Riverside building boundary spatial characteristics and utilization patterns in China post-urbanization: a case study on Shantang River, Suzhou

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ABSTRACT
Suzhou, a Chinese “water town”, has undergone an essential transformation in the spatial nature of its riverside area post-urbanization. This research focuses on the spatial characteristics and utilization patterns of the building boundary along the Shantang River in Suzhou through field investigation and correspondence analysis. The constituent elements are determined, and then spatial characteristics are analyzed in terms of space type, river encroachment, and urban connectivity. The relationships between these characteristics and four utilization patterns are discussed. The building boundaries along the river have undergone a fundamental change within the modern era. There are significant relationships between utilization patterns and space type, river encroachment, and urban connectivity. The results presented here can provide workable guidance for effective further development of riverside spaces in Suzhou and beyond.

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1. Introduction
1.1. Research background and purpose
Suzhou is a typical Chinese riverside town. In the work Travels of Marco Polo\textsuperscript{1}, Suzhou was referred to as the “Oriental Venice”. The river system and surrounding urban structures have been continuously under development since the city was first established in 514 BC. After its initial establishment, the river system underwent further construction in the Tang (618–907), Song (960–1279), and Yuan (1271–1368) Dynasties, reaching a peak in the late Ming Dynasty (1368–1644) (Shi, Fan, and Wu 2017). According to the Suzhou Water Conservancy Department’s calculation of the Suzhou Watercourse Map, in the Ming Dynasty, the total length of the rivers in the city was about 86 km; there were 41 river branches running north-south and 80 running east-west at that time. After the Qing Dynasty, the Suzhou river system entered a phase of decline. By 1985, the city’s river branches numbered only 78 with a length of about 46.82 km (Chen 2012). There has been a tremendous change in the way of life and industry in Suzhou alongside economic development and urbanization in recent decades. Waterway transportation is growing increasingly limited as roadways dominate the city’s modes of transportation. This particular change has had a dramatic impact on the spatial structure of Suzhou on the whole.

The river was originally regarded as the most important urban facility in Suzhou, but today, it has a relatively very low rate of public utilization. The river space has also undergone an essential change from urban to private, and even to abandonment – this is especially true in regards to the spatial form of the building boundaries along the river. In this study, a section of the Shantang River in Suzhou was used as a research object. The spatial characteristics of the riverside building boundary were investigated to explore the impact of urbanization on the Suzhou river space and ways in which its utilization has transformed in the modern era. The results presented here can provide a sound theoretical basis for the effective usage and/or redevelopment of Suzhou’s riverside spaces.

1.2. Previous research
There have been valuable contributions to the literature on the space and utilization of Suzhou’s riverways. Yan et al. (2002), for example, extracted waterway patterns from maps of Suzhou in various eras to examine their spatial characteristics from the Song Dynasty to 1997. Liu (2000) used historical material to define the development of Suzhou waterways from the city’s establishment to the Qing Dynasty. He (2014) described the relationship between Suzhou urban development and waterway planning. Yu (1986) proposed a series of roles which the riverways perform in Suzhou. Lu, Suzuki, and Miura (1998) analyzed the waterside space of Suzhou in the Qing Dynasty from Suzhou’s Golden Age; they defined structural relationships between...
waterway spaces and waterside roads, squares, and buildings accordingly. Zhu and Tsuchimoto (2007) also based their research on Suzhou’s Golden Age, defining the composition of the waterside commercial space in Suzhou as well as banquet tables and other public activities taking place at the waterside. Chen et al. (2014) surveyed riverside residents by questionnaire to find that some residents of the Shantang area habitually discharge domestic waste into the river and that most residents of the Xiaohong area directly discharge their domestic sewage into the river.

The Suzhou riverways are indeed an important part of the city’s long history. Public activities were once entirely centered around the river. Today, fundamental changes have occurred introducing a series of problems such as low utilization rates and pollution to the river and riverside spaces throughout Suzhou. Despite an abundance of research on the historical development, water pollution, and public space in historical periods of the city, there has been little research on the building boundary space along the river in modernity.

