

RESEARCH

Open Access



Assessing the dynamic vitality of public spaces in tourism-oriented traditional villages: a collaborative active perception method

Sheng Liu¹, Zhenni Zhu^{1,2}, Yichen Gao^{1,3*} and Shanshan Wang¹

Abstract

Public spaces in traditional villages are the root of the development, preservation, and inheritance of rural cultural heritage. However, these spaces in tourism-oriented traditional villages continue to suffer from issues such as inconsistent vitality, more competition than cooperation, and inefficient revitalisation. Limited by the low precision of spatiotemporal data in rural areas, previous static and materialised vitality evaluation methods have failed to explore the dynamic nature of the flow of people in traditional village public spaces. This study investigated a collaborative active perception method using Wi-Fi probes and static snapshots to assess their dynamic vitality. An empirical study was conducted using Yantou Village in Lishui City, China, as an example. The empirical results indicate that this method can qualitatively and quantitatively analyze the spatiotemporal variations and the scenarios of the dynamic vitality of small public spaces in traditional villages, deepening the cognitive depth of their vitality from time and humanity, providing a basis for the spatiotemporal synergistic enhancement of their public spaces, and offering insights for their revitalisation.

Keywords Traditional village, Heritage tourism, Dynamic vitality, Public space, Active perception

Introduction

Research background

Traditional villages are global rural heritage sites that usually refer to villages formed earlier and have rich traditional resources [1]. They can fully represent the production and life, social and cultural levels, and ethnic characteristics of a certain historical period or specific regional unit [2]. However, these traditional villages are often located in remote areas and have historically relied on traditional agriculture or handicrafts for their

livelihoods, often being unable to balance the economic costs of heritage protection and survival. Therefore, in Asia and Europe, traditional villages have begun developing tourism to enhance the vitality of their heritage for self-survival. Public spaces in traditional villages are defined as open areas within a traditional village that can be clearly distinguished by the boundaries of buildings and environmental elements [3]. They serve as venues not only for villagers' activities and interactions but also for tourists to experience the village's historical culture [4]. First, for tourism-oriented traditional villages, public spaces are the key spatial carriers for whether the village can successfully attract tourists to stay for a long time; thus, enhancing the vitality of these public spaces is of great significance. Worldwide, many cases exist where revitalising public spaces has successfully spurred the growth of traditional village tourism. For example, the town of Nanyang Guyuhe raised spatial awareness and promoted sustainable heritage tourism in the region

*Correspondence:

Yichen Gao

gaoyc@hzcu.edu.cn

¹ School of Art and Archaeology, Hangzhou City University, Hangzhou 310015, China

² School of Design and Architecture, Zhejiang University of Technology, Hangzhou 310023, China

³ College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

by connecting tourism to public spaces [5]. The Dataran Pahlawan Historical Plaza in Malacca elevated its tourism value and significance through its events, ensuring the sustainable preservation of its historical relics [6]. Second, as traditional villages transition from agricultural to tourism, there is a growing need to improve their public areas. For example, in 2021, China issued the ‘Opinions on Strengthening the Protection and Inheritance of Historical and Cultural Heritage in Urban and Rural Construction’, deploying important tasks such as ‘increasing public space in traditional villages through micro renovation, coordinating rural construction with the protection and utilization of traditional villages’ [7]. Many tourism-oriented traditional villages in China are upgrading their public spaces to enhance village tourism vitality.

However, phenomena of vitality disharmony and competition still exist that exceed concurrence in the public spaces of tourism-oriented traditional villages. Specifically, there are significant variations in the vitality of these public spaces with dynamic complexity and diversity in both space and time. For example, some scholars found significant variations in the use of traditional village public spaces in Qiandaohu Town, Hangzhou, during the day and night, as well as during the peak and off-peak seasons [8]. Some scholars also discovered that the tourism vitality of public spaces in a traditional village in Jingmen, Hubei, presented a multicentre spatial distribution feature around the village [9]. When enhancing these public spaces, it is important to explore the dynamic variations and scenario patterns of their vitality to generate targeted, differentiated, and coordinated strategies. Therefore, we propose the following research question: How do we deeply understand the spatiotemporal variations and scenario patterns of public space vitality in traditional villages?

Related research

Vitality can be defined as the capacity to survive and the power to live or grow [10]. Scholars have previously believed that rural vitality is a prosperous attribute [11]. Given that traditional villages prioritise the preservation of a complete agrarian cultural settlement and emphasise the conservation of both tangible architectural forms and the transmission of intangible cultural heritage [12], this study believes that the vitality of public spaces in traditional villages is their comprehensive ability to maintain a complete survival status.

Scholars have studied the vitality of the community and public heritage sites. In the construction of an indicator system for vitality assessment, there are two main approaches: single- and multi-factor fusion. Among these, single-factor measurements are often characterised by the pedestrian flow per unit of time and space

[13, 14]. For example, Zumelzu assessed the neighbourhood vitality of five Chilean communities by counting pedestrians using the gate method [15], whereas Ding measured the street and alley spatial vitality of three tourism villages in China based on pedestrian volume [16]. Multi-factor fusion measurement is often based on separate dimensions; for instance, Zhang developed an indicator system based on historical, usage, and sustainable value, quantitatively evaluating public space vitality in nine historical and cultural districts in Beijing [17].

Current assessments of the vitality of public heritage spaces are mainly static and often construct metrics based on heritage characteristics. For example, Saputra et al. evaluated the vitality of traditional villages around Indonesian cultural heritage sites using 11 vitality indicators such as function and activity [18]. Niu et al. measured the vitality of a waterfront space in the ancient city of Suzhou using WeChat heat map data [19]. Rastegar et al. assessed street vitality in Johor Bahru City’s downtown area, where architectural history is concentrated, by using factors related to diversity and activity [20].

However, research on urban heritage and public spaces has explored variations in vitality over different periods. For example, Mu et al. analysed the temporal fluctuation characteristics of spatial vitality in three community parks in Zhengzhou [21]. Liu et al. studied the hourly tourist landscape preferences and spatiotemporal distribution in the historical districts of Fuzhou City during weekdays and weekends [22]. Kang used Seoul as an example to compare changes in community vitality during three specific times (mornings, work hours, and evenings on weekdays and weekends), and analysed the relationship between environmental characteristics and neighbourhood vitality during different time periods [23].

Research on time-segmented vitality has also been initiated in rural areas but has not yet delved into small-scale public spaces. For example, Chen et al. used population heat data to evaluate the overall time-segmented vitality of traditional villages [24], while Gong et al. analysed the spatiotemporal variations in the spatial vitality of township units in the Pianxia River Plain using multi-source data [25]. The primary obstacle to dynamically assessing the vitality of rural public spaces is the difficulty of collecting data from rural heritage regions. Traditional interview-based research methods suffer from high subjectivity and low efficiency. Many studies have used mobile phone signalling, social media, and other methods to analyse the vitality of heritage spaces [26, 27]. However, such location data cannot reflect people’s true perceptions of spatial vitality, and their spatial accuracy is low in rural areas (approximately 500 m) [28], making it

unsuitable for humanistic research on small-scale spatial vitality in traditional villages.

Active perception monitoring has recently emerged in the research on urban themes. This monitoring, which involves installing sensors at fixed positions or on mobile carriers, can flexibly perform small-scale, high-precision, and spatiotemporal continuous monitoring of humanistic environments through locations, images, videos, and other media [29–31]. For example, the Osaka University team assessed the walkability of streets by employing eight variables—walking score, greenery, openness, relative walking width, motor vehicle density, non-motor vehicle density, noise, and light—utilising a synergistic approach that combines the active monitoring of cameras, acoustics, and night optical instruments [32]. Martani, from the University of Cambridge, used infrared depth sensors and RGB cameras to monitor pedestrian flow at the London Bridge Train Station [33]. Zhou employed Wi-Fi probe request data to evaluate the spatiotemporal patterns of crowd behaviour during huge social events at Singapore’s urban historic sites [34]. This type of collaborative active monitoring using multiple sensing devices has promoted the refined and humanised evaluation of dynamic vitality in small-scale spaces, but has rarely been applied in rural areas.

