and our interactions with both our environment and each other.

As one of the most important basic elements in the typo-morphology's study, the boundary and organizational mode of plot represent the distribution of land property rights and are also an important structural and orderly foundation for urban form and architectural texture. The discussion of the relationship between land property rights, urban morphology, and human behavior in the field of typo-morphology is an important basis and reference for the present study. However, due to changes in China's political and land system after 1949, as well as a series of historical events, property rights relations in the existing residential historic areas have become more complex and diverse (Zhang, 2012). The research and design must first clarify the evolution process and status quo of property rights in this specific environment, and then going deeper into the building level from a more microscopic perspective, expanding the conservation and regeneration theory and practice.

Before 1949, private land ownership was generally practiced in Chinese cities, and the land was surveyed and registered by the government. Both officials and individuals could own and trade land freely. Overall, a household occupied a piece of land. After 1949, the land system began to change from private to public ownership. The first area to be transformed was rural land, while the private land and houses of urban residents were still recognized. Since 1951, Chinese governments at all levels have recognize and registered the private land and houses of urban residents in accordance with the law. The owner of a private house can obtain a "Real Estate Ownership Certificate" with the old "Real Estate Deed" of the Republic of China, which contains the property number, location, boundary, ownership, etc., and signifies that this piece of land is private property. As of 1956, there were 53,000 private householders in Nanjing, who occupied a building area of 6.38 million square meters, which accounted for about 50% of the city's total urban housing area, of which 2.57 million square meters of housing were used for lease (Clitherow, 2012).

As the contradiction between urban population growth and urban housing shortages became increasingly prominent, in 1956, the socialist reform of private housing was

officially launched, setting a starting point for the transformation of urban private rental houses (for example, 150 square meters in Shanghai and Nanjing, and 225 square meters in Beijing). The excess area would be leased uniformly by the state, meaning that the homeowner would gradually be paid a fixed rent within a certain period to transform the ownership. The fixed rent given to the homeowner was 29.6% and was paid monthly from July 1958 to October 1966. In this way, the leased property rights gradually changed from private to state-owned (Nanjing Local Chronicle Compilation Committee, 1996).

In 1966, many private house owners were forced to hand over their property to the public. When urban residents were decentralized to the countryside in 1969, the private houses of the decentralized households were all purchased by the government at low prices. These houses were then sublet to the growing urban population. In 1976, that the government re-implemented the private housing policy, returning properties that were given to the public for free and compensating owners for the private housing it acquired at low prices. However, the returned real estate only accounted for a small part of that which was acquired.

Throughout these periods, numerous urban private lands and houses were subdivided. Most of them were leased to new urban residents and gradually transformed into state-owned properties, with just a small number remaining as private property. Simultaneously, the property rights of land and houses began to separate: multiple households could occupy a single plot, and each of them had independent housing property rights.

According to the 1982 Constitution of China, urban land property currently belongs to the state. Private, unit, or government real estate management departments at all levels have the right to use land, and this right can be transferred in accordance with the law. The property rights of houses correspond to private houses, unit-owned public houses, and state-owned public houses according to the different rights holders (Zhang, 2018) (Table 1).

Our investigation revealed that in most of the historic areas of Chinese cities, a complex coexistence of multiple property rights exists to varying degrees. There are at least three types of correspondence between land-use rights and house ownership. First, most state-owned and unit-owned property plots correspond to public housing, although the original plot or building is sub-leased to several households, or even more than a dozen. Second, privately held land parcels correspond to private houses; however, with the continuous subdivision of land use rights, for example, via inheritance and sales, a building may be divided into multiple land parcels with different property rights. Third, in a small number of plots, public and private houses coexist within the same plot due to historical issues (Fig. 1).

This complex coexistence of multiple property rights has affected the evolution of the physical space and residential behavior in the historic areas of China on three levels. First, at the physical space level, several cases of different Chinese cities show that the mixture of public and private property rights, unclear borders, and high population density have led to the infringement of various illegal structures (mainly kitchens, toilets, and storage spaces) on the public domain (streets, courtyards, etc.), destroying the traditional courtyard building types and fabric (Dong et al., 2019; Duan and Zhang, 2017).

Second, at the social level, public rental housing belongs to the national welfare system: Tenants' rents have been very low for a long time, and they only have rights for use, rather than ownership and disposal rights. The real estate department has ownership of these properties; however, the rent collected is insufficient to support the cost of house repairs. Under this system, both the government and tenants lack the funds and motivation to maintain buildings and improve infrastructure. Meanwhile, a few private house owners are also unable to repair their properties independently due to issues, such as adjacent houses and shared courtyards (Duan and Zhang, 2017). Consequently, houses in historic areas have gradually become dilapidated, and traditional layouts and styles are not preserved. Residents with a little economic strength gradually choose to move out of the area, while the left-behind population is aging and marginalized. Accordingly, many historic areas are in a state of decline in terms of both physical and social aspects.

