A Human-oriented Exploration of Data-informed Urban Design: A Case Study in Shanghai

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Abstract. As an effort to create lively urban places for the public, urban design requires an in-depth understanding of people's needs. With the help of multi-sourced urban data, for example, location-based services (LBS), morphological, social media, and crowd-sourced review data, this study proposes a systematic framework supporting urban design analytics. Specifically, LBS data helps to capture the spatial-temporal vitality and construct a target user portrait. The morphological data including street networks and functions helps to identify the problematic areas requiring spatial interventions. Social media and crowd-sourced review data can help measure people's perceptions. Lujiazui Water Ring, an area lacking urban vitality and requiring urban renewal, is selected as the case study. This analytical framework performs well, contributing to the development of human-centered design by providing continuous measurements of an "unmeasurable" quality across large-scale areas. It also makes a step forward in integrating science and design.

Keywords: Multi-sourced Urban Data, Human-oriented, Data-informed Urban Design, Design Science, Shanghai.

1 Introduction

In recent years, urban development in the era of stock renewal has taken a turn toward refinement [1]. Humanization and quality have become significant urban design trends [2]. Experience-based planning and design have often made it difficult to accurately assess and control these aspects [3]. The emergence of new urban data and the application of new technologies can change this situation and help designers develop macroscopic perceptions of urban design sites with a human-scale perspective. Currently, despite the emergence of novel data and technologies in the field of urban research, their application remains limited to the examination of specific urban phenomena. A comprehensive and universal framework for human-centered urban design analysis has yet to be established. Therefore, it is imperative to build a human-centered urban research framework summarized from classical research. On the basis of this framework, a data-informed urban design analysis paradigm can be established that is based on multi-sourced data and new urban analysis techniques, which are both practical and scalable. This approach enables the fine-grained measurement of previously "unmeasurable" urban quality. By integrating the classical humanistic urban research perspective with multi-sourced data and new technologies, this study aims to advance urban design towards refinement and scientific rigor. It will also promote the development of human-oriented and high-quality urban environments.

2 Literature Review

The field of urban research has witnessed a surge in innovative approaches to analyzing urban problems, owing to the recent emergence of novel urban data and technologies. These analytical techniques have harnessed the extensive and accessible nature of multi-sourced data to facilitate a precise understanding and quantification of the urban environment on a large scale. An early example is the analysis of spatio-temporal urban human activity based on location-based services (LBS) data conducted by MIT Senseable City Lab [12]. More studies have proven the value of LBS in portraying the population distribution of a region [13, 14]. In terms of accessibility, street network analysis has been widely studied [15, 16] and analysis tools such as sDNA (Spatial Design Network Analysis) have emerged [17, 18]. Some scholars have also used social media check-in data to investigate urban space preference and urban attractiveness [19-22]. Furthermore, spatial quality has been measured in several studies using crowd-sourced data [23]. Other studies identify urban functional areas based on Point of Interest (POI) data [24-26], and so on (see Table. 1).

The utilization of new urban data and technologies has demonstrated their efficacy in the examination of urban issues. The emergence of numerous analysis methods has facilitated the exploration of comprehensive data-informed urban design. For instance, Ye et al. have integrated Space Syntax, Space Matrix, and Mixed-use Index to support a specific stage in urban design [27]. Similarly, Guo et al. and Tang et al. have employed multi-source data to aid in the design of urban public spaces and greenways [28, 29]. While these investigations are of great importance, an all-encompassing analytical framework that can be universally applied throughout the entire process of urban design, with a focus on human-oriented considerations, has yet to be formulated. Consequently, a preliminary step entails the examination and establishment of a human-oriented urban research framework. Specifically, the inquiry seeks to address the query: What are the key elements of a human-oriented urban design that necessitate consideration?

Table 1. Typical applications of new urban data and analytics technologies.

Research objective	Data type	Analytical technique	Researcher/ developer
Intensity of urban activity	LBS data	GIS analysis	Ratti et al.
Population distribution	LBS data	GIS analysis	França et al.; Patel et al.
Spatial accessibility	Morphological data	Spatial design network analysis	Cardiff University
Space preference and urban attractiveness	Social media data	Spatial statistics	Wakamiya et al.; Hasan et al.; Shen and Karimi; Wang et al.
Spatial quality	Crowd-sourced data	Spatial statistics	Shi et al.
Urban functional areas	POI data	GIS analysis	Zhai et al.; Hu and Han; Bao et al.
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3 Conceptual Framework