Overall, the evaluation of vitality in small rural spaces is still static and materialized. However, collaborative active monitoring, which has been employed in cities, may alleviate the bottleneck and assist traditional villages in achieving vitality assessments with high spatiotemporal accuracy and human-centered perception.

Research objectives

In summary, limited by data collection in rural areas, previous studies lacked applicable methods for analysing the spatiotemporal variation in the vitality of public spaces in traditional villages. Therefore, a failure to quantitatively and dynamically assess the nuanced differences and humanistic scenarios of their vitality has impeded the time-separated synergistic enhancement of public spaces in tourism-oriented traditional villages. Therefore, the main objective of this study is to construct a dynamic assessment method for the vitality of public spaces in traditional villages with high spatial and temporal accuracy and human perception, elevating the existing perception from ‘static and materialized’ to ‘dynamic and humanistic’ with an in-depth exploration: (1) an accurate and comprehensive measurement of dynamic vitality and (2) a humanistic analysis method of the dynamic vitality scenario. We hope that this method provides a scientific basis for enhancing the vitality of public spaces in traditional villages through spatiotemporal synergy and humanism.

Method

Method framework

This innovative article introduces collaborative active perception technology and constructs an assessment method for the dynamic vitality of public spaces in traditional villages from the perspective of refinement and humanisation (Fig. 1). Collaborative active perception includes Wi-Fi probes and static snapshots, whereas dynamic vitality assessment includes comprehensive measurement and key scenario pattern analysis with five dimensions. Taking Yantou Village in Lishui as an example, this study demonstrates the practicality of this method, to check whether it can accurately analyse the dynamic vitality of public spaces in a tourism-oriented traditional village.

Indicator system

This study argues that the vitality of public spaces in tourism-oriented traditional villages lies both in space and time attributes. Therefore, this study constructed its index system based on the dimensions of space and time. In the space dimension, some scholars have found that the dynamic vitality variations of public spaces in traditional villages mainly lie in the intensity of people’s retention and the ability to provide connections for people’s movement in adjacent spaces [9, 35]. In the time dimension, some researchers found that the relevant dynamic vitality differences lie in the durability and stability of attracting crowds [8, 36]. Therefore, this study constructed a index system from the dimensions of space and time, and selected four indicators: retention intensity, retention connection intensity, retention durability, and retention stability, and explored the calculation of them (Table 1).

Data acquisition and processing based on Wi-Fi probe monitoring

Reasons for selecting Wi-Fi probes for monitoring

A Wi-Fi probe is a sensing device that can scan surrounding mobile devices and obtain the time, geographic location, and MAC (Mac Access Control) address of the device being scanned [37]. Compared to the reliance of the Global Positioning System (GPS) on volunteers and the challenges posed by Bluetooth’s low detection rate [34, 38], Wi-Fi probes are not only readily available and easy to instal, but also have high efficiency in collecting people’s flow. With a spatiotemporal accuracy that reaches 1 s and a radius of 0.01 m [34], they are well-suited for precisely and dynamically sensing people’s flow and duration of stay in the small public spaces of traditional villages.

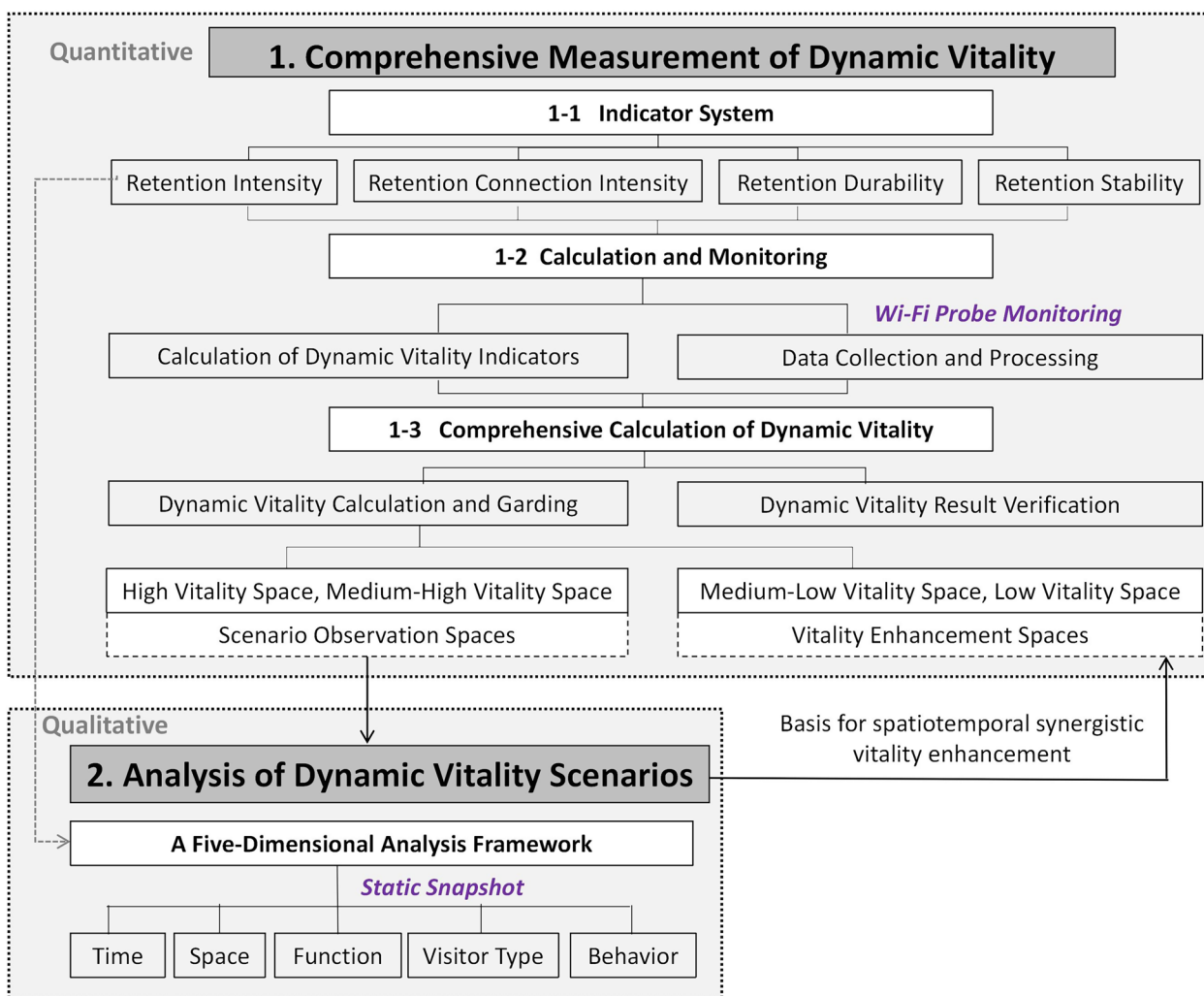


Fig. 1 Method framework

Data collection

This study used iSen model TZ4007pro WiFi probes. Each probe was conducted to a portable charging device and protected with a waterproof covering (Fig. 2). These devices sent real-time data to a cloud service after capturing Wi-Fi probing requests from mobile devices. The monitoring period lasted 1 week, including five weekdays and two weekends. For specific monitoring periods in the experiment, please refer to section [Study area](#) Study area.

Data processing method

After monitoring, the data must be desensitised and pre-processed to isolate the indicators $P_{i,j}$ and $P_{b,i,j}$ related to the flow of people and $t_{a,i,j}$ and $n_{i,j}$ related to the length of stay. Data preprocessing method for indicators related to people flow. First, after removing frequently and randomly appearing addresses [34], we filtered the probe request records within each public

space based on the RSSI. Second, based on the MAC address and timestamp information, the number of MAC addresses appearing in each space on an hourly and minute basis was counted. This derived the people’s flow per hour ($P_{i,j}$) and people’s flow per minute ($P_{b,i,j}$) for each public space.