There have also been previous studies on the external space through spatial elements. Zhang et al. (2020) studied the space of Shantang Street and divided its spatial elements into “basic” and “activity” categories, summarizing the notable aspects and correlations among each of them. Saito et al. (2009) studied courtyard space in Milan in terms of indoor elements, wall elements, moving line equipment elements, landscape elements, attached elements, and paint lines. Saito, Tatsumi, and Almazán (2019) studied public-private boundaries as per ground elements, boundary elements, and activity elements. Fang et al. (2019) divided space into structural and commercial elements to explore the characteristics of Shanghai Lilong. The method used in the present study to explore spatial characteristics based on constituent elements was inspired by their work.

2. Research object and methods

2.1. Research object

The Shantang River is located in the northwest of the ancient city of Suzhou, with a total length of about 3,600 m (Figure 1). Draft History of Qing, Changzhou County Chronicles, and other materials indicate that the famous poet Bai Juyi presided over the excavation of the river channel when he was the leader of Suzhou in 825. The river not only met shipping demands but also became a popular location for socializing, making Shantang a highly prosperous part of Suzhou at that time. The prosperity of the Shantang River was recorded in classic works of literature such as The Dream of Red Mansions and Qingjialu. The famous painting Suzhou’s Golden Age provides a detailed description of the humanistic style of the Shantang River. Indeed, the Shantang River has historically been a very important urban facility and public space in Suzhou.

![Figure 1](image-url). The location of the object.
The object of this study is a section of Shantang River about 430 meters west of Guangji Road. The spatial structure is characterized by land and water in parallel, which is a typical feature of Suzhou’s waterways. Like most of the ancient waterways, it has also declined from its former prosperity. Unlike other parts of Shantang that have been developed into scenic spots, individuals have spontaneously transformed segments of the study area for residential and commercial purposes. In this process, a large number of unconventional spatial elements have emerged and dramatically altered the form of the riverside space. This study centers on the building boundary space along the river and its utilization characteristics. Many original one-family buildings in this area have been divided into multiple rooms now used by multiple households. However, as per the focus here on the riverside boundaries, the unit division is based on riverside family structures with a total of 88 samples (Figure 2).

### 2.2. Research methods

A total of 88 samples from a field survey were taken as the basic data for analysis. The types and characteristics of the constituent elements of the riverside building boundaries were first defined and divided into ground elements, wall elements, component part elements, landscape elements, and life overflow elements. Five types of boundary spaces along the river were determined according to combinations of these constituent elements: surface-emphasized type, block-emphasized type, platform-emphasized type, path-emphasized type, and mixed space type. The projected area of the constituent elements on the river was used to evaluate the level of boundary space encroachment on the river. The distance from the main entrance along the street was used to evaluate the urban connectivity of the boundary space. Differences in river encroachment and urban connectivity were then attributed to different boundary types. Methods such as correspondence analysis were used to explore the relationship between the utilization pattern and boundary spatial characteristics (e.g., space type, river encroachment, urban connectivity) (Figure 3).

Correspondence analysis is a multivariate statistical technique first proposed by Herman Otto Hartley (Hirschfeld). It is conceptually similar to principal component analysis, but applies to categorical rather than continuous data. After inputting the crosstab data of the two categorical variables (Figure 16),
correspondence analysis can provide a means of displaying or summarizing a set of data in two-dimensional (2D) graphical form (Dodge and Commenges 2006; Hirschfeld 1935). The 2D graph is the "correspondence map".

SPSS annotation 11 was used in this study to obtain a correspondence map that reveals the relationship between the two groups of categorical variables under analysis. All categorical variables are distributed in the form of points on the correspondence map. The two types of variables are considered to have a stronger relationship when the points of different categories on the corresponding map are relatively close (Figure 17). The degree of similarity between variables of the same category is determined as per a vector from the center (0,0) to any two points (same category): the two types are similar if the angle is acute, as a smaller angle indicates closer similarity (Figure 18).