Third, at the implementation level, in the past few decades, to balance funds and achieve profit during the renewal process, many declining traditional blocks and buildings were expropriated and demolished, and replanned into large singular plots for unified development. The private property rights were ignored and merged, resulting in residents have either voluntarily moved out or been forcibly relocated to resettlement houses on the outskirts of the city. This process has also triggered a series of social conflicts and contradictions (Liu and Li, 2011).

The coexistence of multiple property rights due to changes in land systems, policies and regulations, and a series of subsequent historical issues is an important and unique characteristic of historic areas in Chinese cities. It also led to the gradual decline at both physical and social levels, and caused conflicts in implementation. For a long time, planning and design just focused on physical objects, rather than people, and did not consider property rights as the connection between people and objects; therefore, it was difficult to implement (Zhang et al., 2006; Han, 2022). The lack of attention to the property rights relationship and graphical methods that can be used to visually present this relationship are key factors that have restricted the research, design, and practice of the conservation and regeneration of historic areas in China.

3. Methods

To address the predicament of the conservation and regeneration of Chinese cities' historic areas, an intuitive graphical method that can present the relationship between property rights, physical space forms, and human behaviors is required. It will assist the interpretation of the impact of changes in property rights on the evolution of these physical space forms and human behaviors in both diachronic and synchronic dimensions, and provide direction for regeneration design and policy.

Table 1 The evolution of urban land and housing property rights in China (source: the authors).

	Before 1949	1950–1953	1956–1966 Socialist reform of private housing	1966–1976	1982 Constitutional amendments	1988 Constitutional amendments	Status quo
Land property rights	Private ownership	Recognize and register the private ownership of urban land and houses in accordance with the law, and issue "Real Estate Ownership Certificates"	All privately owned urban open space, i.e., street-based real estate, was nationalized after appropriate measures.	All private land in cities was nationalized.	The amended Constitution states: "The land of the city belongs to the State."	Land use rights can be transferred based on the law.	Land ownership: State Land use rights: • Private • Unit-owned • State-owned
House property rights			Setting a starting point for the transformation of urban private rental houses. The excess area would be leased uniformly by the state.	• Forced to hand private property over to the government or unit • Low-cost acquisition of decentralized households	Reimplementation of the private housing policy: • Return of private real estate confiscated • Compensation for the low-cost acquisition of decentralized households		House property rights • Private houses • Unit-owned houses • State-owned houses

3.1. Graphic method construction

More than half a century ago, the Italian school of urban morphology, represented by Muratori and Caniggia, used typological map as the main graphical tool in the study of traditional towns (Muratori, 1959; Caniggia, 1963). This type of map includes a ground plan of all the buildings in a city, block, or plot, and can simultaneously present the overall spatial form and building types. They also drew "speculative typological maps" of important historic periods based on complete urban archaeological maps and other historical archives. The typological map clearly shows the evolution of physical space, but it is difficult to reveal the social reasons for the evolution due to the lack of property rights boundaries.

Kropf (2018) identified physical features of plot boundaries and buildings from aerial photography, and overlayed in red of property boundaries from the cadastral plan. Song (2021) expanded method for describing and analyzing access structure based on the area structure (Marshall, 2016) and the generic multilevel diagram of urban form (Kropf, 2014). However, due to the research resolution, both of them did not go deep into the building layout level.

Hillier (1996) developed justified graphs as an intermediary that connects physical attributes with social and cultural attributes in the configuration theory to present the relationship between physical space and social organization. The same method was used by Hanson (1998) to analyze housing plans and added the room function to the justified graphs, revealing the social and cultural patterns hidden within the house type, that is, the deep "genotype" characteristics. These studies exploited the possibility of quantitative research between space and behavior, but mostly focus on single property right.

The aforementioned scholars respectively paid attention to the evolution of physical space, the distinction between property and physical boundary, the relationship between space and social organization, and formed effective graphic methods. However, when they were used directly in the study of Chinese historic areas, the complex property rights relations and limited historic documents became two major obstacles. Therefore, this study focused on adaptive improvement and integration of the above methods and proposed a three-step methodological framework to establish the comprehensive presentation of space, property rights, and human behavior.

(1) Typological map with property rights was created to present the current spatial structure, building layout, and land and house property rights.
(2) The speculative typological map and functional layout were inferred, based on historical cadastral maps and traditional building types.
(3) Residential behavior abstracted as graphs were superimposed on physical elements and property rights.