Data preprocessing method for indicators related to retention durability. This study considers the same MAC continuously monitored in the same public space as a single visit. If the MAC address was not continuously detected for more than 5 min, the single retention was assumed to have ended. Based on the MAC address and timestamp information provided by the detection request records, the time difference between the first entry and exit of the same MAC address in the monitoring range during a single hourly retention was calculated. The result obtained is the individual’s single retention length in the public space ($t_{a,i,j}$), and the number of MAC

Table 1 Indicator system for comprehensive calculation of dynamic vitality

Dimension	Indicator	Concept	Calculation	Formula ^c
Space	Retention Intensity	The ability to attract crowds	The people's flow per square meter per hour	$D_{ij} = \frac{P_{ij}}{S_j} D_{ij}$; the retention intensity of space j at hour i ; P_{ij} : the people's flow in space j at hour i ; S_j : the area of space j
	Retention Connection Intensity	The ability to provide connections for crowds in adjacent spaces	Building a network by using public spaces as nodes and people's flow between the nodes as edges, then calculating the degree centrality of each node ^a	$C_{ij} = k_{ij} \sqrt{\frac{P_{ij}-P_{j-1}}{k_{ij}}} C_{ij}$; the retention connection intensity of space j at hour i ; P_{ij} : the people's flow in space j at hour i ; k_{ij} : the number of adjacent nodes for space j
Time	Retention Durability	The ability to attract people to stay for a long time	The average duration of crowd stay	$T_{ij} = \frac{\sum_{a=1}^{n_{ij}} t_{a,ij}}{n_{ij}} T_{ij}$; the average duration of crowd stay in space j at hour i ; $t_{a,ij}$: individual a 's single retention length in space j at hour i ; n_{ij} : the total number of people who stay in space j at hour i
	Retention Stability	The ability to maintain high people's flow for long-term retention	The cumulative duration when measuring people's flow exceeds the standard people's flow ^b	$F_{ij} = \frac{\sum_{b=1}^{60} M(\frac{P_{b,ij}}{S_j})}{60} F_{ij}$; the retention stability of space j at hour i ; $P_{b,ij}$: the people's flow in space j at minute b in hour i ; $M(P_{b,ij}/S_j)$: the indicator to determine whether the people's flow in space j at minute b in hour i ($P_{b,ij}$) exceeds the standard people's flow (Q_s). When $P_{b,ij}/S_j \geq Q_s$, $M(P_{b,ij}/S_j) = 1$, otherwise $M(P_{b,ij}/S_j) = 0$

^a Node centrality: Using undirected weighted networks, the final degree centrality of a node is determined by the number of adjacent nodes and the weight of connected edges

^b Standard people's flow (Q_s): formulated based on the people's capacity index in the "General Specification for Calculation of Tourist Capacity in Chinese Tourist Attractions" (0.1–0.2 person/h m²)

^c Data sources: P_{ij} and $P_{b,ij}$ are from people's flow data monitored by WiFi probes; $t_{a,ij}$ and n_{ij} are from length of stay data monitored by WiFi probes. The processing methods for these data are detailed in section [Data processing method](#); S_j and k_{ij} are calculated based on the topographic map

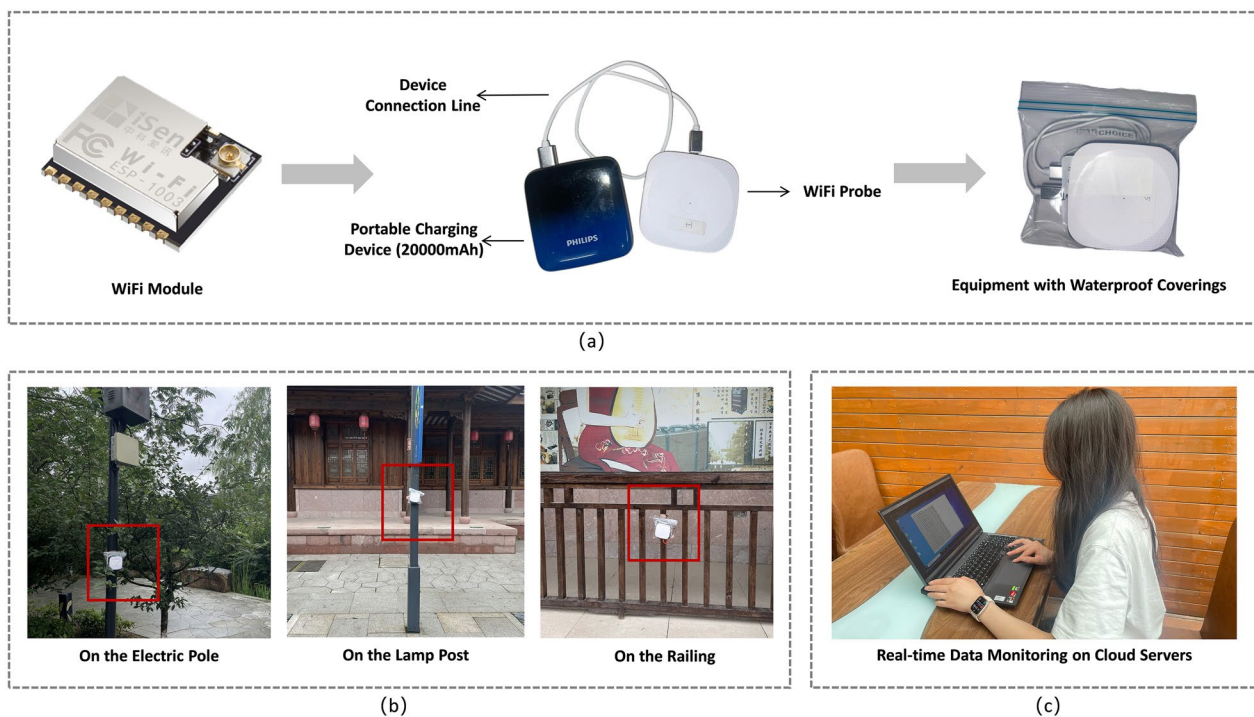


Fig. 2 Monitoring methods using WiFi probes. **a** The setup of WiFi Probes. **b** The installation of WiFi Probes. **c** Real-time data monitoring

addresses monitored in the public space during that hour is considered the hourly number of visitors ($n_{i,j}$).

Comprehensive calculation of dynamic vitality

Calculation and grading method

To minimise the impact of subjective human factors in assigning weights to indicators and enhance the objectivity of the results, this study used the entropy method [39] to assign weight values to each indicator following their standardisation. Subsequently, a weighted sum was calculated to derive the comprehensive value of the dynamic vitality. We used the natural breakpoint method [40] to divide the comprehensive value of the dynamic vitality of each public space into four levels: high, medium-high, medium-low, and low. The comprehensive value of the dynamic vitality of medium-low and low-vitality spaces is relatively low, making them suitable for renovation and upgrading. Spaces with high and medium-high vitality may have comprehensive vitality, hosting a variety of activities. These can serve as subjects for observing dynamic vitality scenarios, thereby laying the groundwork for the spatiotemporal synergistic vitality enhancement of both medium-low and low vitality spaces.

Result verification method

Vitality is an abstract concept. To ensure the accuracy of the measurement results, a questionnaire survey was

conducted to verify the results of the comprehensive measurement of dynamic vitality from a humanistic perspective. In the experiment, the study randomly invited 70 villagers and tourists to rate the vitality of public spaces based on their experiences and took the average of these ratings as the survey value of the dynamic vitality. After normalizing the questionnaire survey value and the comprehensive calculation of dynamic vitality, the two were tested for consistency using the Kendall coefficient [41] in SPSS 22.0. A coefficient greater than 0.9 indicates that the assessment result has a certain degree of credibility and stability [42].

Analysis of dynamic vitality scenario

A five-dimensional analysis framework for dynamic vitality scenarios

Previous studies have often analysed crowd behaviour in two spatial dimensions, such as investigating the correlations between spatial structure types and tourist behaviour characteristics, or studying tourist behaviour from time and spatial distribution [21, 22]. This article constructs an analysis framework for the dynamic vitality scenarios of traditional village public spaces in five dimensions: 'time-space-function-visitor-behavior'. Based on a comprehensive calculation of dynamic vitality, this analysis can further incorporate spatial function,

visitor type, and visitor behaviour to balance dynamism and humanism.