The examination of urban space through a human-oriented lens has been a longstanding area of inquiry [4]. To establish a coherent and structured conceptual framework, this investigation summarizes the established theories. Initial research emerged to critique modernist urban planning, with a focus on topics such as the diversity of urban spaces [5] and socio-economic effects [6]. Since then, numerous scholars have endeavored to qualitatively theorize about public space [7], place perception [8], and walkability [9, 10], covering the fundamental issues of human-centered urban research. To amalgamate the diverse dimensions of urban studies, several frameworks have been proposed over the years. One well-known example is the 5D model (density, diversity, design, destination accessibility, and distance to transit) [11]. It is employed to assess urban built environments from a human-centered perspective. However, for urban design purposes, a more intricate set of factors must be considered. This study consolidates classic human-oriented research topics and proposes a human-centered conceptual framework that adapts to the needs of urban design, drawing on the 5Ds theory. The framework is encapsulated in the dimensions of population composition, street network accessibility, urban spatial quality, and function composition. Population composition extends beyond density to encompass socio-economic attributes. Street network accessibility encompasses the 5D theory of destination accessibility and distance to transit. Urban spatial quality and environmental design are interconnected and manifested through urban vitality. Function composition corresponds to diversity. Furthermore, the aforementioned themes have been thoroughly scrutinized by past human-oriented urban researchers, with the necessity and significance of these themes extensively documented (see Table 2).

Table 2. The connection between human-oriented conceptual framework and classical theory.

	Jane Jacobs	Henri Lefebvre	William H. Whyte	Kevin Lynch	Montgomery John
Population composition	Cities need dense populations.	All people should be widely involved in the development of the city.	Different spaces have different appeals to different groups of people.	Urban space should be accepted by people of different classes and personalities.	
Street network accessibility	Streets need to be short to allow for constant turning and a sense of freshness.	Streets should be joined, not divided.	Small-scale urban spaces such as streets are important.	The direction, accessibility and systematicity of the street are important.	The diversity of street life is important.
Urban spatial quality	Cities need high-quality facilities to provide people with places to move around.		Cities need leisure and entertainment places.	Good urban space should be imaginable.	It is possible to improve the quality of urban space through planning and design.
Function composition	Cities need a mix of functions.	Spaces should be diverse.		A region should have common morphological features and functions.	Mixed urban zoning promotes diversity.

4 Methodology

The next step is to create a data-informed urban design analysis framework (see Fig. 1) that integrates the human-oriented conceptual framework with multiple sources of data and technology. It covers four aspects of the conceptual framework: i) population composition, ii) street network accessibility, iii) Urban spatial quality, and iv) function composition. Corresponding analytical methods to support urban design are constructed. To ensure the rigor and validity of the analysis, generally accepted data and analysis methods are selected based on existing research. These methods ensure precise measurement and high efficiency while being suitable for the entire process of urban design.

This study employs LBS data for user characteristic analysis in urban design through geographic analysis. The ease of access to LBS data and its rich information content, including age and income, provide sufficient support for the overall positioning of the project. Accessibility analysis involves the study of block scale and the research of street network characteristics. They are realized through morphological data and sDNA tools. The use of sDNA tools can quickly diagnose the street network structure and is well-suited to the iterative process of the program. For spatial attractiveness analysis, social media check-in data and crowd-sourced data are considered good indicators of the attractiveness distribution of the space. Spatial-temporal LBS, Meituan, and Weibo check-in data are used for a comprehensive evaluation of spatial vitality, facility density, service quality, and city image, taking into account the actual situation in China. POIs data are the most widely used for function composition analysis. The identification of function composition and functional mix in the area is achieved through POIs data and geographic analysis technology, which enable a three-dimensional study of function ratio, functional mix, and distribution of featured streets.

Drawing upon the comprehensive integration of the aforementioned analyses, targeted recommendations can be postulated for street network optimization, urban node creation, scene design, facility enhancement, and function guidance. This human-oriented technical framework holds universal applicability and can function as a benchmark for urban renewal and design across a diverse range of cities and regions.

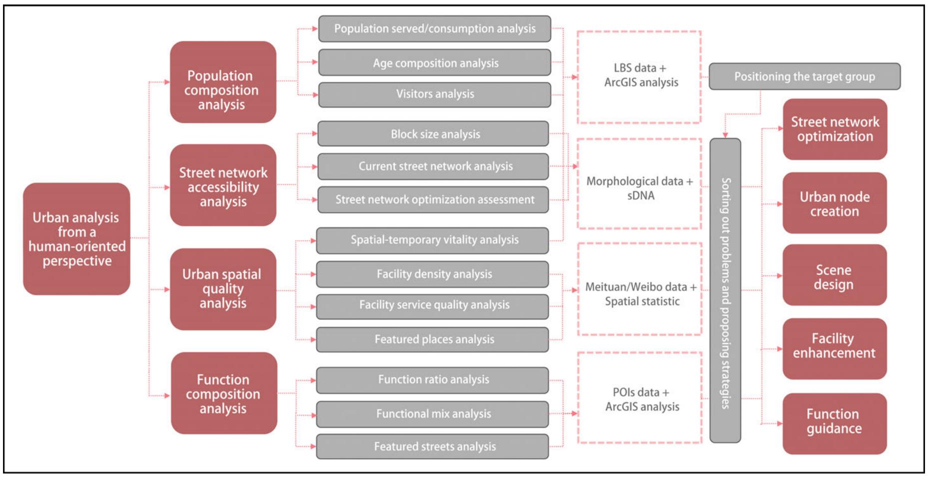

Fig. 1. Analysis framework.