In the first step, typological map is the best way to present all the physical imprints left in a historic area. Based on that, our team surveyed all 216 property plots and

Fig. 1 The relationship between land property and housing property in historic areas: (a) Public housing—multiple public housing tenants in the same property rights plot; (b) Private housing—the land and house have been subdivided due to inheritance; (c) A mix of public and private—public housing and private housing coexist in the same property rights plot (source: the authors).

more than 1,300 building units of the Xiaoxihu area, drew typological map of the entire area, and then overlayed the property rights information on it through detailed property surveys and residents' interviews. Fig. 2 shows one part of the new map with property rights, called "property typological map". On the base map of walls, columns, doors, windows, etc. drawn by black lines, we used red solid lines to outline the boundary of the land property rights, and marked the name of each house property owner in the corresponding rooms (indicated with letters in the figure). The new property typological map more clearly shows the boundaries of the property rights plots, and their internal building layout and housing property rights distribution. The map also became the co-working base map for communication between the research team, the implementation team, and the residents.

In the second step, the drawing of speculative typological map is important for the comparative analysis of the diachronic evolution of urban form and building type (Trisciuoglio and Dong, 2017). However, different from European cities, traditional Chinese urban maps prepared mainly fall in two categories, descriptive and analytical, and accurately surveyed information was very limited and could not be directly used (Gu and Zhang, 2014). Taking Nanjing as an example, the earliest drawings that clearly identify the urban street system, plot organization, and architectural texture are the aerial images of Nanjing taken by the Aircraft Squadrons United States Asiatic Fleet in 1929 and the 1:1000 cadastral map of Nanjing City surveyed and mapped by the Nanjing Land Bureau in 1936.

Specific to the building layout inside each plot, traditional Chinese residential buildings rarely have design or survey drawings; however, they have distinct characteristics. While researching the evolution of residential building types in Guangzhou, Gu (2008) proposed that the principal rural building type and early urban building type were steps in the development process of several later building types. In the southern part of the old city in Nanjing, the characteristics of traditional courtyard buildings are more obvious. Relevant research (Nanjing Bureau of Planning and Natural Resources, 2014) took the existing Ming and Qing Dynasty buildings in the southern part of the old city as

Fig. 2 Part of property typological map of Xiaoxihu area (source: the authors and the Xiaoxihu research and design team of Southeast University).

samples and summarized their typical layout. As shown in Fig. 3, a typical traditional courtyard building was arranged in sequence along the depth of the plot, including (from the outside to the inside) the gatehouse, courtyard, main hall, courtyard, inner house, courtyard, and inner house. The superposition of this typical layout and the physical features from aerial images and cadastral map helped with the drawing of "speculative typological maps" (Fig. 4).

The third step involved the presentation of residential behavior, which was the most difficult and important aspect of the research. The investigation of Xiaoxihu area showed that, on the one hand, the behavior of residents living together in the same plot was limited by property rights and space; on the other hand, complex property rights and crowded indoor spaces stimulated behaviors, which were broke through property rights and space restrictions, and obeyed the default agreement among neighbors. Based on the configuration theory and justified graphs, in this step, we added property rights and expanded the joint graphical presentation method of "space-property-function". First, we superimposed land property rights (solid red line) and housing property rights (red dotted line) on the typological maps, using two-letter combinations to mark the room functions of different households (for example, CL represents the living room of household C) and short lines between directly connected rooms. Second, we distinguished the levels of publicness of different functional rooms according to the property boundary: outside the land property boundary is public space, which was represented by ● inside the housing property boundary is private space, which was represented by ○; inside the land property boundary and outside the housing property boundary is semi-public space, also called shared space, which was represented by ◍. Finally, the diagram was abstracted as justified graphs, and the red solid lines were added to indicate the common doors for several

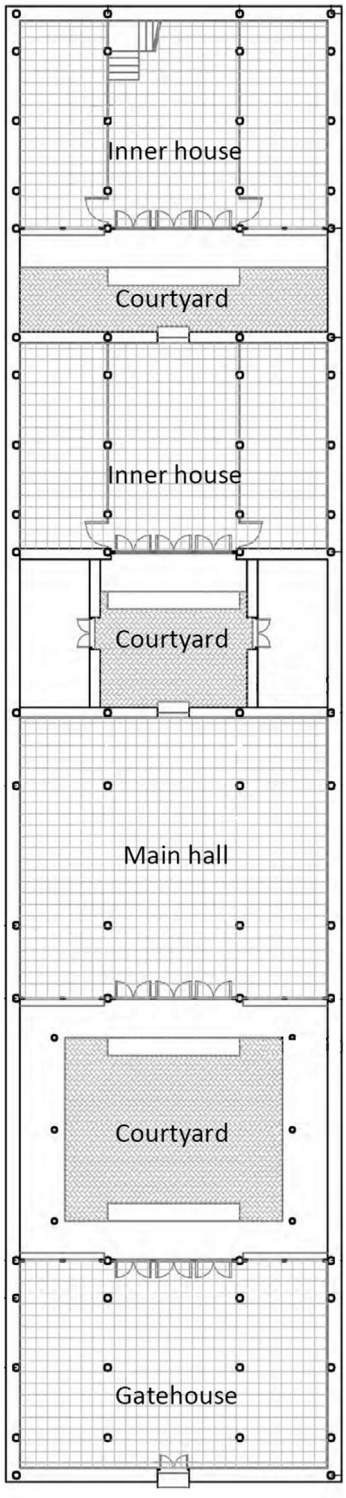


Fig. 3 Layout of traditional residential buildings in Nanjing (source: the authors and Nanjing Bureau of Planning and Natural Resources).