Key space and time selection

Comprehensive information on visitor types and behaviours can be obtained during periods of high retention intensity in high and medium-high vitality spaces; thus, the objectivity of analysing the pattern dynamic vitality scenario can be guaranteed. This study selected high vitality and medium-high vitality spaces as observation spaces based on a comprehensive calculation of dynamic vitality and selected the time with the highest retention intensity for focused observation.

Analysis of function, visitor type and behaviour in the space based on static snapshot

This study divided traditional village public spaces into four functional types: historical, commercial, recreational, and living. Visitor types were divided into two categories: individuals and groups. Visitor behaviours can be divided into four categories: taking photos, walking, resting, and trading. By analysing the dynamic situational differences in space functions, visitor types, and behaviours in high and medium-high vitality spaces, the results may provide an analytical perspective for the synergistic

enhancement of functions and activity organisation in low and medium-low vitality spaces.

The static snapshot method [43] was selected to observe and quantitatively analyse visitor types and behaviour. This involves analysing visitors’ type and behaviour based on a photo taken every five minutes within the key observation time and space.

Study area

Yantou Village, Lishui City, Zhejiang Province, China, was used as the study area. Yantou Village is a traditional national-level village adjacent to the 4 A level scenic area of the Guyan Scenic Resort. It attracts a substantial number of tourists, exceeding 300,000 annual visits. However, there are significant disparities in the dynamics of people’s flow in public spaces, necessitating a high demand to improve these spaces with vitalities of varying grades. Thus, the village presents an excellent case study.

There were 26 public spaces in Yantou Village. However, some cannot be accessed in the long term because of construction or limited openings. Only 17 of these spaces were selected for the study, and Wi-Fi probes were placed accordingly (Fig. 3). We monitored the space for 1 week, from 13 November to 19 November 2023, covering five weekdays and two weekends from 8:00 am to 8:00 pm each day. During the monitoring period, a perception

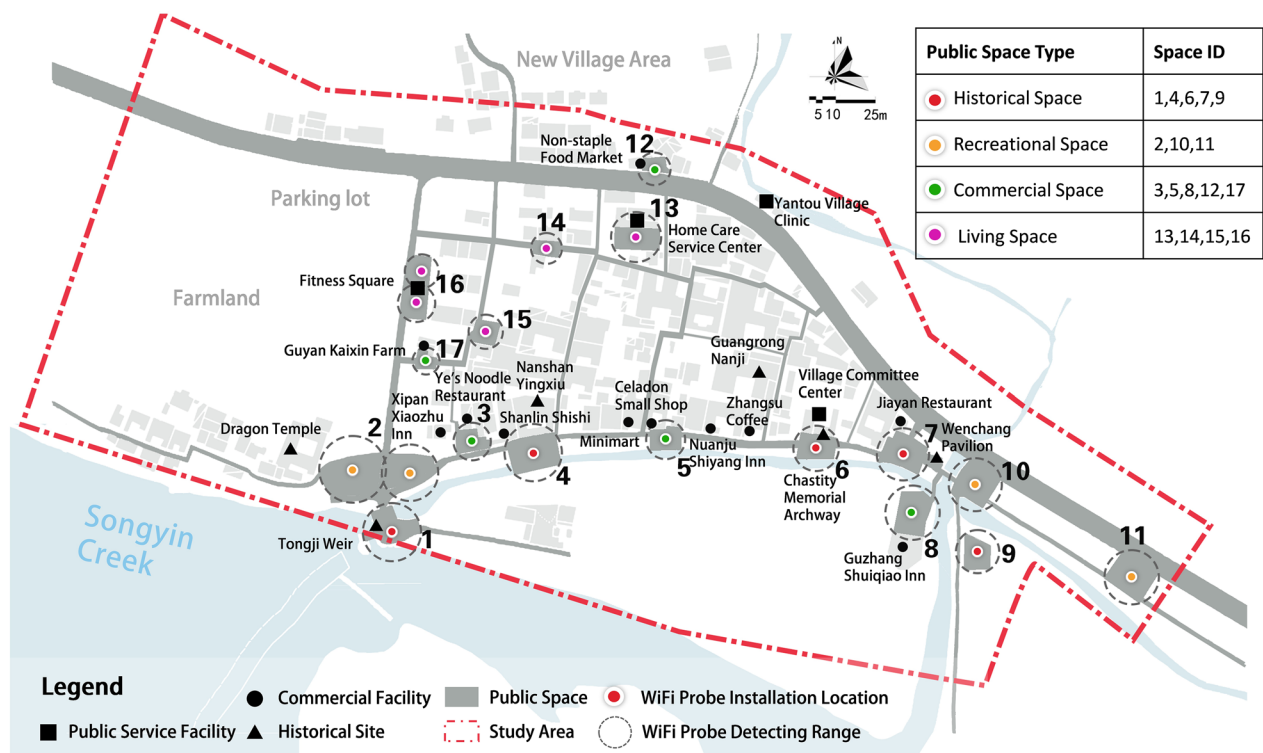


Fig. 3 The location of 17 public spaces and the WiFi probes in the study area

questionnaire survey on dynamic vitality and static snapshot photography were conducted simultaneously.

Result

Comprehensive measurement of dynamic vitality

Calculation of dynamic vitality indicators

According to the calculations (Fig. 4), all four vitality indicators of the public spaces along the river in Yantou Village were high, but varied cross the whole village. First, the retention intensity was uneven distributed, with only four public spaces along river showing relatively high values. Second, the retention connection intensity in the public spaces along the river (Spaces 1–10) all demonstrated high levels, with an average value of 0.576. Third, the retention durability was on an average low, with significant spatial variances and an uneven distribution, such as Spaces 3 (11.492) and 5 (11.723) having high retention durability values, and Space 13 showing the lowest (3.326). Fourth, retaining stability was highly valued in public spaces along the river, but the total difference was not substantial.

Comprehensive calculation of dynamic vitality

After calculation (Fig. 5), the comprehensive dynamic vitality values of public spaces in Yantou Village were low, with an average score of 0.368, ranging from 0.029 to

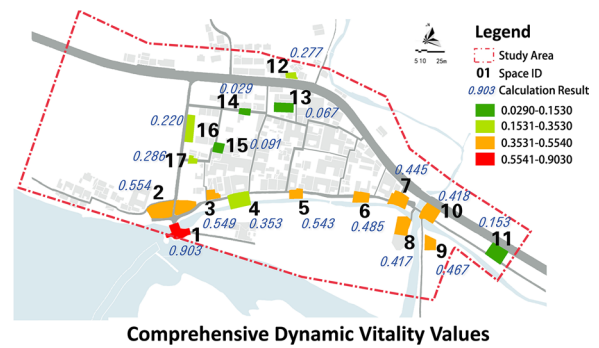


Fig. 5 Comprehensive dynamic vitality values of public spaces in Yantou Village

0.903, and a large polarisation difference, showing a clear normal distribution, which was consistent with the actual situation. After using natural breakpoints to grade, we found there was one high vitality space, eight medium-high vitality spaces, four medium-low spaces and four low vitality spaces in Yantou Village. First, the only high vitality space in the village (Space 1, with a vitality value of 0.903), has a famous historical relic that encourages people to linger for a long time to enjoy the scenery. Second, the four low vitality spaces indicated a pressing need for vitality improvement, as their average value was