3. Boundary spatial characteristics

3.1. Constituent elements and space type

Although buildings along the river had a unified style in the city’s infancy, a wealth of constituent element has appeared since over a series of spontaneous transformations; the building boundary spaces are now quite diverse. A field collection was performed to determine five types of constituent elements in the building boundary space along the river: ground elements, wall elements, component part elements, landscape elements, and life overflow elements. Ground elements can be further sub-divided into none (N), entity platform (EP), entity steps (ES), overhanging platform (OP), overhanging steps (OS), floating below (FB), and pillar support (PS). Wall elements include the door (Do), window (Wi), and gallery (G). Component elements are air conditioning (AC), canopy (Ca), duct (Du), security window (SW), railing (R), and fence (F). Landscape elements include the potted plant (PP), lantern (La), and tree (T). Life overflow elements include the waterpot (Wa), mop (M), litterbin (Li), clothesline (Cl), and unused goods (UG) (Figure 4).

Based on the constituent elements and combinations thereof, the riverside building boundaries were split into five types over a total of five categories and 10 sub-categories. The main feature of the surface-emphasized type is that the boundary along the river is highly unified above and below the waterline. The wall is the primary spatial characteristic. The “solid” surface type refers to a completely closed wall surface, while the “surface-opening” type indicates doors or windows opening toward the water. The “surface-attachment” type is defined by components such as air conditioners or rain canopies with a unified wall above and below. The main feature of the block-emphasized type is a protrusion above the water with a suspended lower part, including "gallery protruding" and "indoor space protruding" types. The main feature of the platform-emphasized type is a platform extending toward the river; this includes "entity" and "overhanging" platform types, the former of which extends into the water and the latter of which hangs over the river but does not contact the water surface. The main feature of the path-emphasized type is steps connecting the building.

| Ground elements       | None (N) | Entity platform (EP) | Entity steps (ES) | Overhanging platform (OP) | Overhanging steps (OS) | Floating below (FB) | Pillar support (PS) |
|-----------------------|----------|----------------------|--------------------|---------------------------|------------------------|---------------------|---------------------|
|                       | ![Image](ground_elements.png) | ![Image](ground_elements.png) | ![Image](ground_elements.png) | ![Image](ground_elements.png) | ![Image](ground_elements.png) | ![Image](ground_elements.png) | ![Image](ground_elements.png) |
| Wall elements         | Door (Do) | Window (Wi) | Gallery (G) | Air conditioning (AC) | Canopy (Ca) | Duct (Du) | Security window (SW) | Railing (R) | Fence (F) |
|                       | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) | ![Image](wall_elements.png) |
| Component part elements | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) | ![Image](component_part_elements.png) |
| Landscape elements    | Potted plant (PP) | Lantern (La) | Tree (T) | Waterpot (Wa) | Mop (M) | Litterbin (Li) | Clotheslines (Cl) | Unused goods (UG) |
|                       | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) | ![Image](landscape_elements.png) |
| Life overflow elements | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) | ![Image](life_overflow_elements.png) |

Figure 4. Constituent elements.
and the river within the spatial boundary; this is similarly divided into “entity” and “overhangs” steps sub-types. The mixed space type encompasses some variety of the above spatial characteristics (Figure 5).

More than half of the total area observed in this case study is occupied by the surface-emphasized type; this is followed by the block-emphasized type, platform-emphasized type, path-emphasized type, and mixed space type accounting for 53.4% (47), 17.0% (15), 11.4% (10), 9.1% (8), and 9.1% (8), respectively. The surface-opening type and surface-attaching sub-types are the most common under the surface-emphasized type category (22 and 20 samples, respectively) and the solid surface type is least common (5). In the block-emphasized type, indoor space protruding sub-type (11) is more common than the gallery protruding sub-type (4). The

Figure 5. Types of space by constituent elements.
number of entity platform type samples is 6 under the platform-emphasized type category and the overhangs platform type is 4. Within the path-emphasized type category, entity and overhangs types account for 3 and 5 of the samples, respectively.

