The Renewal of the Space Under the Bridge Based on Thermal Analysis

Taking the Bayi Bridge as an Example

Master's Thesis by Jiangge He
MSc. Program in Architecture for Heritage
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Student Jiangge He
Supervisor Riccardo Pollo
Co-supervisor Anja Pejovic

Abstract

With the advancement of global urbanization, under-bridge spaces in cities often become idle gray areas. Donghu District, Nanchang, where Bayi Bridge is located, faced a severe aging problem, and the under-bridge space has become an important social and activity venue for surrounding elderly residents. This study conducts multidimensional research on the space under the Bayi Bridge through site analysis, questionnaire survey, ENVI-met microclimate simulation, and case studies. The questionnaire survey shows that the elderly's main needs focus on infrastructure such as seating and toilets, as well as activities like chess and light exercise, while the existing community elderly services are severely insufficient. Microclimate simulation indicates that the Physiological Equivalent Temperature (PET) in the shaded area under the bridge is stable with short heat stress duration, and the thermal comfort is significantly better than that of the surrounding areas. This study proposes targeted design strategies: preserving existing shade trees, demolishing idle buildings, arranging core functional areas in low heat stress regions, improving high heat stress areas through waterscape and grove, constructing activity venues with lightweight camphorwood frame, and optimizing functional layout to meet the elderly's needs for daily life, social interaction, and spiritual and cultural activities. This research provides a feasible plan for the aging-friendly renewal of urban under-bridge spaces.

Keywords: Under-bridge space renewal; Aging-friendly; Microclimate simulation; Thermal comfort; Functional optimization

Contents

1. Introduction

By 2050, the total global population is predicted to increase from 8.1 billion to over 9 billion, of which approximately 70% will live in cities (Esch et al., 2017). Population growth and related global urbanization pose one of the major challenges for a sustainable future (Esch et al., 2017). Since the 1990s, China's rapid urbanization has led to significant economic growth and urban prosperity (Sun et al., 2020). At the same time, in the rapid process of urbanization, people gradually realize that prioritizing the scale and speed of urbanization over other factors undermines the essential values of urban space. The current urbanization process in China presents typical rapid expansion characteristics, lacking a coordinated planning concept and a reasonable spatial layout. In addition, the urban terrain obstacles formed by historical legacy problems have collectively led to a large amount of idle and wasted marginal land. These surplus lands located on the outskirts of cities are often constrained by multiple factors such as complex property rights, unclear functional positioning, and difficulty in transformation, making them difficult to reuse. The space under the elevated bridge is one of the most representative types of remaining land in such cities – they are both fragmented spaces left behind by urbanization and witnesses to the disorderly planning in the process of urban development. These forgotten corners not only result in inefficient use of land resources, but also disrupt the continuity of urban space, becoming a spatial governance challenge to be solved in the process of urbanization.

The gray space under elevated bridges has become a unique phenomenon that cannot be ignored in modern urban development. These transitional areas formed by massive transportation infrastructure often give people a repressed visual experience – the shadows cast by concrete columns, the sense of closure formed by the top structure, and the continuous traffic noise, collectively shaping the common impression of dim and noisy spaces. However, with the deepening of urbanization and the increasing scarcity of urban land resources, these previously overlooked spaces under bridges are showing new dimensions of value. From the perspective of spatial resource utilization, the area under the elevated bridge contains enormous development potential. Its large-scale spatial characteristics and unique location advantages provide new possibilities for improving urban spatial utilization. More importantly, if these spaces under bridges are redefined as an important component of urban public open spaces, it can not only effectively alleviate the current situation of insufficient supply of urban open spaces, but also meet the growing demand for leisure activities among citizens. The transformation of this spatial function is not only a creative reuse of urban land resources, but also a response to the demand for improving the quality of life of modern urban residents.

Meanwhile, the urban heat island (UHI) phenomenon is one of the main negative impacts of urbanization (Oke, 1982). From 2000 to 2013, the overall average surface temperature in the main urban area of Nanchang increased by 1.64℃ (Zhang et al., 2017). The urban heat island effect brings many disadvantages to people's lives,but it also does not conform to the current concept of sustainable development. Microclimate regulation can have a positive impact on the urban heat island effect, and improving the physical environment of public spaces can also enhance people's thermal comfort experience. The design of public spaces based on microclimates has become crucial for contemporary urban builders. Microclimate is crucial for improving the quality of urban public space, improving the living environment, and promoting urban development. Compared to larger urban areas, the climate in small areas is more standardized, which provides an opportunity to develop design guidelines based on microclimates to promote sustainable development and enhance the vitality of the space under the bridge.

This study takes the spaces under the Bayi Bridge in Nanchang city, Jiangxi Province as a typical case and conducts multidimensional environmental analysis through a systematic research framework (Fig. 1). In the literature research stage, a systematic review of domestic and foreign cases of space renovation under bridges was conducted, with a particular focus on the latest practices in climate adaptive design, in order to establish a theoretical foundation for subsequent research. The on-site research process adopts SWOT analysis to comprehensively evaluate the current situation of the site, while recording in detail the architectural form characteristics, pavement material properties, and vegetation distribution, and recording the surrounding buildings. In terms of humanistic needs research, a special questionnaire was designed for the elderly as a special user group. Through a combination of in-depth interviews and face-to-face surveys, users' real demands for spatial functionality, comfort, and other aspects were collected. At the technical level, a three-dimensional microclimate model is constructed using ENVI-met software, which inputs multidimensional data including building geometric parameters, material thermal performance, plant transpiration rate, etc. Through numerical simulation, a physiological equivalent temperature (PET) spatial distribution map is generated, and the quantitative relationship between thermal stress duration and spatial use intensity is analyzed. With the aim of effectively alleviating heat stress and improving the comfort level in the space under the bridge.

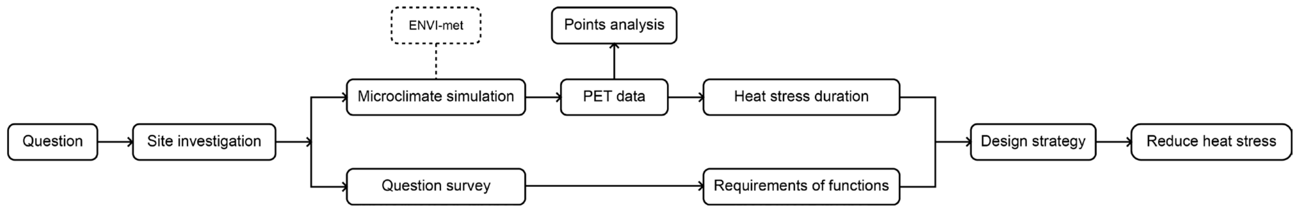

Fig. 1 Methodology Flowchart

2. Background

In the process of rapid urban development, the elevated bridge system, as an important infrastructure to ease the traffic pressure, continues to expand in construction scale. While these three-dimensional transportation networks improve traffic efficiency, they also create a large number of overlooked spaces under bridges in the urban fabric. These spaces currently mainly undertake auxiliary municipal functions, providing venues for basic services such as environmental sanitation maintenance, road maintenance operations, greening management, and temporary parking. Due to the lack of comprehensive planning and long-term management mechanisms, these transition areas that should have been full of vitality have gradually evolved into negative gray spaces. The physical division formed by the elevated structure not only severs the continuity of the urban landscape, but also causes spatial fragmentation at the psychological level, resulting in the under-bridge area, which could have become a forgotten corner of the city. This situation not only reflects the backwardness of planning concepts in the process of rapid urban development, but also exposes the shortcomings of public space management.

2.1 Bayi bridge

Before the 1930s, transportation across the Gan River was provided solely by ferries. To improve this situation, the Zhongzheng Bridge started construction in 1934 and was completed in 1936 (Fig. 2). This bridge, with a total length of 1077 meters, was once an important transportation artery in Nanchang. After the outbreak of the War of Resistance Against Japan in 1937, the Chinese army bombed the bridge in 1939 to prevent the Japanese army from attacking (Fig. 3). After the Japanese occupation of Nanchang, it was quickly repaired, making it a military transportation channel. During the civil war in 1949, the bridge was severely damaged again. After the war, the government organized repairs and renamed it Bayi Bridge. In 1995, the construction of the New Bayi Bridge began 50 meters upstream of its original site. This cable-stayed bridge, with a total length of over 3000 meters, set a record for the fastest construction and lowest cost among bridges of the same scale in China. The current Bayi Bridge (Fig. 4), which opened in 1997, has a total length of 6 kilometers, a main bridge of 1045 meters, a deck width of 28 meters, four lanes in both directions, and a designed speed of 60 kilometers per hour. It is not only the first cable-stayed bridge in Jiangxi Province, but also an important passage connecting Jiangxi and other provinces. (Qiang, 2020)

Fig. 2 Zhongzheng Bridge
https://baijiahao.baidu.com/s?id=1641568806780591906&wfr=spider&for=pc, [August 2019]

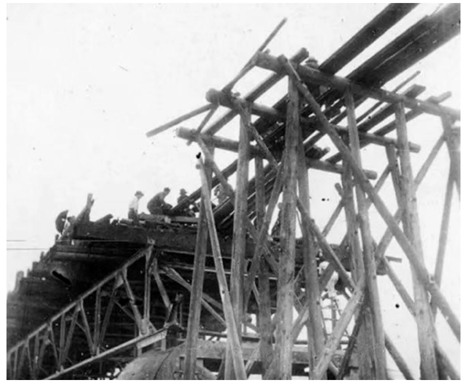

Fig. 3 The destroyed Zhongzheng Bridge
https://baijiahao.baidu.com/s?id=1827048526377406140&wfr=spider&for=pc, [March 2025]

Fig. 4 Bayi Bridge
https://baijiahao.baidu.com/s?id=1843541663133711974&wfr=spider&for=pc, [April 2025]

2.2 The utilization of under-bridge spaces

Since the 1960s, the issue of space under urban bridges has attracted the attention of scholars. Researchers believe that the space under the bridge is a lost space that affects the urban environment and hinders urban communication (Tian, 2024). They advocate the concept of “people-oriented” and suggest that not only the traffic function of the elevated bridge should be considered, but also the usage needs of the city and residents for the space under the bridge should be given attention (Roger, 2008). At the end of the 20th century, research on the reuse of space under urban bridges adopted a qualitative and quantitative approach, discussing the characteristics of elevated bridges themselves, the basic conditions of their environment (Kinoshita et al., 1999), and the needs and preferences of surrounding populations for the spatial environment (Lak et al., 2019).

Chinese scholars have always focused on traditional transportation spaces in the study of urban bridge spaces, and related research can be summarized into two aspects: firstly, exploring the improvement of landscape environment under bridge spaces around the effects of light, air pollution, etc. (Li, 2001); The second is to explore ways and design strategies for enhancing the utilization of space under bridges based on local practices, focusing on the land use of surrounding cities and the needs of residents (Huang, 2019).

Fig. 5 Elderly residents in the space under the bridge (Photo by Author)

The space under the Bayi Bridge has now become a gathering place for the daily activities of elderly people in the surrounding communities (Fig. 5). Even in the hot summer weather, this place attracts a large number of elderly people to cool off and socialize. The shaded area under the bridge became their preferred place, where the elderly sat or stood chatting, playing cards, and chess. Although there are cooling facilities such as air conditioning indoors, these elderly people still prefer to step out of their homes and come to the bridge to socialize with their peers. This phenomenon reflects the strong demand of the elderly for social activities and the important role of public spaces in meeting this demand.

2.3 The impact of high temperatures on the elderly

Due to the urban hear island effect, urban areas are particularly affected by hot weather. The high temperature period has an impact on urban residents, especially for the elderly, they are affected by heat stress, the incidence rate and mortality of the elderly is predicted to increase during and after high temperature. (Allex et al., 2013)

Climate change will further increase the number, intensity, and duration of heat waves in the future, affecting most land areas (IPCC, 2007). Long term and intense heat waves will have a negative impact on the living conditions of urban residents. Vulnerable populations, particularly the elderly, face more severe health impacts, due to their reduced ability to cope with heatwaves (Jalalzadeh Fard et al., 2021; Sheridan & Allen, 2018). Due to the accelerated aging of urban elderly population (Luo, 2021), the issue of how to reduce the impact of heat waves on the aging population within urbans is predicted to become even more important in the future.

3. Case studies

Here are three cases from different parts of the world (Fig. 6). For different problems, there are different solutions that can provide reference.

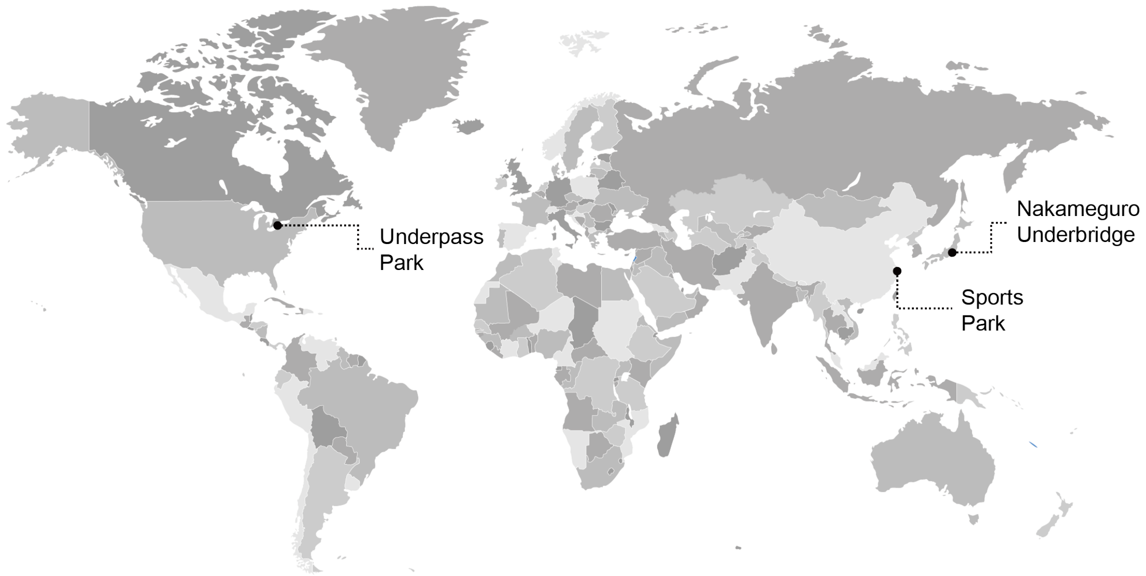

Fig. 6 Case distribution map

3.1 Underpass Park

Underpass Park is a highly imaginative public space in a rather unexpected place. Located beneath a complex of existing highway overpasses in Toronto's downtown, an otherwise forgotten and derelict remnant has been transformed into an active public park providing diverse recreational and social opportunities while connecting new and existing local neighborhoods and nearby parks. This unique public space is part of Waterfront Toronto's revitalization efforts of the celebrated new West Don Lands neighborhood. It serves to link Corktown Common, River Square and the neighborhoods of both sides of the overpass complex through the provision of safe and animated public realm design. (PFS Studio, 2016)

This renovation fully embodies the wisdom of plant selection and spatial design (Fig. 7). Local plants have been carefully selected, not only to adapt to the challenges of urban environments, but also to inject vitality into the site in a seasonal manner, softening the rigidity of concrete while providing habitat for urban wildlife. The strip wall structure cleverly divides the activity area, and the curved design of the wooden benches not only continues the overall style, but also provides warm seating for resting people. Its flowing form naturally guides the flow of people and avoids crowding. The combination of tall grass and landscape adds wildness to the space, while the integration of children's playground equipment lights up the colors, making the entire venue attractive to families. (PFS Studio, 2016)

In Fig. 8, lighting design is the core of nighttime experience. The columnar arch is revitalized under colorful lighting, enhancing the spatial hierarchy and creating a safe and dreamy atmosphere for the night. Ground LED lights continuously bring vitality to the landscape through dynamic patterns and color changes. This renovation not only reshapes the functionality and aesthetics of the space under the bridge, but also makes it a catalyst for community vitality. Whether it's the shade of greenery during the day or the interplay of light and shadow at night, this place has become a shared stage for residents to socialize, entertain, and relax, strengthening the bond between people and the city. (PFS Studio, 2016)

In conclusion, this project is a testament to the power of thoughtful urban regeneration. It demonstrates that through careful planning, innovative design, and the integration of art and nature, even the most neglected urban areas can be transformed into vibrant community hubs that celebrate the beauty of the urban environment while fostering ecological sustainability and social interaction.

Fig. 7 Strip wall, color and newly planted landscape
https://www.gooood.cn/2016-asla-underpass-park-by-pfs-studio-with-the-planning-partnership.htm, [December 2016]

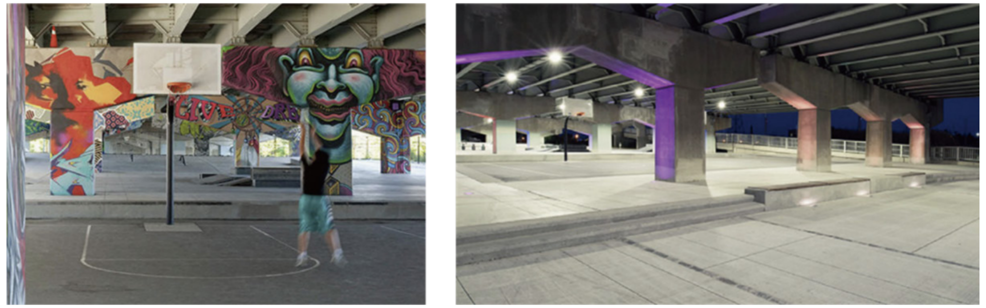

Fig. 8 The combination of art and sports, light design
https://www.gooood.cn/2016-asla-underpass-park-by-pfs-studio-with-the-planning-partnership.htm, [December 2016]

3.2 Nakameguro Underbridge

Meguroku in Tokyo is one of the upscale districts with very convenient transportation. It is known as a low-key yet fashionable trendy gathering place that Tokyo locals love to go to for leisure gatherings. There are various restaurants, cafes, grocery stores, and dessert shops lining on both sides of the street. The predevelopment elevated space was a narrow open space that had been sealed off for a long time. The elevated space at the east exit of Nakameguro Station felt oppressive, and even during the day, the lighting was very dim. With the entry of numerous popular shops, the number of visitors has increased, and the quality of urban transportation public spaces under elevated roads has been greatly improved and enhanced. (Wu, 2019)

The spatial transformation under the railway viaduct has successfully transformed the originally monotonous transportation ancillary area into a vibrant urban commercial corridor through commercial revitalization and artistic intervention (Fig. 9 and Fig. 10). The dynamic space creation strategy revitalizes the 700 meters long area under the bridge by introducing diverse business formats – the three-dimensional façade of the store and the continuous undulating sunshades form a flowing visual rhythm, retaining the uniqueness of each merchant while forming a cohesive narrative through a unified green vegetation belt and art installation. The art wall designed by artists transforms infrastructure into a cultural carrier, with abstract patterns echoing the digital lighting of elevated structural columns, creating a rhythmic sense of light and shadow interweaving at night. These design elements together dissolve the coldness of concrete structures, providing pedestrians with a comfortable environment for shade and rest, and creating a lively commercial atmosphere through color collision and material contrast, ultimately achieving the organic integration of industrial heritage and contemporary urban life. (Wu, 2019)

In summary, the transformation of the space under Nakameguro Elevated Road has been achieved through a combination of dynamic space planning, diverse facade designs, communal design elements, artistic installations, and the creative use of structural components. This has not only revitalized a previously underutilized space but also contributed to the urban fabric by creating a destination that fosters community interaction and economic activity.

Fig. 9 Predevelopment elevated space 1, across from the exit of Nakameguro Station
https://www.sohu.com/a/237770526_720180, [June 2018]

Fig. 10 Predevelopment elevated space 2, commercial entrance space
https://www.sohu.com/a/237770526_720180, [June 2018]

3.3 Sports Park

The transformation of the overlooked and underutilized space beneath the Central Interchange network in Beixinjing Street, Changning District, Shanghai, into a vibrant public area is a testament to innovative urban design. The initial design concept recognized the negative perception associated with spaces under bridges, characterized by darkness, neglect, and an unwelcoming atmosphere. The strategy was to leverage the potential of these spaces by introducing distinctive design elements that would not just overcome the challenges but also create a positive identity for the area. This was achieved using bright and imaginative color schemes, animal-themed patterns, and functional landscape elements (Holmes, 2023).

The vibrant pink color scheme and flamingo theme have completely redefined the urban landscape (Fig. 11), transforming mundane concrete structures into eye-catching landmarks (Holmes, 2023). These bold design choices inject energy into the formerly monotonous space, creating an instantly recognizable visual identity. The flamingo motifs adorning bridge pillars serve as artistic markers, guiding visitors through the revitalized area while establishing a cohesive aesthetic.

Functional upgrades have turned the space into an interactive public destination, with Rock Basketball Park providing dynamic recreational opportunities complemented by serene riverside seating areas. The strategic lighting design enhances both safety and ambiance, extending the venue's usability into the evening hours. Artistic interventions like the spiral staircase encircling bridge columns introduce sculptural elements that play with perspective, while golden willow trees swaying amidst the pink backdrop add natural texture to the urban canvas. (Holmes, 2023)

As show in Fig. 12, this multi-sensory experience reaches its zenith at night when the layered illumination system comes alive. Carefully positioned lights amplify the pink tones' vibrancy, casting reflections on the Suzhou River to create a dazzling waterfront spectacle. The interplay of artificial lighting with public art installations transforms the space into an ever-changing panorama, where design elements work in harmony to create a destination that's as photogenic as it is functional, offering panoramic views that evolve with the time of day. The result is a lively urban oasis that balances playful aesthetics with practical amenities, redefining underutilized infrastructure as a beloved community gathering space.

The Flamingo Park, with its bold and imaginative design, stands out in stark contrast to the surrounding environment, offering a refreshing change from the old memories of Beixinjing. It has become a regional landmark in Changning District, not only providing outdoor leisure spaces for the immediate community but also serving as a destination for residents across Shanghai.

In conclusion, the revitalization of space under the Central Interchange network in Beixinjing Street exemplifies the power of creative urban design in addressing the challenges of underused public spaces. Through a combination of bold design choices, functional enhancements, and the introduction of public art, the project has created a new destination that enriches the community and contributes to the overall vibrancy of the city.

Fig. 11 Bright colors and paintings, seats
https://www.hhlloo.com/a/Shanghai-Lowline-Park.html, [September 2022]

Fig. 12 A vibrant basketball park, multi-level nighttime lighting
https://www.hhlloo.com/a/Shanghai-Lowline-Park.html, [September 2022]

4. The renewal of the space under the bridge

The renewal of the space under the bridge integrates users needs, microclimate optimization, and spatial function reconstruction, aiming to transform the space under the bridge into an elderly friendly public place with practicality, comfort, and cultural value. Solved existing problems such as insufficient facilities, poor thermal comfort, and safety hazards, and explored the balance between space utilization efficiency and the quality of life of the elderly. The update process combines the regional characteristics of the humid subtropical climate in Nanchang and the living habits of the elderly, forming actionable design strategies and implementation plans.

4.1 Preliminary analysis

Preliminary analysis is the foundation for the renewal of the space under the bridge. Through multidimensional investigation and research, the basic conditions, environmental background, advantages and disadvantages, and internal conditions of the site are analyzed to determine the basis for subsequent design and strategy formulation.

4.1.1 Site description

Nanchang City (site location) is located at a Latitude of 28°68′N and a Longitude of 115°85′E in southeastern China. It is one of the central cities of the Yangtze River Midstream Urban Megalopolis and the political, economic, cultural, and transportation center of Jiangxi Province. The climate of the city is classified as a humid subtropical climate, with hot and humid summers and cool and humid winters. The city is known as a “furnace” due to summer temperatures that can exceed 30-40℃. The city’s climate throughout the year presents typical characteristics of warmth and humidity, with an average annual rainfall of about 1600mm; the annual average temperature is around 23℃.

The site is located at the core area of Nanchang City, surrounded by a dense network of elevated transportation (Fig. 13). The main body of the Bayi Bridge spans over the site, forming a typical urban gray space. The surrounding buildings show a clear gradient distribution: one super high-rise landmark building and three high-rise buildings form a modern skyline, while the rest of the area is dominated by old residential buildings, presenting an overall style of interweaving old and new. As an important part of the old city area of Nanchang, the residential areas in this region generally suffer from a shortage of public service facilities, especially the supporting facilities around the site. The current site function is a simple urban park, with a moderate amount of tree vegetation planted inside and two antique buildings preserved. However, the latter is currently idle and has not been put into actual use.

Fig. 13 Axonometry view of site

4.1.2 Surrounding environment

As the central urban area of Nanchang, the capital of Jiangxi Province, Donghu District has shown typical characteristics of population aging. According to the latest statistical data, by the end of 2022, the elderly registered residence population aged 60 and above in the district has reached 106200, accounting for 24.51% of the total registered residence population in the district, which has far exceeded the international aging social standards. It is worth noting that in the elderly population structure, the population aged 80 and above is particularly prominent, with a population of over 14000 people, accounting for 13.18%. This demographic feature poses higher requirements for the aging friendly transformation of urban public services systems.

The space under Bayi Bridge has become an indispensable social activity venue for the elderly in the surrounding community. The emergence of this phenomenon is closely related to the insufficient support facilities in the surrounding residential areas. The residential buildings in this area are generally old, and the construction of community public service facilities is lagging, especially lacking specialized elderly activity centers. In such a large environment, the space under the bridge has naturally become an ideal choice for elderly residents' daily gatherings due to its open space and convenient geographical location. Every day, there are lots of elderly people engaging in various activities, either sitting around chatting, doing simple fitness exercises, or organizing chess and card entertainment. This semi open space naturally formed by the elevated bridge has become an important activity area for the surrounding elderly people.

Two concentric circles with different functional meanings can be drawn around the center point of the site: a building influence scope with a radius of 3 kilometers and a 15-min pedestrian scale with a radius of 1.2 kilometers (Fig. 14). The former gathers diverse cultural facilities such as large museums, libraries, science museums; medium-sized community cultural centers, and small exhibition halls, while the latter, although in line with the 15-min pedestrian scale concept, has the shortcomings of a single facility type and insufficient scale. The 15-min pedestrian scale concept aims to create accessible and sustainable urban communities where essential services, employment, learning and leisure activities are within 15 minutes' reach by walking, bicycle or public transport (Davide, 2024). This spatial distribution creates stark contrast – the resources in the building influence scope are abundant but have low utilization rates, especially for the elderly population, where transportation connections and physical energy consumption become the main obstacles, although the 15-min pedestrian scale is convenient and accessible, it is difficult to meet the high-frequency and diverse cultural needs, and there is a lack of comprehensive venues for hosting large-scale activities.

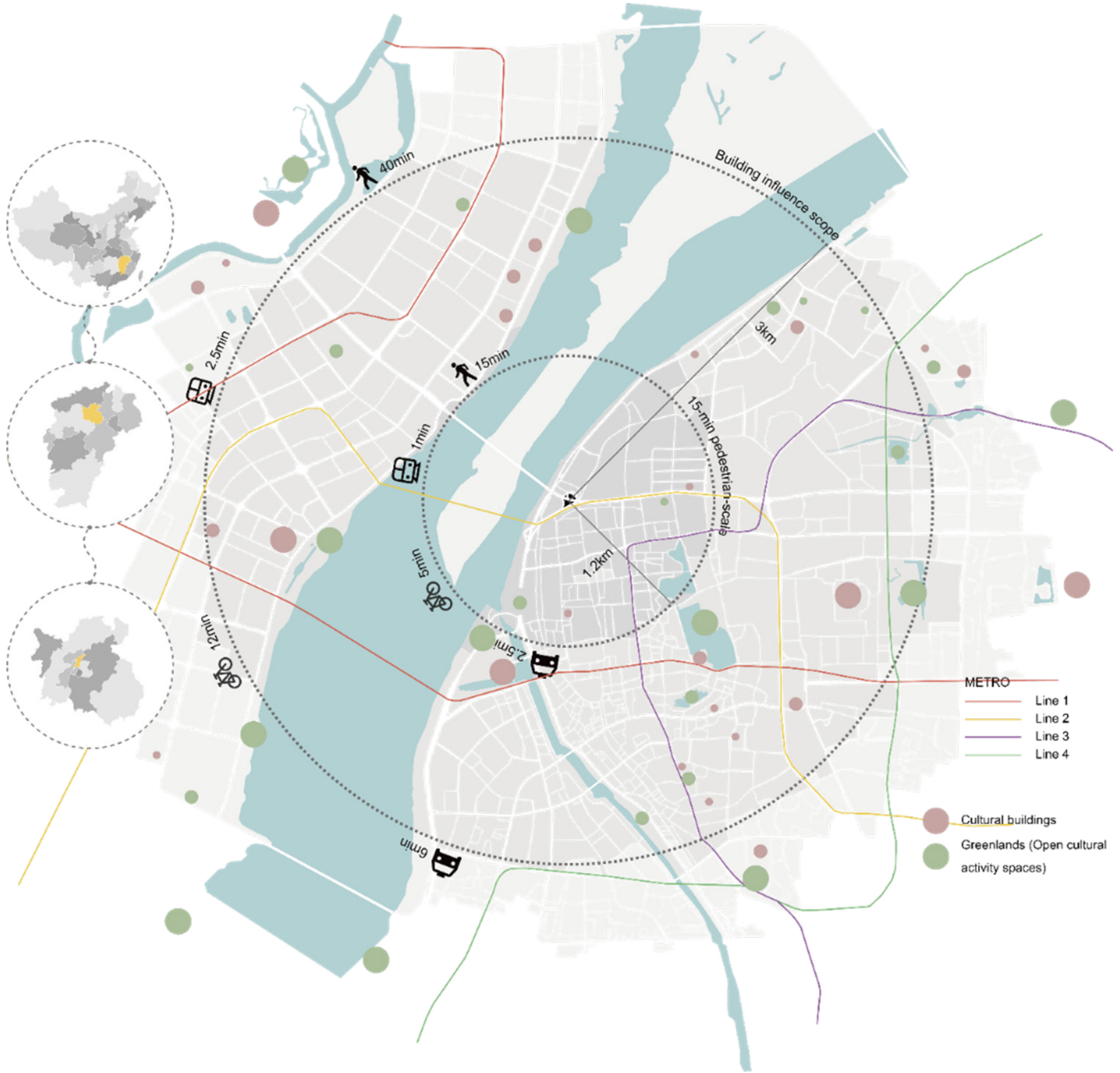

Fig. 14 Surrounding environment

4.1.3 SWOT analysis

The feasibility and core contradictions of the renewal of the space under the bridge were comprehensively evaluated from four dimensions: strength (S), weakness (W), opportunity (O), and threat (T), combined with factors such as site characteristics, user needs, and urban environment, providing targeted basis for subsequent design strategies.