households, while red dashed lines as the personal doors. This kind of justified graph superimposed with property rights information can clearly show the spatial functions and attributes (public/shared/private) of different households, and offer quantitative data, such as the spatial depth value, connectivity value, which reflects residential behaviors in multi-family units.

Through the above three steps, the physical space layout, the property rights boundaries, and the space occupation within each property plot could be drawn superimposed, and abstracted into justified graphs. The advantage of this graphic method is that it connects not only urban form and building type in different spatial levels, but also the spatial attributes (physical space) and social attributes (property rights, human behavior) of architecture. Furthermore, it offers the possibility for the quantitative analysis of property rights and human behaviors.

3.2. The case study

To verify the effect of the proposed graphic methods, this paper takes the Xiaoxihu historic area, Nanjing as the case study. Xiaoxihu is listed as the second-class historic area identified by the government, where the overall layout has retained the traditional urban texture of the Ming and Qing dynasties (1368—1912) relatively completely, but different residential building types from these dynasties to modern times have been mixed together with the changing times. The current 4.69 ha of land is divided into 216 property rights plots, and a total of 810 households live there. The diverse residential building types and complex property rights relationships in Xiaoxihu can represent the status quo of most unrenewed Chinese urban historic areas.

Conzen (1969) has defined the morphological period according to the construction date and the town plan type, and divided Alnwick, a small historic town into different plan-units. Whitehand et al. (2007, 2011) applied the method to the historic areas of Chinese cities such as Beijing, Guangzhou, and Pingyao, and summarized Chinese plan-unit types.

Following the town-plan analysis method by Conzenian School, in this case study, through comparison of typological maps of the first and second steps, the Xiaoxihu area could be categorized into seven typical plan-units according to both construction date and type. Type A is a well-preserved traditional courtyard houses built in the Ming or Qing dynasties (Before, 1912); which are mostly single-story buildings with a wooden structure. Type B includes residences imported from Western countries during the Republic of China era (1912—1949) and can be divided into Subtype B1, a two-story single-family house with a brick-concrete structure, and Subtype B2, including townhouses with 16 households in four groups. Type C is a one- to two-floor courtyard house built or renovated in the 1950 s—1960s, Subtype C1 is similar to the traditional courtyard building layout, while Subtype C2 has changed significantly. In addition, there are Type D, apartments built by government agencies, military units, institutions, and some social groups after the 1960s to meet the needs of their employees with three to five floors, and Type E, various public buildings with diverse building layouts and forms built after the 1970s. The latter two types are completely different in form, height or function from the first five. Therefore, this study selected typical samples in the first five types: A, B1,

Fig. 4 Part of speculative typological map of Xiaoxihu area (source: the authors and the Xiaoxihu research and design team of Southeast University).

B2, C1, and C2, and focused on a comparative study in the two dimensions of diachrony and synchrony based on the "space-property-function" maps and justified graphs in 1930' and 2016 (Table 2).