5 Urban Data Analysis: A Case Study in Shanghai

This study takes the waterfront urban design of Lujiazui as an example. Located in Pudong New Area, Shanghai, it includes renewing and designing a 12.5 km long waterfront segment and residential area. To facilitate the analysis of practical problems and fine-grained guidance, the areas of Lujiazui waterfront space were divided into different areas. The waterfront segment is formed by expanding 50m from the river centerline to both sides. The area formed by radiating about 500m outward from the river centerline is the residential area. It is divided into four waterfront segments and residential areas according to the different local administrations to which they belong (see Fig. 2), distinguished by Yangjing (Y), Huamu-Zhangjiabang (H-Z), Huamu-Shiji (H-S), and Weifang-Tangqiao (W-T).

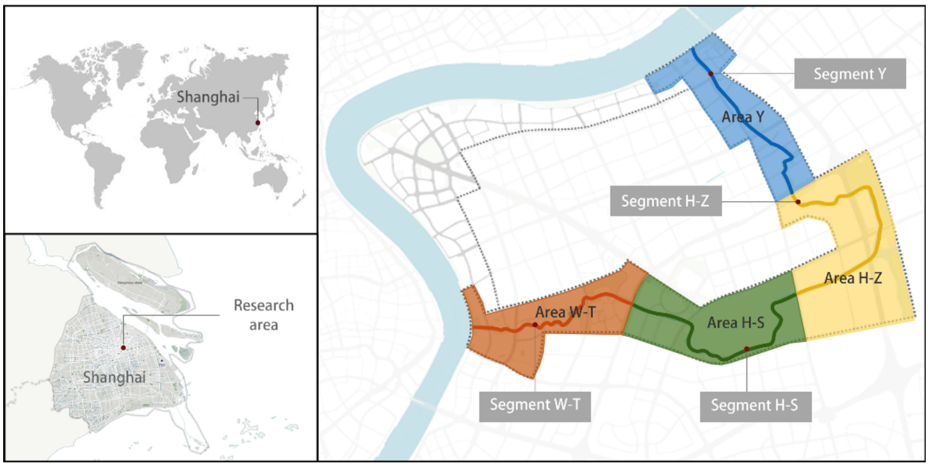

Fig. 2. Research area.

5.1 Analysis of Population Composition Based on LBS Data

Identifying the target population is crucial for urban design and is the first step in this analysis framework. Based on a large sample size of LBS data and MAC codes of cell phones, a multidimensional portrait analysis of the targeted groups can be achieved. The LBS data of Shanghai were obtained through a third-party data service provider. The data were based on a 250m*250m grid, including three "weekday + weekend" sets on April 17 and 20, 2019, May 28 and 30, 2020, and January 14 and 16, 2021. The raw data are in CSV files with grid ID and user numbers as retrieval basis, respectively. After data cleaning, the age composition, consumption level, residence, and workplace distribution of the population were analyzed (see Fig. 3). The main target groups of urban design and their needs can be inferred from this.

The results of the analysis of the population characteristics include four charts (see Fig. 4). The first and second represent the analysis of the population and consumption level in the area, respectively. Among the actual population served, the total population served is higher in the Y and W-T areas. On the other hand, the consumption level data indicate a higher percentage of high consumption in the H-Z area and a higher ratio of low consumption in the W-T area. The third chart represents the age composition analysis. The youth ratio in the W-T area is the highest among the four areas. There is a higher proportion of middle-aged people in the H-Z and H-S regions. There is a higher proportion of older adults in the Y region. The fourth chart analyzes the actual use of the waterfront space. The number of visitors to the Y and W-T segments is significantly higher than that of the other two segments. In addition, all four segments are dominated by residents, with a low proportion of external visitors. The user portrait of each area provides a basis for differentiated strategies. In conclusion, the waterfront area is relatively closed and further research is needed in terms of accessibility and distribution of facilities.