4.1.3.1 Strength

The site is located at the core area of the city center, adjacent to the main transportation artery, and has significant geographic advantages and development potential. The space under the bridge, with its unique floor height structure, can be flexibly transformed into various functional formats such as parking lots, commercial complexes, or community green spaces. It can create sustainable income through market-oriented leasing and effectively improve the quality of life of surrounding residents. As there is an important node connection between bus hubs and subway stations, this area naturally has abundant pedestrian flow advantages, especially under the shade of elevated structures, which can form a comfortable semi outdoor activity space in summer, further strengthening its value as a vibrant node of the city.

4.1.3.2 Weakness

Fig. 15 Traffic volume
https://m.huxiu.com/article/386687.html, [October 2020]

The space under this elevated bridge not only serves the urban transportation function, but also faces multi-dimensional environmental challenges. As an important component of urban transportation arteries, the area under the bridge carries a huge daily traffic flow. This high-frequency vehicle traffic flow not only brings potential safety hazard, but also has a significant impact on the surrounding environment due to the continuous traffic noise. The massive volume of concrete structures creates a certain degree of oppression visually, and the coordination with the overall urban landscape needs to be improved (Fig. 15). From the perspective of spatial structure, there are significant differences in floor height in the area under the bridge, and some spaces appear low and cramped due to structural limitations. This irregular three-dimensional layout not only poses difficulties for daily cleaning and maintenance, but also easily forms hygiene blind spots. Dampness is another typical feature of the space under the bridge, and the shielding effect formed by the elevated structure keeps the ground in a damp state for a long time, which is not conducive to the growth of green plants and inconvenient for pedestrian traffic. In addition, the serious shortage of recreational facilities and structural vibration problems further reduced the comfort level of space use. These factors are intertwined and together constitute the core contradiction that needs to be systematically resolved in the renovation of space under the bridge.

4.1.3.3 Opportunity

The space under this elevated bridge, with its unique geographical location and spatial characteristics, contains rich commercial development potential. As an important node connecting the cross-strait tourism belt, the area under bridge can be planned as a characteristic commercial zone, introducing boutique retail stores, themed cafes and other formats, which can provide tourists with a resting place and activate commercial vitality. In summer the natural shaded area formed under the bridge becomes the preferred place for surrounding residents to escape the heat and cool off (Fig. 16). By adding leisure seats, sunshade facilities, etc., it can be transformed into a public space for daily communication and activities of community residents. The location advantage of being located at the core area of the city center, coupled with the convenient transportation of adjacent bus and subway stations, makes the area under the bridge a high-quality advertising spaces can not only improve space utilization, but also create considerable economic benefits. In response to the current mixed traffic situation, scientific planning can be used to achieve pedestrian and vehicle separation, setting up independent bicycle lanes and pedestrian walkways, which not only ensures traffic safety but also improves spatial quality. In addition, the artistic transformation of space under the bridge is also worth paying attention to. By inciting artists to create murals and setting up sculpture installations, not only can the environment be beautiful, but it can also add cultural atmosphere to the city, making the originally monotonous space under the bridge radiate new vitality and energy.

Fig. 16 Space under the bridge (Photo by Author)

4.1.3.4 Threat

The renovation and utilization of the space under this elevated bridge face various practical challenges. Firstly, government regulations have strict requirements for the renovation and use of urban public spaces, which may require significant investment in compliance reviews during the planning phase. Secondly, the public may hold a relatively conservative attitude towards the renovation of the space under the bridge, especially when it involves changing the original function or appearance, which can easily lead to community disputes. The mature shopping centers and residential areas in the surrounding area also constitute direct competition for supporting activity spaces, which often have more complete supporting facilities and higher utilization rates. In addition, fluctuations in the economic environment cannot be ignored, and investors may be more cautious during the economic downturns. From a physical perspective, the height limitation of the space under the bridge is an objective limiting factor, and some areas may not be able to meet certain functional requirements. These factors are intertwined and together constitute the complex background that needs to be considered for the renovation of the space under the bridge.

S Strength

1. Location: The site is in the city center and is a major road with convenient transportation.
2. Multifunctional development possibility: The height of the space under the bridge is diverse and can be used for various purposes, such as parking lots, commercial facilities, green spaces, etc.
3. Economic benefits: income can be generated through leasing.
4. Community development: helps to improve the quality of life of residents in surrounding communities.
5. High pedestrian flow: There are bus terminals and subway stations in the area under the bridge, and the surrounding areas are residential areas, which can bring a large amount of pedestrian flow.
6. In summer, elevated structures can protect the space under the bridge from strong sunlight exposure

W Weakness

1. Safety hazards: There may be safety issues caused by high traffic volume
2. Noise pollution: High traffic volume leads to high noise levels
3. Visual impact: The bridge may affect the beauty of the city
4. High maintenance costs: Maintenance and management costs may be higher
5. Vibration caused by bridges
6. Limitations of space: Due to the limitations of the elevated bridge structure, the height of the space under the bridge is limited, and some spaces are relatively low, which may cause obstruction of vision
7. Underneath elevated bridges, it is easy to form shaded areas, resulting in damp ground, which is not conducive to plant growth and pedestrian walking
8. Although there is a parking lot, it has been fenced and currently can only accommodate small vehicles such as motorcycles and bicycles
9. Traffic chaos in some areas of the space under the bridge
10. Not enough seats provided for surrounding residents
11. Automobile exhaust pollution

O Opportunity

1. Commercial development: Both sides of the river are tourist belts, which can introduce commercial facilities such as retail stores and cafes
2. Community activity space: Surrounding residents like to cool off in the shade under the bridge in summer, which can be used as a community activity space
3. Advertising space: Located in the city center area, there are bus terminals and subway stations under the bridge, with high pedestrian traffic, which can be used for advertising and increasing revenue
4. Diversion of people and vehicles: bicycle lanes and pedestrian walkways can be set up to improve the current situation of traffic chaos
5. Artistic treatment of the space under the bridge, such as adding decorations such as murals and sculptures, can enhance the environment

T Threat

1. Regulatory restrictions: Government regulations may restrict modifications and use
2. Public acceptance: The public may hold a conservative attitude towards its renovation
3. Competitors: Competition in other similar spaces, such as surrounding shopping malls and residential activity spaces
4. Changes in economic environment: Economic downturn may lead to a decrease in investment
5. Limitations on the height under the bridge

Fig. 17 SWOT summary

4.1.4 Current situation inside site

After analyzing the current situation inside the site, it can be found that there are significant problems with the actual usage needs and spatial status of the elderly population. Elderly residents around the site generally tend to choose shaded areas such as under the main bridge as their daily activity areas, where they enjoy cool breeze, play cards and chat, and rely on the water and food services provided by mobile vendors (Fig. 18). However, the existing problems of the site cannot be ignored: the lack of shade treed in the riverside area has led to excessively hot environment, and elderly residents are unwilling to stay there; the aging friendly design of public toilets is lacking, and the number of seats under the main bridge is insufficient, forcing elderly residents to bring their own seats; electric motorcycles parked randomly not only affect traffic efficiency but also pose safety hazards; despite the presence of police kiosks, internal security forces still need to be strengthened. In addition, there is a visual conflict between the white walls at the bottom of the building and the surrounding landscape, and although the internal landscape space is vacant, there is no one to rest, resulting in low resource utilization. However, the dense trees on the site are worth preserving as they provide valuable shade for elderly residents; the existing mobile vendors can also meet the basic living needs of residents, but they bring hygiene problems, reflecting the value of providing convenient services.

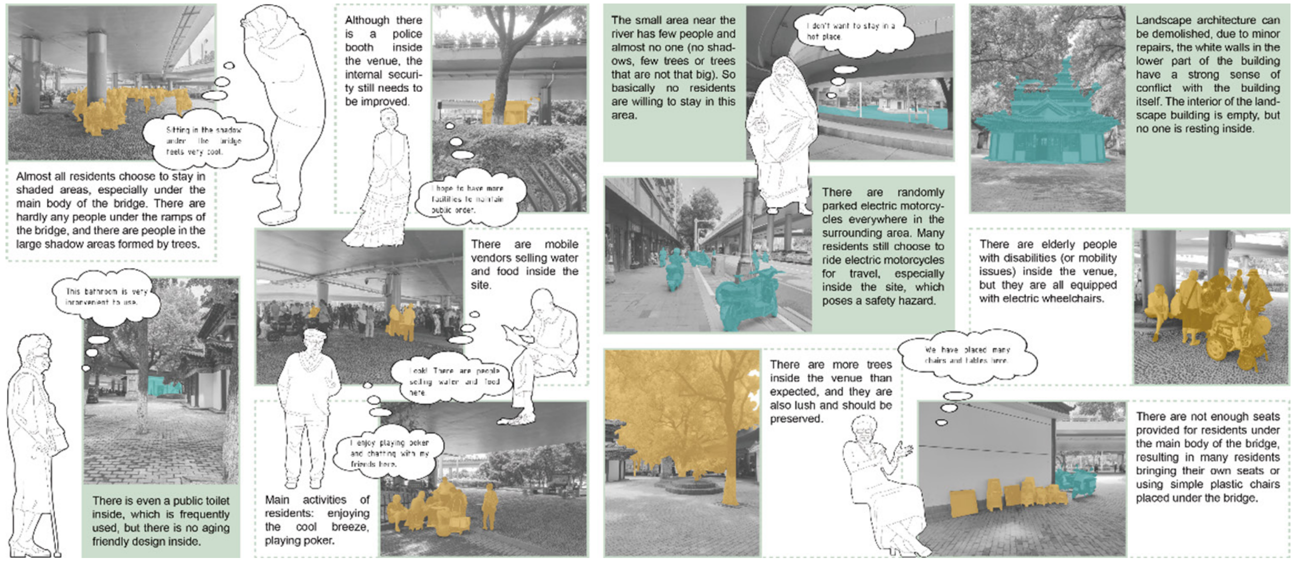

Fig. 18 Current situation inside site

4.2 Questionnaire survey

With the acceleration of urbanization, how to activate and utilize urban negative space has become a key focus in improving urban quality. At the same time, the aging trend of China's population structure not only brings social pressure but also new development opportunities – the consumption demand of the elderly in health preservation, cultural tourism, leisure, and entertainment fields continues to grow, opening new directions for related industries. By focusing on the transformation potential of the space under the bridge and the actual needs of the elderly population, methods for the coordinated development of urban surplus space and aging society can be explored.

4.2.1 Survey design

Taking the space under the Bayi Bridge in Nanchang as an example, in order to understand the usage needs of the elderly population in the area, this survey adopts a combination of questionnaire survey and field observation to collect key data such as activity preferences, usage frequency, and functional expectations of the elderly population. Considering the physical and educational status of the elderly, a face-to-face survey is conducted. These research results will provide a basis for subsequent spatial optimization design, creating aging-friendly public spaces that combine practicality and humanistic care.

By collecting questionnaire and conducting statistics, the evaluation and opinions of the elderly on the renovation of the space under the Bayi Bridge, their activity needs, and the current situation of the space under the bridge can be obtained.

4.2.2 Survey results and analysis

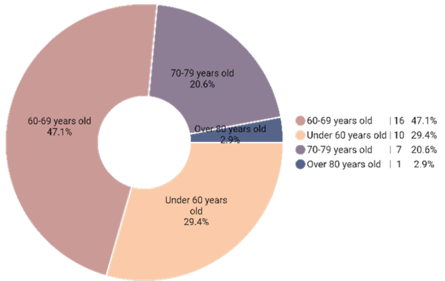

Fig. 19 Age distribution

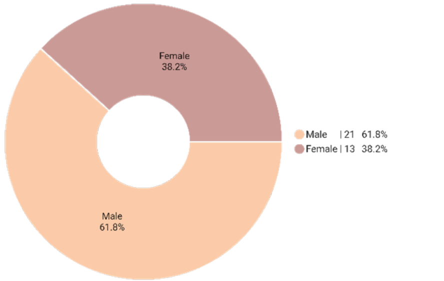

Fig. 20 Gender distribution

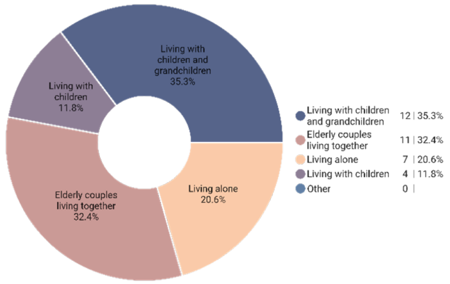

Fig. 21 Current living situation

The date of the investigation is July 30th, 2024. The sample size for this survey is 34 people, with 34 responses and 34 valid questionnaires. The effective response rate of the survey questionnaire is 100%.

People under 60 years old account for 29.4%, people aged 60-69 account for 47.06%, people aged 70-79 account for 20.59% (Fig. 19), and people over 80 years old account for 2.94%. For elderly people over 80 years old, due to their physical condition, they could not answer the questionnaire truthfully and effectively. Therefore, although the survey subjects were randomly selected, this data cannot represent the age distribution of the entire active population in the space under the bridge.

There were a relatively large number of males participating in the survey, accounting for 61.8%, with relatively few women accounting for 38.2% (Fig. 20). During the survey, men were more willing to participate in the survey. Although the survey subjects were randomly selected, this data cannot represent the gender distribution of the entire active population in space under the bridge.

Most of the participants live with someone, accounting for 79.4% of the total (Fig. 21). Among them, 32.4% of elderly couples live together, 11.8% live with their children, and 35.3% live with their children and grandchildren. Surprisingly, 20.6% of people live alone, and this group of elderly people lack companionship and rely more on social interaction. Therefore, creating a good social environment is essential for these elderly people who are active under the Bayi Bridge.

Fig. 22 demonstrates that 76.5% of the surveyed population participates in social activities every week. Although 23.5% of people do not participate in social activities every week, most of them gave reasons for not being able to attend, such as being temporarily absent from social activities due to physical reasons or other reasons (such as travel). This data and their responses indicate that social activities are important for this group of people.

Fig. 23 demonstrates that 88.2% of the participants have their own interests and hobbies, while only 4 people believe they have no interests or hobbies, accounting for 11.8%.

Half of the surveyed individuals always participate in social activities; 26.5% frequently participate in social activities, and only 23.5% do not participate in social activities very frequently (Fig. 24). The number of people who never participate in social activities is 0. Therefore, it can be concluded that the surveyed population has great enthusiasm for participating in social activities.

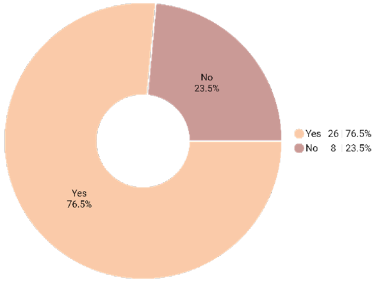

Fig. 22 Weekly participation in social activities

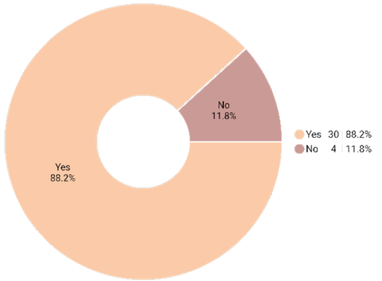

Fig. 23 Participants with hobbies and interests

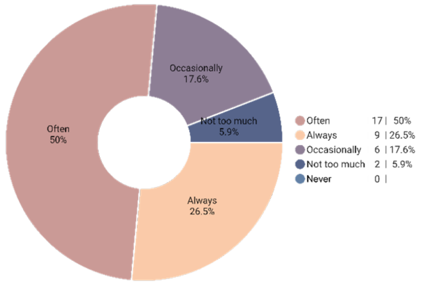

Fig. 24 Social event frequency

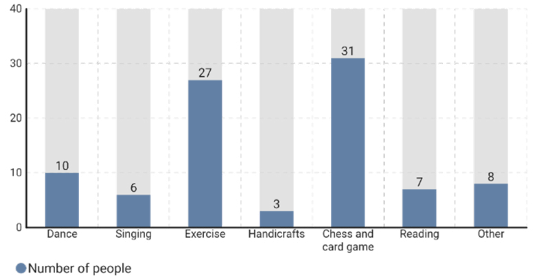

Fig. 25 Types of activities participated in

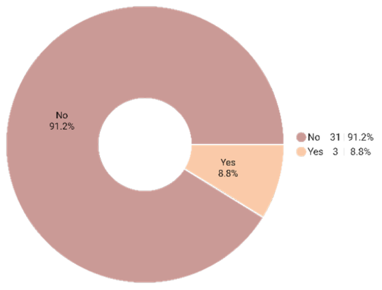

Fig. 26 Organization of community activities

Most of the participants like chess and cards (Fig. 25). There were many elderly people playing cards inside the site, and the tables and chairs for playing cards were all their own. Secondly, 27 people participated in sports activities. A small number of people have participated in activities like dancing, singing, handicrafts, and reading. In addition, 8 people also mentioned that they have participated in other types of activities, such as traveling, poetry recitation, instrument playing, and so on.

Fig. 26 demonstrates that 91.2% of the surveyed individuals do not regularly engage in elderly activities in their communities, and many elderly people report that their communities have never engaged in elderly activities. Only 3 participants stated that their community regularly conducts elderly activities. Due to the limitations of the times, the residential communities in the old city area do not have dedicated staff and organizations for this purpose, so they rarely carry out regular elderly activities. Many residential communities in old urban areas lack corresponding supporting facilities. Even if the community holds an event, most people are not satisfied with it. They believe that the main shortcomings of activities for elderly people in the community are low activity frequency, followed by long duration and inappropriate activity types. A small number of people criticized the monotony of the event theme and believed that the gifts after the event were not attractive. No participants complained about the high frequency of activities, indicating the passive participation of the community in the welfare of the elderly. Some people also raised concerns about poor hygiene conditions at the site.

Fig. 27 demonstrates that 85.3% of the participants said that there was no activity rooms specially designed for the elderly around their communities. Many participants did not know whether there was activity rooms specially designed for the elderly around their communities. Only 5 people reported having activity rooms specially designed for the elderly around their community, accounting for 14.7%. Due to the limitations of the times, many residential communities in old urban areas lack corresponding supporting facilities.

Most participants hold a negative view on this issue, accounting for 79.4% (Fig. 28). Among them, 6.8% hold a dissatisfied view, and 17.6% hold a relatively dissatisfied view, 17.7% of the participants hold a positive view on this issue, among which 2 people hold a satisfied view, accounting for 5.9%, and 4 people hold a relatively satisfied view, accounting for 11.8%. Additionally, one person holds a general view on this issue, accounting for 2.9%.

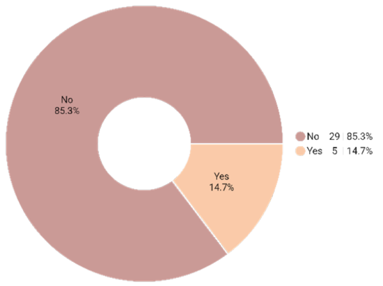

Fig. 27 The situation of community activities held

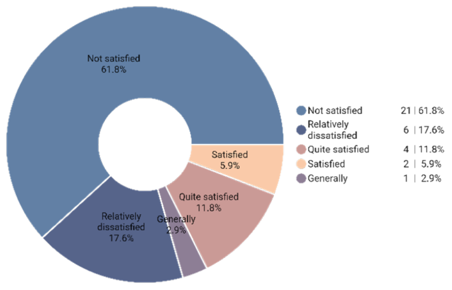

Fig. 28 Evaluation of activities held in the community

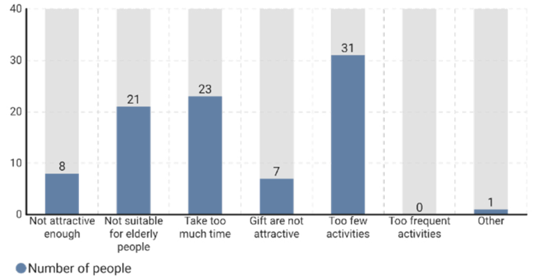

Fig. 29 Shortcoming of activities held in the community

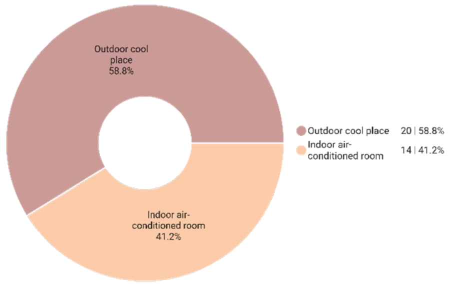

Fig. 30 Preference for air conditioning cooling and natural cooling

The main shortcoming of the surveyed people in carrying out activities for the elderly in the community is that the frequency of activities is too low (Fig. 29). Secondly, the duration of activities carried out is too long, and activities that are not suitable for the elderly to participate are also important shortcomings. Eight people think that the theme of the event is single and not attractive enough, and 7 people think that the gifts given at the end of the event are not attractive enough. None of the participants thinks that the frequency of activities is too frequent, which indirectly indicates that the community is not actively engaged in activities for the elderly. Another person chose other reasons, believing that the hygiene of the activity venue was not good.

The questionnaire outputs (Fig. 30) indicate that 20 people are willing to choose a cool place to stay outdoors, accounting for 58.8%; and 14 people prefer to stay indoors in air-conditioned rooms to cool off, accounting for 41.2%. The elderly in China rely less on air-conditioning, and most of them think it is unhealthy to stay in air-conditioning rooms. So, among the elderly, those who prefer outdoor shade will account for a higher proportion. It proved that although the elderly think it is unhealthy to stay in air-conditioned rooms, they choose to stay in air-conditioned rooms when the temperature is highest in the hot summer, and then come to the space under the bridge when the temperature is slightly lower for various activities.

For the 20 people who expressed a preference for outdoor cool place in the previous question were asked additional questions (Fig. 31). Eighteen people believed that outdoor natural environments were healthier than indoor air-conditioned rooms and 11 people believed that outdoor environments are more conducive to socializing. Seven people are just more accustomed to staying outdoors, 3 people believe that staying outdoors to cool down can save electricity, and one person chooses another reason, explained that it was due to family reasons.

For those 20 people who expressed a preference for outdoor cool place in the previous question were asked additional questions. Fig. 32 indicates that everyone believes that having a quiet environment is important, with 18 people stating that being close to nature is important to them, followed by air flow velocity, greater social convenience, and natural light.

Most of the surveyed people come here for leisure, entertainment, and socializing, while a small number come here for the purpose of participating in physical exercise and regulating emotions, without choosing to prevent diseases or other reasons (Fig. 33). This data will help to understand the current situation within the site and its personnel.

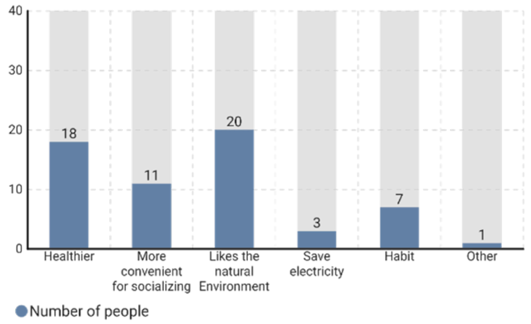

Fig. 31 The main reasons for choosing natural cooling

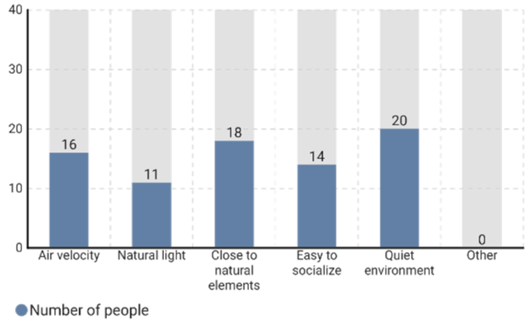

Fig. 32 The most important factor for natural cooling

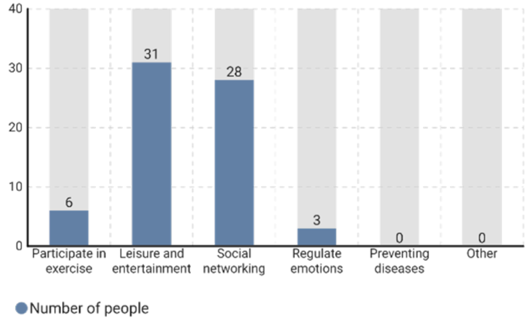

Fig. 33 The purpose of coming to the site

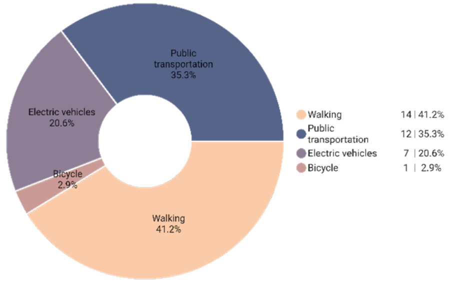

Fig. 34 Type of transportation

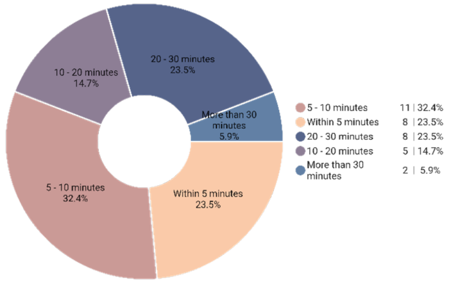

Fig. 35 The time required to arrive at the site

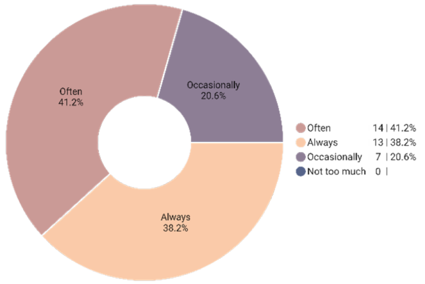

Fig. 36 Frequency of coming to the site

The highest number of people choose to walk here, with 14 people, accounting for 41.2% (Fig. 34). Next is the number of people taking public transportation, with 12 people, accounting for 35.3%. Seven people chose to ride electric motorcycles here, accounting for 20.6%. Only one person chose to ride a bicycle here, and cycling in the city may not be a safe choice. But there are still many electric motorcycles inside the site. This has had a certain adverse effect on the safety of the site.

Fig. 35 indicates that 32.4% of people spent 5-10 minutes or less reaching this location, with 11 people; 23.5% of people take less than 5 minutes to arrive here, similarly, 23.5% of people take 20-30 minutes to arrive here, and 14.7% of people take 10-20 minutes to arrive here. Finally, at least 2 people, accounting for 5.9%, took more than 30 minutes to arrive here. From the current data, it seems that there are not many patterns.

Fig. 36 demonstrates that 14 people always come here, accounting for 41.2%, 13 people often come here, accounting for 38.2%. Occasionally, 7 people come here, accounting for 20.6%. None of the participants has expressed that they don't come here much. There are many people who have shown high enthusiasm for coming here.

Fig. 37 indicates that half of the people prefer to come here in the afternoon, followed by those who prefer to come here in the morning, with 7 people, accounting for 20.6%. Similar in number are those who like to come at night, with 6 people, accounting for 17.6%. There are still 4 people who do not have a fixed time, accounting for 11.8%. Half of the people prefer to come inside the site during the hottest time of the day, so reducing the thermal stress inside the site is important.

Fig. 38 indicates that most participants tend to come alone, with a total of 22 people, accounting for 64.7%. The number of people who tend to come with family and friends is the same, both are 6 people, accounting for 17.6%. Finally, none of the participants chose the option of organizing club activities, which indirectly reflects that there are no formal organizers on this site, and almost all the people who participate here come spontaneously.

Fig. 39 indicates that only 3 people believe that the public facilities under the bridge can meet the needs of the elderly, while the remaining 31 people indicate that the public facilities under the bridge cannot meet their activity needs. The public facilities under the bridge do need further improvements.