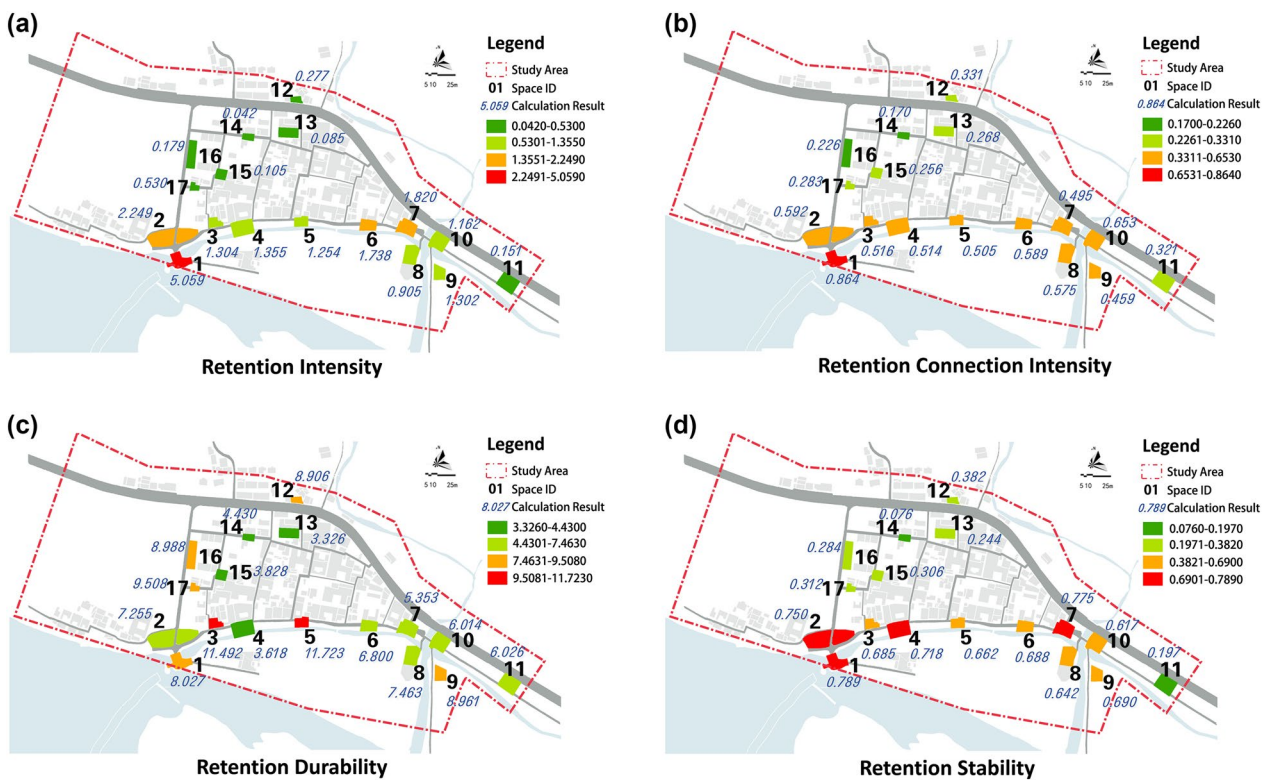


Fig. 4 Calculations of dynamic vitality indicators in Yantou Village

significantly low (0.184), such as Space 13 (0.067), Space 14 (0.029), and Space 15 (0.091), which are mostly located in the village’s interior and are primarily used by locals with low utilization rates.

Verification of comprehensive vitality

We invited tourists and villagers to evaluate the dynamic vitality of the public spaces in Yantou Village based on their actual perceptions during on-site visits, successfully collecting 70 valid questionnaires (31 villagers and 39 tourists). The questionnaire results into SPSS 22.0. for the reliability analysis and obtained a Cronbach’s coefficient of 0.891, indicating high reliability across all questionnaire outcomes. Therefore, the study assessed the consistency of the average scores of every public space from the questionnaires and calculated the values of the comprehensive dynamic vitality (Fig. 6), resulting in a Kendall harmony coefficient of 0.908, which is greater than 0.9. This indicates that the two measures were highly consistent and that the calculated value of the comprehensive dynamic vitality of each public space is closely related to the actual perception; thus, the results were objective and valid.

Dynamic analysis of the pattern of vitality scenarios

Key spatiotemporal selection

We chose nine high and medium-high vitality spaces in Yantou Village, obtained from the comprehensive value of dynamic vitality as the key observation spaces. Based on the analysis of the results of these spatial retention intensities, the periods with the highest weekday retention intensity were 10:00–11:00, and the times with the highest weekend retention intensity were 10:00–11:00 and 14:00–15:00. Therefore, these three periods were selected as the key observation times.

Scenario pattern features

According to statistics (Fig. 7), a comparison of the scenarios of dynamic vitality on weekend mornings (10:00–11:00) and afternoons (14:00–15:00) revealed that the commercial spaces and historical spaces were mainly composed of tourist groups, reaching 65% and 54%, respectively. Recreational spaces were mainly composed of individual tourists, accounting for the highest proportion (81.25%). Moreover, in terms of behavioural dynamics, the proportion of photos taken in commercial and recreational spaces in the afternoon (8.33% and 18.75%, respectively) was higher than that in the morning (3.10% and 3.13%, respectively). However, the behaviour in the morning was more diverse, and the sum of the percentages of taking photos, resting, and trading was more than 40%. Second, compared trading in historical and recreational spaces which accounted for less than 1.7% in both periods, the proportion of trading in commercial spaces was relatively high, reaching 34.96% and 11.46% on weekend mornings and afternoons, respectively. Third, the proportions of photography activities during the morning and afternoon hours of weekends in historical spaces, were 28.34% and 29.94%, respectively, which significantly surpassed the percentages in the other two types of spaces.

According to the statistics (Fig. 7), a comparison of the scenarios of dynamic vitality on weekdays and weekends from 10:00 to 11:00 showed that, first, groups of tourists dominated all key spaces, accounting for more than 50%. On weekend mornings, the percentages of individual and group tourists in commercial and recreational areas were almost equal (53.56% and 46.44%, respectively, in commercial spaces, and 53.85% and 46.15%, respectively, in recreational spaces). Second, historical-cultural spaces showed more photo-taking behaviour on both weekdays and weekends, accounting for 37.80% and 28.34%,

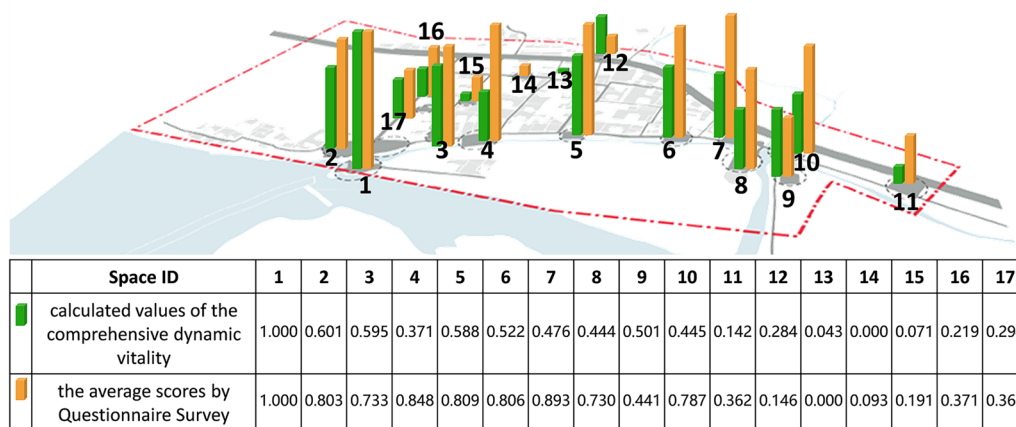


Fig. 6 A comparison of the dynamic vitality results by comprehensive calculations and questionnaire surveys