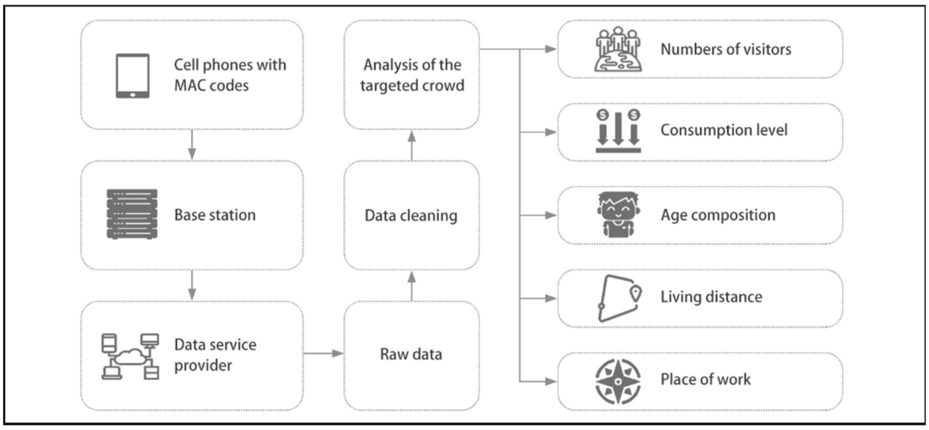

Fig. 3. Technical process of LBS analysis.

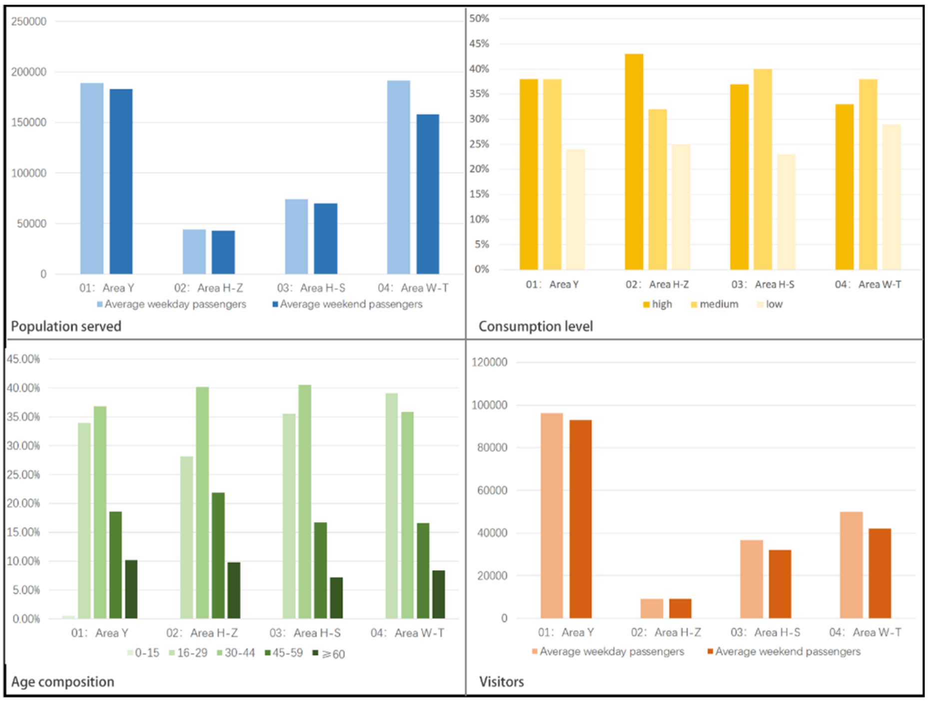

Fig. 4. Four user portrait charts based on LBS data.

5.2 Analysis of Street Network Accessibility Based on Morphological Data and sDNA

The preliminary research indicates that there are problems with the spatial accessibility of the site, which is due to the riverbank breakpoints to some extent. First, the analysis of blocks and street network data was used to examine the overall traffic situation. The results of the block analysis reveal that the scale of blocks closer to the river is generally larger. This is not conducive to the increase of overall waterfront accessibility. Another result shows that the overall street network density is unevenly distributed; it is necessary to establish a judgment on accessibility through quantitative analysis of the street network.

This study used the sDNA tool for fine-grained street network characterization. The street network data were used as a basis and streets within blocks that were not open to the public were removed. Only public streets were retained and accessibility was calculated from a pedestrian perspective using 400 m as the analysis radius (see Fig. 5). From a macro viewpoint, the overall accessibility of the area is low. There is a lack of waterfront public streets along the river in the Y area and the H-Z area. The broken strips of bridges and riverbanks have a greater impact on the overall accessibility. Many public streets along the river in the H-S area have high accessibility. Additionally, the opposite side of Shiji Park is a gated community with relatively low accessibility. For the W-T area, there are differences in the distribution of internal accessibility. It is recommended to open the public waterfront streets through various means. This study summarizes the collapse points of accessibility. A total of 12 waterfront and 16 bridge breakpoints have been identified as renovation priorities by integrating the current environment. SDNA tools will also be used to calculate accessibility enhancement benefits in the subsequent design stage.