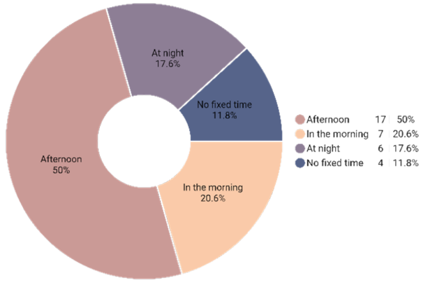

Fig. 37 Time to arrive at the site

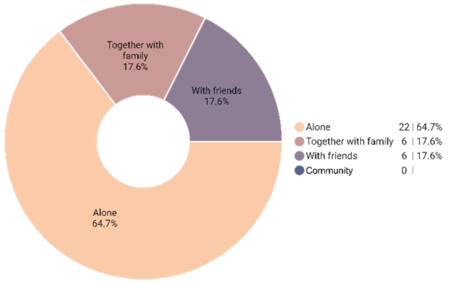

Fig. 38 Visitor accompaniment patterns

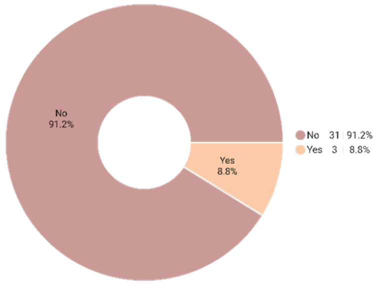

Fig. 39 If the public facilities can meet the needs of the elderly

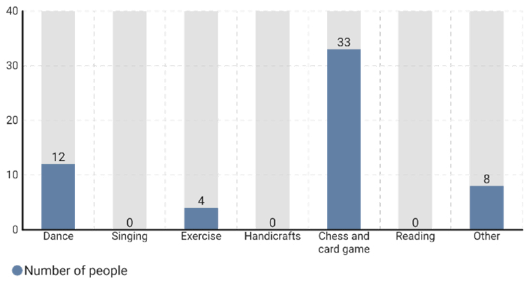

Fig. 40 Facilities within the site

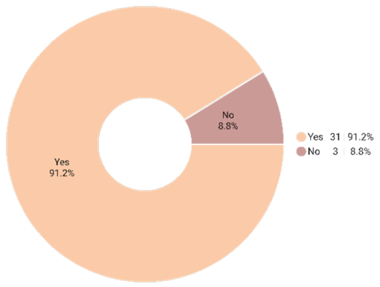

Fig. 41 Is it affected by noise

Fig. 40 indicates that 33 out of 34 people are participating in chess and card activities here. There are many people concentrating in one place playing poker at the site. Next is dance, which 12 people have participated in here; 8 people chose other options, and these 8 people explained that they like to chat here or just sit. None of the participants chose singing, handicrafts, or reading. And most people believe that the facilities under the bridge cannot meet the needs of the elderly, so the public facilities under the bridge do need further improvement.

Fig. 41 indicates that only 3 people believe that the noise here will not affect them, and 31 out of 34 people, accounting for 91.2%, think that the noise here will have a significant impact on them. The noise inside the venue did not actually come from the vehicles driving on the bridge deck, but from the people singing live broadcasts inside the site. These people used audio equipment and other devices, which brought considerable noise. So, it is necessary to solve the noise source in the design.

Fig. 42 demonstrates that most of the people believe that fitness activities such as Tai Chi and fast walking are suitable for the elderly. Fourteen people believe that qigong is suitable for the elderly, while a small number of people believe that fitness equipment, aerobics, bicycles, and chess are suitable for the elderly; 7 people chose other activities and explained that they believed chatting and sitting were more suitable for the elderly population. None of the participants liked intense exercise. Many people believe that the lack of sports facilities is a hindrance to doing sports. The elderly are more inclined to engage in light exercise and low intensity sports. So, it's necessary to develop more sports activities suitable for elderly with different physical conditions and add more sports venues and facilities for the elderly.

Fig. 43 demonstrates that most people believe their physical condition is a hindrance to participating in physical exercise, with as many as 29 people. The second reason is that they think sports are too tiring, with 20 people. And the number of people choosing the two options of not being good at sports and lacking suitable venues is 19. There are 17 people who think they don't have a suitable sport. The number of people who think they don't like sports, and the sports field is too far away from home is 12. Some individuals believe that the lack of sports partners and organization is a hindrance to participating in physical exercise. Only one person believes that the obstacle to participating in physical exercise is the lack of professional guidance.

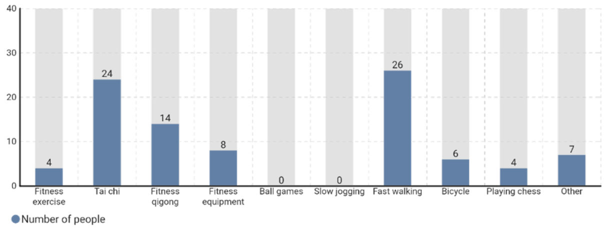

Fig. 42 The exercise status of elderly people

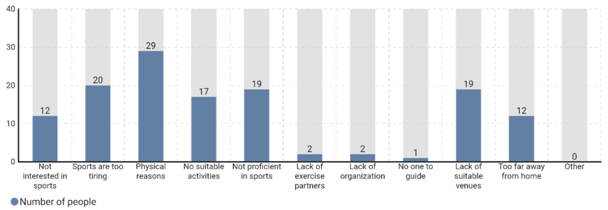

Fig. 43 Reasons for not participating in exercise

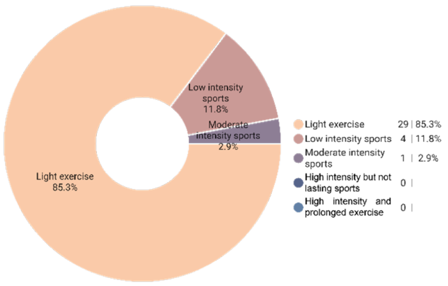

Fig. 44 The intensity of the exercise participated in

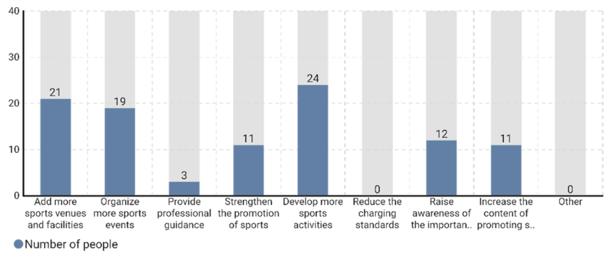

Fig. 45 Sports services for the elderly need to be strengthened

Fig. 44 indicates that elderly people who engage in spatial activities under the Bayi Bridge tend to engage in light exercise, accounting for 85.3%. There are 4 people tend to engage in low-intensity and less intense exercise, accounting for 11.8%. Only one person tends to engage in moderate intensity, intense, and persistent exercise, accounting for 2.9%. Finally, the number of people who choose high-intensity, but not persistent exercise and high-intensity and persistent exercise are both zero. Overall, this chart shows light exercise is the most engaging exercise, while high-intensity exercise is relatively less.

Fig. 45 indicates that developing more sports activities suitable for elderly people with different physical conditions is the highest choice, with 24 people choosing. Indicating that most participants hope to develop more sports activities suitable for elderly people with different physical conditions. Secondly, adding more sports venues and facilities suitable for elderly is the second most common choice, with 21 people. Next is to organize more sports events for the elderly, with 19 people choosing. The selection of similar numbers includes strengthening the promotion of safety knowledge about sports activities for the elderly, raising their awareness of the importance of sports activities, and increasing the content of sports and fitness popularization knowledge for the elderly, indicating a moderate interest in sports related knowledge among the surveyed population. Other options include providing professional guidance for elderly sports activities, with only 3 people made the choice. None of the participants has chosen the option of lowering the fees for sports facilities for the elderly.

Fig. 46 demonstrates that staying under the bridge for more than 2 hours is the highest choice, with 31 people, accounting for 91.2% of the total. And 8.8% of people choose to stay under this bridge for 1-2 hours. None of the participants chooses to stay here for less than half an hour or between half an hour and an hour. Overall, the participants tend to stay in the activity space under this bridge for a long time.

Fig. 47 indicates that 31 people believe that seats need to be added to the site. Adding tables is the second most common option. And 18 people chose to add and emphasized the need for toilets, 11 people suggested adding fitness equipment, 6 people suggested adding book racks, and 5 people suggested adding more green plant decorations. None of the participants wants to add shading facilities. In addition to these options, there are also strong suggestions to establish a senior canteen to provide convenience for the elderly. In addition, people also hope to add wireless networks, as well as increase free drinking water points and temporary storage cabinets. A small number of people hope to have first aid kits and accessible pathways. Almost all elderly people on site are equipped with smartphones, so the participants also suggested increasing phone charging points and Wi-Fi.

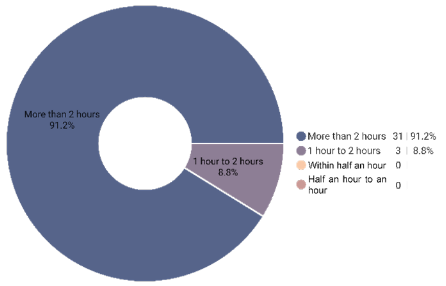

Fig. 46 Time spent at the site

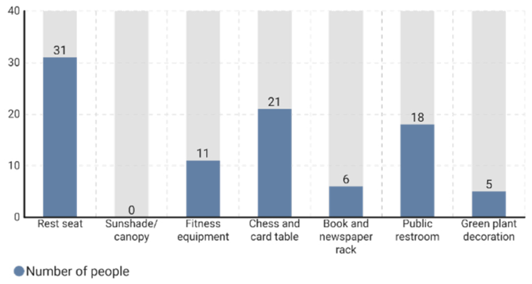

Fig. 47 The demand for facilities

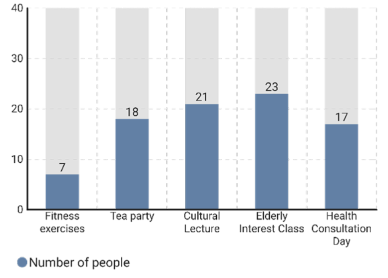

Fig. 48 The demand for activities

For the demand for activities at the space under the bridge, holding an elderly interest class (such as calligraphy and teaism) is the highest choice, with 23 people (Fig. 48). Next are cultural lectures, with 21 people choosing this option. The number of people who hope to hold a tea party and those who hope to hold health consultations are not much different, with 18 and 17 people respectively. Only 7 people hope to hold aerobics classes, indicating that the surveyed individuals have little interest in aerobics classes. Overall, the participants have a great interest in adding activities.

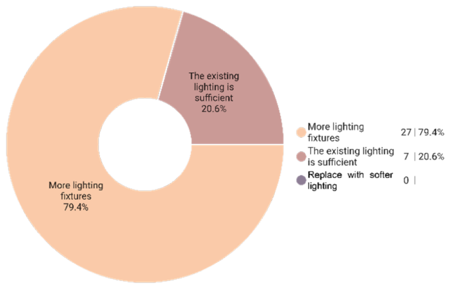

Fig. 49 Suggestions for the lighting

Fig. 49 indicates that 27 people believe that space under the bridge needs more lighting, accounting for 79.4%. 7 people believe that the existing lighting in the space under the bridge is sufficient. None of the participants thinks that softer lighting is needed inside the venue. There was no streetlamp inside the site, and they could only use the streetlamp on the side road for lighting at night.

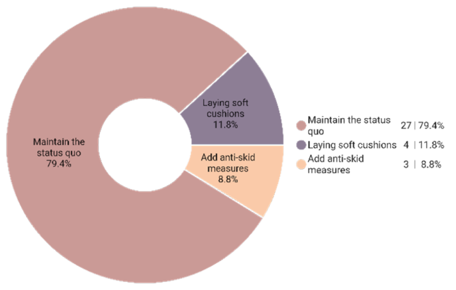

Fig. 50 Suggestions for the paving

Fig. 50 demonstrates that 27 people believe that the ground of the space under the bridge only needs to be maintained in its current state. In response, they explained that the pebbles laid on the ground can massage the soles of the feet and be beneficial to the body. There are 4 people who believe that soft cushions should be installed, accounting for 11.8%. In addition, some people believe that anti slip measures should be added, accounting for 8.8%.

For the convenient facilities that hope to be added in the space under the bridge. Adding a wireless network is the highest choice, with 29 people choosing this option (Fig. 51). Next is the addition of free drinking water points, with 21 people. Next are toad temporary storage cabinets for 7 people. The options of first aid kit and barrier free access have the same number of participants, both with 2 people, indicating that the participants are not very interested in these two options. And none of the participants chooses a public phone. Almost all the elderly on the site were equipped with smart mobile phones. Therefore, in addition to these options, the participants also suggested adding mobile phone charging places.

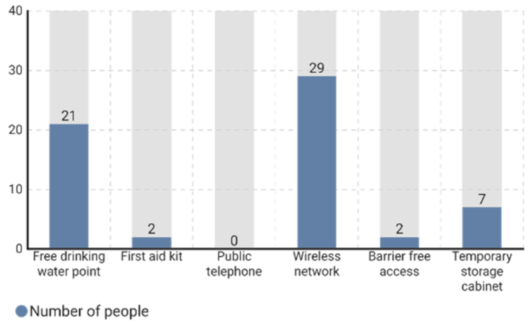

Fig. 51 Convenient facilities that hope to be added

Fig. 52 demonstrated that 15 people believe that the safety of the site is average, 10 people believe that the interior of the site is relatively safe, and 6 people believe that the interior of the site is not very safe. Some people believe that the interior of the site is very safe. None of the participants thinks the interior of the site is very unsafe. In general, it is believed that the interior of the site is not very safe. And some people explain that there are people riding electric motorcycles on the pedestrian walkway inside the venue. These participants believe that there are many people playing poker inside the venue. And because of playing poker, conflicts often happen here, so it is necessary to add security.

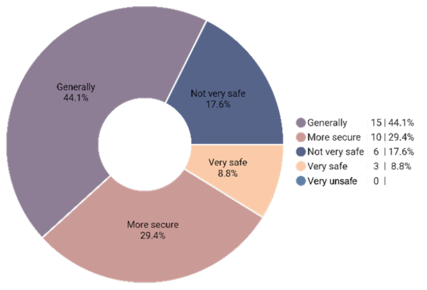

Fig. 52 Security feedback

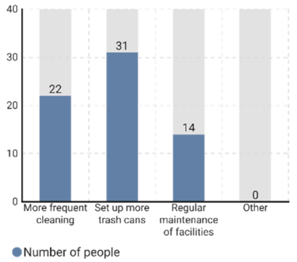

Fig. 53 Suggestions for the plot and maintenance of the site

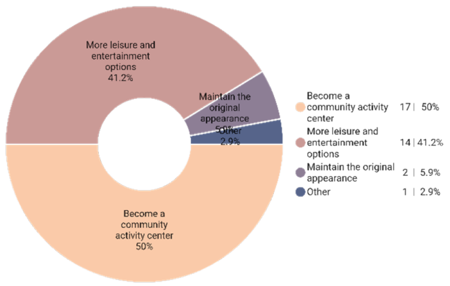

Fig. 54 Overall expectations for renovation

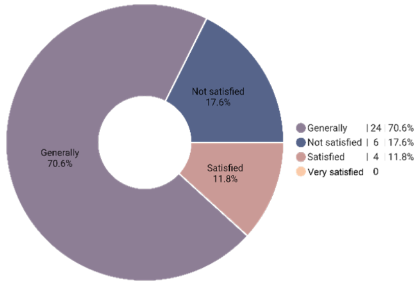

Fig. 55 Satisfaction with the comfort level of the site

Fig. 53 indicates that 31 people believe that more garbage bins should be installed for the cleaning and maintenance of the space under the bridge. Secondly, 22 people believe that the interior of the site should be cleaned more frequently. Finally, 14 people believe that regular maintenance should be carried out on various facilities inside the site. And there would be hawkers selling food here at noon and in the evening, generating garbage. Therefore, it is necessary to strengthen the cleaning and maintenance of the site.

In response to the overall expectation for the renovation of the space under the bridge, 17 people hope that this space under the bridge can become a community activity center in the future, accounting for 50% (Fig. 54). Secondly, 14 people hope that this venue can provide more leisure and entertainment options in the future. Next, some participants hope that the site can maintain its original appearance and pay attention to internal maintenance. Another option was chosen as 'other' that the space under the bridge becomes a green space for the city in the future.

Most people rated the comfort level of the space under the bridge as average, with a total of 24 people, accounting for 70.6% (Fig. 55). Six people rated the comfort of the site as unsatisfactory, accounting for 17.6%, and 4 people rated the comfort of the site as satisfactory, accounting for 1.8%. None of the participants expressed great satisfaction. Overall, people inside the site are not very satisfied with the comfort level inside the site.

Fig. 56 indicates that 31 people believe that the space under the bridge needs additional seats. Most of the seats inside the site were brought from their homes, and most of the participants suggested adding seats with backrests. Secondly, 9 people chose the option of 'other' and suggested adding toilets. Although there are public toilets on site, they all use squat toilets, which are not friendly to the elderly. And 4 people suggested adding handrails to the bathroom. Finally, the number of people who chose to add facilities specifically for disabled people, set up emergency stations, and provide wheelchair rental services was 0. In addition to these options, there are also strong suggestions to establish a senior canteen to provide convenience for the elderly.

Fig. 57 demonstrates that 33 out of 34 people do not want children-related facilities to be provided in space under the bridge. Only one person wishes to provide facilities related to children. There were almost no children on the site either on weekdays or weekends. These participants mentioned that they are not very willing to bring their grandchildren to play inside the site, mainly due to the safety of the site, and they believe that there are many people playing poker inside the site, which is not a good place for children to play.

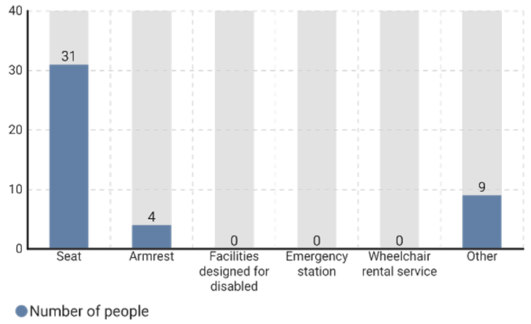

Fig. 56 Aging-friendly facilities needed

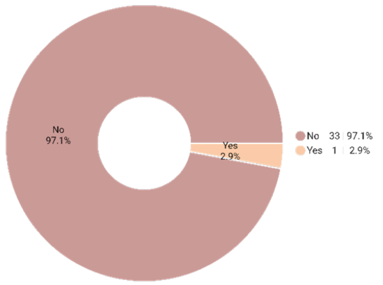

Fig. 57 Willingness to add facilities for children

4.2.3 Outcomes

The survey focuses on the activity needs of the elderly, the current status of space use, and optimization expectations, providing data support for the aging-friendly renovation of the space under the bridge and helping to create a practical and humane elderly-friendly public space.

The participants are mainly elderly people, with a relatively higher willingness to participate among males. Most of them live with their families, and there are also some elderly people living alone. This group of people living alone has a more urgent need for social interaction. Overall, participants have outstanding social enthusiasm, with most having personal interests and hobbies, and frequently participating in various social activities, with a strong dependence on offline socializing.

In terms of space utilization, the space under the bridge has become an important leisure and social place for the elderly in the surrounding area, with core uses focused on leisure and entertainment, social interaction, as well as mild physical exercise, emotional regulation, and other needs. Participants prefer low-intensity activities such as chess, dance, chatting, and walking. The participants mainly use walking and public transportation to travel to the site, and some choose to ride electric motorcycles, which poses certain safety hazards. Most people travel frequently and stay for a long time, with their travel time mostly concentrated in the afternoon. Some people choose to go in the morning or at night to avoid the high temperature during the day, and most of them gather spontaneously without organized activity arrangements.

For the evaluation of the current spatial situation, the participants have low satisfaction with the existing facilities, believing that the current public facilities are difficult to meet the actual needs, especially the lack of basic infrastructure suitable for the elderly, such as comfortable seats and elderly friendly bathrooms. The existing bathrooms also do not fully consider the convenience of elderly use in facility configuration. There are obvious shortcomings in the site environment, with prominent noise interference issues, mainly from the audio equipment used in on-site activities. At the same time, the safety of the site is also highly concerned, and factors such as electric motorcycles travel and potential conflicts during activities have become factors affecting safety. In terms of functional requirements, most respondents hope to transform the space into a community activity center or add more leisure and entertainment options. They have a strong demand for organized activities such as elderly interest classes, cultural lectures, and health consultations. In terms of supporting facilities, participants look forward to adding convenient services such as wireless internet, free drinking water points, and mobile phone charging points. At the same time, participants hope to improve the lighting conditions of the site, strengthen daily

cleaning and maintenance, and increase the configuration of garbage bins. In terms of aging friendly details, in addition to infrastructure, elderly canteens, bathroom handrails, etc. have become key demands. However, most participants do not want to add children's related facilities, believing that the current site environment and safety conditions are not suitable for children's activities.

At the community service level, there is a serious shortage of activity supply for the elderly in the surrounding communities. Not only do they lack specialized elderly activity rooms, but there are also very few regular elderly activities. Existing activities are difficult to meet the needs of the elderly in terms of frequency, type, and theme. Elderly people tend to prefer light exercise, and the main obstacles to participating in sports are limited physical conditions, uncomfortable exercise intensity, and lack of suitable venues. Participants expect to have more sports programs and exclusive venue facilities that are suitable for different physical conditions.

Based on the comprehensive survey results, the renovation of the space under Bayi Bridge should clarify the core position of a community-based aging friendly leisure and social center, focus on the mild activities and social needs of the elderly, and retain the spontaneously formed core activity site. Facility optimization should prioritize addressing the shortcomings of elderly friendly facilities, improving convenient facilities, strengthening environmental governance, regulating activity order, improving site comfort and safety, and meeting the needs of the elderly.

4.2.3.1 Functions required

According to the comprehensive analysis of the survey results, the functional needs of residents around the site show a clear hierarchy (Fig. 58): they have the most urgent requirements for the configuration of restaurants, chess and card rooms, and toilets, which directly affect the convenience of daily life and the basic condition for social interaction; the demand for secure offices, parking lots, gymnasium and leisure spaces is at a moderate level, as these facilities play an important role in ensuring safety, facilitating transportation, and promoting health; however, the demand for reading rooms, classrooms, teahouses, and multifunctional rooms, markets, and healing spaces is relatively low. Although these facilities can enrich spiritual and cultural life, they are not a priority consideration at the current stage.

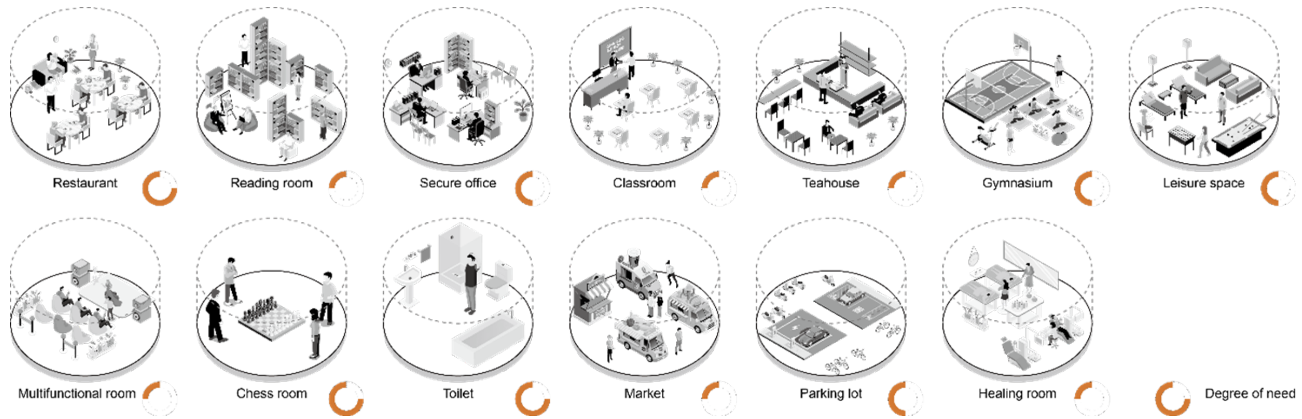

Fig. 58 Basic functions

4.2.3.2 Enhanced functions

Based on meeting the basic functional requirements, in order to reduce the time spent by the elderly on playing poker, improve the quality of spiritual and cultural life of the elderly and enhance the project, the venue has specially added exhibition space, cinema facilities, and meditation area, aiming to create a rich spiritual environment for the elderly through artistic and cultural experiences and spiritual healing (Fig. 59). In addition, during in-depth research, elderly residents in the surrounding area specifically expressed the hope that convenient service facilities can be improved within the venue, including wireless networks covering the entire area, convenient mobile phone charging points, free drinking water supply points, practical storage cabinets, and reasonably distributed garbage bins. These detailed designs will effectively enhance the convenience and comfort of site.

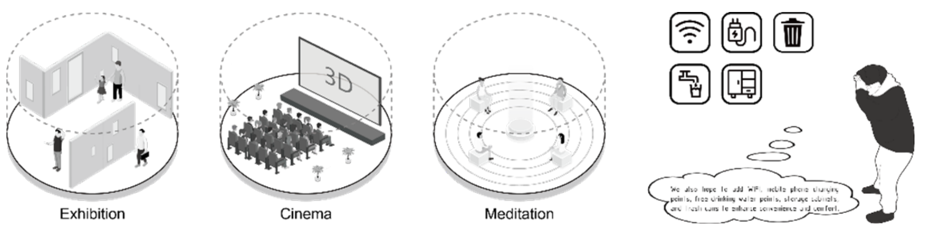

Fig. 59 Enhanced functions

4.3 Microclimate analysis

In order to further explore the reasons why elderly residents around the site prefer to gather in space under the bridge, grasp the temperature distribution characteristics of the area, and provide a basis for improving the thermal comfort of elderly activities. A detailed 3D microclimate model was constructed using ENVI-met software at the technical level (Fig. 60). Select the hottest day of 2024 in the local area for 24-hour simulation, and input relevant parameters such as site geography, climate, human body, and building materials, etc. numerical simulation techniques were used to successfully generate physiological equivalent temperature (PET) spatial distribution maps for different time periods of the day. Representative observation points selected within and around the site (including the shadow core area under the bridge, non-shadow areas under the bridge, and surrounding residential areas) were compared and analyzed, and the physiological equivalent temperature spatial distribution map was further classified twice according to the suitable range of elderly thermal perception and human health, resulting in a thermal stress duration map. These data achievements have laid a solid theoretical foundation for optimizing site design and formulating scientific and reasonable environmental control strategies.

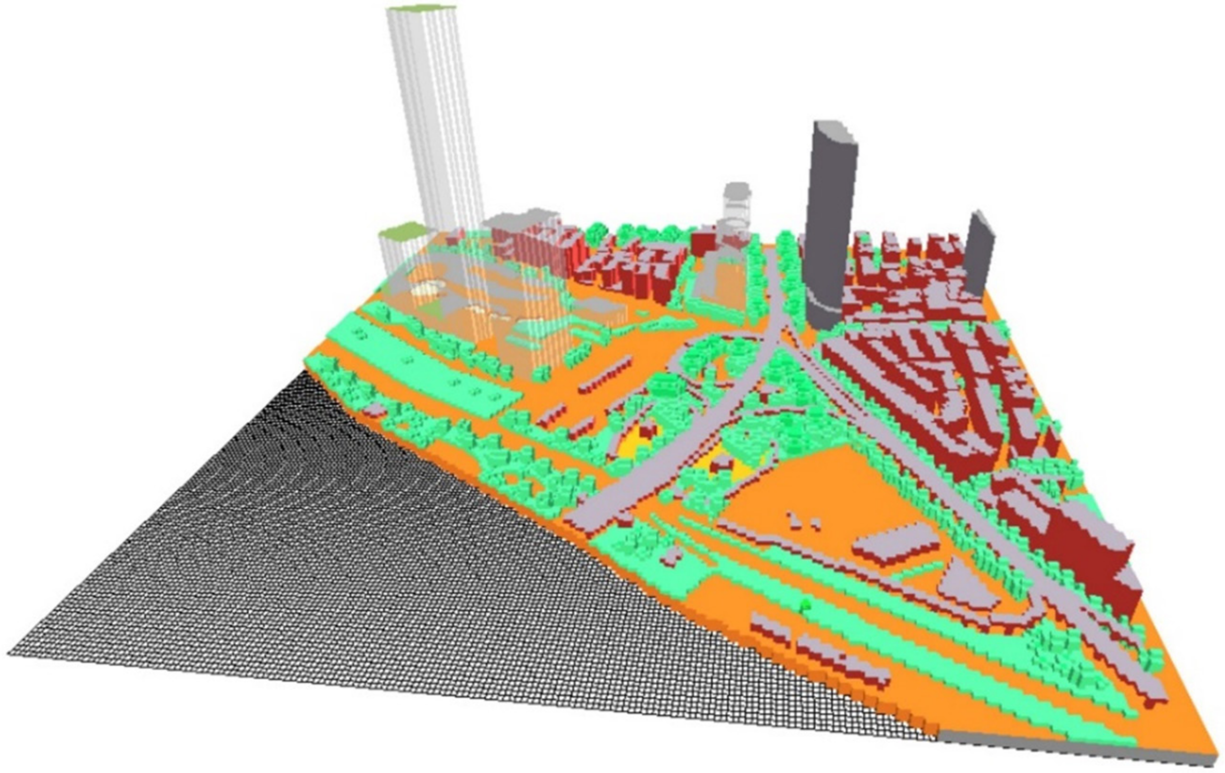

Fig. 60 The 3D model in ENVI-met

4.3.1 Simulation model with ENVI-met

The simulation was implemented by ENVI-met, which typically models the impact of urban planning on environment variables and microclimate (Ali & Li, 2018). ENVI-met is a three-dimensional microclimate model that was originally proposed by Bruse and Fleer's team at the University of Mainz, Germany, in 1998 (Bruse & Fleer, 1998). The software model is based on CFD and thermodynamics (Kim & Jong, 2020). It can simulate the interaction process between the ground, vegetation, buildings, and the atmosphere in a small space. ENVI-met is mainly supported by the Biomet tool for calculating the thermal index and the Albero tool for creating a new vegetation model (Xiao & Yuizono, 2022). With horizontal resolutions of 0.5-10m, time steps of up to 10s (Lu, 2017). It is also particularly suitable for simulating microenvironments on medium and large scales (Xiao & Yuizono, 2022). Model performance is mainly related to the setting of basic parameters for spatial grid resolution, vegetation models, and building materials. The precise running performance determines the difference between the simulation and realistic scenarios.

To ensure the accuracy of the model and reproduce the thermal stress of the site under extreme climate conditions, a 24-hour continuous simulation was conducted on the hottest day in Nanchang in 2024, July 24th, with a maximum temperature of 39℃ (Fig. 61). The climate data was sourced from the EPW map file provided by Ladybug Tools, which is used in building performance analysis and environmental design to simulate how a building will interact with its climate. Based on relevant parameter configurations (Tab. 1), the simulated space and time zone are set with the space under the Bayi Bridge as the center, covering an area of 600m×600m and a height limit of 600 meters. A three-dimensional grid division of 200×200×39 is used in the X, Y, and Z directions, with a grid resolution of 3m ×3m ×3m, and a total simulated area of 360000m2. The reference time zone is GMT+8, and the geographical coordinates of the site are 28°68′N and 115°85′E, with a climate type of subtropical humid climate (CFA).