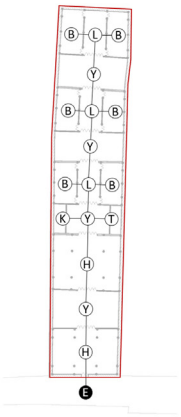
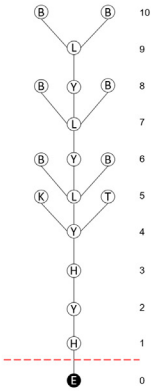
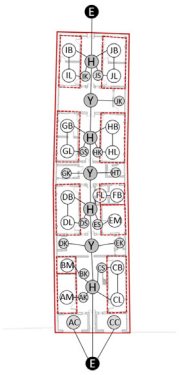
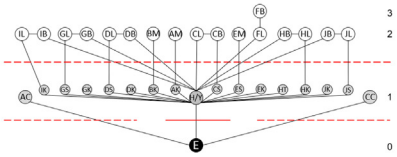
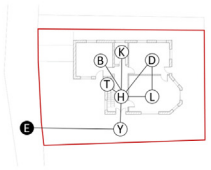
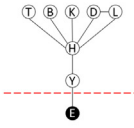
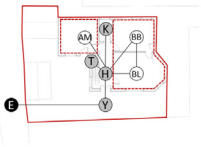
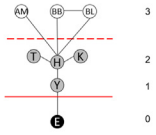
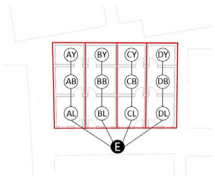
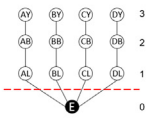
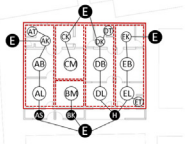
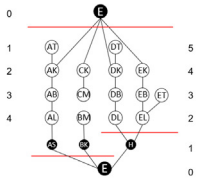
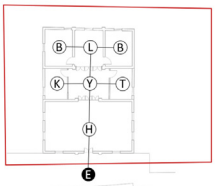
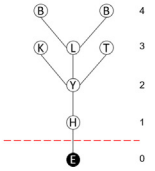
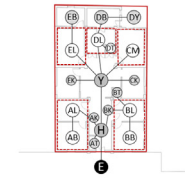
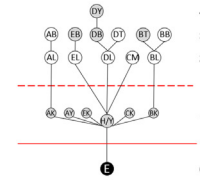
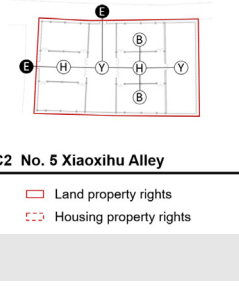
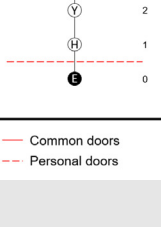
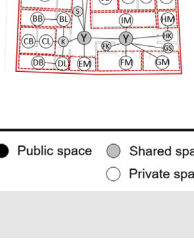
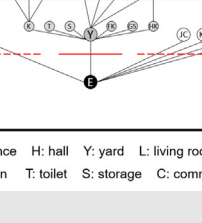
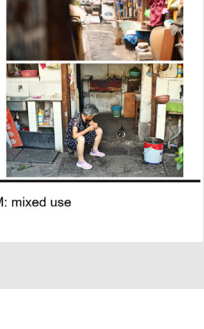
3.3. Diachronic and synchronic analysis

Specifically, following the pairwise comparisons on the "space-property-function" maps, we can observe the distribution of various functional rooms by comparing the physical space boundary and the space occupation boundary, while reveal the illegally added building parts by comparing the property rights boundary and physical space boundary. Moreover, comparing the property rights boundary and the space occupation boundary shows the encroachment of the shared space and public space by residents and the publicness of different functional spaces.

And, the abstract justified graphs provide quantitative data such as depth value, and connectivity value (Table 3), more intuitively reflects the spatial structure, publicity, and residential behaviors in the complex physical and property rights condition.

In summary, with the graphic method proposed in this study, we can analyze the evolution of physical space form, publicity, space structure, etc. of the same building type as the property rights changed through a diachronic

Table 2 Graphs of five samples in Xiaoxihu area (source: the authors).

Space-Property-Function in 1930'	Justified Graph in 1930'	Space-Property-Function in 2016	Justified Graph in 2016	Images in 2016
				
A No.41 Madao Street				
				
B1 No. 13 Duicao Alley				
				
B2 Nos. 15-18 in Zhuqueli Alley				
				
C1 No. 31 Duicao Alley				
				
C2 No. 5 Xiaoxihu Alley				

Land property rights
Housing property rights
Common doors
Personal doors
Public space
Shared space
Private space
E: entrance H: hall Y: yard L: living room B: bedroom M: mixed use
K: kitchen T: toilet S: storage C: commercial

Table 3 Maximum depth value and maximum connectivity value of the five samples (source: the authors).

	Maximum depth value		Maximum connectivity value	
	1930s	2016	1930s	2016
Sample A	10	3	4	21
Sample B1	3	3	5	6
Sample B2	3	3	2	3
Sample C1	4	4	4	9
Sample C2	4	3	4	11

comparison, and the similarities and differences of the property distribution and human behaviors between different building types through a synchronic comparison.

4. Result: the five building types in Xiaoxihu area

Five typical samples representing different types were selected to analyze the evolution of property rights, building layout, usage mode and spatial structure from the 1930s to 2016.

4.1. Type A: courtyard houses from the Ming and Qing Dynasties (before 1912)

No. 41 Madao Street is a courtyard house built during the Qing Dynasty. It can be inferred from the historic maps that the narrow plot contained five three-bay buildings and four courtyards. The entire plot belonged to one family, with the entrance hall, main hall, and inner house arranged in sequence from the outside to the inside, and the degree of privacy was gradually increased.

After the socialist reform of private housing in the 1950s, it was transformed into state-owned public housing. The plot is occupied by 10 families. Each occupies or shares the east or west bay of the three-bay building, and the middle bays have become semi-public shared halls connected to the same shared courtyards. The original independent main entrance was transformed into a common gate, and each household also has a personal door within the scope of their own housing property rights to ensure privacy and safety.