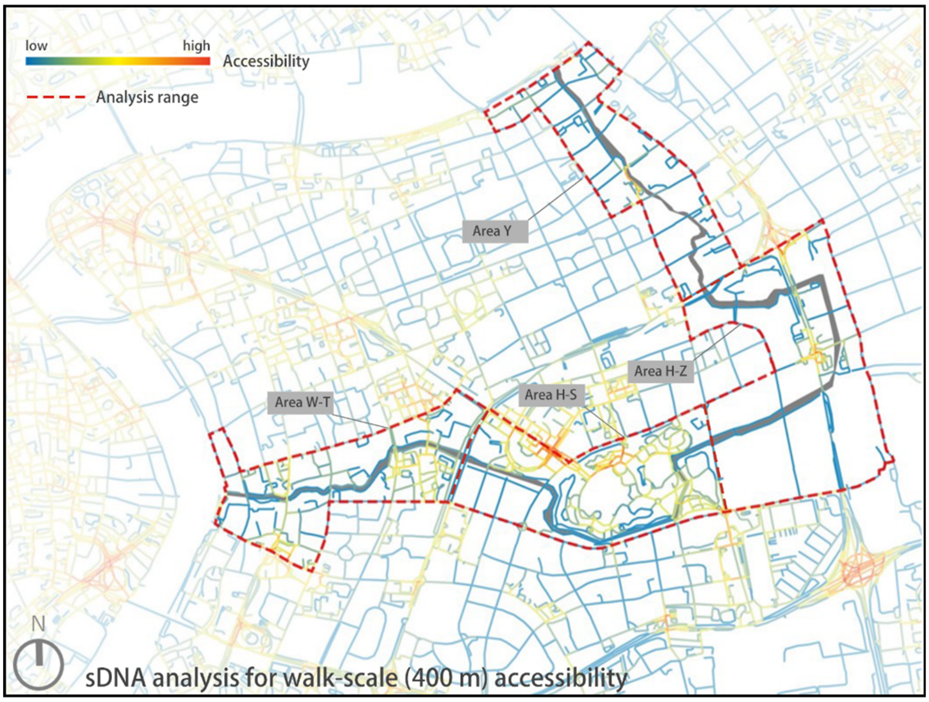

Fig. 5. sDNA analysis for walk-scale (400m) accessibility.

5.3 Analysis of Urban Spatial Quality Based on LBS and Meituan/Weibo Data

Human-centered urban design focuses not only on physical design but also on the quality of space. A large sample of LBS data can reflect behavior and its spatial and temporal distribution, which can be used for spatial-temporal vitality analysis of a large area. The data of Meituan, one of China's most popular consumer service APPs, includes the spatial distribution, user rating, and average transaction value of commercial facilities in a district. Such data can characterize the quality of facilities. In addition, the Weibo check-in data containing spatial information can indicate the attractiveness of spaces in the city and can also be used to analyze the imageability of public space.

This study analyzed hourly interval LBS data for a week (May 19, 2019-May 2, 2019). The spatial heat distribution of the center of Shanghai was obtained by aggregating the weekend vibrancy as a representative. The data recorded the number of cell phone transmissions and their coordinates by time. The results were visualized by kernel density and contour analyses. The research established that East Nanjing Road and its surroundings form the most vibrant area. In Pudong, weekend vibrancy values are generally low in all regions except Lujiazui. The analysis of commercial facility density based on Meituan data reveals that the density of the study area is low. Among the existing service facilities, the density of those in the Y and W-T areas is slightly higher than in the other two areas. Analysis of the service quality of the facilities indicated the level of the waterfront area is significantly lower than that of the central Lujiazui. Furthermore, the distribution of high-scoring shops is scattered. The distribution of facility grades also suggests similar conclusions. Finally, the analysis results of Weibo check-in data show the distribution of featured places in the city. The data contain information such as check-in time, location tags, and coordinates of Weibo users. The data were analyzed in a similar manner to LBS-based heat analysis. The featured places of the city diminish from northwest to southeast with Shiji Avenue as the axis. The urban space of the planning area generally lacks imageability. Shiji Park is located on the axis but fails to play the role of a node. All three aforementioned conclusions indicate that the urban design area lacks nodal spaces of high spatial quality and attractiveness. The functional layout also needs to be optimally adjusted with reference to the current assessment.