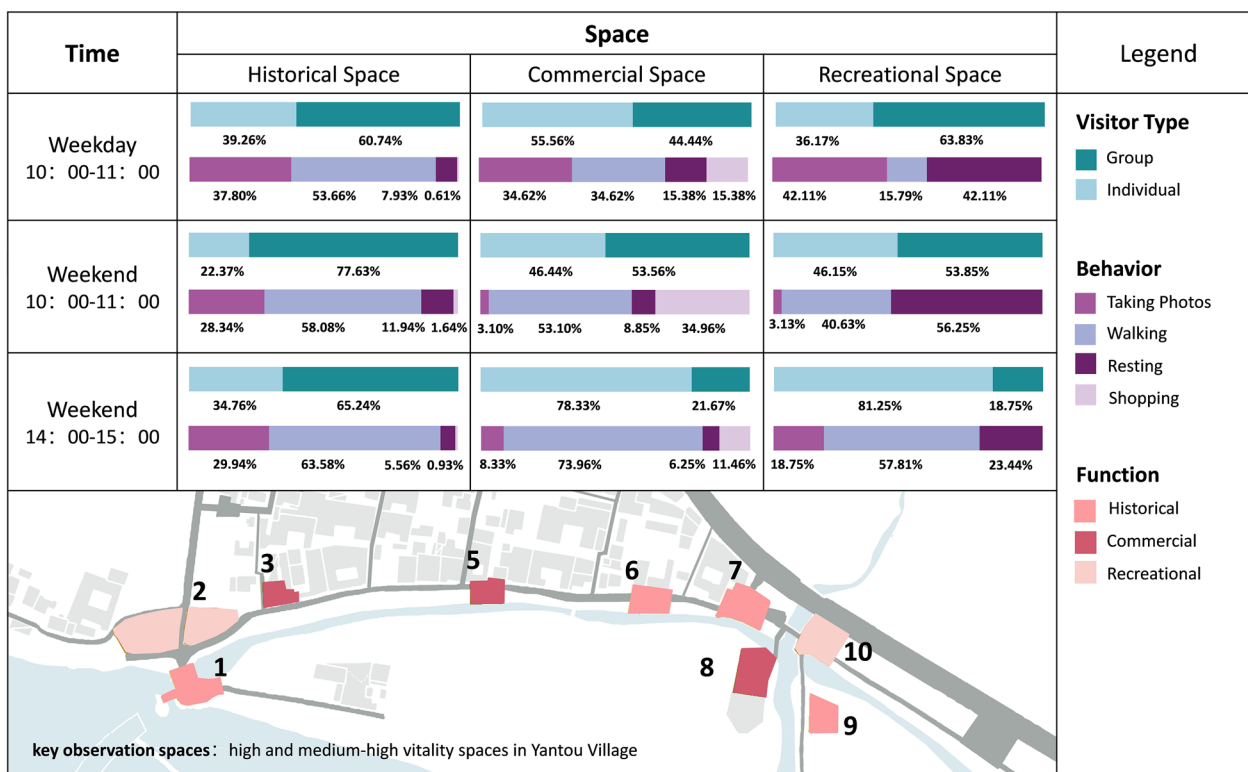


Fig. 7 A comparison of dynamic vitality scenarios in five dimensions

respectively. The proportion of people resting in recreational spaces was relatively high, with 42.11% and 56.25% resting in these two periods, respectively. Third, on weekdays, the proportion of photos taken in these three types of spaces was high, above 34.62%. On weekends, the proportion of photo-taking behaviour was small, especially in commercial and recreational spaces, where the percentages were 3.10% and 3.13%, respectively.

Discussion

Applicability of the assessment

The assessment can scientifically analyse the dynamic vitality of public spaces in tourism-oriented traditional villages, clarify the foundation for spatiotemporal synergistic vitality enhancement for these public spaces, and help differentiate renewal strategies based on grades of comprehensive dynamic vitality. Taking Yantou Village in Lishui as an example, this method can be used to develop the following strategies.

Space enhancement strategies based on dynamic vitality grades and features

When enhancing the vitality of public spaces in Yantou Village, it is advisable to differentially allocate policies, funds, and management efforts based on the varying grades of existing dynamic vitality, incorporating various

renewal focuses and specific vitality features. For example, if Yantou Village focuses on improving low vitality public spaces, it can renovate the four low vitality spaces, especially public spaces 11 and 13. If Yantou Village focuses on establishing high vitality public space networks, it can develop strategies to enhance the vitality along its waterfront public spaces. One high vitality and eight medium-high vitality spaces along the river can be connected and upgrading the historical, cultural, and commercial attractions in these nine spaces along the river can create a vibrant waterfront scenic belt.

Space enhancement strategies based on dynamic vitality scenario analysis

When enhancing the vitality of public spaces in Yantou Village, effective spatiotemporal synergistic strategies can be developed to adapt to the dynamics of visitor type and behaviour in medium and low vitality spaces, based on the scenario patterns of high and medium-high vitality spaces. For instance, the results of this study demonstrated that the highest retention intensity in high and medium-high vitality spaces in Yantou Village was between 10:00–11:00 and 14:00–15:00, with group tourists taking photos and resting as the main behaviours. Therefore, when synergistically enhancing their medium-low and low vitality spaces, time and functional mismatches should be

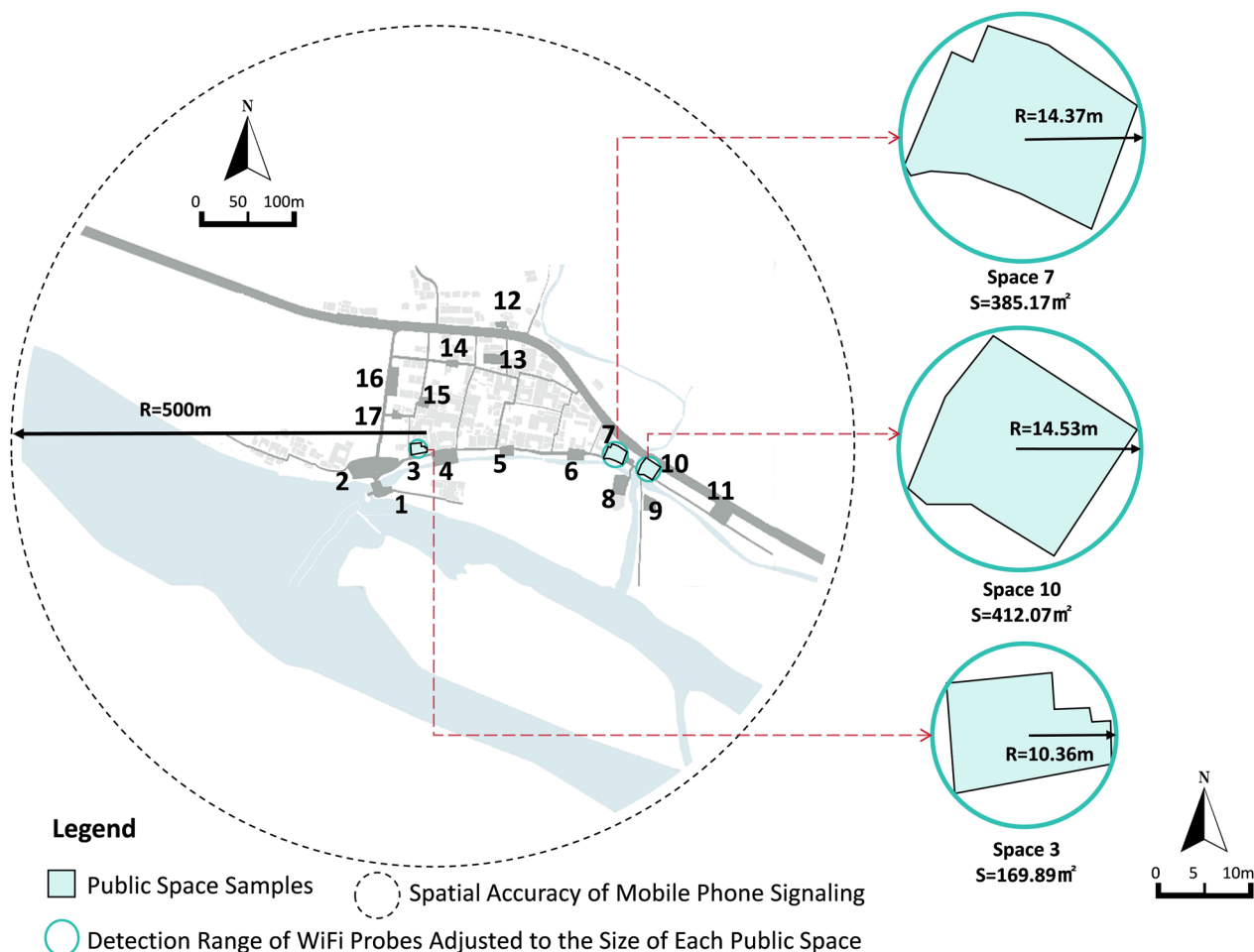


Fig. 8 A spatial accuracy comparison between mobile phone signaling and WiFi probes used in a traditional village

considered, with a focus on enhancing the crowd-attraction strategy from 11:00 to 14:00. Since this period is considered lunchtime, it is advisable to develop additional catering services around medium-low and low vitality spaces, offering lunches and other casual services tailored to accommodate tourist groups at noon.