A total of 58 space type cases show continuity in order from west to east. That is, the space types of adjacent samples are the same in this case accounting for 65.9% of the study area. As said area was largely formed by spontaneous transformation, the agglomeration of space types suggests, to a certain extent, that an individual’s spontaneous transformation of his or her space is affected by neighboring individuals. There appears to be a mutual reference between transformations (Figures 6 and 7).

| Number | Space Sub-Type | Space Type |
|--------|----------------|------------|
| #1     | surface-opening | surface-emphasized |
| #2     | surface-opening | surface-emphasized |
| #3     | gallery protruding | block-emphasized |
| #4     | indoor space protruding | block-emphasized |
| #5     | overhang steps | path-emphasized |
| #6     | surface-attachment | surface-emphasized |
| #7     | indoor space protruding | block-emphasized |
| #8     | surface-opening | surface-emphasized |
| #9     | surface-attachment | surface-emphasized |
| #10    | gallery protruding | block-emphasized |
| #11    | gallery protruding | block-emphasized |
| #12    | indoor space protruding | block-emphasized |
| #13    | overhangs platform | platform-emphasized |
| #14    | mixed space type | mixed space |
| #15    | surface-opening | surface-emphasized |
| #16    | surface-opening | surface-emphasized |
| #17    | surface-attachment | surface-emphasized |
| #18    | surface-attachment | surface-emphasized |
| #19    | overhangs platform | platform-emphasized |
| #20    | surface-opening | surface-emphasized |
| #21    | solid surface | solid surface |
| #22    | overhang steps | path-emphasized |
| #23    | surface-opening | surface-emphasized |
| #24    | surface-attachment | surface-emphasized |
| #25    | surface-opening | surface-emphasized |
| #26    | surface-attachment | surface-emphasized |
| #27    | surface-attachment | surface-emphasized |
| #28    | solid surface | solid surface |
| #29    | mixed space type | mixed space |
| #30    | mixed space type | mixed space |
| #31    | surface-opening | surface-emphasized |
| #32    | indoor space protruding | block-emphasized |
| #33    | indoor space protruding | block-emphasized |
| #34    | entity platform | platform-emphasized |
| #35    | mixed space type | mixed space |
| #36    | gallery protruding | block-emphasized |
| #37    | solid surface | solid surface |
| #38    | surface-attachment | surface-emphasized |
| #39    | entity platform | platform-emphasized |
| #40    | solid surface | solid surface |
| #41    | surface-attachment | surface-emphasized |
| #42    | overhang steps | path-emphasized |
| #43    | surface-opening | surface-emphasized |
| #44    | entity steps | path-emphasized |
| #45    | entity platform | platform-emphasized |
| #46    | surface-opening | surface-emphasized |
| #47    | solid surface | solid surface |
| #48    | mixed space type | mixed space |
| #49    | surface-attachment | surface-emphasized |
| #50    | surface-attachment | surface-emphasized |
| #51    | surface-attachment | surface-emphasized |
| #52    | surface-attachment | surface-emphasized |
| #53    | mixed space type | mixed space |
| #54    | entity platform | platform-emphasized |
| #55    | entity platform | platform-emphasized |
| #56    | mixed space type | mixed space |
| #57    | surface-attachment | surface-emphasized |
| #58    | overhang steps | path-emphasized |
| #59    | overhangs platform | platform-emphasized |
| #60    | surface-attachment | surface-emphasized |
| #61    | surface-attachment | surface-emphasized |
| #62    | overhangs platform | platform-emphasized |
| #63    | overhang steps | path-emphasized |
| #64    | overhangs platform | platform-emphasized |
| #65    | surface-opening | surface-emphasized |
| #66    | path-entire steps | path-emphasized |
| #67    | indoor space protruding | block-emphasized |
| #68    | indoor space protruding | block-emphasized |
| #69    | indoor space protruding | block-emphasized |
| #70    | indoor space protruding | block-emphasized |
| #71    | entity steps | path-emphasized |
| #72    | surface-attachment | surface-emphasized |
| #73    | surface-attachment | surface-emphasized |
| #74    | surface-attachment | surface-emphasized |
| #75    | surface-attachment | surface-emphasized |
| #76    | surface-attachment | surface-emphasized |
| #77    | surface-attachment | surface-emphasized |
| #78    | mixed space type | mixed space |
| #79    | surface-opening | surface-emphasized |
| #80    | entity platform | platform-emphasized |
| #81    | indoor space protruding | block-emphasized |
| #82    | indoor space protruding | block-emphasized |
| #83    | surface-opening | surface-emphasized |
| #84    | surface-attachment | surface-emphasized |
| #85    | surface-opening | surface-emphasized |
| #86    | surface-attachment | surface-emphasized |
| #87    | surface-attachment | surface-emphasized |
| #88    | surface-attachment | surface-emphasized |