Since the small usage area of each household (19.2—26.8 square meters), the shared space is occupied under rules agreed by the residents themselves. The additional wing rooms on the east and west sides of the courtyards accommodate some of the residents' kitchens and toilets, and the rest have set up kitchens or pile up debris on both sides of the shared hall close to their respective houses, leaving only the necessary traffic aisles. Residents A and C also used the illegal additional buildings along the street for commercial lease.

The "space-property-function" superimposed diagrams was abstracted as justified graphs. The 1930s′ graph shows that the traditional residential space expanded in the depth direction, with a maximum depth value of 10. As to 2016, the spatial structure changed from vertical to horizontal. The halls and yards can be regarded as the central space node with the same spatial depth value and the maximum connectivity value, as there is no gate between. Most families' kitchens, toilets, and storage spaces are nested within it, without an obvious division of space and property rights. Meanwhile, the main function rooms, such as the living rooms, bedrooms, etc., have additional doors, mostly at a depth value of 2—3, and are closely related to the shared halls.

No. 41 Madao Street is a very typical case of a traditional courtyard house designed for one family being transformed into collective housing for several families. Other traditional courtyard buildings in the block basically follow a similar evolutionary model.

4.2. Type B1: single-family house from the Republic of China era (1912—1949)

No. 13 Duicao Alley is a two-story brick-concrete structure private villa with a front garden built in the 1930s. The first floor was used as a living room and dining room, while the second-floor housed bedrooms. Both the architectural layout and style were imported from Europe.

After the socialist reform of private housing, this villa also became state-owned public housing. Although the appearance of the building is well preserved, the internal layout and use are completely different today. With the entrance hallway and the kitchen facing the hallway as the boundary, each floor is occupied by two families on the left and right sides. The original courtyard outside the villa, as well as the internal kitchen, toilets, stairs, and corridors, have become semi-public spaces shared by all households. The main rooms of each household are at the depth value of 2—3, revolving around the hall, which transforms from single family living space to multiple families shared space.

4.3. Type B2: townhouses from the Republic of China era (1912—1949)

Nos. 15—18 in Zhuqueli Alley is one of the four single-story townhouses built during the Republic of China period. It was divided into four independent apartments, with the living room, bedroom, and backyard arranged from south to north. This group of buildings is completely different from the courtyard houses of the Ming and Qing Dynasties, rendering a new type of courtyard building "collage" in the Xiaoxihu area.

After 1949, this building was also converted into public housing. The original four houses were occupied by five households sharing one plot. Unlike other cases, there was no shared space in type B2, so the encroachment mainly occurred in the northern private courtyard and the southern public alley. On the north side, the backyard was transformed into indoor space, and kitchen, toilet facilities and a secondary entrance were added; on the south side, the public space of about 1.3 m in the alleys is occupied by all the households. Households A and B prolonged the original sloped roofs and built single-story buildings for storage and kitchens, respectively. Households C and D

Fig. 5 "Space-property-function" maps in the typological map (source: the authors and the Xiaoxihu research and design team of Southeast University).

built light steel roofs and partial walls occupying the alley space to establish entrance space.

In this way, when calculated from the single entrance in the relationship diagram, the maximum depth value of the space reaches 5; however, the actual maximum depth value of the rooms does not exceed 3, due to the opening up of the two sides. This is different from the one-way linear space structure in the 1930s. On-site investigations also revealed that residents' lives are closely linked to the public alleys, and many living functions are spread out.

4.4. Type C1: courtyard houses built in the 1950s—1960s (traditional layout)

No. 31 Duicao Alley was a traditional courtyard house inside a large plot on the 1936 cadastral map. After the socialist reform of private housing, it also became public housing, with independent land property rights, and shared by 5 households. According to the house property rights, the middle bay of the entrance building, inner courtyard, wing room, and backyard should all be shared spaces. However, due to the small available area, they were divided by the residents according to their own agreement. Two households, A and B, built kitchens and toilets in the public halls, while another two households, C and E, use the wing rooms on both sides of the inner courtyard as kitchens. Households D and E even added bedrooms in the backyard to expand their usage area.

The abstracted justified graph for this building is very similar to that of sample A: The space structure transforms from vertical to horizontal. Now the depth value of the main space is around 2—3, and daily activities are

Table 4 Summary of diachronic comparison (source: the authors).

	1930s	2016
Property rights	117 plots	216 plots, 810 households
Building layout	Buildings and courtyards	Courtyards occupied by illegal construction
Access mode	One house gate	One common gate and several personal doors
Publicity	Public-private	Public-shared-private
Spatial structure	Vertical	Horizontal

Fig. 6 Distribution of seven building types in Xiaoxihu (source: the authors).

conducted in and around the shared space, including the inner courtyard and public hall.