Advantages of evaluation methods in terms of spatiotemporal accuracy and operability

Traditional village public spaces are small in scale, typically ranging from 15 m to 70 m in length. Although big data are widely used in vitality research on urban public spaces, their spatiotemporal accuracy in rural areas is low [44, 45]. For instance, mobile phone signalling data in rural areas are often unstable [46], with a spatiotemporal accuracy of 500 m and more than 1 h [28], making it difficult to precisely measure small-scale space vitality dynamics in rural areas. However, the spatiotemporal accuracy of the Wi-Fi probe was 0.01 m per second [47], and the measurement range could be actively adjusted according

to the actual size of the public space to maximise precise coverage. Compared to the evaluation of mobile phone signalling data, Wi-Fi probes can significantly improve the spatiotemporal accuracy of the evaluation (Fig. 8). Wi-Fi probe devices are inexpensive, with low usage thresholds, simple operation, and easy installation.

Current shortcomings and future prospects

The research has some limitations: (1) The comprehensive calculation of dynamic vitality based on Wi-Fi probe monitoring is still difficult to cover for people who do not use mobile phones, such as the elderly and children, who make up a portion of the rural population. Thus, it cannot perfectly match the actual flow of people in small public spaces¹, resulting in slight data discrepancies.

¹ The measurement range of Wi-Fi probes cannot completely overlap with the actual spatial range, and there may still be errors in monitoring the residence of people in the edge areas of public spaces, possibly monitoring people within a range of about 5 m outside the space.

(2) Scenario analysis based on static snapshots requires many workforce and multi-day photo shoots to collect and process the large amount of photographic data. In the future, we will investigate the capability of artificial intelligence to upgrade static snapshots and quickly identify visitor type and behaviours in traditional village public spaces. We can also add onsite monitoring, conduct differentiated comparisons, and summarise the patterns of dynamic vitality in diverse types of traditional villages.

Conclusion

Public spaces serve as the foundation for attracting visitors to traditional tourism-oriented villages and are the root vitality for the development, preservation, and inheritance of such rural cultural heritage. Furthermore, it is an important spatial feature for maintaining the value and connotations of traditional village heritage sites. The current assessment of vitality is hampered by low spatiotemporal data accuracy and a lack of knowledge of time-segmented vitality.

Therefore, this study employed a collaborative active perception method based on Wi-Fi probes and static snapshots to dynamically assess the vitality of public spaces in traditional villages. Taking Yantou Village in Lishui, China as an example, seven-day on-site monitoring was conducted, revealing dynamic variances and scenario patterns of its public space vitality: (1) The comprehensive vitality of Yantou Village's public spaces was relatively low, with a large disparity unevenly distributed among high and medium-high vitality spaces centred along the river. (2) During the key observation period, public spaces in Yantou Village with high and medium-high vitality were dominated by individuals on weekend afternoons and groups of people on weekdays and weekend mornings. (3) Compared to weekend afternoons, people's behaviours were more diverse during the key observation periods on weekdays and weekend mornings; on weekend mornings, resting and trading occurred more frequently in recreational and commercial spaces, while taking photos was more common in historical spaces.

This method can dynamically and humanistically analyse the spatiotemporal variations and scenario patterns of the vitality of small public spaces in traditional villages. First, it may upgrade the relevant vitality assessment method from 'static and materialized' to 'dynamic and humanistic', deepening the theoretical understanding of people's flow in traditional villages in the context of cultural tourism. Second, this method is helpful for scientifically understanding the phenomenon of regional vitality differentiation and revealing the causal laws of utilizing its vitality evolution. Third, it may offer the groundwork for spatiotemporal synergistic vitality enhancement in

traditional villages while also providing insights into their revitalization.

Abbreviations

MAC	Mac Access Control
GPS	Global Positioning System
RSSI	Received Signal Strength Indication

Acknowledgements

Authors thank the National Natural Science Foundation of China (Grant Number 51908495) for the financial support of this study.

Author contributions

S.L.: conceptualization, methodology, writing and review; Z.Z.: experiment, data curation, analysis and writing; Y.G.: review and editing; S.W.: experiment, data curation. All authors read and approved the final manuscript.

Funding

This research was funded by the National Natural Science Foundation of China (Grant number 51908495).

Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

Received: 23 July 2024 Accepted: 27 September 2024

Published online: 04 October 2024

References

- Feng J. The dilemma and outlet of traditional villages: also on traditional villages as another kind of Cultural Heritage. *Folk Cult Forum*. 2013;01:7–12. <https://doi.org/10.16814/j.cnki.1008-7214.2013.01.002>.
- Zhang H, Chen J, Zhou C. Research review and prospects of traditional villages in China. *City Plan Rev*. 2017;41(4):74–80.
- Abusaada H, Elshater A. Revealing distinguishing factors between space and place in urban design literature. *J Urban Des*. 2021;26(3):319–40. <https://doi.org/10.1080/13574809.2020.1832887>.
- Xing Y, Leng J. Evaluation of public space in traditional villages based on eye tracking technology. *J Asian Archit Build Eng*. 2024;23(1):125–39. <https://doi.org/10.1080/13467581.2023.2229410>.
- Xu Y, Rollo J, Jones DS, et al. Towards sustainable heritage tourism: a space syntax-based analysis method to improve tourists' spatial cognition in Chinese historic districts. *Buildings*. 2020;10(2):29. <https://doi.org/10.3390/buildings10020029>.
- Zakariya K, Harun NZ, Mansor M. Place meaning of the historic square as tourism attraction and community leisure space. *Procedia - Soc Behav Sci*. 2015;202:477–86. <https://doi.org/10.1016/j.sbspro.2015.08.196>.
- The General Office of the CPC Central Committee and the General Office of the State Council. Opinion on strengthening the protection and inheritance of historic and cultural heritage in the course of urban-rural development. 2021. https://www.gov.cn/gongbao/content/2021/content_5637945.htm. Accessed 1 Jul 2024.
- Xu D, Zhang Z, Zhu W, et al. Compatible or exclusive? Mechanism study on different preferences of public space between villagers and tourists in the tourism-oriented villages. *New Archit*. 2022;03:101–6.
- Song J, Zhu Y, Chu X, et al. Research on the vitality of public spaces in tourist villages through social network analysis: a case study of Mochou Village in Hubei, China. *Land*. 2024;13(3):359. <https://doi.org/10.3390/land13030359>.
- Lavrusheva O. The concept of vitality. Review of the vitality-related research domain. *New Ideas Psychol*. 2020;56:100752. <https://doi.org/10.1016/j.newideapsych.2019.100752>.