In terms of human body and clothing parameters, based on the physiological characteristics of the core users of the space under the bridge – the elderly, a simulated human body is set as a 60 year old male, with a height of 1.65m and a weight of 65kg, mainly in a standing posture, a walking speed of 1.21m/s, a static insulation value of 0.5clo for clothing, a basal metabolic rate of 61.32W, and a working metabolic rate of 80.00W, which conforms to the physiological consumption state of daily activities of the elderly. In terms of materials and surface parameters, the building façade adopts a combination of brick walls and insulated glass, the roof is made of concrete material, and the paving includes concrete pavement and asphalt road. All materials parameters are based on actual engineering standards. The model also reproduces the building layout, vegetation distribution, and surface morphology within the site, ensuring that the simulated scene is consistent with the height of the real site. The initial air temperature is 31.2℃, the initial air temperature is 31.2℃, the initial relative humidity is 23.9%, the initial wind speed is 2.0m/s, and the initial wind direction is 142°, providing accurate initial boundary conditions for thermal environment simulation.

Through the above parameters configuration, the ENVI-met model can fully capture the dynamic changes in microclimate under the Bayi Bridge, providing reliable numerical simulation support for subsequent physiological equivalent temperature (PET) analysis, thermal comfort assessment, and thermal stress duration calculation.

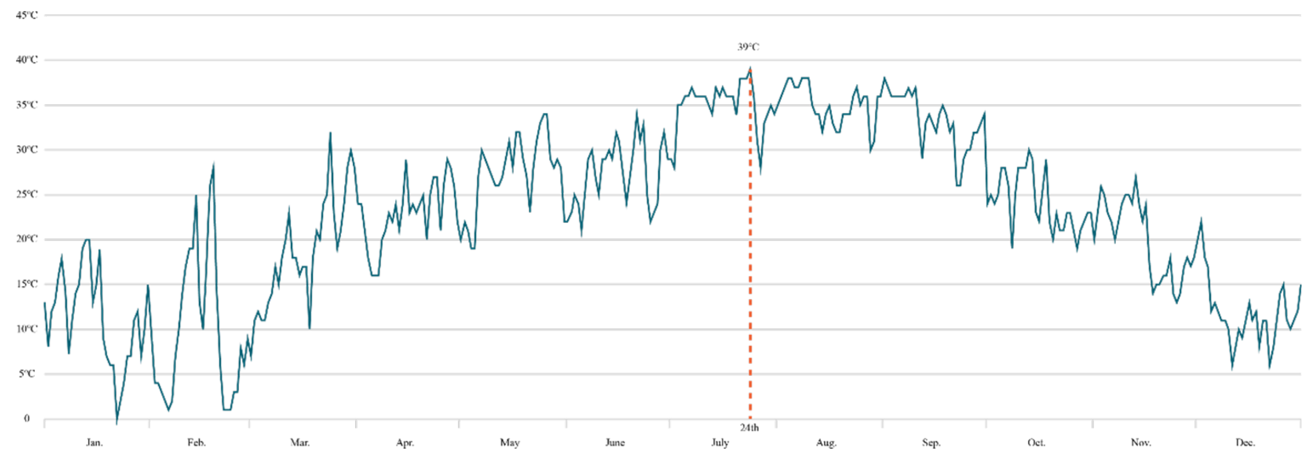

Fig. 61 Temperature of Nanchang in 2024 (Data from The China Meteorological Data Service Center)

Site specifications	Name of location	Nanchang
	Position on earth	28°68′N
		115°85′E
	Reference time zone	GMT+8
	Climate	CFA
	Grid dimension	200*200*39 Grids
	Size of x, y, z grid cells	3m*3m*3m
Time of simulation	Simulation date	24.07.2024
	Start time	00:00
	Simulation duration (h)	24
Body parameters	Age of person (y)	60
	Gender	Male
	Height (m)	1.65
	Weight (kg)	65
	Body position	standing
	Walking speed (m/s)	1.21
Clothing parameters	Static insulation outdoor (clo)	0.5
Body metabolism	Basal rate (W)	61.32
	Work metabolism (W)	80.00
Model materials	Building materials (facades)	Brick wall
		Heat protection glass
	Building materials (roofs)	Concrete wall
	Pavements	Concrete pavement
	Roads	Asphalt road
Primary meteorological data	Initial air temperature (℃)	31.2
	Initial relative humidity (%)	23.9
	Initial wind speed (m/s)	2.0
	Initial wind direction (°)	142

Tab. 1 Parameters configuration

4.3.2 Thermal comfort analysis

PET is defined as the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body is maintained with core and skin temperature equal to those under the conditions being assessed (Höppe, 1999).

The physical equivalent temperature (PET) is very effective, as a single thermal index, to evaluate the thermal component of any given microclimate, and its units '℃' make it convenient for a layperson to easily understand it as an indicator of thermal stress (Deb & Alur, 2010).

After completing the simulation, the raw data of PET was obtained (Fig. 62, Fig. 63, Fig. 64, Fig. 65, Fig. 66 and Fig. 67). This data is presented in the form of distribution maps, illustrating the distribution of PET values across different time periods throughout the day. In the obtained PET data, the lowest value is 22.08℃ and the highest value is 60.41℃.

In the early morning hours, there have been obviously localized high-temperature areas in densely built areas, while the PET values in the shadow areas of buildings, under bridges, green spaces, and water bodies remain relatively low. The blue and yellow color blocks also clearly distinguish the thermal comfort differences between densely built areas, under bridges, green spaces, and water bodies. As time goes by, the high-temperature area begins to rapidly expand, and the originally cool blue area continues to shrink. In the afternoon to evening, the PET values in the entire simulation area generally increase, and most of the simulation area is covered with a brownish yellow color representing high heat. Only the shaded areas under bridges, buildings, and a few areas with dense vegetation or near water bodies can maintain a relatively mild state, the thermal discomfort in the city also reaches its peak throughout the day.

From the details of spatial distribution, densely populated areas are always concentrated areas of thermal pressure - densely populated buildings and roads continue to store heat under high temperatures in summer, keeping the PET values in these areas at a high level. Although shaded areas, green spaces, water bodies can continue to play a cooling role and maintain local coolness, their buffering range is also constantly shrinking under the influence of overall environmental temperature rise. The PET value of the space under the bridge is always lower than that of the surrounding environment.

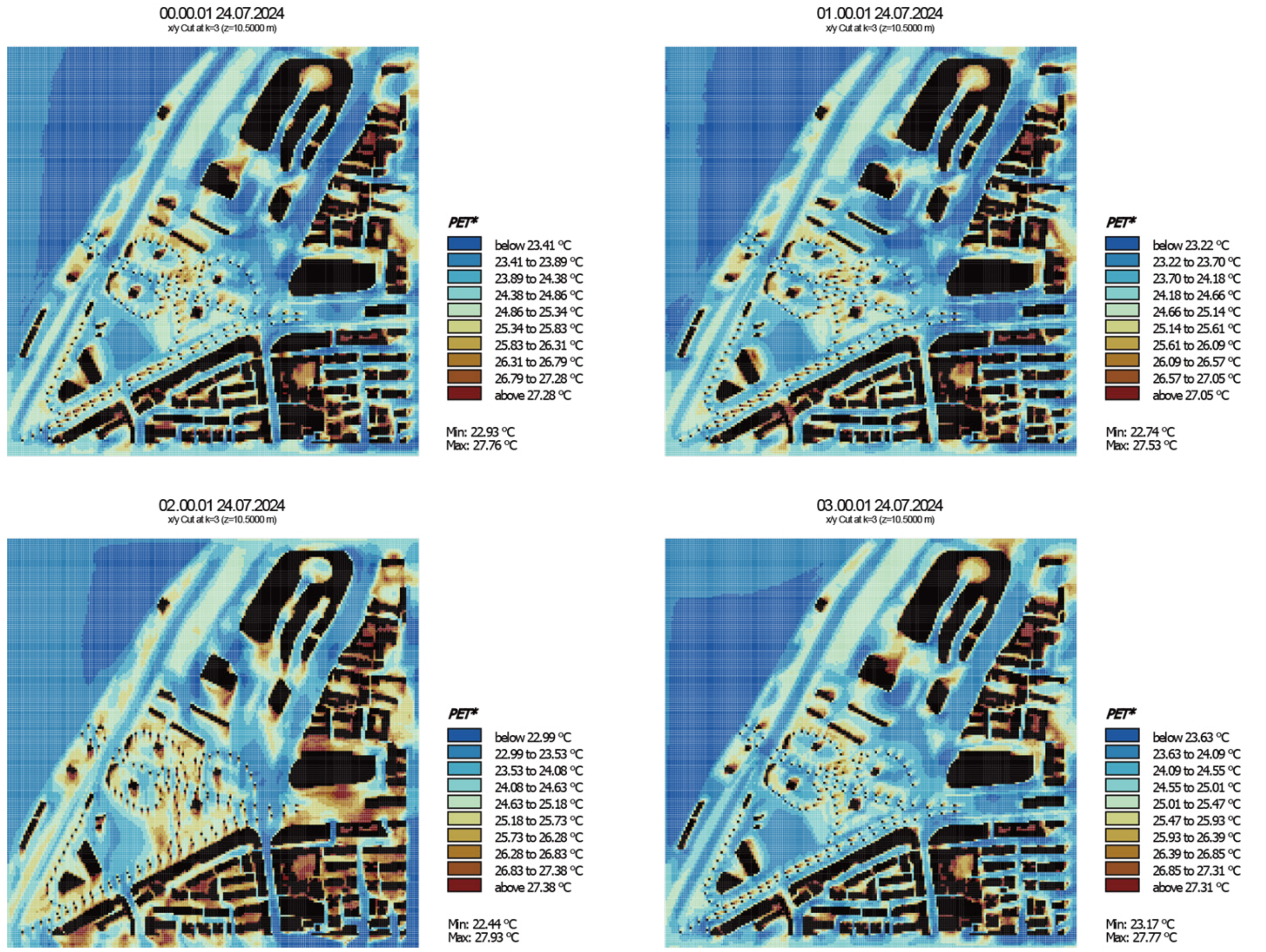

Fig. 62 Original PET maps 1

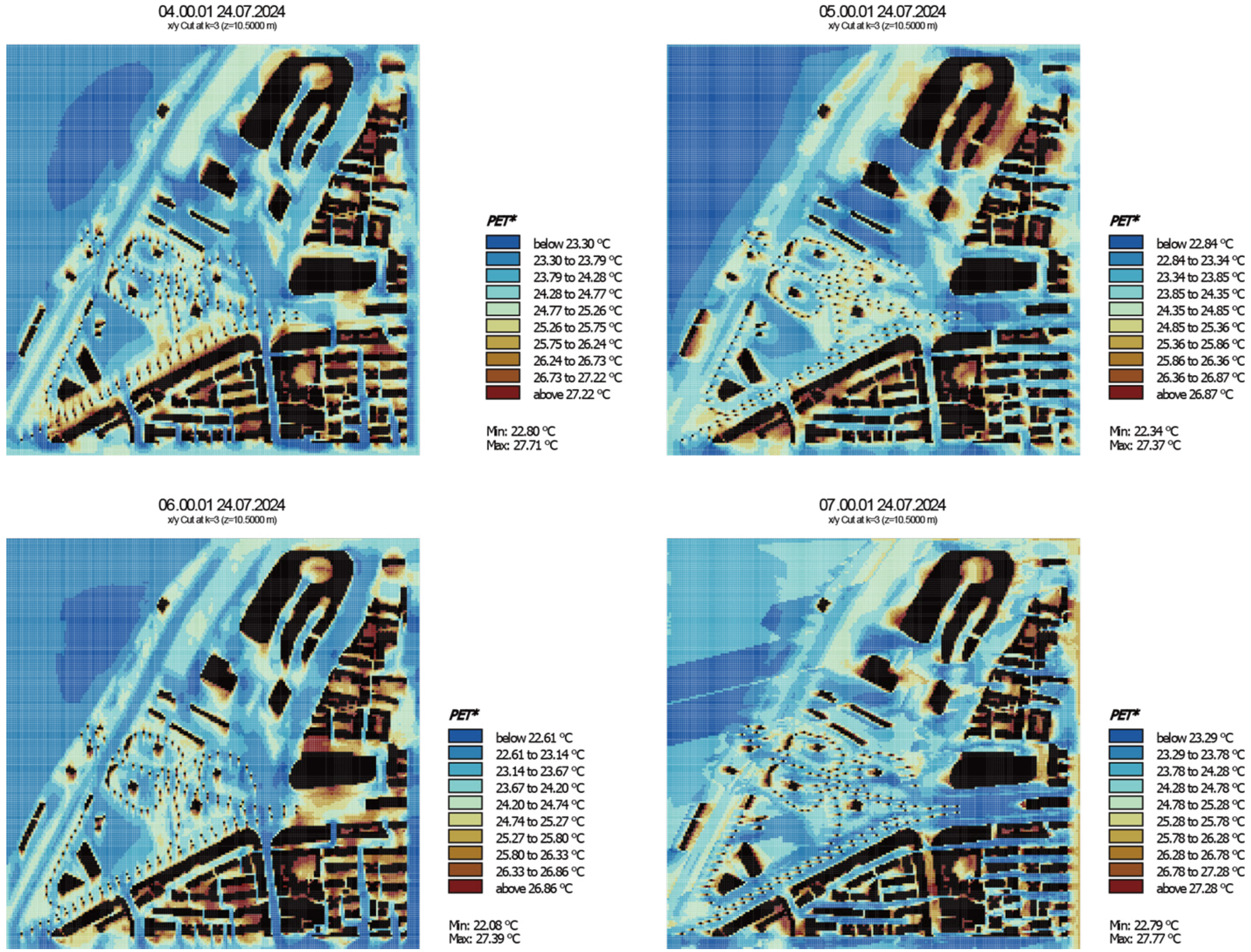

Fig. 63 Original PET maps 2

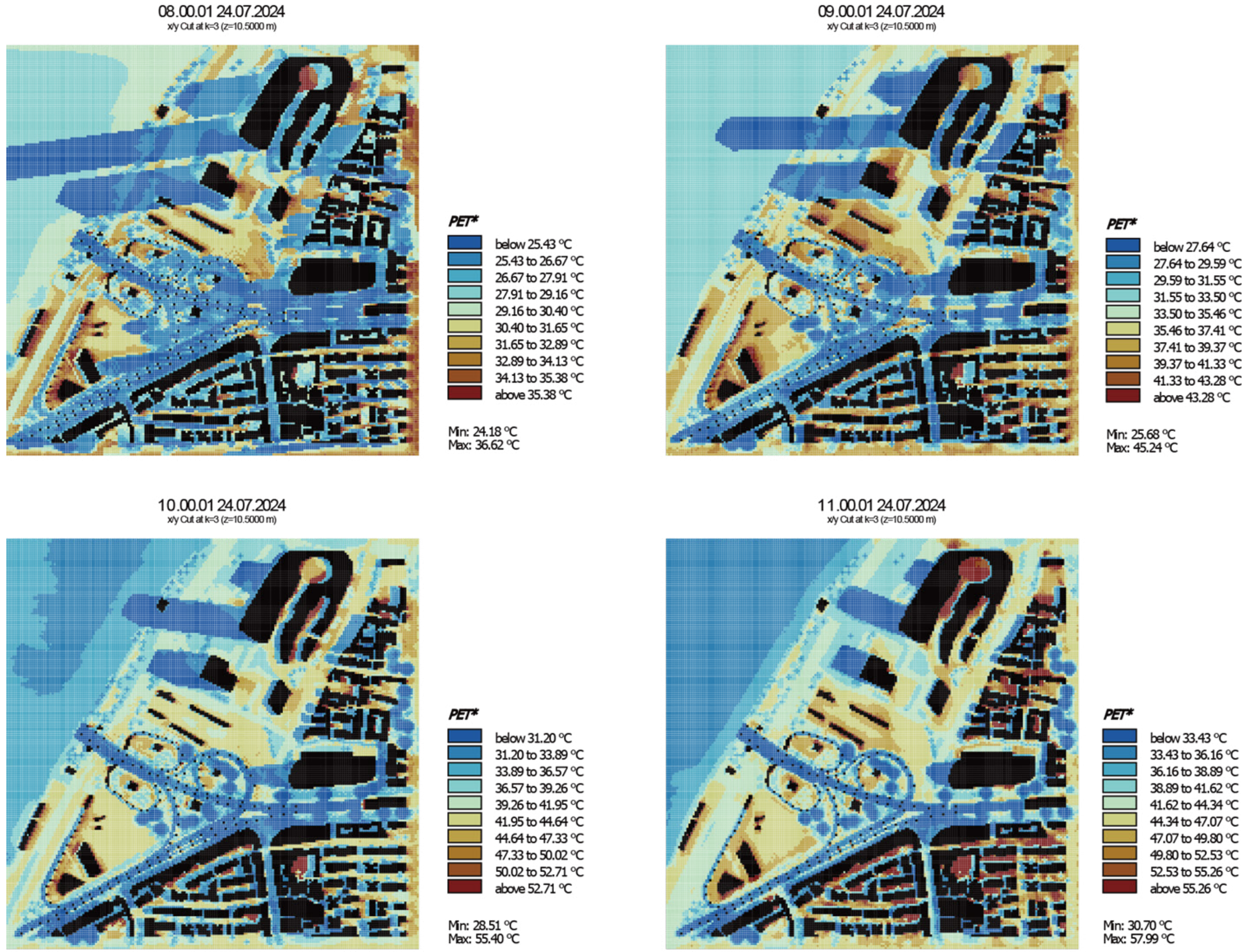

Fig. 64 Original PET maps 3

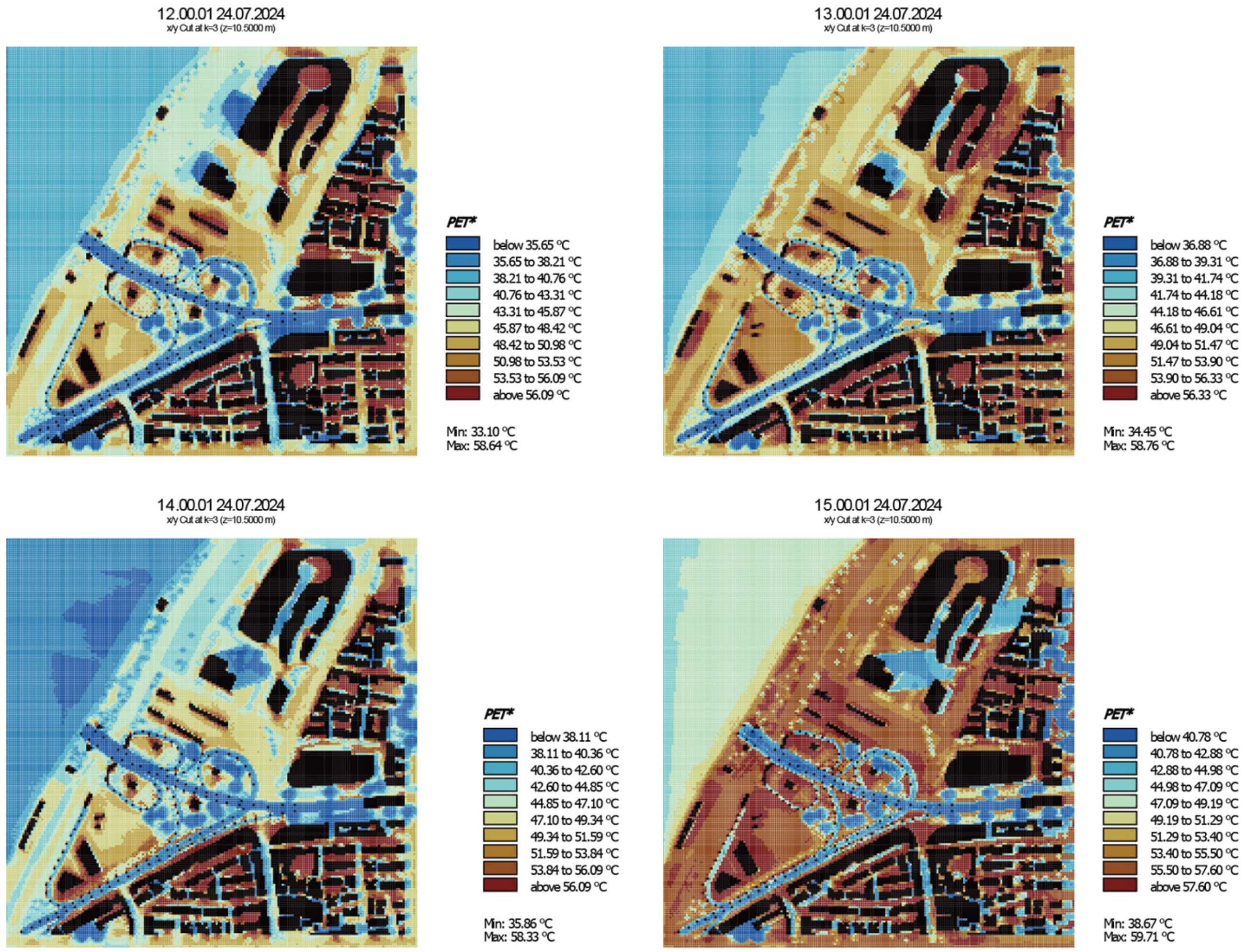

Fig. 65 Original PET maps 4

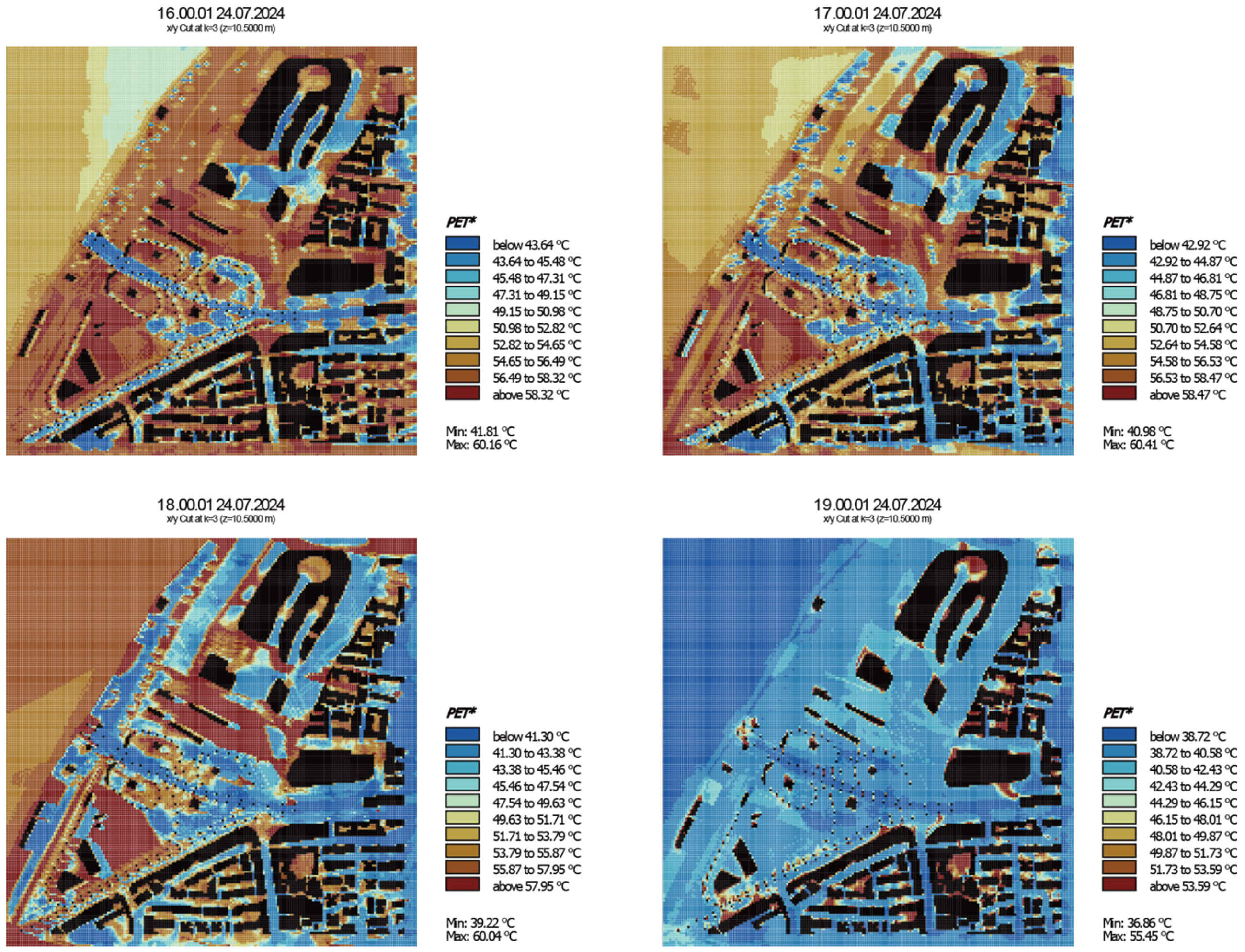

Fig. 66 Original PET maps 5

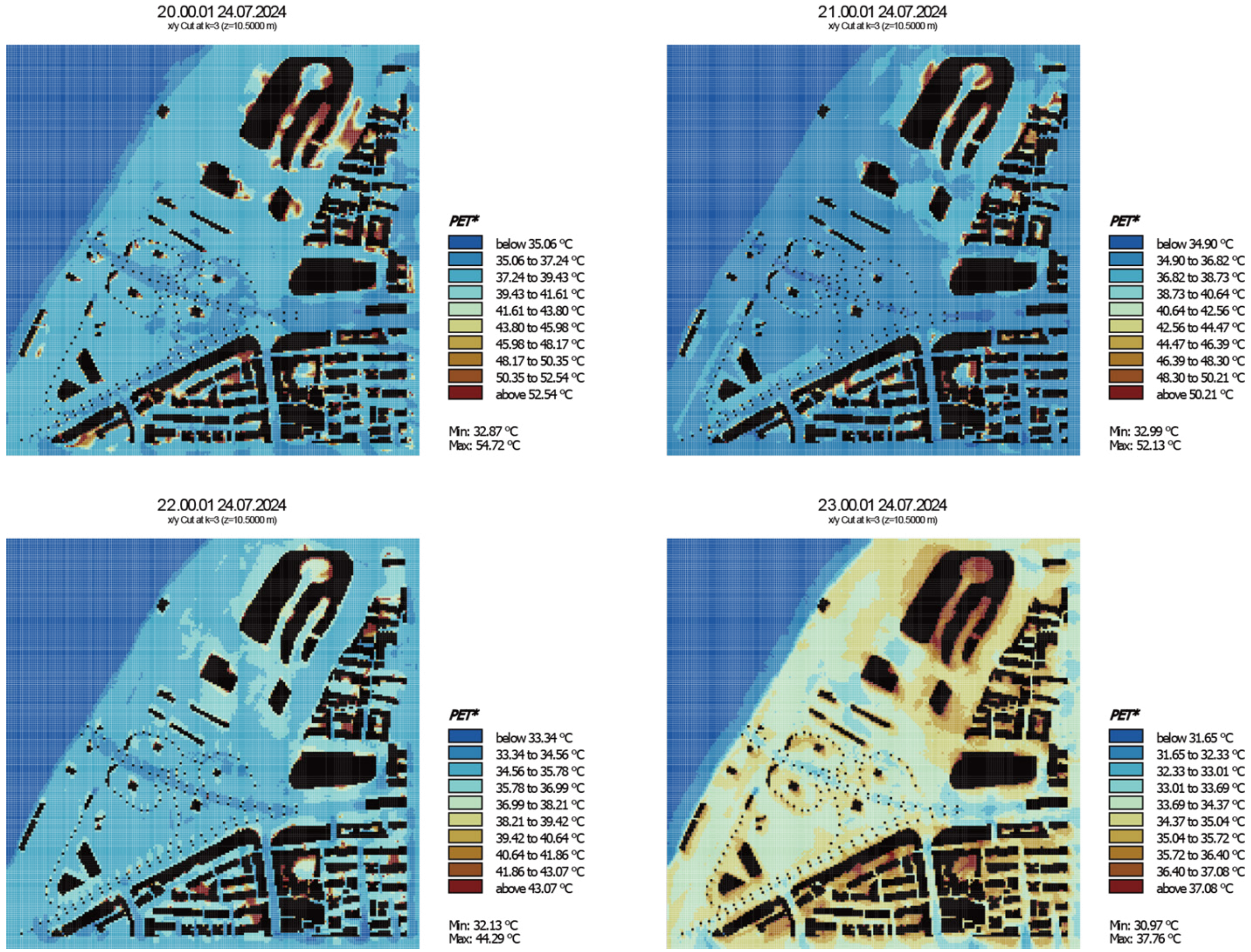

Fig. 67 Original PET maps 6

4.3.2.1 Point analysis

In order to further explore the phenomenon of elderly residents preferring to gather in the space under the bridge (Fig. 68), this study selected six representative observation points in the map selection process, including four located in the core area of the site and two taken from surrounding residential areas, forming a spatial comparison sample. In the internal point selection of the site, the space under the bridge was selected as the key observation object, and two points numbered 1 (X=104, Y=72, Z=3) and 2 (X=89, Y=77, Z=3) were chosen; at the same time, in order to eliminate the interference of the special characteristics of the space under the bridge, control points 3 (X=108, Y=82, Z=3) and 4 (X=96, Y=66, Z=3) were set up in the non-bridge area. The selection of surrounding residential areas takes into account geographical balance, with one observation point set up in each of the residential areas in the northeast and south directions of the site, namely point 5 (X=168, Y=126, Z=3) and point 6 (X=89, Y=35, Z=3), to ensure that the sample coverage of different residential environments. This selection scheme not only maintains the integrity of spatial logic, but also effectively controls environmental variables through comparative setting, providing a scientific basis for subsequent analysis.