4.5. Type C2: courtyard houses built in the 1950s—1960s (modified layout)

No. 5 Xiaoxihu Alley is a courtyard house that was renovated and modified in the 1950s. On the cadastral maps from 1937 to 2016, the boundary of the plot is basically the same; however, the architectural layout, the number of residents and their behaviors have been completely changed.

At present, there are a total of 12 households living in the plot. Households K and H are private houses, while the others are public houses. The four households A, K, J, and I are entered directly from Xiaoxihu Road, and three of them rent out all or part of their houses for commercial. The other eight households are entered through the shared L-shaped courtyard, where many simple stoves, toilets, and washing and storage facilities have been built. The depth value of the main use spaces, such as the living rooms and bedrooms, is also between 2 and 3.

Returning these "space-property-function" maps back to the typological map of the entire block can more clearly show the spatial composition of different building types from streets to plots to each household, thereby establishing the relationship between typology and morphology (Fig. 5).

5. Discussion: how property rights affect the change of space and behavior

The above five cases represent the courtyard building types formed in the Xiaoxihu historic area during different periods. The graphical method proposed in this study can visually present the superposition of space, property rights, and behavior, and provide quantitative data such as depth value, and connectivity value, helps deepen the related discussion at both the diachronic and synchronic levels.

5.1. Diachronic comparison

Through a diachronic comparison of all the samples, four main changes from the 1930s to 2016 can be summarized (Table 4). The first and most obvious change is the subdivision of property rights, which is also the root cause of other changes. In sample A, B1, and C2, the land property remains and the housing property are subdivided. In sample B2, although the land property is merged and transferred from private to public, the housing property are subdivided. In sample C1, both land and housing property are subdivided. Overall, the total area of Xiaoxihu has not changed much during the eighty years, but the number of plots has increased from 117 to 216, and the number of households to 810, which means on average there are 4 households living

Table 5 Publicity level of the spaces occupied by main functions (source: the authors).

	Living room	Bedroom	Kitchen	Toilet	Commercial
Sample A	Private	Private	Shared	Shared	Shared
Sample B1	Private	Private	Shared	Shared	
Sample B2	Private	Private	Private or public	Private	
Sample C1	Private	Private or shared	Shared	Shared	
Sample C2	Private	Private	Shared	Shared	Private

together in one plot. The average living area of each household has decreased from about 500 square meters to 27 square meters.

The second change is the building layout, mainly manifested in the encroachment on shared and public spaces by illegal constructions. Due to the serious shortage of use area within the housing property rights, residents have occupied the shared yards and halls one after the other, even public street space in sample B2. In addition to the illegal construction in the courtyard (mainly used as kitchens, toilets, and storage), simple stoves and washbasins have also been installed in the corners of the halls and courtyards to provide cooking and washing facilities. These changes were reflected in all cases. As a result, the texture of the courtyard building is becoming unclear, and the quality of the living environment deteriorates.

The third is the change of access mode and publicity. In 1930s, one household occupied one piece of land, with one house gate facing the street. With the subdivision of property rights, most cases become two kind of access control (sample A, B1, C1, C2): one common gate in the land property boundary, which is usually open to the public street, and several personal doors in the housing property boundary to keep privacy and safety. With the change of access methods, shared spaces are added between the original public and private spaces.

The fourth change is the spatial structure, which can be seen from the abstract justified graphs. The traditional Chinese courtyard house, sample A, C1, C2, has changed from a vertical space structure to a horizontal juxtaposed structure with shared space (directly connected courtyards and halls) as the core. Meanwhile, as an imported product during the Republic of China, the spatial structure of sample B1, B2 has not changed much, but the private hall in type B1 has become shared.

The diachronic comparison shows that the subdivision of property rights and the consequent co-existence of multiple families, as well as the lack of useable space, are the most important factors that have led to changes in spatial forms and residential behaviors.

5.2. Synchronic comparison

A synchronic comparison showed that the evolution of building types was not continuous. In the 1929 aerial photograph, the urban fabric of Nanjing's old city was almost entirely composed of one- to two-story courtyard buildings. Under the overall control of plot boundaries and continuous gables, similar building sizes and spatial organization patterns were adaptable when laid out in plots of different shapes, producing a harmonious and rich overall urban texture. The single-family villa and townhouse building types from the Republic of China era were imported and did not inherit the traditional architectural organization. After 1949, the new courtyard houses partly inherited the traditional form and partly changed significantly. Meanwhile, multi-story residential buildings and public buildings, which were often large-scale buildings constructed by merging many small plots, completely destroyed the plots' organization mode and traditional texture. All the types appearing in different periods are randomly collaged, meaning the whole block presents a collection of multiple texture types (Fig. 6).

Although the types of residential buildings are diverse, following the subdivision of property rights, the residential behavior within different building types tends to be consistent (Table 5).