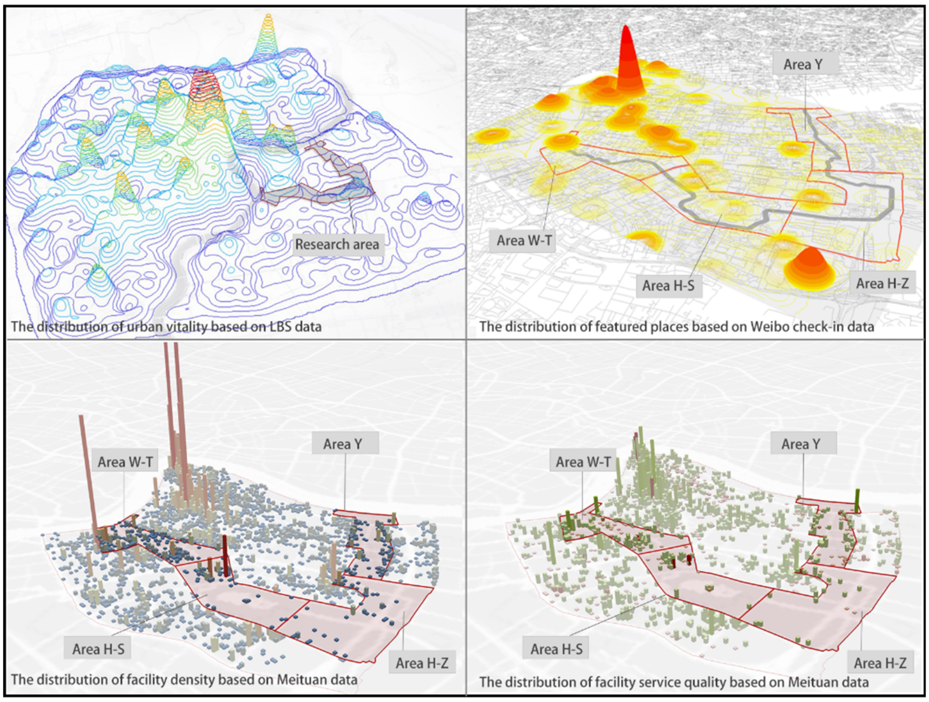

Fig. 6. Analysis of spatial attractiveness based on LBS and Meituan/Weibo data.

5.4 Analysis of Function Composition Based on POIs Data

The function composition study of the Lujiazui waterfront area plays a vital role in the function planning of urban design. This section analyzes the function composition from function ratio, functional mix, and featured streets. POIs data were used and combined with geographic analysis. First, from the overall sub-area function ratio, all four areas have significant differences in their function composition. The functional mix of the area is then examined. The Mixed-use Index (MXI) quantifies the degree of the land-use mixture based on the percentages of the gross floor area of dwellings, working places, and commercial facilities occupying all the floors of blocks [27]. The analysis results are presented in a ternary diagram (see Fig. 7). The higher the mixture, the closer they are to the center of the triangle. The results of the overall calculation for the four zones indicate that the research area has a low degree of functional mixture; the blocks are single-functional. Among them, the Y area has more dwellings and working places. The H-Z area has more housing and a lack of amenities. The H-S area has more commercial facilities. The other part is the identification of the featured streets in the area (see Fig. 8). The analysis is conducted by connecting the function points of POIs in the 55m range on both sides of the street to the street segments through spatial join analysis. We calculated the proportion of various types of functions in each street segment and determined the dominant feature of the streets. The results indicate that the study area has significantly fewer featured streets than the surrounding areas. The types are scattered and not strongly continuous. At the same time, the distribution of each area is different. The featured street types in the Y area are rich but poorly systematic, with a strong sense of fracture on both sides of the waterfront. The H-Z area has sparse street networks and an extreme lack of featured streets. The H-S area is mainly streets dominated by landscapes and sports facilities. The W-T area is relatively rich in featured streets. The analysis of function composition supports the differentiated development strategy of each area and the planning of featured nodes in the later stage.