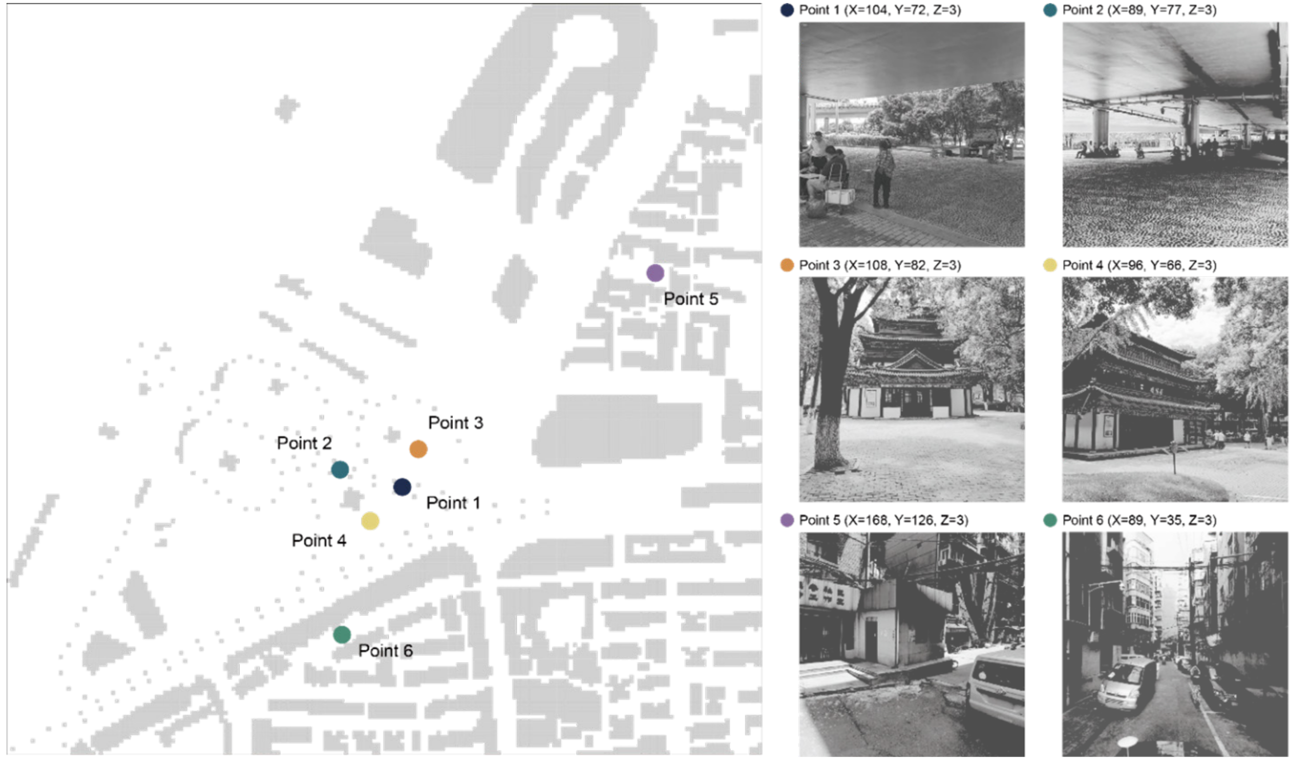

Fig. 68 Points distribution map

The PET data obtained for the whole day (Tab. 2, Tab. 3, Tab. 4, Tab. 5, Tab. 6 and Tab. 7)was plotted into a line chart (Fig. 69). This chart presents the physiological equivalent temperature (PET) changes at 6 locations on July 24, 2024. It can be seen that from around 00:00 – 09:00, PET at various locations is generally in the low range of 20-30℃, with small fluctuations and similar values; starting from 10:00, PET at various locations began to differentiate: Point 5 showed the most significant increase, rapidly breaking through 50℃ and continuously fluctuating violently between high regions (approaching 60℃ multiple times); Point 6, Point 4 and Point 3 also rose significantly simultaneously, maintaining a high level of 40-58℃ with significant fluctuations; however, Point 1 and Point 2 only showed a mild increase, stabilizing in the range of 30-40℃, and the temperature difference gradually increased compared to the first four points. After 20:00, PET at all points showed a downward trend, with high values (especially Point 5) still showing significant fluctuations, while low values (Point 1 and Point 2) maintained a relatively stable downward rhythm, and the temperature difference between each point gradually decreased.

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	24.84	33.09	36.81	27.39	0.00	0.00	-32.43	-40.79	0.95	26.19	22.00	18.34
24.07.2024	01.00.01	0.00	24.75	33.02	36.81	27.27	0.00	0.00	-32.44	-40.25	0.88	25.96	21.92	18.22
24.07.2024	02.00.01	0.00	24.11	32.49	36.81	27.04	0.00	0.00	-29.82	-46.51	1.39	25.94	22.27	18.16
24.07.2024	03.00.01	0.00	24.89	33.13	36.81	27.33	0.00	0.00	-31.63	-40.16	0.79	25.75	22.34	17.98
24.07.2024	04.00.01	0.00	23.78	32.21	36.81	26.72	0.00	0.00	-28.64	-47.05	1.30	25.38	22.39	17.63
24.07.2024	05.00.01	0.00	24.44	32.76	36.81	26.96	0.00	0.00	-30.23	-41.26	0.79	25.14	22.43	17.23
24.07.2024	06.00.01	0.00	23.24	31.76	36.80	26.31	0.00	0.00	-27.33	-48.74	1.38	24.88	22.36	17.02
24.07.2024	07.00.01	0.00	23.70	32.14	36.80	26.64	0.00	0.00	-27.79	-47.61	1.28	25.16	22.63	17.36
24.07.2024	08.00.01	0.00	24.81	33.06	36.81	27.60	0.00	0.00	-27.91	-47.39	1.30	26.16	23.59	18.21
24.07.2024	09.00.01	0.00	28.22	34.55	36.88	29.48	0.08	0.00	-25.78	-36.28	0.74	27.69	25.97	19.32
24.07.2024	10.00.01	0.00	30.65	34.79	36.92	30.71	0.19	0.00	-19.18	-31.87	0.82	29.03	28.49	20.44
24.07.2024	11.00.01	0.00	31.51	34.88	36.93	31.28	0.21	0.00	-20.53	-26.06	0.95	30.47	28.13	19.79
24.07.2024	12.00.01	0.00	33.40	35.05	36.97	32.18	0.30	0.00	-18.50	-18.83	0.96	31.89	29.00	20.75
24.07.2024	13.00.01	0.00	35.37	35.23	37.01	33.10	0.40	0.00	-15.76	-10.38	0.71	33.23	30.10	20.53
24.07.2024	14.00.01	0.00	35.77	35.26	37.02	33.29	0.43	0.00	-17.60	-8.00	0.93	33.89	29.52	22.12
24.07.2024	15.00.01	0.00	38.83	35.50	37.08	34.70	0.68	0.00	-13.98	3.41	0.89	36.09	30.97	24.35
24.07.2024	16.00.01	0.00	40.81	35.64	37.12	35.59	0.91	0.00	-12.12	10.98	1.16	37.33	31.73	26.56
24.07.2024	17.00.01	0.00	40.15	35.59	37.11	35.27	0.86	0.00	-12.69	8.00	1.04	36.89	31.50	26.24
24.07.2024	18.00.01	0.00	39.14	35.50	37.09	34.69	0.93	0.00	-14.12	2.40	1.29	35.86	30.94	27.82
24.07.2024	19.00.01	0.00	37.29	35.36	37.05	33.96	0.66	0.00	-14.78	-7.17	1.92	34.51	30.57	26.73
24.07.2024	20.00.01	0.00	36.17	35.27	37.03	33.25	0.71	0.00	-15.65	-12.56	1.30	33.44	30.18	27.35
24.07.2024	21.00.01	0.00	34.85	35.16	37.00	32.59	0.56	0.00	-17.06	-16.69	1.00	32.40	29.60	25.98
24.07.2024	22.00.01	0.00	33.73	35.06	36.98	32.23	0.42	0.00	-18.26	-22.14	1.42	31.98	29.09	25.28
24.07.2024	23.00.01	0.00	33.33	35.03	36.97	31.88	0.41	0.00	-18.94	-21.67	0.94	31.34	28.83	24.51

Tab. 2 Data of Point 1

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	23.99	32.39	36.81	27.08	0.00	0.00	-29.95	-47.97	1.65	26.21	22.12	18.34
24.07.2024	01.00.01	0.00	24.17	32.54	36.81	27.04	0.00	0.00	-30.68	-45.18	1.30	25.98	22.02	18.22
24.07.2024	02.00.01	0.00	24.16	32.53	36.81	27.07	0.00	0.00	-29.70	-46.43	1.36	25.93	22.36	18.16
24.07.2024	03.00.01	0.00	24.08	32.46	36.81	26.98	0.00	0.00	-29.56	-46.25	1.32	25.78	22.33	17.96
24.07.2024	04.00.01	0.00	23.75	32.19	36.81	26.73	0.00	0.00	-28.41	-47.64	1.36	25.42	22.45	17.63
24.07.2024	05.00.01	0.00	24.96	33.19	36.81	27.19	0.00	0.00	-31.65	-37.35	0.53	25.04	22.40	17.23
24.07.2024	06.00.01	0.00	23.10	31.64	36.80	26.26	0.00	0.00	-27.29	-49.55	1.50	24.95	22.25	17.02
24.07.2024	07.00.01	0.00	24.59	32.88	36.81	27.08	0.00	0.00	-30.15	-41.24	0.78	25.22	22.59	17.35
24.07.2024	08.00.01	0.00	26.18	34.20	36.83	28.25	0.00	0.00	-31.53	-37.45	0.55	26.14	23.56	18.21
24.07.2024	09.00.01	0.00	26.53	34.37	36.85	29.01	0.01	0.00	-28.38	-45.50	1.28	27.70	24.86	19.31
24.07.2024	10.00.01	0.00	30.70	34.80	36.92	30.54	0.21	0.00	-24.52	-24.66	0.52	29.37	26.67	20.48
24.07.2024	11.00.01	0.00	31.91	34.92	36.94	31.41	0.23	0.00	-20.35	-23.71	0.83	30.65	28.23	19.80
24.07.2024	12.00.01	0.00	34.13	35.12	36.98	32.56	0.33	0.00	-15.74	-17.84	0.99	32.17	29.99	20.82
24.07.2024	13.00.01	0.00	36.61	35.33	37.03	33.67	0.48	0.00	-11.12	-8.33	0.54	33.52	31.75	20.60
24.07.2024	14.00.01	0.00	37.19	35.37	37.04	33.97	0.51	0.00	-10.75	-7.08	0.84	34.10	31.91	22.09
24.07.2024	15.00.01	0.00	42.99	35.79	37.17	36.73	0.86	0.00	8.22	4.17	0.97	36.49	38.35	24.43
24.07.2024	16.00.01	0.00	53.83	36.44	37.45	38.20	1.00	0.00	14.83	9.96	1.28	37.90	40.99	26.61
24.07.2024	17.00.01	0.00	54.46	36.66	37.56	38.07	1.00	0.00	14.67	3.06	0.72	37.25	41.15	26.26
24.07.2024	18.00.01	0.00	45.22	35.92	37.23	36.34	1.00	0.00	6.40	-0.04	1.62	35.92	37.92	27.82
24.07.2024	19.00.01	0.00	37.88	35.41	37.06	34.26	0.67	0.00	-11.15	-7.54	2.20	34.58	31.82	26.73
24.07.2024	20.00.01	0.00	36.75	35.31	37.04	33.47	0.78	0.00	-13.04	-11.59	1.06	33.45	31.09	27.35
24.07.2024	21.00.01	0.00	35.61	35.22	37.02	32.82	0.67	0.00	-15.32	-13.50	0.62	32.46	30.25	25.96
24.07.2024	22.00.01	0.00	33.84	35.07	36.98	32.34	0.42	0.00	-16.48	-23.74	1.61	31.98	29.70	25.28
24.07.2024	23.00.01	0.00	33.95	35.09	36.98	32.08	0.47	0.00	-17.30	-19.27	0.69	31.32	29.44	24.52

Tab. 3 Data of Point 2

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	24.01	32.40	36.81	27.21	0.00	0.00	-27.98	-51.04	1.88	26.27	22.84	18.34
24.07.2024	01.00.01	0.00	23.56	32.03	36.80	26.94	0.00	0.00	-27.06	-53.34	2.13	26.03	22.76	18.23
24.07.2024	02.00.01	0.00	24.10	32.48	36.81	27.18	0.00	0.00	-27.25	-50.46	1.65	25.98	23.18	18.16
24.07.2024	03.00.01	0.00	24.05	32.43	36.81	27.06	0.00	0.00	-27.92	-48.99	1.51	25.83	22.90	17.99
24.07.2024	04.00.01	0.00	24.19	32.55	36.81	26.97	0.00	0.00	-28.58	-45.82	1.14	25.44	22.79	17.63
24.07.2024	05.00.01	0.00	23.78	32.21	36.81	26.66	0.00	0.00	-28.48	-46.23	1.19	25.18	22.45	17.24
24.07.2024	06.00.01	0.00	23.12	31.66	36.80	26.23	0.00	0.00	-27.45	-48.93	1.42	24.87	22.21	17.00
24.07.2024	07.00.01	0.00	22.96	31.52	36.79	26.38	0.00	0.00	-25.84	-53.82	2.01	25.28	22.64	17.37
24.07.2024	08.00.01	0.00	24.18	32.54	36.81	27.41	0.00	0.00	-25.12	-54.01	1.96	26.19	24.01	18.21
24.07.2024	09.00.01	0.00	26.19	34.21	36.83	28.90	0.00	0.00	-26.14	-50.02	1.51	27.46	25.47	19.31
24.07.2024	10.00.01	0.00	29.59	34.69	36.90	30.66	0.12	0.00	-15.44	-45.14	1.78	29.11	29.64	20.41
24.07.2024	11.00.01	0.00	39.05	35.51	37.08	34.93	0.49	0.00	23.03	-29.45	0.87	30.34	42.56	19.79
24.07.2024	12.00.01	0.00	46.07	35.99	37.24	38.29	0.75	0.00	58.29	-25.73	1.05	31.85	52.90	20.72
24.07.2024	13.00.01	0.00	50.35	36.25	37.35	40.29	0.84	0.00	78.43	-18.97	1.35	33.54	58.39	20.51
24.07.2024	14.00.01	0.00	48.02	36.11	37.29	39.25	0.93	0.00	54.82	-12.87	0.89	33.86	52.07	22.08
24.07.2024	15.00.01	0.00	57.05	37.57	38.36	43.46	1.00	0.00	115.12	-13.05	2.44	36.21	68.38	24.36
24.07.2024	16.00.01	0.00	58.25	37.99	38.50	44.79	1.00	0.00	124.44	-2.92	2.68	37.70	70.84	26.56
24.07.2024	17.00.01	0.00	58.47	38.06	38.50	45.41	1.00	0.00	125.66	-8.44	1.83	37.03	71.17	26.23
24.07.2024	18.00.01	0.00	42.57	35.75	37.16	36.27	0.94	0.00	7.45	1.93	2.93	35.93	38.07	27.81
24.07.2024	19.00.01	0.00	39.50	35.53	37.10	34.91	0.81	0.00	-2.12	-6.81	1.46	34.60	34.86	26.72
24.07.2024	20.00.01	0.00	37.51	35.38	37.05	33.97	0.73	0.00	-6.35	-14.81	1.76	33.53	33.35	27.35
24.07.2024	21.00.01	0.00	35.59	35.22	37.02	33.09	0.55	0.00	-9.72	-20.97	1.50	32.38	32.09	25.94
24.07.2024	22.00.01	0.00	35.11	35.18	37.01	32.77	0.53	0.00	-11.95	-20.12	1.08	31.98	31.32	25.28
24.07.2024	23.00.01	0.00	34.09	35.10	36.99	32.32	0.43	0.00	-13.73	-23.27	1.09	31.41	30.64	24.51

Tab. 4 Data of Point 3

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	24.17	32.54	36.81	27.23	0.00	0.00	-29.33	-48.35	1.63	26.27	22.51	18.34
24.07.2024	01.00.01	0.00	23.81	32.23	36.81	26.98	0.00	0.00	-28.67	-49.91	1.77	26.03	22.40	18.22
24.07.2024	02.00.01	0.00	24.00	32.40	36.81	27.08	0.00	0.00	-28.37	-49.26	1.62	25.99	22.70	18.16
24.07.2024	03.00.01	0.00	24.08	32.46	36.81	27.01	0.00	0.00	-28.90	-47.19	1.37	25.78	22.58	17.97
24.07.2024	04.00.01	0.00	24.29	32.64	36.81	26.99	0.00	0.00	-29.60	-43.96	1.02	25.45	22.52	17.63
24.07.2024	05.00.01	0.00	24.24	32.60	36.81	26.84	0.00	0.00	-30.16	-41.98	0.85	25.13	22.27	17.22
24.07.2024	06.00.01	0.00	23.01	31.56	36.80	26.20	0.00	0.00	-27.31	-49.83	1.55	24.93	22.16	17.02
24.07.2024	07.00.01	0.00	23.99	32.38	36.81	26.75	0.00	0.00	-28.87	-44.95	1.06	25.15	22.50	17.35
24.07.2024	08.00.01	0.00	25.33	33.50	36.81	27.86	0.00	0.00	-29.27	-43.64	0.98	26.22	23.59	18.21
24.07.2024	09.00.01	0.00	26.61	34.38	36.85	29.10	0.01	0.00	-26.81	-47.17	1.37	27.70	25.42	19.31
24.07.2024	10.00.01	0.00	30.14	34.74	36.91	30.52	0.16	0.00	-20.63	-33.52	0.92	29.00	27.95	20.40
24.07.2024	11.00.01	0.00	37.17	35.37	37.04	34.01	0.43	0.00	11.19	-27.68	0.85	30.45	38.85	19.75
24.07.2024	12.00.01	0.00	45.14	35.93	37.22	37.88	0.75	0.00	50.26	-23.63	0.90	31.83	50.68	20.74
24.07.2024	13.00.01	0.00	50.54	36.26	37.35	40.53	0.91	0.00	75.74	-17.78	0.95	33.25	57.71	20.49
24.07.2024	14.00.01	0.00	47.55	36.08	37.28	39.02	0.92	0.00	51.01	-11.88	0.87	33.99	51.01	22.15
24.07.2024	15.00.01	0.00	57.87	37.86	38.50	44.43	1.00	0.00	109.52	-11.82	1.41	36.21	67.28	24.34
24.07.2024	16.00.01	0.00	58.29	38.00	38.50	44.69	1.00	0.00	115.10	-5.59	2.02	37.35	68.69	26.56
24.07.2024	17.00.01	0.00	52.07	36.33	37.39	37.85	1.00	0.00	17.54	2.93	1.02	36.81	41.70	26.23
24.07.2024	18.00.01	0.00	43.09	35.78	37.18	36.17	1.00	0.00	5.32	0.76	1.85	35.88	37.45	27.82
24.07.2024	19.00.01	0.00	39.14	35.51	37.09	34.74	0.79	0.00	-3.49	-7.51	1.51	34.49	34.40	26.73
24.07.2024	20.00.01	0.00	37.61	35.38	37.06	33.90	0.82	0.00	-7.76	-12.19	1.12	33.48	32.89	27.35
24.07.2024	21.00.01	0.00	36.13	35.27	37.03	33.19	0.65	0.00	-10.41	-16.42	0.94	32.48	31.91	26.01
24.07.2024	22.00.01	0.00	34.97	35.17	37.00	32.70	0.52	0.00	-12.75	-20.05	1.08	31.98	31.04	25.27
24.07.2024	23.00.01	0.00	34.28	35.11	36.99	32.31	0.47	0.00	-14.45	-20.87	0.84	31.37	30.42	24.51

Tab. 5 Data of Point 4

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	25.69	33.80	36.81	27.79	0.00	0.00	-34.81	-34.37	0.53	26.26	21.94	18.35
24.07.2024	01.00.01	0.00	24.82	33.08	36.81	27.31	0.00	0.00	-32.74	-39.74	0.86	26.02	21.88	18.24
24.07.2024	02.00.01	0.00	26.00	34.06	36.81	27.91	0.00	0.00	-34.92	-32.45	0.38	25.96	22.18	18.17
24.07.2024	03.00.01	0.00	25.83	33.91	36.81	27.84	0.00	0.00	-34.57	-33.38	0.44	26.02	22.15	17.99
24.07.2024	04.00.01	0.00	26.52	34.37	36.85	28.05	0.01	0.00	-36.16	-27.17	0.17	25.47	22.09	17.65
24.07.2024	05.00.01	0.00	24.10	32.48	36.81	26.72	0.00	0.00	-30.66	-41.66	0.86	25.11	21.96	17.23
24.07.2024	06.00.01	0.00	25.59	33.72	36.81	27.50	0.00	0.00	-34.29	-31.63	0.30	25.09	22.03	17.06
24.07.2024	07.00.01	0.00	26.32	34.32	36.85	28.10	0.00	0.00	-33.95	-31.33	0.27	25.47	22.83	17.38
24.07.2024	08.00.01	0.00	28.85	34.62	36.89	29.36	0.13	0.00	-27.20	-26.84	0.22	26.52	25.55	18.24
24.07.2024	09.00.01	0.00	31.11	34.84	36.93	30.72	0.22	0.00	-16.60	-29.35	0.44	27.90	29.41	19.32
24.07.2024	10.00.01	0.00	37.46	35.39	37.05	33.78	0.69	0.00	0.67	-16.10	0.11	29.57	35.60	20.32
24.07.2024	11.00.01	0.00	57.65	37.78	38.50	42.07	1.00	0.00	65.52	-20.42	0.14	30.76	56.33	19.67
24.07.2024	12.00.01	0.00	58.41	38.05	38.50	44.35	1.00	0.00	80.11	-14.61	0.13	32.92	60.28	20.65
24.07.2024	13.00.01	0.00	55.60	37.07	37.85	43.37	1.00	0.00	100.07	-15.93	0.88	34.28	64.41	20.35
24.07.2024	14.00.01	0.00	58.39	38.03	38.50	43.45	1.00	0.00	65.65	-9.86	0.12	34.50	56.57	21.94
24.07.2024	15.00.01	0.00	59.52	38.42	38.50	48.71	1.00	0.00	133.02	-6.77	0.55	36.96	73.10	24.32
24.07.2024	16.00.01	0.00	59.73	38.49	38.50	49.01	1.00	0.00	151.26	-2.46	1.14	38.11	77.17	26.39
24.07.2024	17.00.01	0.00	54.92	36.82	37.65	38.16	1.00	0.00	14.51	1.60	0.58	37.16	41.26	26.16
24.07.2024	18.00.01	0.00	59.95	38.57	38.50	48.33	1.00	0.00	139.03	-13.89	0.70	35.87	74.54	27.79
24.07.2024	19.00.01	0.00	47.45	36.06	37.28	36.12	1.00	0.00	7.72	-6.67	0.64	34.71	38.46	26.68
24.07.2024	20.00.01	0.00	38.43	35.45	37.07	34.35	0.82	0.00	-2.67	-12.95	1.45	33.67	34.60	27.34
24.07.2024	21.00.01	0.00	47.27	36.05	37.28	34.30	1.00	0.00	-8.34	-8.92	0.12	32.89	33.39	26.13
24.07.2024	22.00.01	0.00	37.23	35.36	37.05	33.42	0.94	0.00	-9.18	-10.44	0.18	31.99	32.41	25.24
24.07.2024	23.00.01	0.00	35.41	35.21	37.01	32.79	0.57	0.00	-10.84	-18.07	0.65	31.57	31.71	24.53

Tab. 6 Data of Point 5

Date	Time	Objects ( )	PET* (°C)	T Skin static (°C)	T Core static (°C)	T Cloths static (°C)	Fraction Wet Skin ()	Sweat Rate (g/h)	Radiative Budget Skin (W)	Convective Flux Skin (W)	Wind speed (m/s)	Air temperature (°C)	Mean Radiant Temperature (°C)	Specific humidity (g/kg)
24.07.2024	00.00.01	0.00	24.07	32.46	36.81	27.12	0.00	0.00	-30.75	-46.75	1.58	26.29	21.90	18.34
24.07.2024	01.00.01	0.00	23.83	32.25	36.81	26.93	0.00	0.00	-30.31	-47.54	1.62	26.08	21.83	18.23
24.07.2024	02.00.01	0.00	24.88	33.13	36.81	27.39	0.00	0.00	-32.06	-40.49	0.88	26.03	22.18	18.16
24.07.2024	03.00.01	0.00	23.94	32.35	36.81	26.86	0.00	0.00	-29.74	-46.20	1.32	25.69	22.14	17.97
24.07.2024	04.00.01	0.00	24.95	33.18	36.81	27.29	0.00	0.00	-32.13	-38.28	0.66	25.55	22.21	17.62
24.07.2024	05.00.01	0.00	25.19	33.39	36.81	27.28	0.00	0.00	-33.15	-34.58	0.42	25.09	22.07	17.23
24.07.2024	06.00.01	0.00	23.93	32.34	36.81	26.61	0.00	0.00	-30.17	-42.39	0.90	24.98	21.98	17.05
24.07.2024	07.00.01	0.00	23.76	32.19	36.81	26.62	0.00	0.00	-28.84	-45.80	1.16	25.15	22.30	17.35
24.07.2024	08.00.01	0.00	26.21	34.22	36.83	28.65	0.00	0.00	-26.24	-46.13	1.00	26.62	25.45	18.20
24.07.2024	09.00.01	0.00	28.46	34.58	36.88	29.96	0.08	0.00	-19.27	-44.66	1.32	28.13	28.23	19.25
24.07.2024	10.00.01	0.00	33.24	35.04	36.97	31.86	0.32	0.00	-11.47	-25.07	0.53	29.55	31.33	20.29
24.07.2024	11.00.01	0.00	38.78	35.50	37.08	34.71	0.59	0.00	9.21	-17.28	0.35	31.06	38.37	19.59
24.07.2024	12.00.01	0.00	54.06	36.52	37.48	41.47	1.00	0.00	81.12	-17.65	0.72	33.12	59.29	20.56
24.07.2024	13.00.01	0.00	57.30	37.66	38.43	44.35	1.00	0.00	100.07	-15.30	0.67	34.63	64.88	20.26
24.07.2024	14.00.01	0.00	57.44	37.71	38.48	42.42	1.00	0.00	66.95	-11.69	0.42	34.90	56.64	21.91
24.07.2024	15.00.01	0.00	58.26	37.99	38.50	45.63	1.00	0.00	116.54	-7.11	1.22	36.93	69.02	24.24
24.07.2024	16.00.01	0.00	52.83	36.38	37.41	38.67	1.00	0.00	28.60	7.21	1.84	37.25	44.98	26.41
24.07.2024	17.00.01	0.00	54.75	36.77	37.62	37.47	1.00	0.00	8.48	-0.40	0.41	36.67	39.38	26.14
24.07.2024	18.00.01	0.00	45.94	35.97	37.24	36.52	1.00	0.00	7.48	0.88	1.65	36.08	38.30	27.76
24.07.2024	19.00.01	0.00	39.59	35.54	37.10	34.94	0.83	0.00	-2.03	-6.36	1.37	34.64	34.90	26.73
24.07.2024	20.00.01	0.00	38.14	35.42	37.07	34.08	0.91	0.00	-6.53	-10.29	0.81	33.55	33.33	27.34
24.07.2024	21.00.01	0.00	43.52	35.81	37.19	33.86	1.00	0.00	-10.55	-8.80	0.13	32.74	32.43	26.13
24.07.2024	22.00.01	0.00	35.53	35.22	37.01	32.93	0.56	0.00	-10.95	-18.55	0.94	32.06	31.68	25.26
24.07.2024	23.00.01	0.00	36.05	35.26	37.02	32.83	0.79	0.00	-12.93	-11.77	0.18	31.48	31.08	24.51

Tab. 7 Data of Point 6

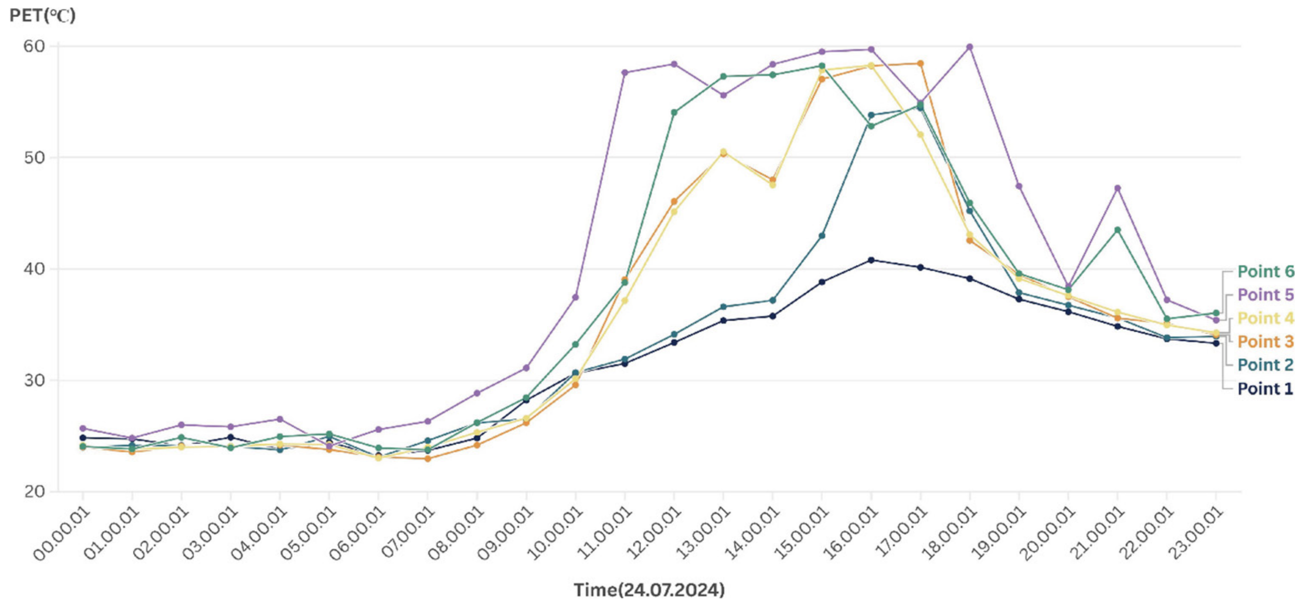

Fig. 69 PET line chart

Based on chart analysis, there are significant differences in the thermal environment performance in different regions. The physiological equivalent temperature (PET) values of Point 1 and Point 2 set in the shaded area under the bridge remain relatively stable, with significantly smaller fluctuations than other points, and the overall values are at a lower level; the PET values and fluctuations amplitude of Point 3 and Point 4 in the non-shaded area of the site are between the shaded area under the bridge and the residential area; Point 5 and Point 6 located within the residential area show the highest PET values and maximum fluctuations amplitude. The gradient distribution of this thermal environment parameter directly reflects the level of thermal comfort in different regions: the shaded area under the bridge is the best, followed by the non-shaded area of the site, and the residential area has the lowest thermal comfort. This discovery provides objective evidence for the preference of elderly residents for activities in the space under the bridge, indicating that shaded environments have a significant effect on improving outdoor thermal comfort.