Figure 6. Space types in the order of waterside buildings.

3.2. River encroachment

The building boundaries along the river are utilized less by the public today than they have been historically. This increase in privatization has transformed the space in many ways including the encroachment of...
river space by constituent elements (e.g., private canopies, platforms, and galleries extending toward the water). The encroachment onto the river represents, to some extent, the degree of privatization of the river space.

An evaluation index for the river encroachment rate was developed in this study to define this spatial phenomenon. The projected area of the constituent elements encroaching on the river space is calculated first, then the encroachment rate of the river is equal to the sum of the projected areas of all the constituent elements encroaching on the river space divided by the bay width (Figure 8).

The average river encroachment rate in the surveyed area is 0.50; 63 samples show a certain level of encroachment on the river, accounting for 71.6% of the total. In effect, encroachment is very common. Among the five space types, the block-emphasized type shows the largest amount of encroachment at a rate of 1.38, followed by the mixed space type (0.75), platform-emphasized type (0.68), path-emphasized type (0.54), and surface-emphasized type with the lowest encroachment rate at 0.13. The river encroachment of each sub-type are consistent with the results of their respective categories: the gallery protruding type is most common (1.68) followed by indoor space protruding type (1.27) (both of the block-emphasized type) followed by the mixed space type (0.75), overhangs platform type (0.74), entity steps type (0.70), entity platform type (0.64), overhangs steps type (0.44), surface-attachment type (0.17), surface-opening type (0.11), and the solid surface type which does not encroach on the river (Figures 9 and 10).

3.3. Urban connectivity

The Shantang River has historically been an important urban public space in Suzhou. In addition to its transportation functions, it provided space for public activities. Suzhou’s Golden Age shows that the public space along the river was once very open and accessible (Figure 11). The buildings along the river generally had two interfaces connecting to the urban space: one facing the street and one facing the river. Pedestrians entered the building through the interface facing the street while boaters could connect with the interior of the building through the interface facing the river. As water transportation has declined, however, the public access to the river has weakened over time; today, buildings rarely have entrances on the riverside. The entrance on the street side is typically the only public interface; there is relatively less urban connectivity along the river boundary and the riverside portions of the city are less open to the public in the modern era than they were historically. These changes have fundamentally transformed the spatial form of building boundaries along the river (Figure 12).

This section discusses the connection between riverside building boundaries and urban space, where urban connectivity is used as an indicator of this spatial characteristic. The distance from the boundary along the river to a given building’s entrance is used to evaluate its connectivity: it is considered to have weaker connectivity and less accessibility when this distance is relatively large. The average distance from the building’s entrance to the boundary space in the observation area is 12.87 m; building #48 is the largest (23.8 m) and #84 is the smallest (5.5 m). There is a significant difference between the maximum distance and the minimum distance. Among the five space types, the path-emphasized type, platform-emphasized type, and mixed space type have generally large distances (14.91 m, 14.07 m, and 14.01 m, respectively) followed by the surface-emphasized type (12.43 m) and block-emphasized type (11.77 m). Among the 10 sub-categories, entity steps and overhangs steps types have the largest distances at 15.23 m and 14.72 m, followed by the solid surface type (14.38 m), entity platform type (14.12 m), mixed space type (14.01 m), overhangs platform type (14.00 m), surface-attachment type (12.29 m), surface-opening type (12.11 m), indoor space protruding type (12.09 m) and gallery protruding type (10.90 m) (Figures 13 and 14).