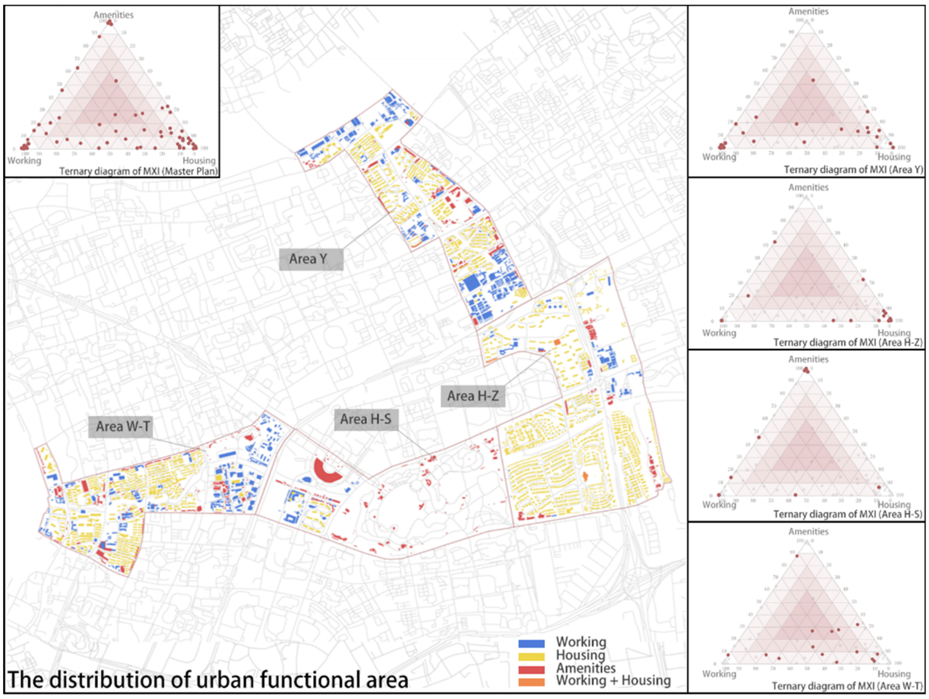

Fig. 7. Analysis of functional mix based on POIs data.

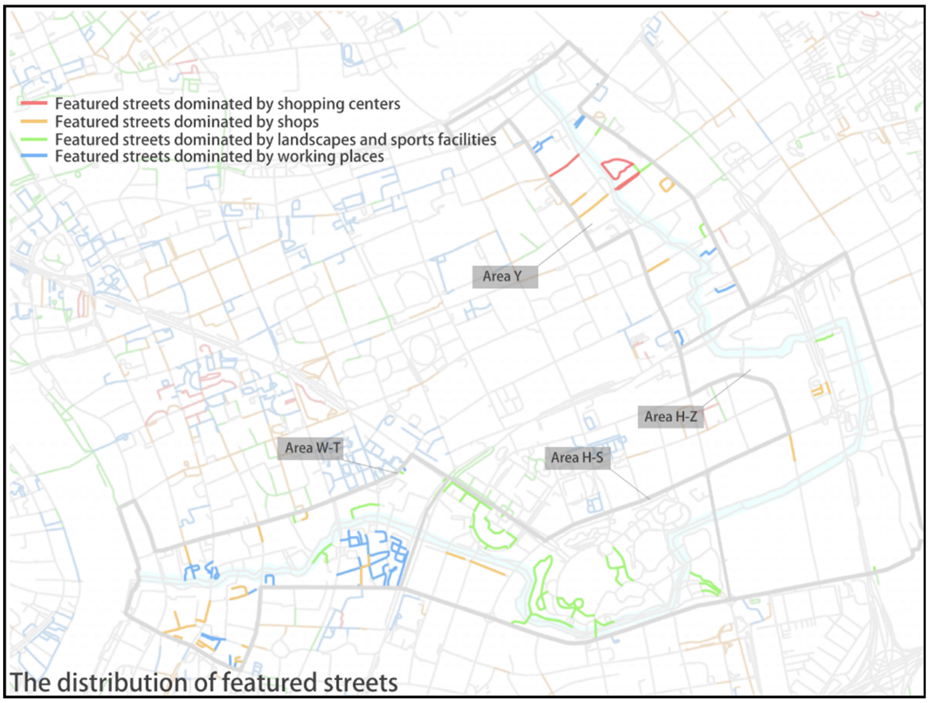

Fig. 8. Analysis of featured streets based on POIs data.

6 Supporting Urban Design Strategies

Through the analysis conducted, a more precise and human-oriented set of guidelines for urban design can be developed. This will enable the targeted proposal of urban design strategies, including but not limited to street network optimization, facility enhancement, urban node creation, scenario design, and functional guidance. The waterfront urban design of Lujiazui can serve as a prime illustration.

Take the example of street network optimization guided by sDNA analysis. The urban design team selected the breakpoints and disconnections that needed to be opened concerning the current analysis of accessibility (see Fig. 9), based on which the network was adjusted. The four waterfront segments were analyzed using sDNA. The results indicate that the average accessibility of the renovated waterfront segments improved by 8.25% compared to the previous one. The street network for waterfront accessibility is significantly improved. The same process can support more rounds of design iterations. In other aspects, the LBS analysis identifies a lack of spatial attractiveness in the four areas. The analysis of the Meituan data indicates the main directions for the improvement of commercial amenities. The Weibo data highlight that the existing urban space requires the development of recognizable places. The examination of the function composition provides a more detailed basis for creating regional nodes and functional layouts. Overall, utilizing the analytical framework established in this study, the design team identified and remedied extant issues while constructing urban designs that were informed by the area's potential (see Fig. 10). This technical framework can also inform the designation of strategies for other urban design projects.