4.3.2.2 The first classification of PET

After obtaining the corresponding data and figures for PET through ENVI-met simulation, the data obtained and figures need to be further integrated and standardized. Referring to the thermal comfort benchmarks of PET for the elderly (Tab. 8), it is divided into 6 levels: slightly cold (17℃≤PET<24℃), neutral (24℃≤PET<31℃), slightly hot (31℃≤PET<38℃), hot (38℃≤PET<44℃), very hot (44℃≤PET<51℃), and extremely hot (51℃≤PET). After completing the first classification, the PET map after the first classification (Fig. 70, Fig. 71, Fig. 72, Fig. 73, Fig. 74, and Fig. 75) can be directly linked to human sensing (Li et al., 2024).

From a temporal perspective, during the period from nighttime to early morning, the entire simulation area is mostly in a slightly cool or neutral comfort zone, with only some areas slightly warm, indicating that the environment during this period is relatively friendly to the elderly. As time progresses, from noon to afternoon, a large area enters a hot or extremely hot state, and the original comfort zone shrinks or even disappears significantly. This is the result of the combination of solar radiation and urban heat island effect. At this time, if elderly people are outdoors, they will face a higher risk of heat exposure. In the evening, the hot and extremely hot areas begin to shrink, while the neutral and slightly hot areas expand again, and some areas even return to a more comfortable state, but there are still some areas that maintain a slightly hot state.

From a spatial perspective, the PET level in local areas is always significantly higher than that in the surrounding areas, these areas are often densely populated with buildings and lack vegetation shade, making them “risk zones” for outdoor activities in summer for the elderly. And spaces with vegetation coverage, shaded area, or waterfront are more friendly “low risk zones” for the elderly.

PET(℃)	Thermal perception	Grade of physiological stress
<4	Extreme cold	Extreme cold-stress response
≥4-11	Very cold	Intense cold-stress response
≥11-17	Cold	Moderate cold-stress response
≥17-24	Slightly cold	Mild cold-stress reaction
≥24-31	Neutral	No heat-stress reaction
≥31-38	Slight hot	Mild heat-stress reaction
≥38-44	Hot	Moderate heat-stress response
≥44-51	Very hot	Intense heat-stress response
≥51	Extreme hot	Extreme heat-stress response

Tab. 8 Thermal comfort benchmarks of PET for the elderly

Note. The thermal comfort benchmarks of PET for the elderly is from “Assessing thermal comfort for the elderly in historical districts and proposing adaptive urban design strategies: A case study in Zhenjiang, China,” by Li Y., et al., 2025, Landscape and Ecological Engineering, 21, pp. 29-46

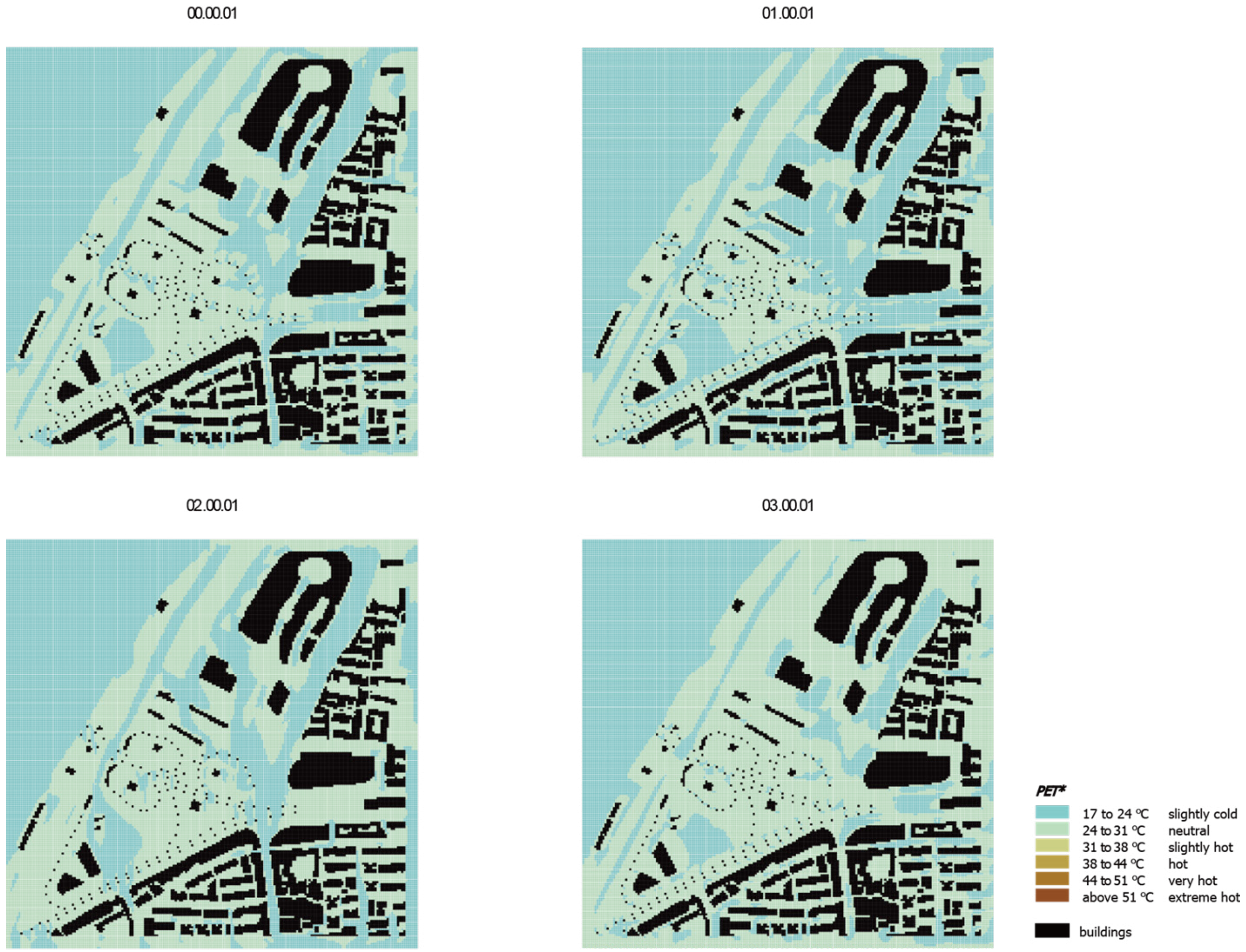

Fig. 70 The PET map after the first classification 1

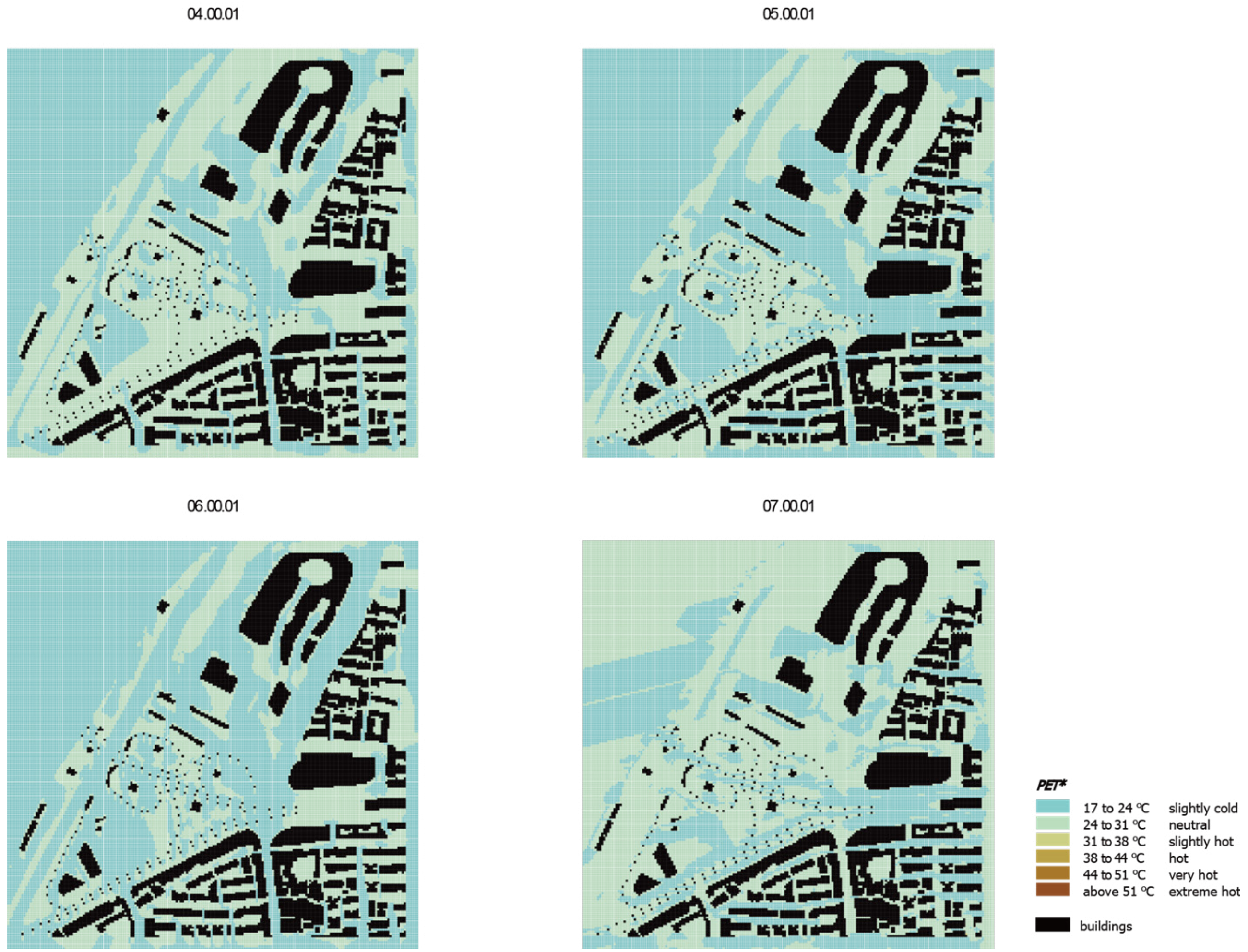

Fig. 71 The PET map after the first classification 2

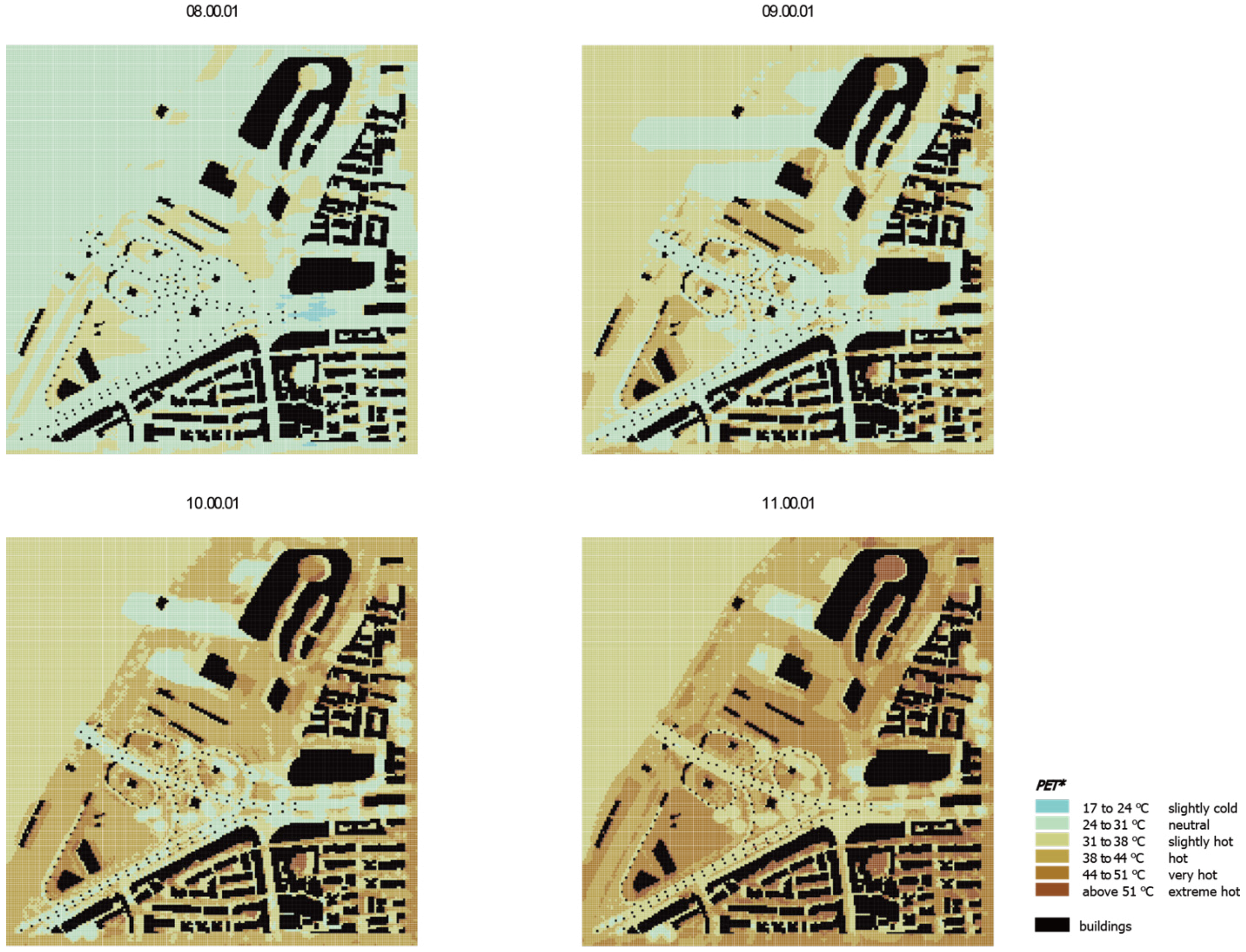

Fig. 72 The PET map after the first classification 3

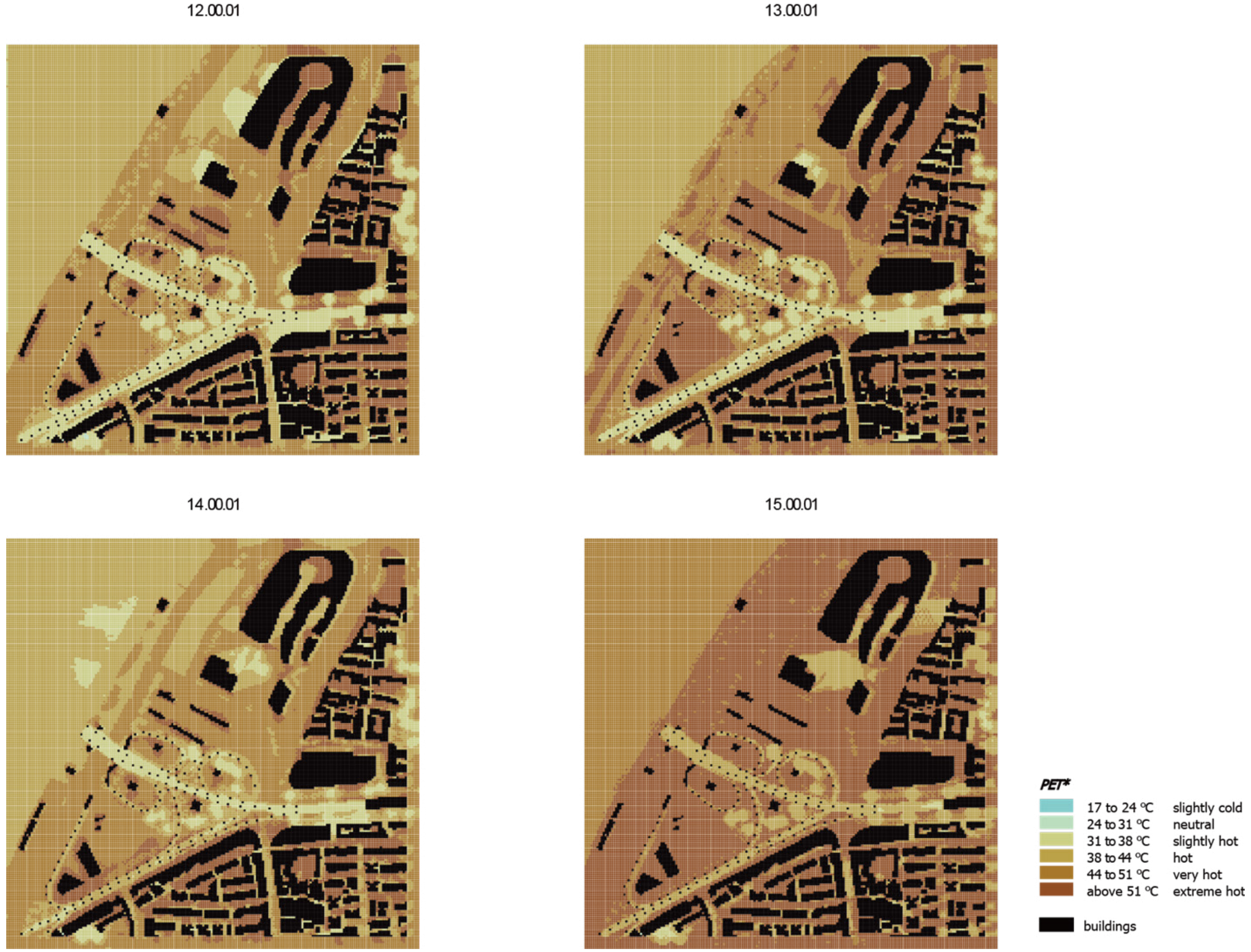

Fig. 73 The PET map after the first classification 4

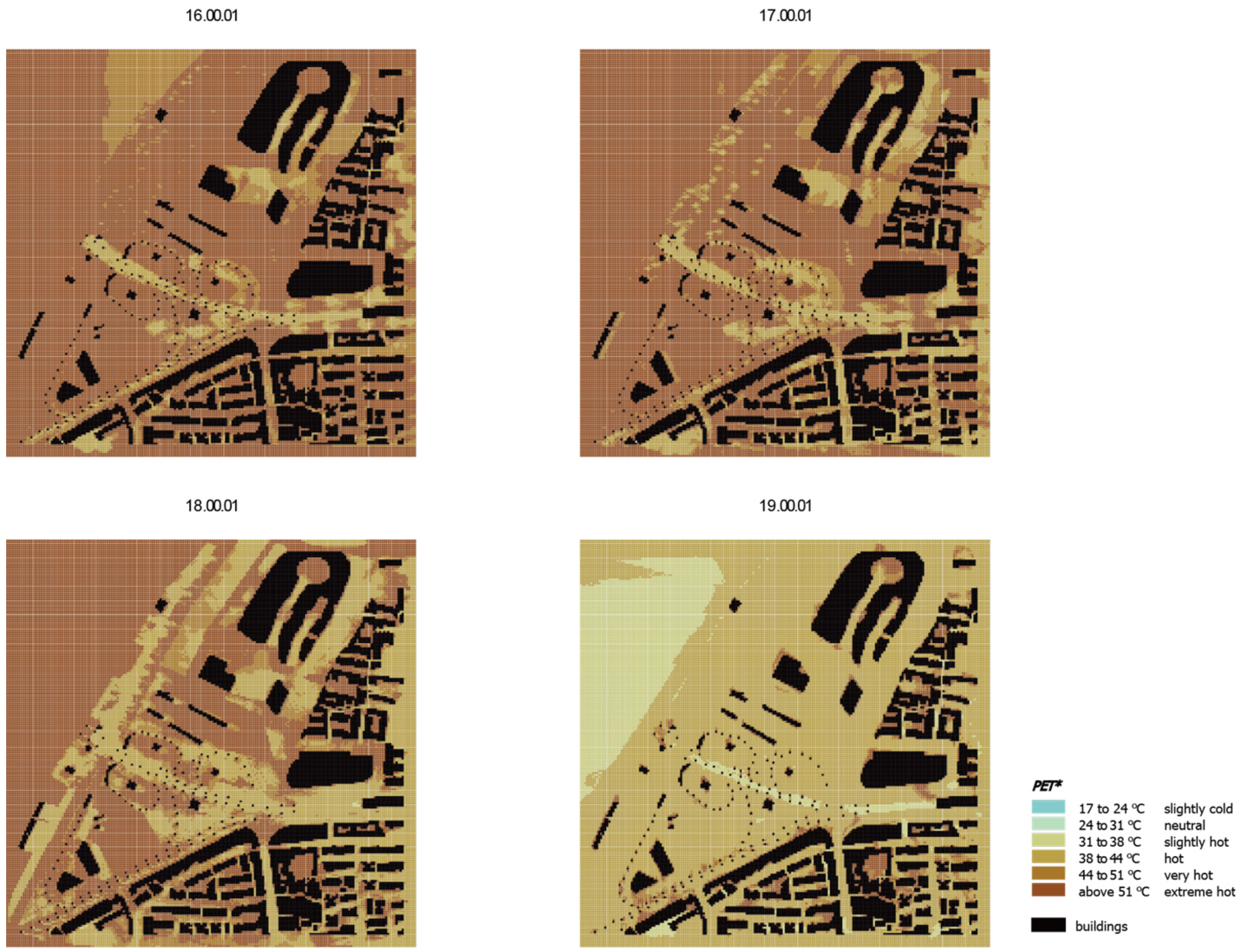

Fig. 74 The PET map after the first classification 5

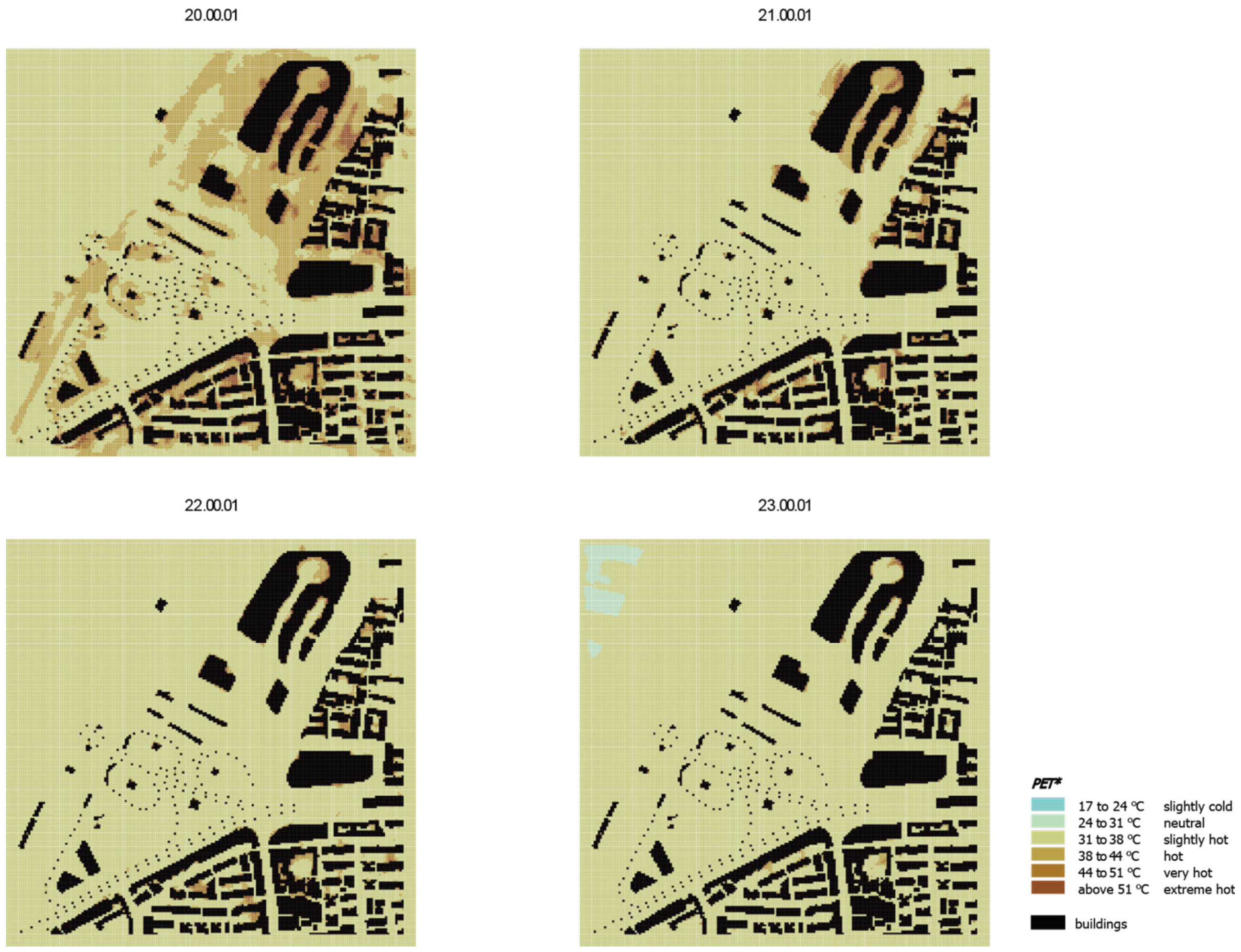

Fig. 75 The PET map after the first classification 6

4.3.2.3 The second classification of PET

In order to account for elderly people's thermal perception under different values of PET, it is necessary to define PET ranges in which elderly feel comfortable (Lin & Matzarakis, 2008).

As mentioned, the thermal comfort benchmarks of PET for the elderly have been utilized as a reference to assessing outdoor thermal comfort. Accordingly, the thermal comfort range would correspond to PET values between 24℃ and 31℃ (neutral perception), while a relatively wider 'acceptable range' for slightly cold, neural, and slightly warm was defined for 17℃ to 38℃ PET, is generally considered to be a healthy range for humans (Lin & Matzarakis, 2008; Makaremi et al., 2012). A PET above 38℃ indicates significant heat stress and poses a serious threat to human health and survival. The PET map after the second classification (Fig. 76, Fig. 77, Fig. 78, Fig. 79, Fig. 80, and Fig. 81) shows the distribution of significant heat stress.

During the nighttime to early morning period, the entire simulation area is dominated by areas with acceptable thermal stress, with only a small number of significant thermal stress areas, indicating that the nighttime temperature is low and the thermal stress is extremely low. And the entire area under the bridge and the shaded area of the tree crown is displayed as an acceptable thermal stress zone, which confirms the protective effect of the shading structure on the stability of the nighttime thermal environment and reserves a natural comfortable space for elderly people's morning activities.

During the noon to afternoon period, the significant thermal stress area expands extensively, concentrated in open areas such as the center of the site and the riverbank without trees, and reaches its peak expansion between 12:00-14:00. At the same time, the acceptable thermal stress area shrinks significantly, forming a thermal environment "island" only in the core shadow area directly below the bridge and the projection area of the crown of trees, explaining the preference of elderly people to gather under the bridge and tree shade for activities.

During the afternoon to nighttime period, the significant thermal stress area gradually shrinks from 16:00, with only a small amount of scattered area remaining after evening. After 20:00, the site returns to an acceptable thermal stress area. In terms of spatial distribution, the acceptable thermal stress area under the bridge expands first, and the acceptable thermal stress range in the shaded area of the tree crown also extends to the surrounding area, providing a continuous comfortable space for elderly people to avoid heat in the afternoon and socialize at night.