4. Relationship between spatial characteristics and utilization

4.1. Utilization patterns

The function of the waterside buildings was investigated in this study. The target area is more diverse than the unified commercial scenic spots in Shantang.
and mainly includes residences (33 cases), clothing stores (15 cases), snack bars (10 cases), restaurants (9 cases), community service facilities (5 cases), vegetable shops (3 cases), fruit shops (2 cases), convenience stores (2 cases), barbershops (1 case), educational facilities (1 case), and unknown facilities (7 cases). Residences account for the largest proportion of the total space among them, indicating that there are still many buildings used as dwellings; the rest support mainly small businesses, catering organizations, and other services (Figure 15).

The space utilization of the waterside building boundaries was mainly determined based on building functions. Several utilization patterns were observed,
Figure 10. River encroachment rate of each space type (2).

Figure 11. Waterside space in Suzhou’s Golden Age.

Figure 12. The change of publicity of building boundaries along the river.
including leisure utilization, rear service utilization, unclear utilization, and mixed utilization patterns. The leisure utilization pattern refers to the utilization of space as a place for activities such as drinking tea, sunbathing, dining, and cooling off. This pattern centers on the landscape attributes of the river (e.g., pleasant scenery, quiet environment). The rear service utilization pattern refers to activities such as cooking, washing, toileting, and laundry. This pattern centers on convenience, as the Shantang River water can be directly gathered from the source at the boundary for domestic use. The direct discharge of domestic sewage into the Shantang River is also still fairly common. The unclear utilization pattern refers to the situation where there is no obvious tendency to use the boundary as the interior of the building is preferred to the portion of the building facing the water. The mixed utilization pattern, which refers to combinations of the above utilization, is least common in the study area. The leisure, rear service, unclear, and mixed utilization patterns account for 15.91% (14), 50.00% (44), 25.00% (22), and 9.10% (8), respectively (Figure 16).

4.2. Relationship between space type and utilization pattern

The cross tabulation data (Figure 16) was input into the SPSS correspondence analysis tool to analyze the correlation between space types and utilization patterns. A map was drawn based on the results in which three obvious clusters emerged. The points of entity platform, overhangs platform, and mixed utilization are relatively close; thus, the entity platform type and overhangs platform type have a strong relationship with the mixed utilization pattern, this cluster can be described as a mixed utilization of platform space. The overhangs platform type is closer to the mixed utilization pattern than the entity platform type.

Similarly, we found that the entity steps, indoor space protruding, and gallery protruding types are strongly related to the leisure utilization pattern, and can be described as a block for leisure on the river. In addition to the block emphasized type, the entity steps type is also often used in leisure activities. The gallery protruding type is closer to the leisure utilization pattern, which means that the gallery protruding type is more related to the leisure utilization pattern than the indoor space protruding type and entity steps type. Surface-attachment, solid surface, surface-opening, overhangs steps, and mixed space types are strongly related to rear service utilization and unclear utilization patterns, which can be described as a mixed space with a surface emphasized type used for rear service or being abandoned. And the surface emphasized type shows more features of unclear utilization (Figure 17).

The utilization pattern similarity in the above relationships was explored as per the angles in the corresponding map. The angle between the unclear utilization pattern and the rear service utilization pattern is very small, indicating that the two are very similar. There is a larger angle with the other two

| Space type          | Number | Distance (m) | Average (m) |
|---------------------|--------|--------------|-------------|
| 1. Solid surface    | 1-15   | 9.3          | 14.30       |
| 2. Surface-opening  | 1-15   | 10.1         | 12.11       |
| 3. Surface-attachment| 1-15 | 9.8          | 12.43       |
| 4. Gallery protruding| 1-15  | 10.7         | 12.97       |
| 5. Indoor space protruding| 1-15 | 11.9         | 11.77       |
| 6. Entity platform  | 1-15   | 12.0         | 14.12       |
| 7. Overhangs platform| 1-15| 12.7         | 14.07       |
| 8. Entity steps     | 1-15   | 13.1         | 15.23       |
| 9. Overhangs steps  | 1-15   | 13.5         | 14.91       |
| 10. Mixed space     | 1-15   | 14.0         | 14.01       |