First, the consistency is reflected in the occupation of the shared or even public spaces by various functions. In terms of publicity, there are two classification methods according to property rights boundary or access control boundary. Except for B2, most cases can be divided into three levels: the public, the shared, and the private, according to land property boundary and housing property boundary, which are represented by ●, ●, and ○. Meanwhile, in the justified graphs, the space level in actual use can be presented by two doors (red solid lines for common doors and red dashed lines for personal doors). In most cases, the two classifications are the same. Residents usually use the rooms within the scope of the housing property as living rooms and bedrooms, and a personal door was constructed to create private space, while other functions, like the kitchens, toilets, and storage mostly occupied the shared spaces without doors.

However, in other cases, the two classifications are contradictory. For example, the two stores along the street in type A are in the property-shared area, but they are privately occupied and used. Two households of sample C1 also occupy the property-shared backyard as private bedroom, and two residents of type B2 occupy the public space along the street to set up kitchens and storage room. These contradictions show the disrespect of the property rights by some residents' spontaneous behavior.

Then, the justified graphs further abstract the residential behaviors by quantifying data. In sample A, B1, C1, C2, the directly connected courtyards and halls as shared spaces have the highest connectivity value up to 21. In sample B2, the streets as public spaces have the highest

connectivity value as there are no shared space. And in all cases, the depth value of the main space used is generally 2 or 3. In other words, residents' lives revolve around the public and shared spaces, courtyards and streets become the core of life.

6. Conclusion

The complex property rights relationship in residential historic areas is a unique issue in Chinese urban development and institutional changes process, and widely exists in most cities. With the transformation of urban land system from private to public ownership, the socialist reform of private housing, and the rapid growth of the urban population after 1949, many urban private land and houses have been subdivided. Most are leased to new urban residents and have been gradually transformed into state-owned property, with only a small proportion remaining as private. At the same time, land and house property rights began to separate: A singular plot was occupied by multiple households, with each holding independent housing property rights. The co-existence of multiple property rights is one of the main reasons for the decline of Chinese urban historic areas and an important difficulty facing conservation and regeneration practice. Although scholars have pointed out this phenomenon and its influence (Zhang et al., 2006; Duan and Zhang, 2017), there are few practice-oriented researches.

Kropf (2018) proposed that as the connection between the person and the land or house, property rights have an intangible and abstract nature. The only tangible expression of property is human behavior. This discourse establishes the relationship between property rights, space, and behavior; however, most of the research cases and results have been discussed at the plot level. In the context of the separation and subdivision of land property rights and housing property rights in the historic areas of Chinese cities, a more microscopic and in-depth graphical method is needed to visualize the relationships between property rights, space, and behavior.

Based on typological maps and justified graphs, this study established a three-step graphical method. The final graph could be used to observe the evolution of the courtyard building from a diachronic perspective, as well as to compare the residential behavior in different courtyards from a synchronic perspective through indicators, such as the buildings' levels of publicness, the depth value, and the connectivity value. Through these steps, the new graphs clearly explained the influence of changes in property rights on the evolution of physical space forms and residential behaviors.

The method proposed in this study was then verified by the case study of Xiaoxihu, a typical example of Chinese historic areas with complex property rights, and two important conclusions were formed.

First, the co-existence of multiple families and the lack of useable space caused by the subdivision of property rights, were the most important factors that led to the changes in spatial forms and residential behaviors. Following the subdivision of property rights, the residential behavior within different building types tended to be consistent.

Second, the study observed the traditional Chinese courtyard buildings' adaptability. From single residences to multi-family residences, from front stores-rear residences to mixed functions, the courtyard architecture showed extensive adaptability. Although the residents' living spaces were small and messy, the courtyard buildings have solved the housing problem caused by the rapidly increasing urban population under the background of a specific era. Residents employed various methods to increase the useable area on the plane and section to meet their basic life needs, which also provided possibilities for future regeneration design.

This study directly and intuitively presents the relationship between the concrete space, abstract property rights and human behaviors, and proposes a graphical presentation and analysis method that is suitable for the analysis of Chinese urban historic areas with complex property rights. There are two possible evolutions and improvements of this research. Firstly, the method can be further tested and verified in more case studies to understand the evolution of the types and forms of historic areas, as well as the internal motivations for this evolution. Besides, other Asian and European countries, such as Japan, Italy, etc., also have a large number of low-rise and high-density residential blocks. Although the property rights relationship is much clearer, there are also cases where the physical boundaries and property rights boundaries are inconsistent (Kropf, 2018). More case studies in different cultural contexts will help to improve the graphical and analytical method proposed in this research. Secondly, the ultimate purpose of this research is to promote policy improvement, and the regeneration design and implementation by presenting the complex property rights and the resulting spatial and behavioral evolution. Subsequent research will also pay more attention to the integration with design and social practice. The above two points will be the future development direction of this research.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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