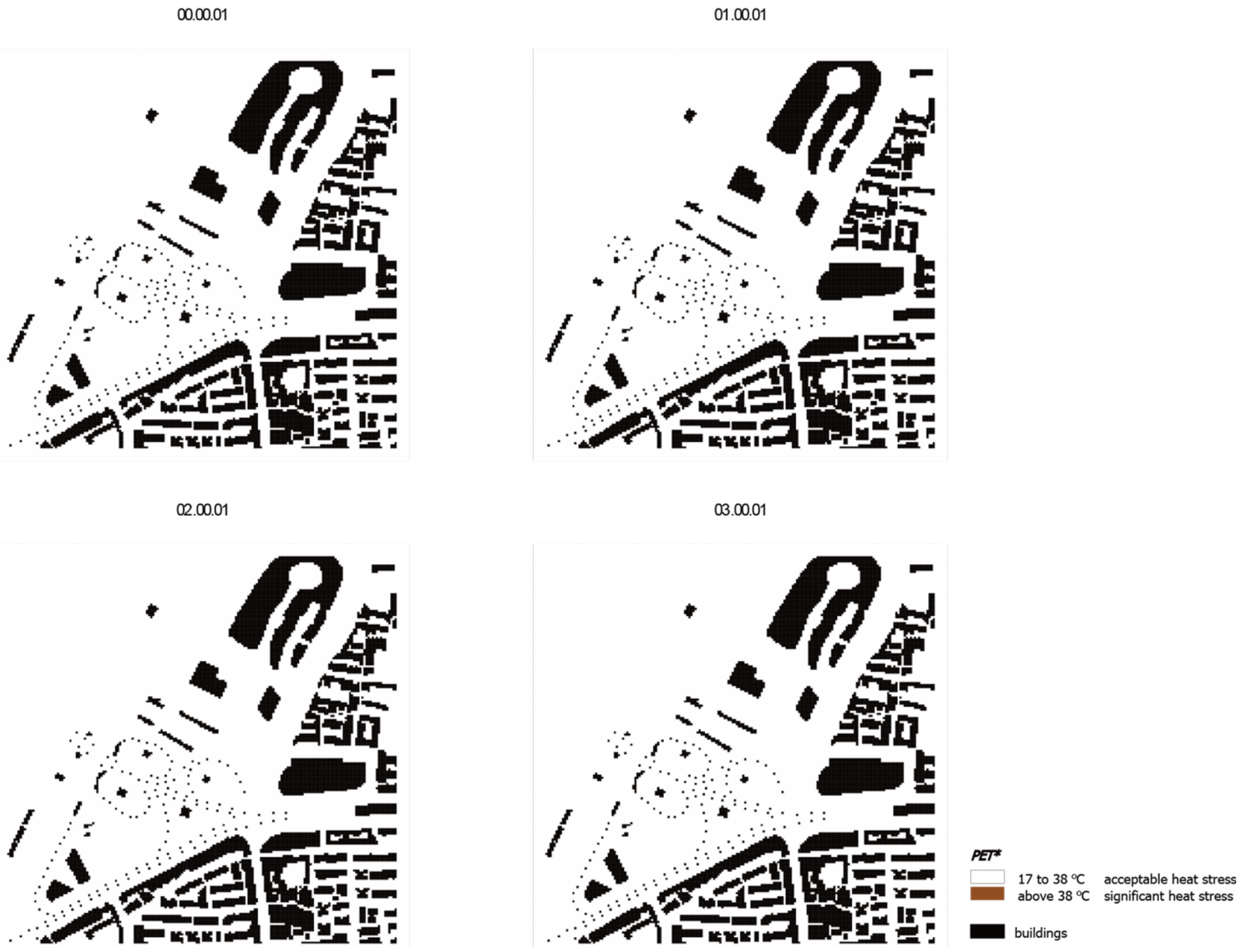

Fig. 76 The PET map after the second classification 1

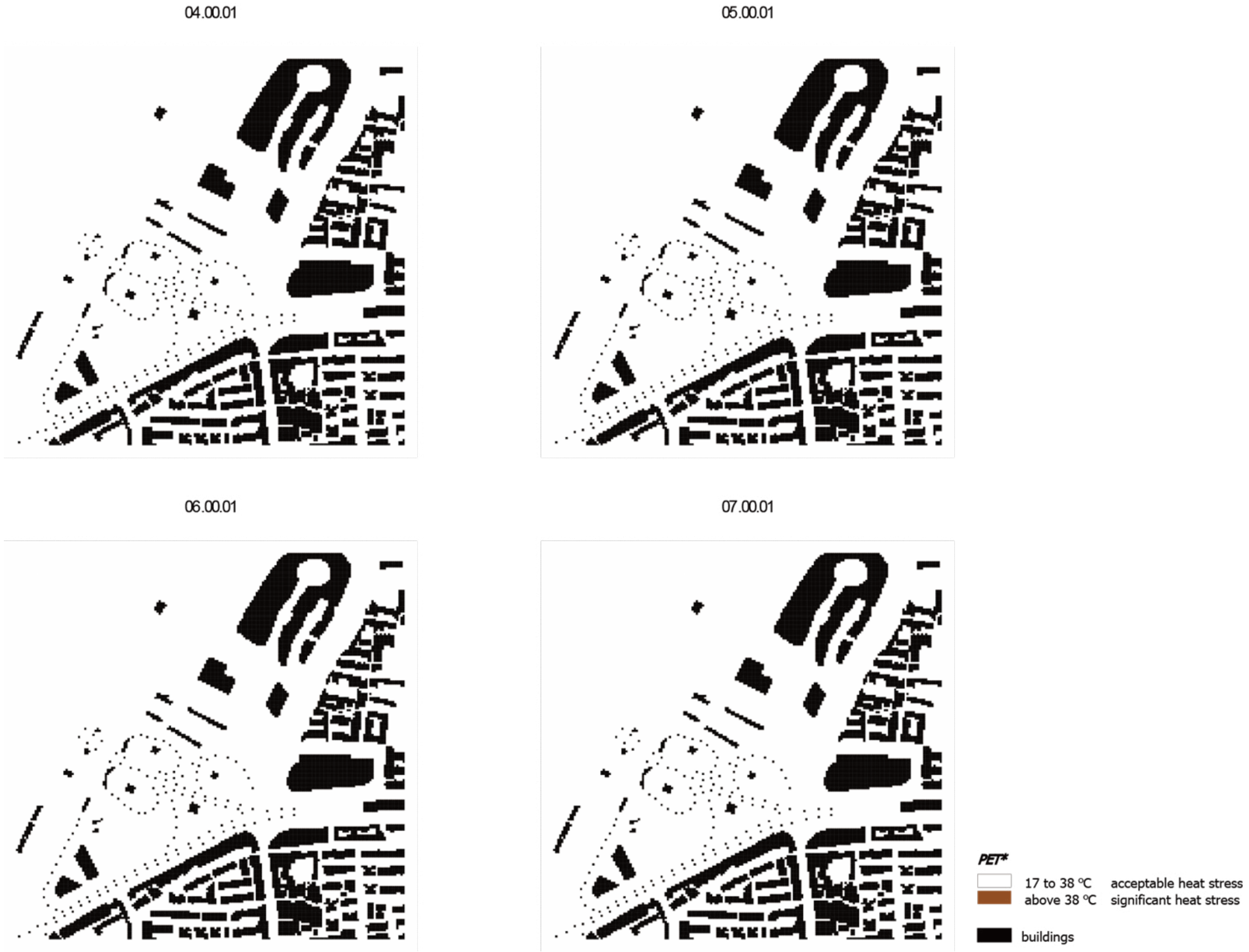

Fig. 77 The PET map after the second classification 2

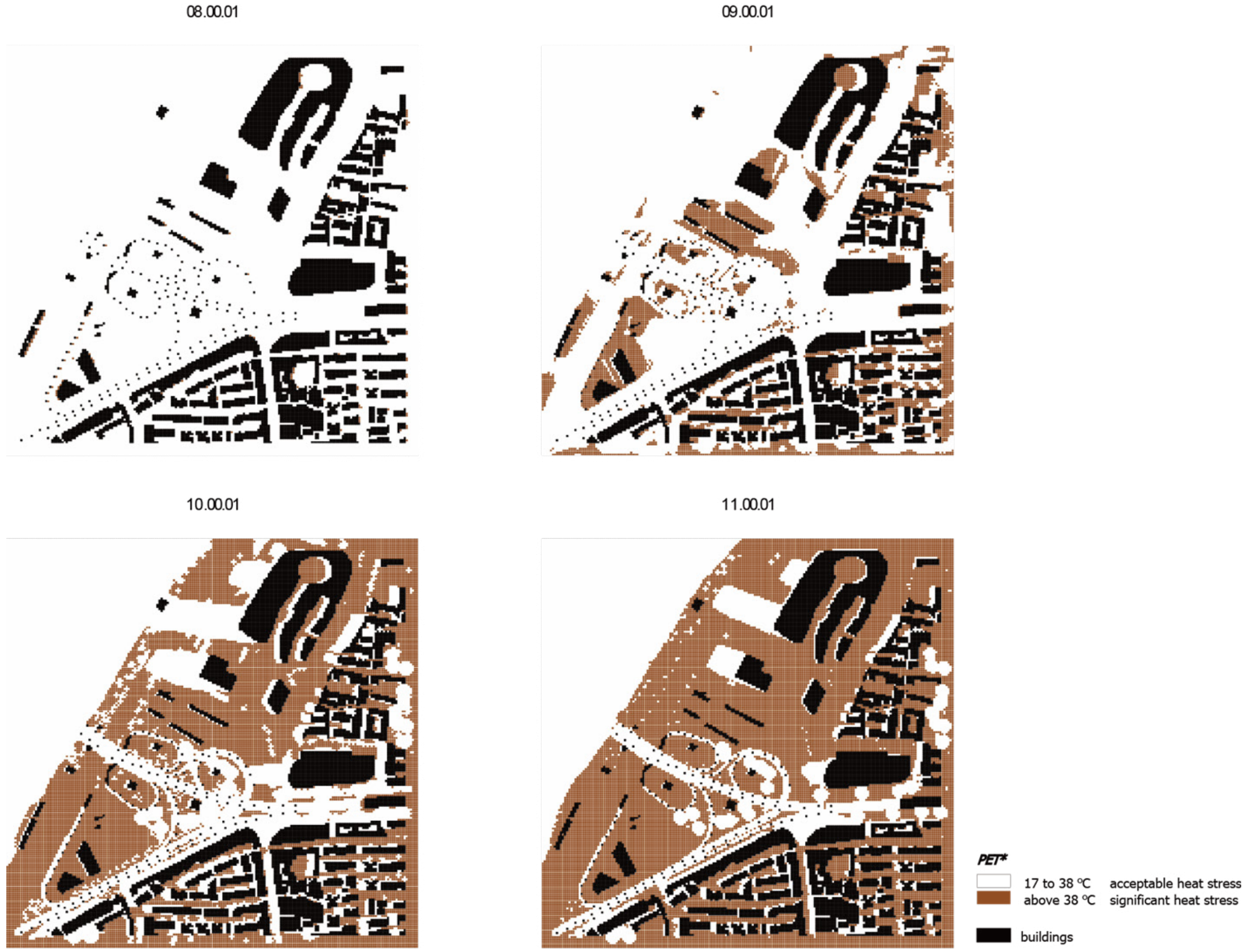

Fig. 78 The PET map after the second classification 3

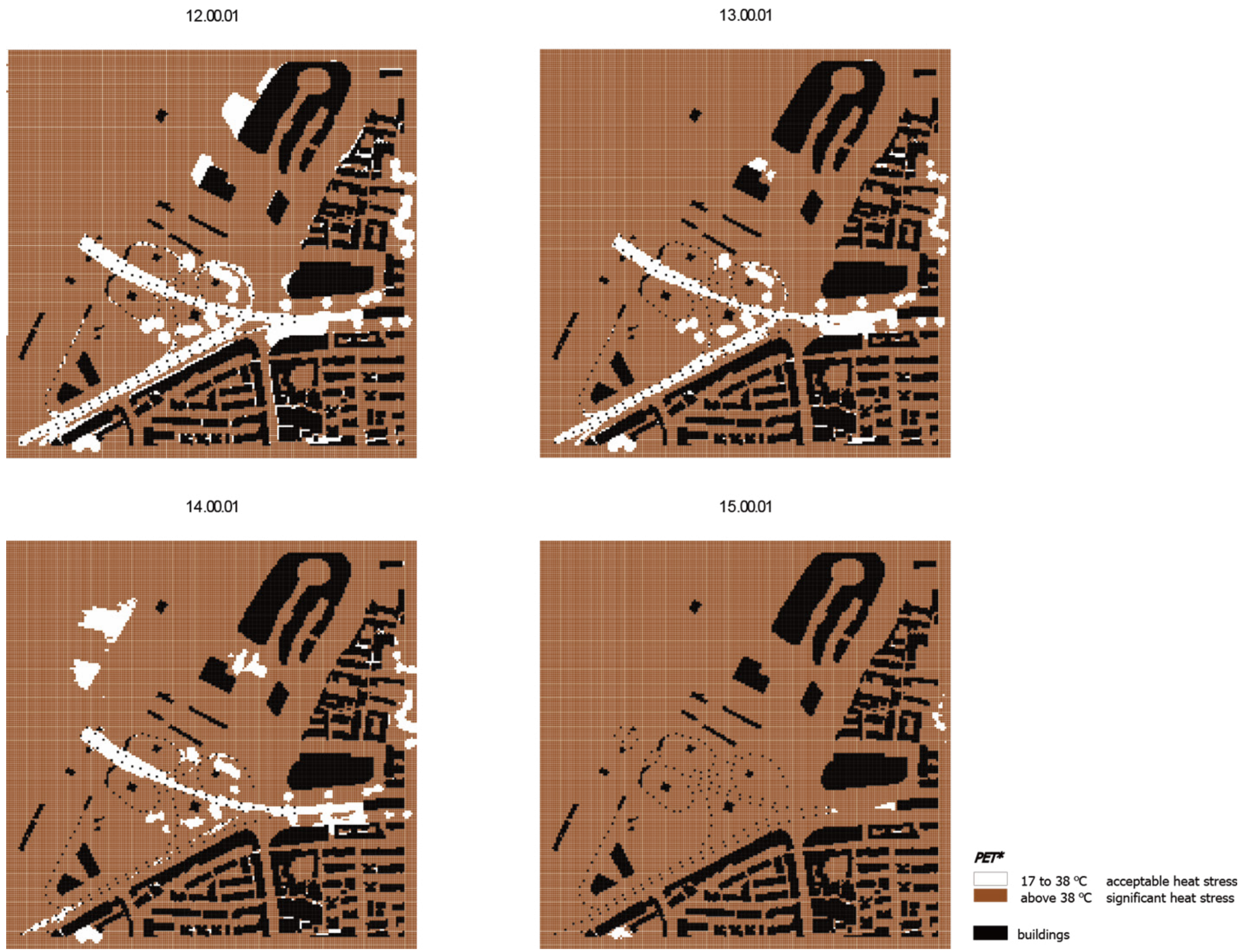

Fig. 79 The PET map after the second classification 4

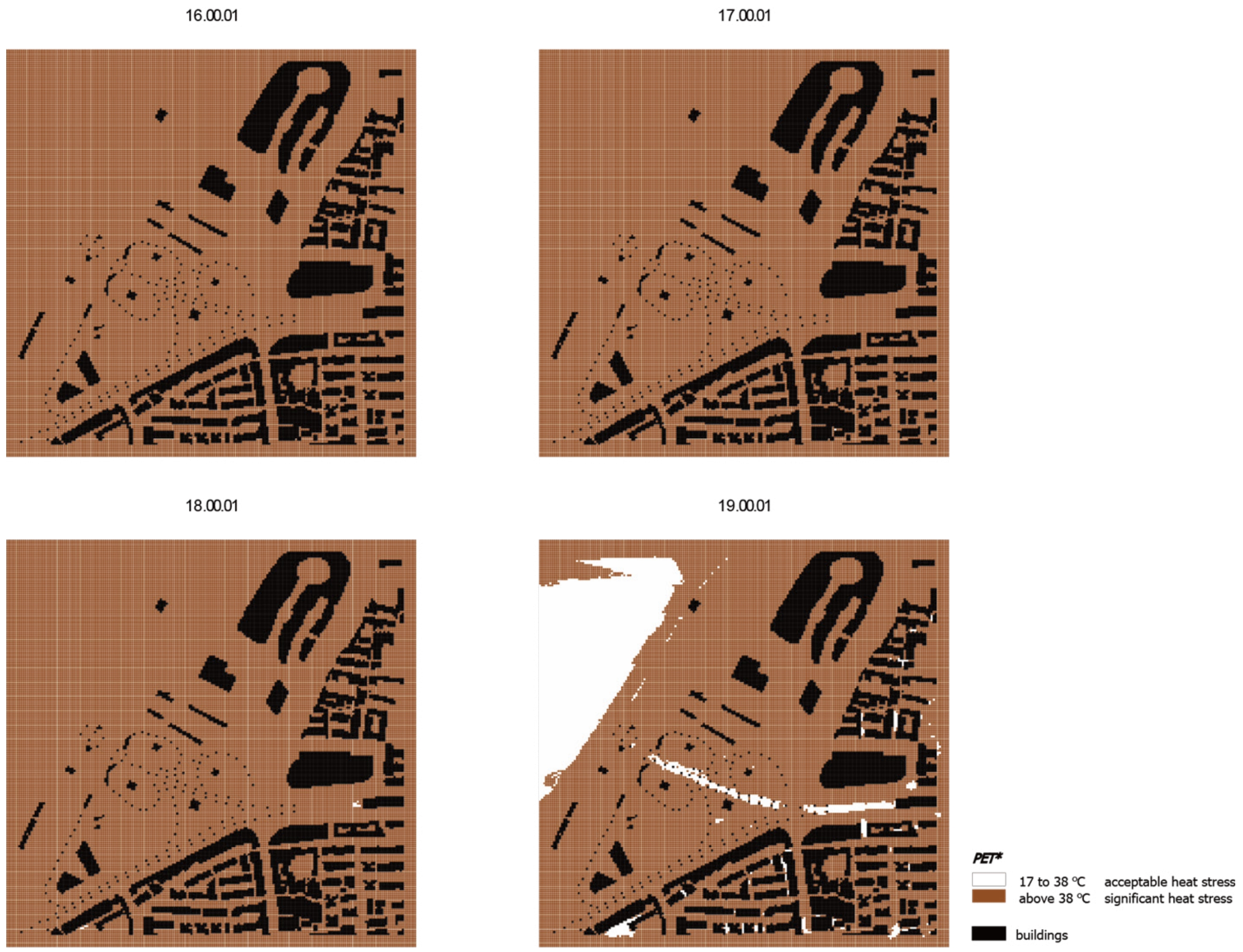

Fig. 80 The PET map after the second classification 5

4.3.3 Heat stress duration

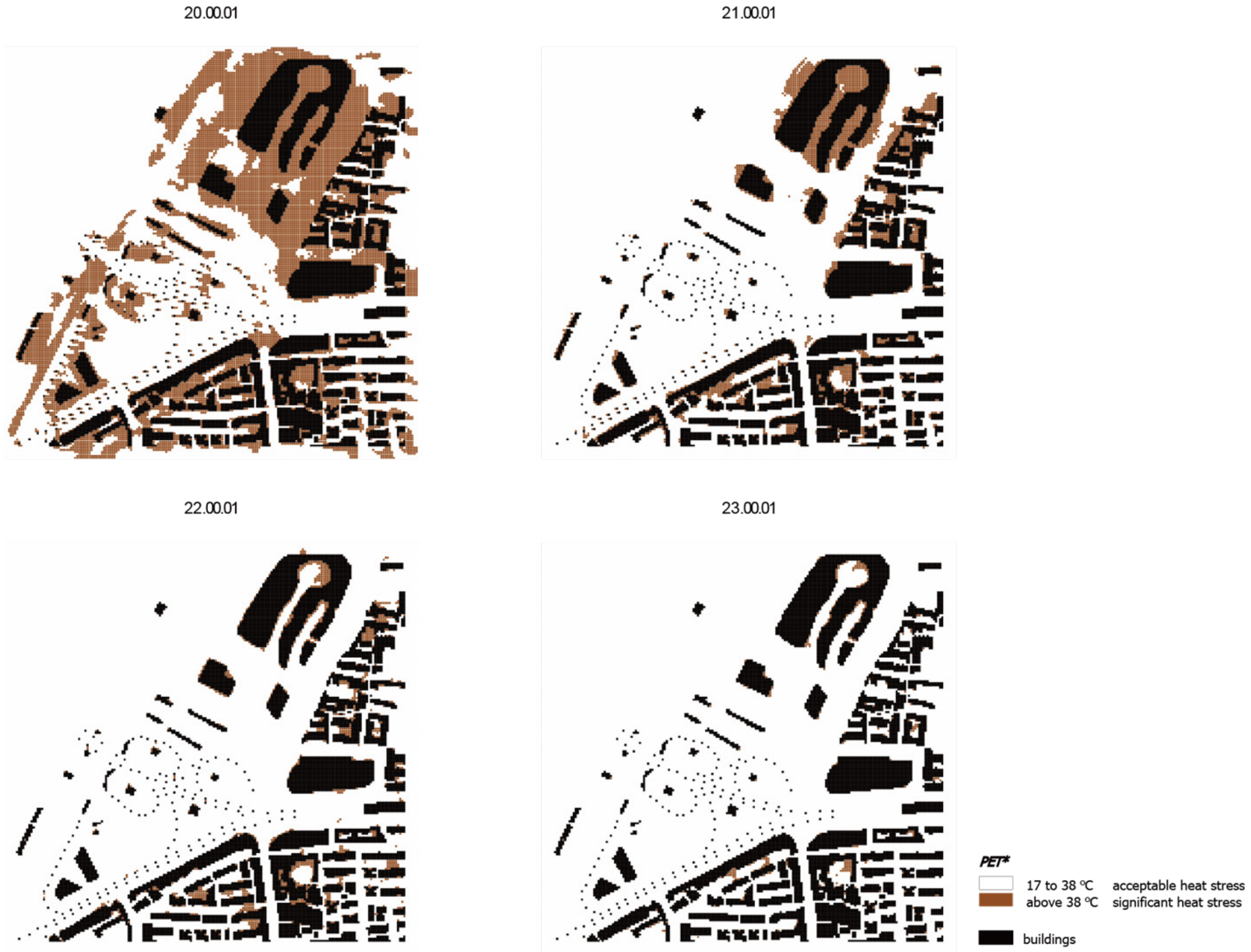

Fig. 81 The PET map after the second classification 6

After classifying PET figures based on the criteria of acceptable thermal stress and significant thermal stress (Fig. 82), the 24 classification results were spatially overlaid to generate a distribution map of duration of significant thermal stress (Fig. 83). This map visually represents the difference in the duration of significant thermal stress in different regions through a gradient color gradient from cool tones (blue) to warm tones (red): cool tone regions correspond to lower significant thermal stress duration, while warm tone regions reflect to higher significant thermal stress duration.

Analysis found that the concentrated areas of lower significant thermal stress duration are mainly distributed under bridges and in the shaded areas formed by tree canopies. Such shading environments effectively shorten the exposure time to significant heat stress by reducing the intensity of solar radiation; the dominant areas of higher significant thermal stress duration are mostly concentrated in open spaces with low vegetation coverage and a lack of shading facilities, and their sustained significant thermal stress state is closely related to the prolonged duration of direct sunlight. This map can provide reference for optimizing the design of this site, guiding the formulation of facility layout and design strategies.

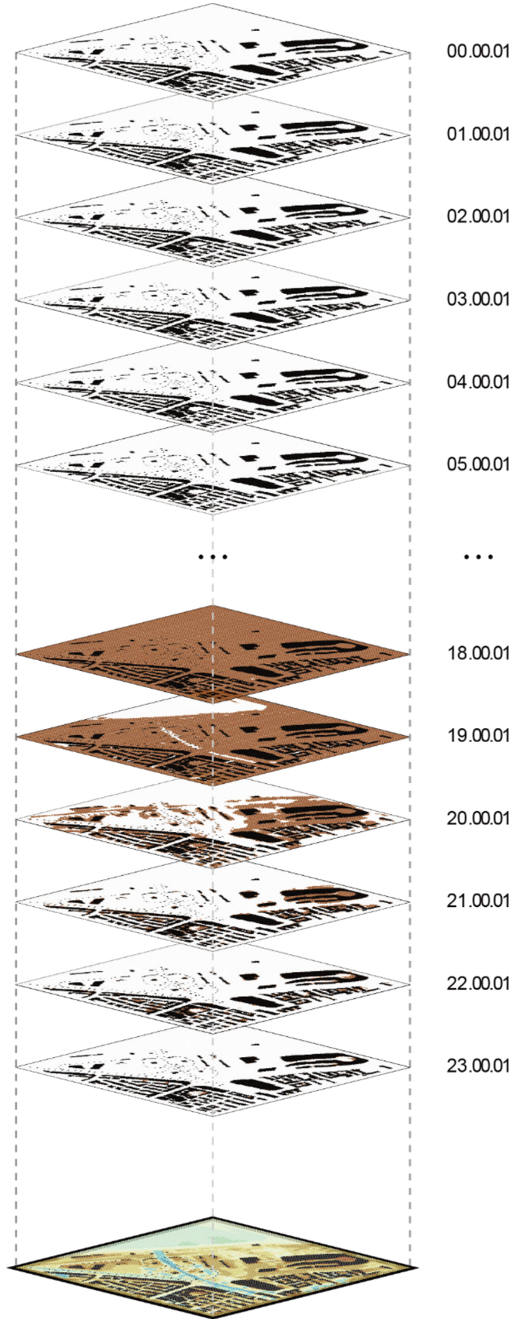

Fig. 82 Overlapping

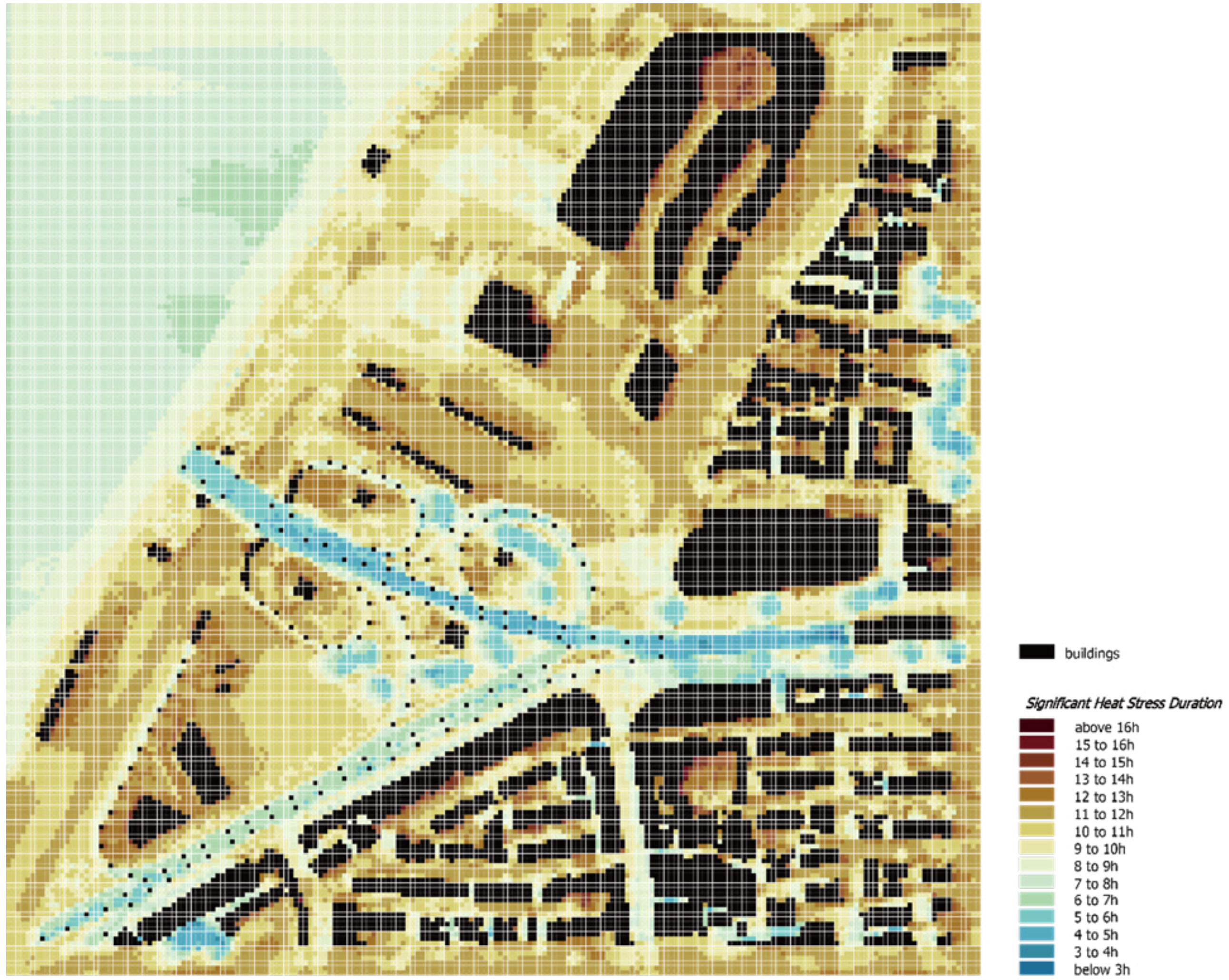

Fig. 83 Significant heat stress duration map

4.4 Design

Based on the analysis of the thermal environment around and inside the site and the results of questionnaire surveys, systematic design optimization can be carried out for the site. By adjusting the spatial layout and other microclimate regulation measures, the thermal comfort experience of the elderly population inside the site can be effectively improved, thus creating a more suitable outdoor activity environment for the elderly under complex climate conditions. The overlooking view is shown in Fig. 84.