Figure 13. Urban connectivity of each space type (1).
utilization patterns, indicating that there are three main utilization pattern tendencies: leisure utilization, mixed utilization, and rear service/unclear utilization patterns. The 10 sub-categories basically conform to the usage affiliations of their five respective categories, but the mixed space type has closer similarity with the platform type. The entity steps type also tends to deviate from the path type and lean toward the block emphasized type (Figure 18).

4.3. Relationship between river encroachment and utilization pattern

The river encroachment rate of each utilization pattern was calculated to explore the relationship between the river encroachment and utilization pattern. The utilization patterns show obvious differences in terms of river encroachment. The river encroachment rate of the leisure utilization pattern is the highest, at 1.06, followed by mixed utilization and rear service utilization pattern at 0.50 and 0.47, respectively. The rate of the unclear utilization pattern is the lowest at only 0.20 (Figure 19).

4.4. Relationship between urban connectivity and utilization pattern

Statistics on the urban connectivity of each utilization pattern were gathered to explore the relationship between them. The space with the highest urban connectivity (11.44 m) is most often used for leisure, followed by the unclear utilization pattern (11.99 m) and the rear service utilization pattern (13.53 m). The space with the weakest urban connectivity (14.20 m) is subjected mostly to mixed utilization (Figure 20).

5. Discussion and conclusion

Constituent elements were used in this study to analyze the spatial characteristics and utilization patterns of the building boundaries along the Shantang River in Suzhou, China. Clear-cut differences in the types of space and utilization were observed, as well as some relationships between spatial characteristics and utilization patterns. Alongside its lengthy history of urbanization, today’s Shantang River is no longer a fully public space but rather has been increasingly privatized, or in certain places, abandoned entirely.

1) There has been a substantial transformation in the riverside building boundaries post-urbanization accompanied by a wealth of new constituent elements. Five space types were defined here based on the constituent elements. The surface-emphasized type was found to be most common, followed by the block-emphasized type, platform-emphasized type, path-emphasized type, and mixed space type. The space types appear to be agglomerated, with a mutual reference between transformations.

2) There is a widespread phenomenon of river encroachment in the building boundary space. The river has been majorly privatized. The block-emphasized type encroaches upon the river the most often followed by mixed space type, platform-emphasized type, path-emphasized type, and surface-emphasized type.

3) The urban accessibility of the riverside boundary space has fundamentally transformed. The
waterway, which once was an important point of connection between the building and the public, is now generally the point farthest away from the building’s entrance. The urban connectivity of this object varies greatly; the block-emphasized type is the most common followed by the surface-emphasized type, mixed space type, platform-emphasized type, path-emphasized type.

(4) The functions of the target area are more diverse than the scenic spots which have undergone unified planning. Residential, commercial, and service-related functions appear to coexist. Space utilization patterns clearly emerged in the target area alongside this diversity of functions. The main usage pattern is rear service utilization, followed by the unclear utilization pattern, leisure pattern, and mixed pattern. The Shantang River is mainly used passively though there is some active usage.

(5) There is a significant relationship between space type and utilization pattern in the building boundaries along the Shantang River. The platform-emphasized type is closely related to mixed utilization pattern, the block-emphasized type and entity steps type are closely related to the leisure utilization pattern, and surface-emphasized, mixed space, and overhangs steps type are closely related to rear service and unclear utilization patterns. The platform is often used as a supplement to the internal space but cannot solely satisfy the needs for a complete activity, so the activities performed there are often mixed; The protruding block is placed on the river so it is often used for leisure activities centered on the landscape; The surface-emphasized type is rarely used or used for simple rear service activities; The path-emphasized type is correlated with strong hydrophilicity in meeting the water demands for rear service as well as enabling citizens to reach the river landscape for personal enjoyment. The mixed space is used more commonly for rear service alone rather than for a diverse array of purposes.