11. Etuk L. 2000 Baseline Assessment of Rural Community Vitality. Oregon: Oregon State University; 2012.
12. Hu Y, Chen S, Cao W, et al. The concept and cultural connotation of traditional villages. *Urban Dev Stud*. 2014;21(01):10–3.
13. Zhang J, Zhang R, Li Q, et al. Spatial differentiation and differentiated development paths of traditional villages in Yunnan province. *Land*. 2023;12(9):1663. <https://doi.org/10.3390/land12091663>.
14. Huang X, Gong P, Wang S, et al. Machine learning modeling of vitality characteristics in historical preservation zones with multi-source data. *Buildings*. 2022;12(11):1978. <https://doi.org/10.3390/buildings12111978>.
15. Zumelzu A, Barrientos-Trinanes M. Analysis of the effects of urban form on neighborhood vitality: five cases in Valdivia, Southern Chile. *J Hous Built Environ*. 2019;34(3):897–925. <https://doi.org/10.1007/s10901-019-09694-8>.
16. Ding J, Gao Z, Ma S. Understanding social spaces in tourist villages through space syntax analysis: cases of villages in Huizhou. *China Sustain*. 2022;14(19):12376. <https://doi.org/10.3390/su141912376>.
17. Zhang Y, Han Y. Vitality evaluation of historical and cultural districts based on the values dimension: districts in Beijing City, China. *Herit Sci*. 2022;10(1):137. <https://doi.org/10.1186/s40494-022-00776-5>.
18. Saputra AA, Surjono S, Meidiana C. Vitality of Giri Kedaton Site as a religious tourism attraction in Sidomukti Village, Kebomas, Gresik. *J Indones Tour Dev Stud*. 2015;3(3):93–104. <https://doi.org/10.21776/ub.jitode.2015.003.03.02>.
19. Niu Y, Mi X, Wang Z. Vitality evaluation of the waterfront space in the ancient city of Suzhou. *Front Archit Res*. 2021;10(4):729–40. <https://doi.org/10.1016/j.foar.2021.07.001>.
20. Rastegar N, Ahmadi M, Malek M. Factors affecting the vitality of streets in downtown Johor Bahru City. *Indian J Sci Res*. 2014;7(1):361–74.
21. Mu B, Liu C, Mu T, et al. Spatiotemporal fluctuations in urban park spatial vitality determined by on-site observation and behavior mapping: a case study of three parks in Zhengzhou City, China. *Urban Urban Green*. 2021;64:127246. <https://doi.org/10.1016/j.ufug.2021.127246>.
22. Liu F, Sun D, Zhang Y, et al. Tourist landscape preferences in a historic block based on spatiotemporal big data—a case study of Fuzhou, China. *Int J Environ Res Public Health*. 2023;20(1):83. <https://doi.org/10.3390/ijerph20010083>.
23. Kang C-D. Effects of the human and built environment on neighborhood vitality: evidence from Seoul, Korea, using mobile phone data. *J Urban Plan Dev*. 2020;146(4):05020024. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000620](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000620).
24. Chen Z, Lin Y, Xie J, Xie Z, Xie X, Ding Z. Research on the impact of landscape quality of traditional village tourism destinations on spatial vitality: an empirical study of Beigang Village in Pingtan County based on multi source data and machine learning. *Ind Constr*. 2023 Dec 4. <https://link.cnki.net/urlid/11.2068.TU.20231204.1037.002>. Accessed 1 Jul 2024.
25. Gong Y, Ji X, Zhang Y, et al. Spatial vitality evaluation and coupling regulation mechanism of a complex ecosystem in Lixiahe plain based on multi-source data. *Sustainability*. 2023;15(3):2141. <https://doi.org/10.3390/su15032141>.
26. Zhang F, Liu Q, Zhou X. Vitality evaluation of public spaces in historical and cultural blocks based on multi-source data, a case study of Suzhou Changmen. *Sustainability*. 2022;14(21):14040. <https://doi.org/10.3390/su142114040>.
27. Ginzarly M, Pereira Roders A, Teller J. Mapping historic urban landscape values through social media. *J Cult Herit*. 2019;36:1–11. <https://doi.org/10.1016/j.culher.2018.10.002>.
28. Zhou J, Hou Q, Dong W. Spatial characteristics of population activities in suburban villages based on cellphone signaling analysis. *Sustainability*. 2019;11(7):2159. <https://doi.org/10.3390/su11072159>.
29. Li M, Liu J, Lin Y, et al. Revitalizing historic districts: identifying built environment predictors for street vibrancy based on urban sensor data. *Cities*. 2021;117:103305. <https://doi.org/10.1016/j.cities.2021.103305>.
30. Martins Gnecco V, Pigliautile I, Pisello AL. Long-term thermal comfort monitoring via wearable sensing techniques: correlation between environmental metrics and subjective perception. *Sensors*. 2023;23(2):576. <https://doi.org/10.3390/s23020576>.
31. Ito K, Kang Y, Zhang Y, et al. Understanding urban perception with visual data: a systematic review. *Cities*. 2024;152:105169. <https://doi.org/10.1016/j.cities.2024.105169>.
32. Li Y, Yabuki N, Fukuda T. Integrating GIS, Deep learning, and environmental sensors for multicriteria evaluation of urban street walkability. *Landsc Urban Plan*. 2023;230:104603. <https://doi.org/10.1016/j.landurbplan.2022.104603>.
33. Martani C, Stent S, Acikgoz S, et al. Pedestrian monitoring techniques for crowd-flow prediction. *Proc Inst Civ Eng - Smart Infrastruct Constr*. 2017;170(2):17–27. <https://doi.org/10.1680/jsmic.17.00001>.
34. Zhou Y, Lau BPL, Koh Z, et al. Understanding crowd behaviors in a social event by passive wifi sensing and data mining. *IEEE Internet Things J*. 2020;7(5):4442–54. <https://doi.org/10.1109/JIOT.2020.2972062>.
35. Soszyński D, Sowińska-Świerkosz B, Kamiński J, et al. Rural public places: specificity and importance for the local community (case study of four villages). *Eur Plan Stud*. 2022;30(2):311–35. <https://doi.org/10.1080/09654313.2021.1948974>.
36. Shen L, Li Y, Lan S, et al. Social benefits evaluation of rural micro-landscapes in southeastern coastal towns of China—the case of Jinjiang. *Fujian Sustain*. 2022;14(13):8036. <https://doi.org/10.3390/su14138036>.
37. Traunmueller MW, Johnson N, Malik A, et al. Digital footprints: using WiFi probe and locational data to analyze human mobility trajectories in cities. *Comput Environ Urban Syst*. 2018;72:4–12. <https://doi.org/10.1016/j.compenvurbsys.2018.07.006>.
38. Chilipirea C, Dobre C, Baratchi M et al. Identifying Movements in Noisy Crowd Analytics Data. In: 2018 19th IEEE International Conference on Mobile Data Management (MDM). 2018; pp. 161–166. <https://doi.org/10.1109/MDM.2018.00033>.
39. Shannon CE. A mathematical theory of communication. *Bell Syst Tech J*. 1948;27(3):379–423. <https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>.
40. Jenks GF. The data model concept in statistical mapping. *Int Yearb Cartogr*. 1967;7:186–90.
41. Croux C, Dehon C. Influence functions of the Spearman and Kendall correlation measures. *Stat Methods Appl*. 2010;19(4):497–515. <https://doi.org/10.1007/s10260-010-0142-z>.
42. Puth M-T, Neuhäuser M, Ruxton GD. Effective use of Spearman's and Kendall's correlation coefficients for association between two measured traits. *Anim Behav*. 2015;102:77–84. <https://doi.org/10.1016/j.anbehav.2015.01.010>.
43. O'Neill E, Kostakos V, Kindberg T, et al. Instrumenting the city: developing methods for observing and understanding the Digital Cityscape. In: Dourish P, Friday A, Editors. *UbiComp 2006: ubiquitous computing*. Berlin Heidelberg: Lecture Notes in Computer Science Springer Berlin Heidelberg; 2006. pp. 315–32. <https://doi.org/10.1007/1185356519>.
44. Iovan C, Olteanu-Raimond A-M, Couronné T, et al. Moving and calling: mobile phone data quality measurements and spatiotemporal uncertainty in human mobility studies. In: Vandenbroucke D, Bucher B, Crompvoets J, editors. *Geographic Information Science at the heart of Europe*. Lecture Notes in Geoinformation and Cartography Springer International Publishing. Cham; 2013. pp. 247–65. https://doi.org/10.1007/978-3-319-00615-4_14.
45. Chen C, Bian L, Ma J. From traces to trajectories: how well can we guess activity locations from mobile phone traces? *Transp Res Pt C-Emerg Technol*. 2014;46:326–37. <https://doi.org/10.1016/j.trc.2014.07.001>.
46. Ghahramani M, Zhou M, Wang G. Urban sensing based on mobile phone data: approaches, applications, and challenges. *IEEE/CAA J Autom Sinica*. 2020;7(3):627–37. <https://doi.org/10.1109/JAS.2020.1003120>.
47. Svečko J, Malajner M, Gleich D. Distance estimation using RSSI and particle filter. *ISA Trans*. 2015;55:275–85. <https://doi.org/10.1016/j.isatra.2014.10.003>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.