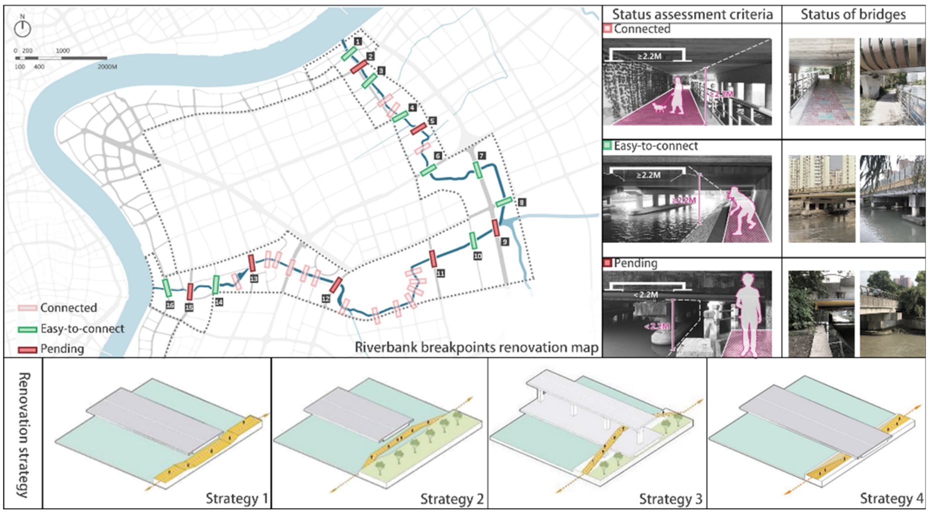

Fig. 9. Riverbank breakpoints renovation map and strategies.

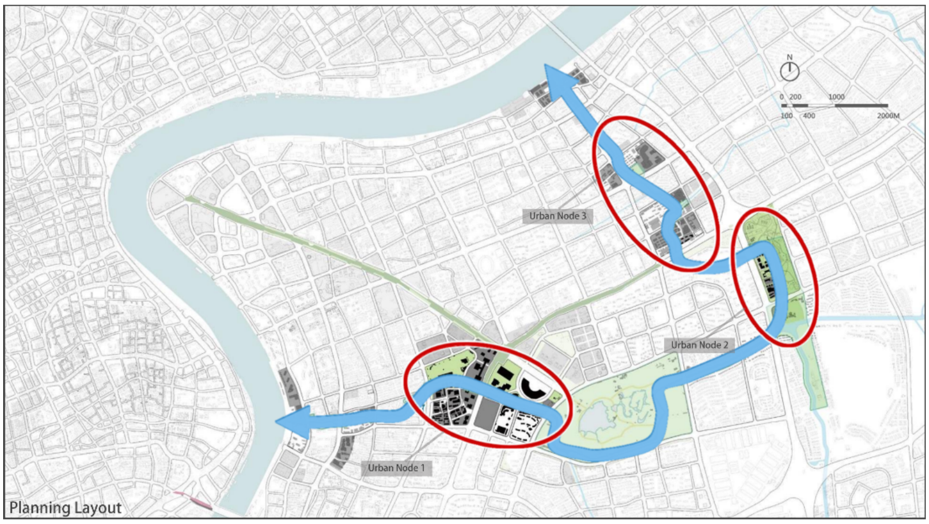

Fig. 10. Urban design plan.

7 Conclusions

This study presents a novel paradigm for data-informed urban analysis that is oriented toward human needs. Utilizing an analytical application case of Lujiazui urban design, the study demonstrates the efficacy of this paradigm. The study has significant implications for the integration of urban design and science.

Firstly, this study proposes a conceptual framework for humanistic urban analysis based on classical theories, elucidating the key aspects of human-oriented urban analysis and design. Secondly, the study constructs an operational framework for urban analysis that combines multi-sourced data and new urban analysis techniques. This framework enables fine-grained and valid measurements of "unmeasurable" quality across large-scale areas, thus enabling a human-centered perspective assessment of the urban environment. Besides, it can be applied to various urban design projects. Thirdly, the framework is scalable and can be used throughout the entire process of urban design to help iterate and optimize the scheme. Lastly, the study emphasizes the importance of bottom-up big data and urban analysis technology in making the urban design more scientific and objective. By incorporating bottom-up practical needs, urban design can promote urban renewal and construction towards refinement, humanization, and quality.

While this study provides a valuable summary of four key dimensions of humanistic urban research, it is important to acknowledge that this division may not be entirely absolute or comprehensive. As more research materials become available, there may be opportunities to refine and expand upon this framework. Additionally, the selection of urban data and technical methods in this study prioritized data accessibility and analytical efficiency. However, as new data types and analysis methods become available, it may be possible to supplement and optimize these methods.

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