(6) The utilization patterns show marked differences in terms of river encroachment. The leisure utilization pattern has the highest river encroachment rate, followed by mixed utilization, rear service utilization, and unclear utilization patterns. The leisure utilization pattern centers on enjoyment of the river landscape, so encroachment on the river is a common aspect of landscape galleries, restaurants, and tea rooms. In the unclear utilization pattern, the use of space is mainly concentrated in the building’s interior and there is no obvious tendency to use the boundary space, so the river encroachment rate is low. The rear service utilization pattern centers on water usage, which involves some encroachment on the river. Equipment such as air conditioners, canopies, and daily necessities overflowing
into the river space encroach some but to a lesser extent than under the leisure utilization pattern.

(7) The utilization patterns also relate to urban connectivity, but the differences are less clear than those between the utilization patterns and river encroachment. The leisure utilization pattern shows the strongest urban connectivity followed by unclear utilization, rear service utilization, mixed utilization patterns. When the distance from the building entrance to the river is small, the boundary along the river is tightly connected with the street space; the river in these cases is often directly adjacent to the main entrance. Public leisure activities are more common in these spaces due to their strong accessibility. However, there are also cases where only internal space is used. When the distance between the building entrance and river is large, the connection to the street space is weak and more space can be arranged in the depth axis. As the end space, the riverway boundary in these cases is often separated from the building entrance by other spaces resulting in greater independence from the public, rear service space is arranged here (e.g., kitchens, bathrooms). A rich internal building space involves mixed usage of the boundary when the distance between the entrance and the river is large enough (Figure 21).
**Figure 18.** Results of the correspondence analysis (2).

**Figure 19.** River encroachment rate of each utilization pattern.
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Annotation

1. Travels of Marco Polo describes the 13th century AD Italian Marco Polo’s journey from Venice to Asia and from China back to Venice, as well as the geographical and cultural features of many Asian and African countries traversed along these routes.

2. The ancient city of Suzhou was located in the south of Jiangsu Province. It was built in 514 BC and has a recorded history of more than 2,500 years. It is one of the 24 historical cities first announced by the Chinese government.

3. Changmen is one of the eight gates of the ancient city of Suzhou. It is located in the northwest of the city. It was named for the Chang family, who thrived in this area.

4. Tiger Hill is located in the northwest of ancient city of Suzhou and has a history stretching over 2,500 years. It has a reputation as the “First Hill in Wuzhong” and is a national 5A-level scenic spot designated by China.

5. Draft History of Qing was edited by the Beiyang Government of China from 1914 to 1927 and records the history of the Qing Dynasty (1616–1912). The book contains 536 volumes.

6. Changzhou County Chronicles is a book published in the Qing Dynasty (AD 1753) as a record of the local history, geography, customs, characters, culture, education, and properties of the Changzhou area in Suzhou.

7. Bai Juyi is a well-renowned realist poet in China, known as one of the three great poets in the Tang Dynasty. He was made the leader of Suzhou in 825 AD.

8. A Dream of Red Mansions was written by Cao Xueqin in the mid-18th century during the Qing Dynasty and is considered one of the four most significant classic novels of Chinese literature.

9. Qing Jialu is a work of Gu Lu (Qing Dynasty) describing the seasonal customs in Suzhou. It reveals much about the local and social history of Suzhou in the Ming and Qing Dynasties.

10. Suzhou’s Golden Age is a famous painting by Xu Yang, a royal painter of the Qing Dynasty. Over a 12-m scale, it depicts the bustling urban landscape of Suzhou at that time.

11. The Statistical Package for the Social Sciences (SPSS) is a modular data management and analysis application created and produced by SPSS, Inc., in Chicago, Illinois (Nie 2003).

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