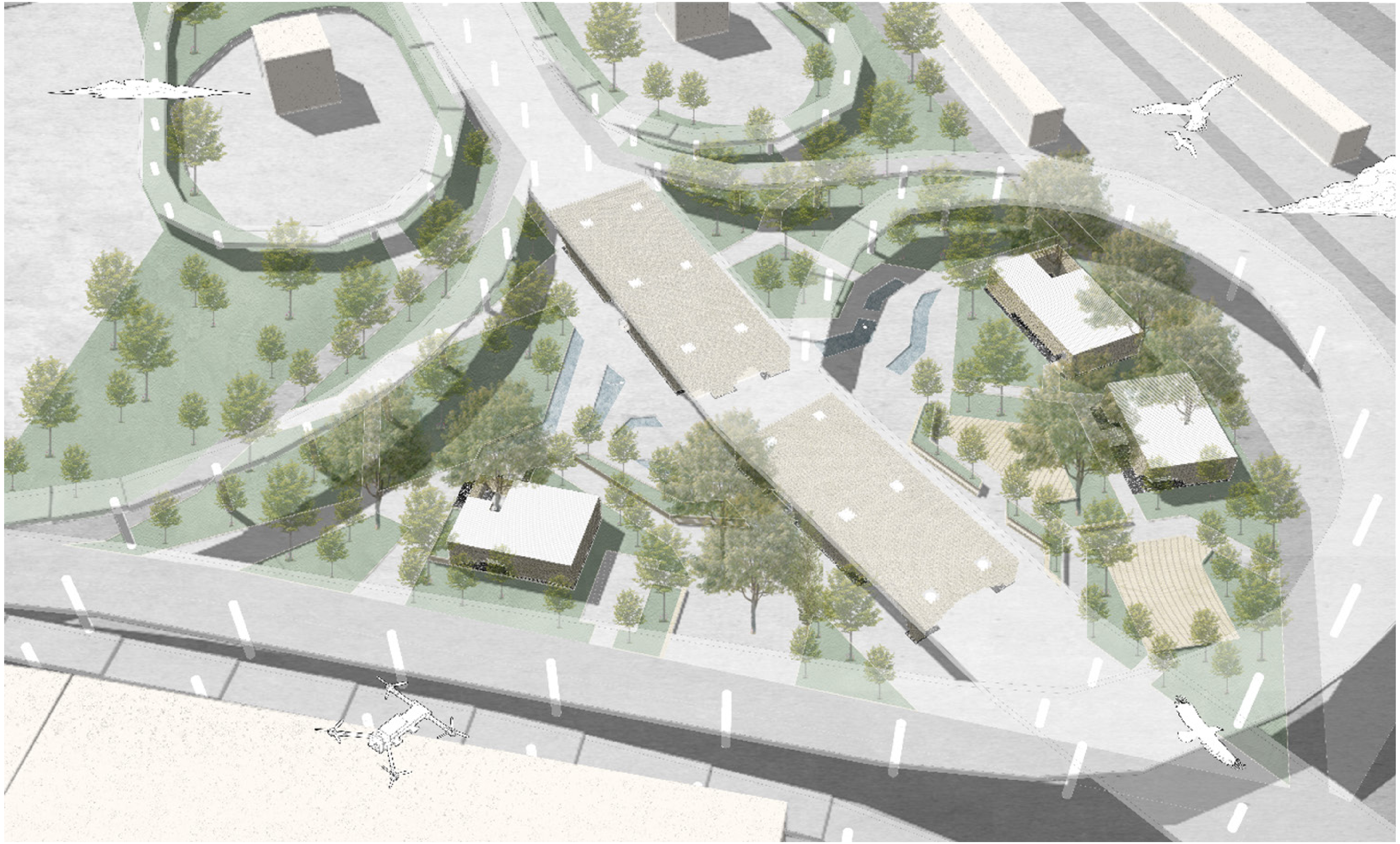

Fig. 84 Overlooking view

4.4.1 Strategy

Fig. 86 Strategy 1

Based on the overlay analysis of the duration map of significant heat stress and the site map (Fig. 85), except for the space under the bridge, the blue low heat risk area shows a significant clustering feature within the site, specifically concentrated around 8 trees. This spatial distribution characteristic indicates that the microclimate environment formed by large trees plays a significant role in alleviating heat stress. Priority should be given to preserving these 8 trees in the site planning, which not only meets the needs of optimizing the thermal environment, but also continues the original ecological characteristics of the site (Fig. 86). At the same time, after functional evaluation, the two antique buildings inside the site only have decorative functions, and their spatial layout is not directly related to the optimization goals of the thermal environment. Therefore, they will be demolished in the planning adjustment to improve the space utilization efficiency of the site.

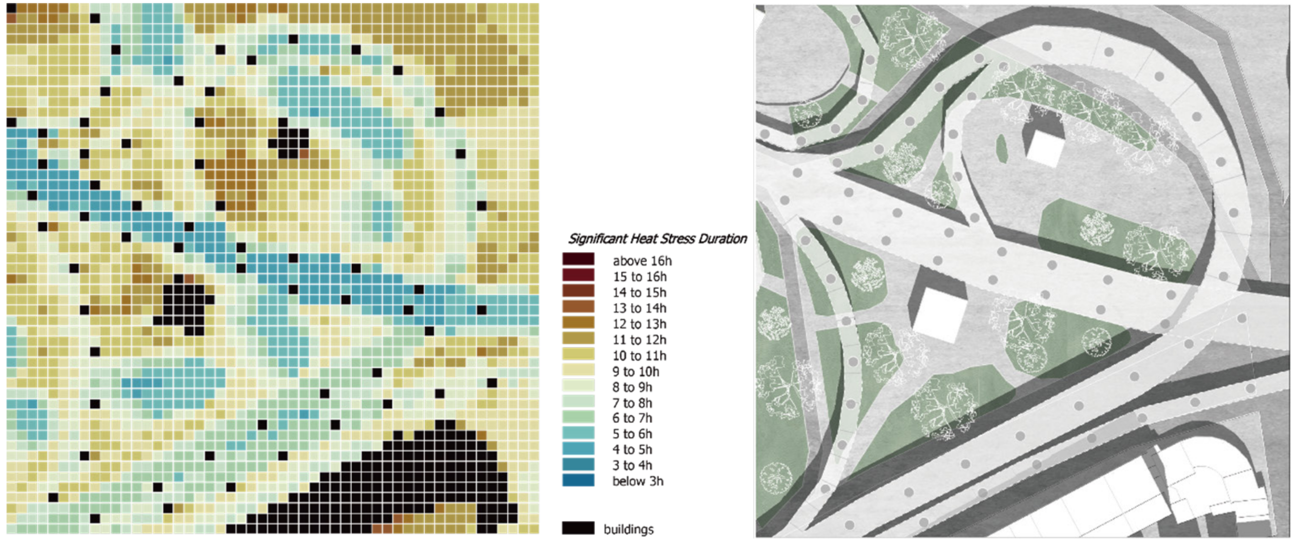

Fig. 85 Significant heat stress duration map and site map

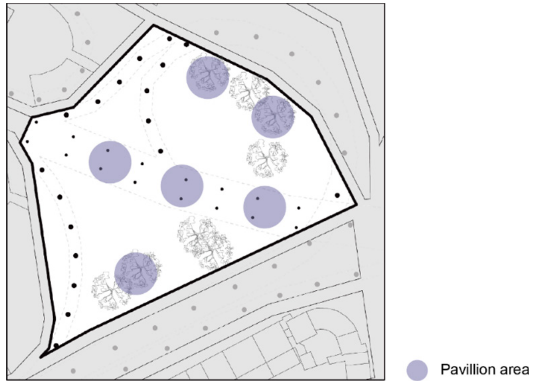

Fig. 87 Strategy 2

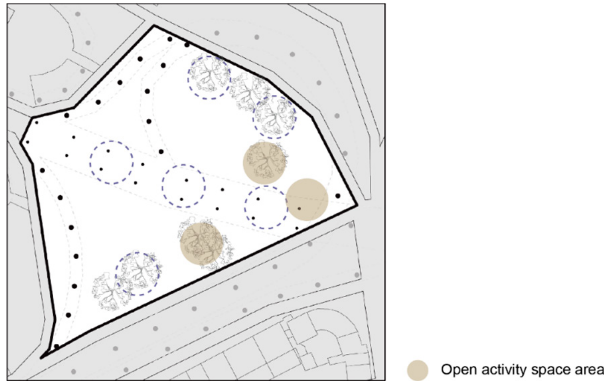

Fig. 88 Strategy 3

Considering the fact that the elderly population in the site spends the longest time inside the pavilion, in order to ensure their health and safety in high temperature environments, the spatial distribution characteristics of the thermal environment in the site were evaluated (Fig. 87), the low heat risk areas represented by blue in the significant heat stress duration map were selected as suitable locations for the pavilion. This region shows a significant advantage in the duration of heat stress, with values significantly lower than other regions. This characteristic can effectively reduce the heat related health risks of elderly people caused by prolonged exposure to high temperature environments. These low heat risk areas can meet the basic needs of group activity space and provide a safer place for the elderly through thermal environment optimization.

Similarly, the plan is to layout some open spaces in the low heat risk areas represented by blue in the graph of significant heat stress duration. This planning strategy fully considers the microclimate characteristics of the site (Fig. 88), and constructs a multilevel thermal environment regulation mechanism by utilizing the natural shading system formed by trees and the physical shading effect of the space under the bridge, effectively reducing the heat stress level in open areas. This layout not only creates a safer and more comfortable outdoor activity environment for the elderly, but also considers the thermal comfort needs of various users in the site.

The central area of the site exhibits high heat stress characteristics in the thermal environment assessment. To improve the thermal comfort of the area in a targeted manner, a waterscape intervention strategy is planned to be introduced (Fig. 89), which effectively reduces surface temperature and thermal radiation intensity through the effects of water evaporation cooling and heat capacity regulation, thereby alleviating the impact of high temperature environment on elderly people inside the site.

The western region of the site exhibits moderate heat stress characteristics, and its thermal environment parameters are at the middle level of the overall thermal spectrum of the site. Although the area is relatively large, the actual pedestrian flow is low, and there is potential for optimizing the thermal environment. To optimize the spatial distribution of the thermal environment, the area is planned to increase the amount of trees (Fig. 90). Through the transpiration of trees and the shading effect of the canopy, a natural cooling mechanism will be formed to effectively reduce surface temperature and heat radiation intensity, thereby alleviating the heat stress level in the area.

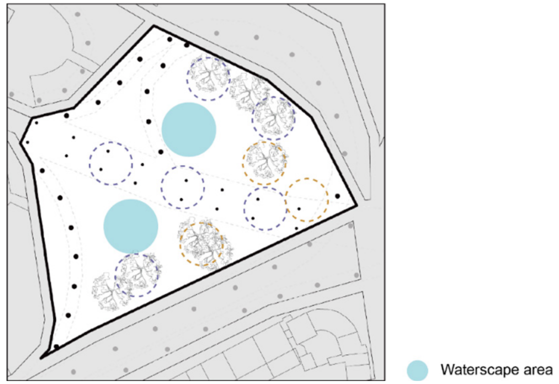

Fig. 89 Strategy 4

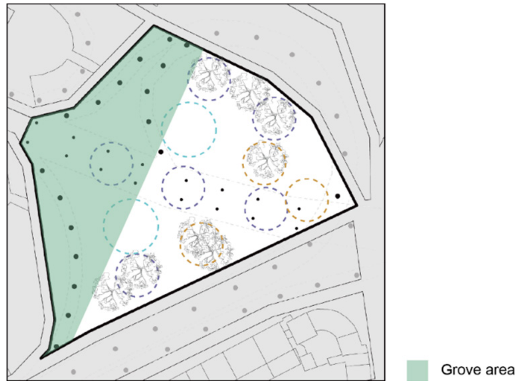

Fig. 90 Strategy 5

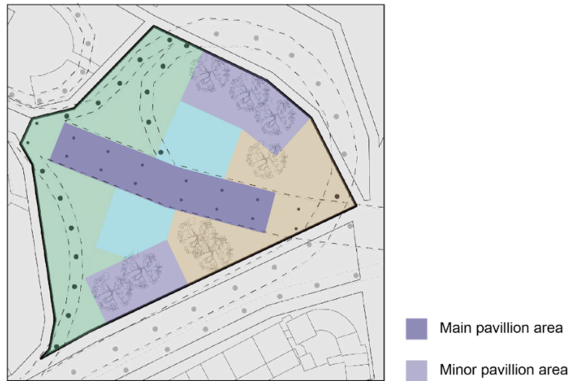

Fig. 91 Strategy 6

In addition, based on the collaboration of site functional requirements and thermal environment distribution (Fig. 91), it is planned to concentrate the core functional facilities with high frequency of use and high service demand in the main pavilion area (low heat stress area under the bridge); at the same time, auxiliary facilities with low usage frequency and scattered service demands will be dispersed and arranged in minor pavilions (shaded areas with low heat stress) to meet basic needs through multi-point coverage. This layout forms a functional environment match with the stable thermal environment guarantee of the main pavilion under the bridge and the decentralized regulation characteristics of the minor pavilion under the shade of trees, ensuring the stable operation of high demand functions in the thermal comfort priority area and optimizing the utilization efficiency of site resources through the flexible distribution of low demand functions.

These strategies form a synergistic effect with the overall thermal environment optimization system of the site, which not only continues the strategy logic of preserving low heat risk areas such as trees and space under bridge, but also compensates for the thermal environment shortcomings in the central area through physical means, and optimizes the thermal environment conditions in areas with moderate heat stress through vegetation coverage. Ultimately, a multi-level thermal comfort control system is constructed, and provides a safer and more comfortable outdoor activity environment for various users in the site.

4.4.2 Wooden frame

Based on the dual needs of optimizing the thermal environment of the site and providing various activity spaces for the elderly (Fig. 92), a lightweight pavilion is planned to be used as the main activity facility carrier. Compared with traditional reinforced concrete buildings, its lightweight structure can not only reduce interference with the thermal environment of the site, but also flexibly meet the diverse activity needs of the elderly through modular layout. The main frame of the pavilion is made of local camphor wood, which not only has excellent insect and mold resistance, but also echoes the ecological material of the trees preserved on the site, strengthening regional characteristics. At the same time, its transparent structural characteristics can promote natural ventilation and effectively alleviate the feeling of stuffiness in summer; the roof is made of semi-transparent corrugated polycarbonate, which is lightweight and can reduce structural loads. At the same time, it provides a uniform and soft lighting environment indoors through diffused light, avoiding the impact of direct strong light on the vision of the elderly.

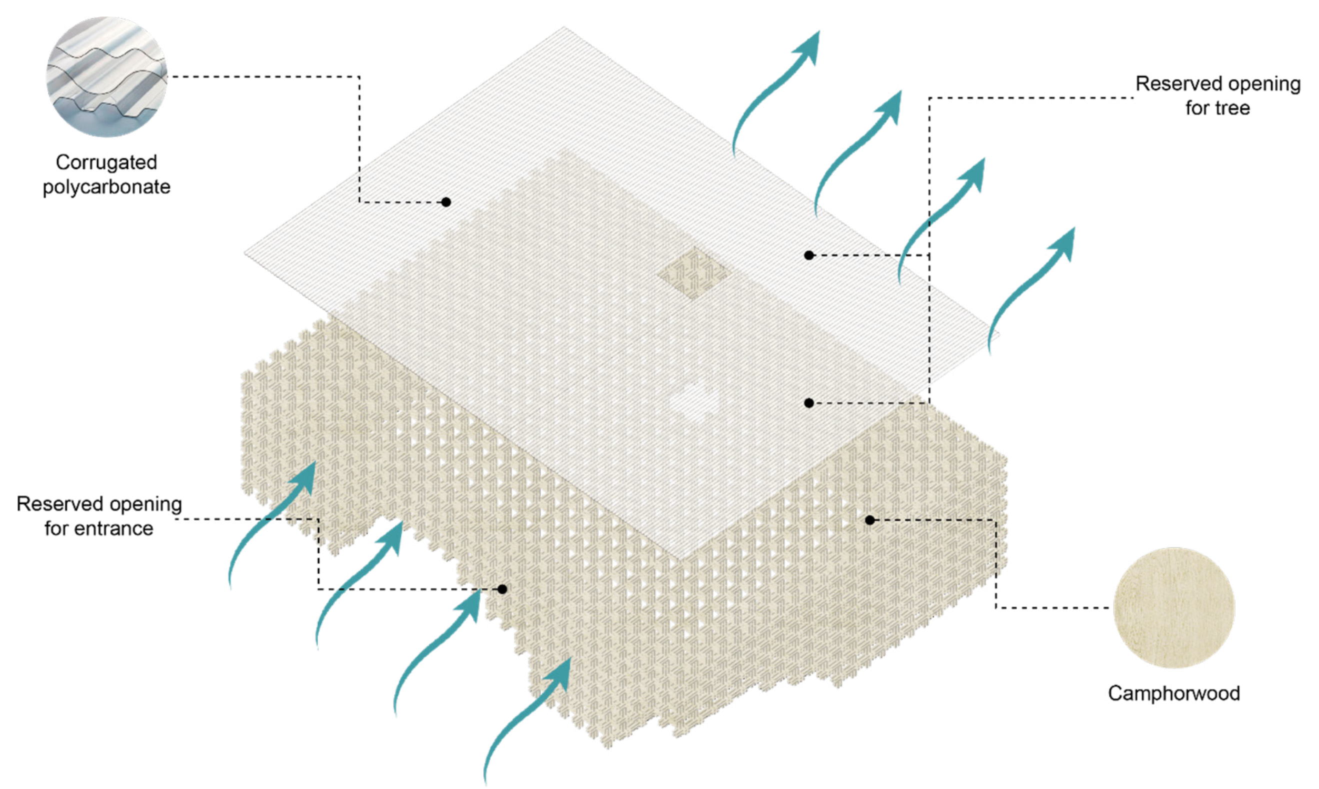

Fig. 92 Wooden frame

4.4.3 Joint method

When constructing the basic unit connection structure of the camphor wood frame, four wooden strips with a cross-sectional size of 5cm×5cm are first combined to form unit wooden strips (Fig. 93). To ensure the strength and stability of the overall structure, three such unit wooden strips are arranged according to a predetermined geometric layout and fixed using specialized steel connectors. Steel connectors are usually made of high-strength steel and firmly connected to wooden strips through bolts, effectively transmitting and dispersing forces, thus forming a basic unit connection structure. This connection method not only preserves the natural characteristics and aesthetics of wood, but also significantly improves the load-bearing capacity and durability of the structure through the addition of steel, providing a reliable connection foundation for subsequent frame construction.

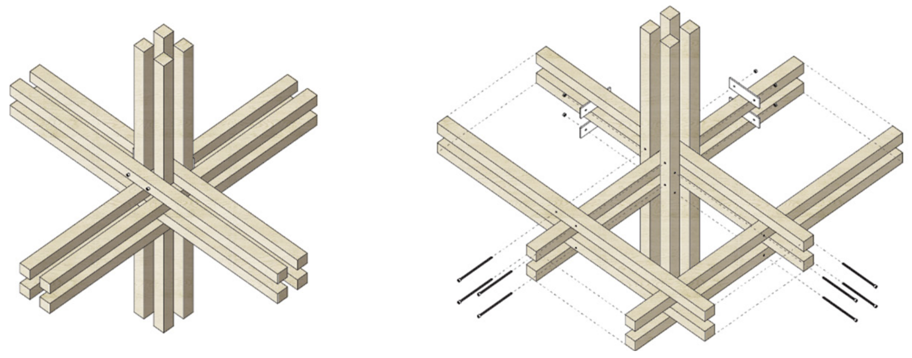

Fig. 93 Detail of the joint

In the connection structure between wooden columns and cement foundations (Fig. 94), the column base connector is used as the key connecting component, which achieves reliable docking with the bottom of the wooden column through its anchor end embedded in the cement base and the exposed connection end. Connectors are usually made of high-strength steel and have undergone rust prevention treatment on the surface to ensure durability in humid environments. When installing, first accurately embed the anchoring end of the connecting piece into the cement foundation. After the concrete reaches the design strength fix the bottom of the wooden column to the exposed end of the connecting piece with bolts to form a rigid connection. This connection method not only utilizes the high bearing capacity of the flexibility of wood. Through the stress transmission effect of the connecting piece, it effectively disperses the concentrated load between the wooden column and the foundation, while allowing for a certain degree of small displacement to adapt to the effects of temperature changes or foundation settlement, thereby ensuring the stability and safety of the overall structure.

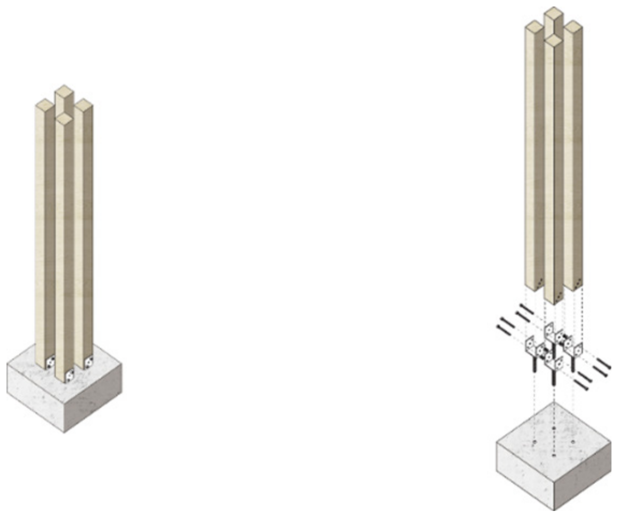

Fig. 94 Detail of connection between column and foundation

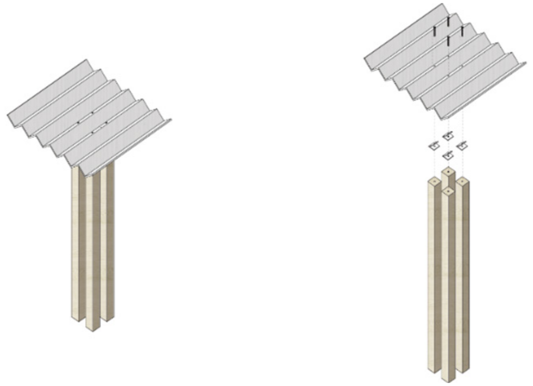

Fig. 95 Detail of connection between column and roof

At the connection point between the wooden column and the roof (Fig. 95), steel connectors are used as key force transmission components, and reliable connection between the wooden column and the roof is achieved through the high-strength steel made connectors. When installing, first fix the lower anchor end of the connecting piece to the top of the wooden column with bolts to form a rigid connection foundation; then connect the roof to the connecting piece through the bolt holes of the connecting piece, forming an overall force system. This connection method utilizes the high tensile and shear properties of steel, effectively transmitting roof loads to wooden columns.

Fig. 96 shows the supporting structure details of loadbearing and non-loadbearing walls in a wooden frame structure. Both constructions use a stable cement foundation as the loadbearing base, which transmits the load downwards through vertical wooden columns and is mainly supported by wooden beams (flooring joist). These beams further support the wooden floor, forming a complete transmission path. The difference lies in the functional positioning of the connecting components (wooden mullion) of the wooden boards: for loadbearing wall, wooden mullion serve as key load transmission components, which need to efficiently transfer the vertical load borne by the wall downwards to the wooden beams, and ultimately be carried by the cement foundation; for non-loadbearing wall, wooden mullion only serve to fix the wooden boards and do not need to participate in the transmission of vertical loads, this structure focuses more on maintaining the stability of the wall and facilitating installation.

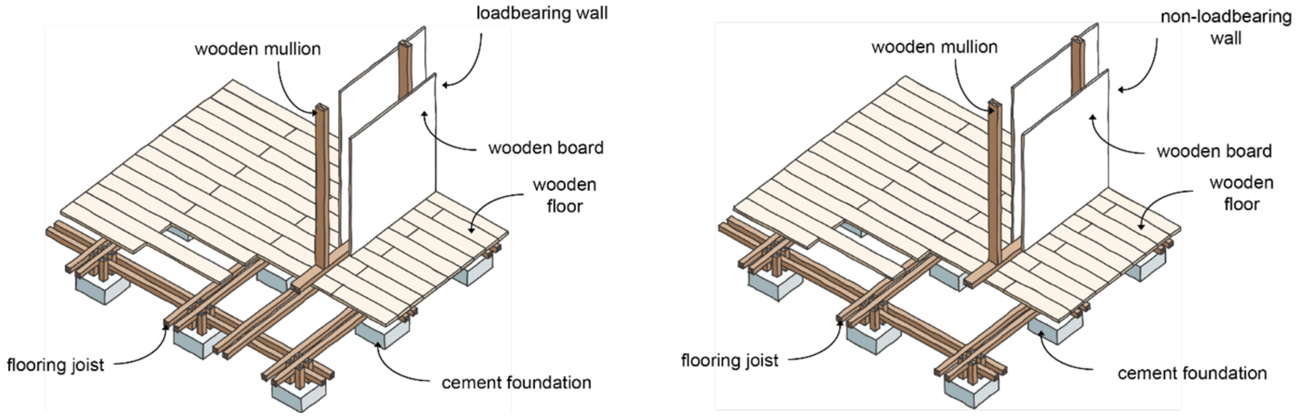

Fig. 96 Providing subfloor support to walls

The window design uses a rotatable wooden board as the core component, which can be opened and closed through simple rotation operation (Fig. 97). Users can easily rotate the wooden board and combine it with the external wooden frame to ensure air circulation.

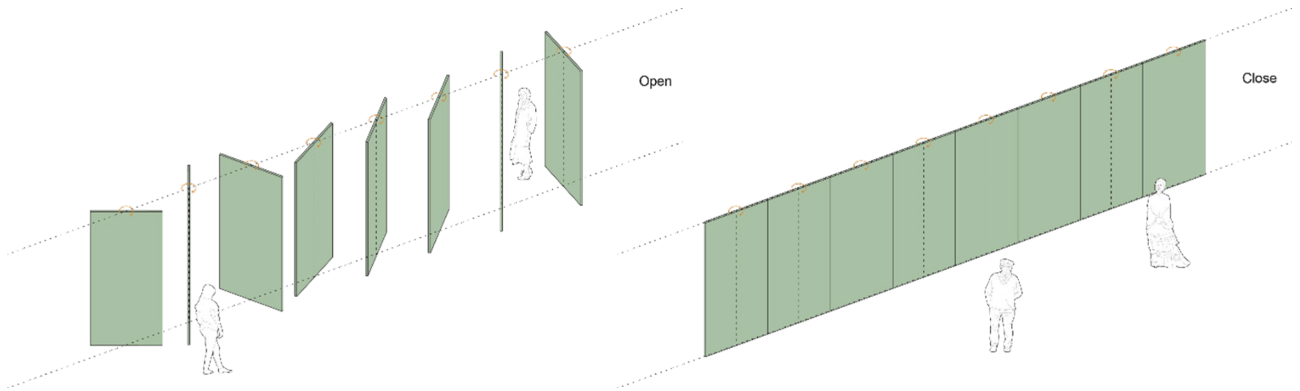

Fig. 97 Rotating wooden window

4.4.4 Functional layout

When planning the spatial layout of the main and minor pavilions, full consideration was given to the differences in thermal stress characteristics in different areas. Due to its significant advantage of low thermal stress, the space under the bridge has a relatively low level of thermal stress, and this low thermal stress area presents a large and concentrated distribution characteristic, which can provide stable thermal environment conditions for large facilities. The low thermal stress area under the shade of trees has a small and scattered distribution characteristic, although the overall thermal stress is low, the distribution is relatively scattered. According to this, the main pavilion is planned to be prioritized in the space under the bridge to fully utilize its large and concentrated low thermal stress advantage (Fig. 98), ensuring that the main pavilion maintains a good operating condition in complex thermal environments. At the same time, the minor pavilion will be scattered in shaded areas such as tree shade, utilizing their small and dispersed low thermal stress distribution characteristics to achieve rational use of space and coordination of overall layout.

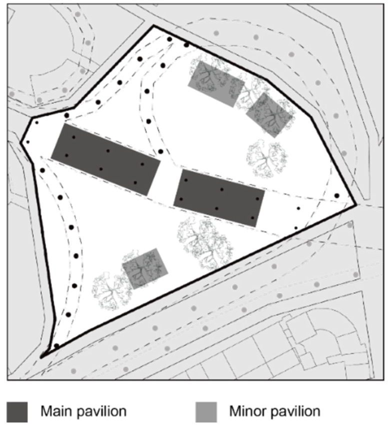

Fig. 98 The location of pavilion

Based on the survey results, the functional requirements of the site were analyzed and divided into three levels of requirements. Among these functions, restaurant, chess room and toilet are listed as the highest level of demand. These facilities are directly related to the convenience of elderly people's daily lives and the basic needs of social interaction, and are the core elements to ensure their quality of life; security office, parking lot, gymnasium and leisure space are in moderate demand and play an indispensable role in ensuring safety, facilitating transportation, and promoting health; the demand for reading room, classroom, teahouse, multifunctional room, market and clinic are relatively low, but still needs to be included in the overall planning. In addition, exhibition space, cinema facility and meditation area have been specially added to the site, aiming to create a rich spiritual environment for the elderly through artistic and cultural experiences and spiritual healing.

Based on the above requirement analysis, an optimized design of the functional layout was carried out (Fig. 99). The main pavilion, at the core region, has a relatively large area, so the highest demand functions such as restaurant, chess room and toilet are set here to meet the concentrated needs of elderly people's daily activities. For moderate demand functions, considering that the reading room and teahouse require a relatively quiet environment, they are set up together with specially added exhibition space and meditation area in the secondary pavilion, which ensures the convenience of functional use and creates a suitable atmosphere. Meanwhile, gymnasium, cinema and market suitable for outdoor environments are arranged in outdoor activity areas, fully utilizing natural conditions to provide diverse activity spaces for the elderly. Other functions are reasonably distributed within the main pavilion according to actual needs, ensuring the comprehensiveness and practicality of the site's functions. Through this layout design, a comprehensive site function distribution system has been constructed that not only meets the basic needs of the elderly, but also emphasizes spiritual and cultural experiences.

Fig. 99 Ground floor plan

4.4.5 Exploded axonometric drawings

Fig. 100, Fig. 101, Fig. 102, Fig. 103, and Fig. 104 are exploded axonometric drawings of the core building of the site, clearly presenting the spatial composition and functional zoning of the main pavilions and minor pavilions. Among them, the main pavilions are the centralized carrier of high-frequency usage functions. The minor pavilions include three independent functional modules: exhibition, reading room, and teahouse, arranged in a dispersed layout to adapt to the low thermal stress area under the shade of trees. It demonstrates the combination relationship and relative position of various functional spaces, reflecting the layout strategy of “the main pavilions focus on carrying core needs, and the minor pavilions disperses and supplements characteristic functions”, and echoes the design concept of modular construction of wooden frames, representing the corresponding relationship between building structure and functional zoning.

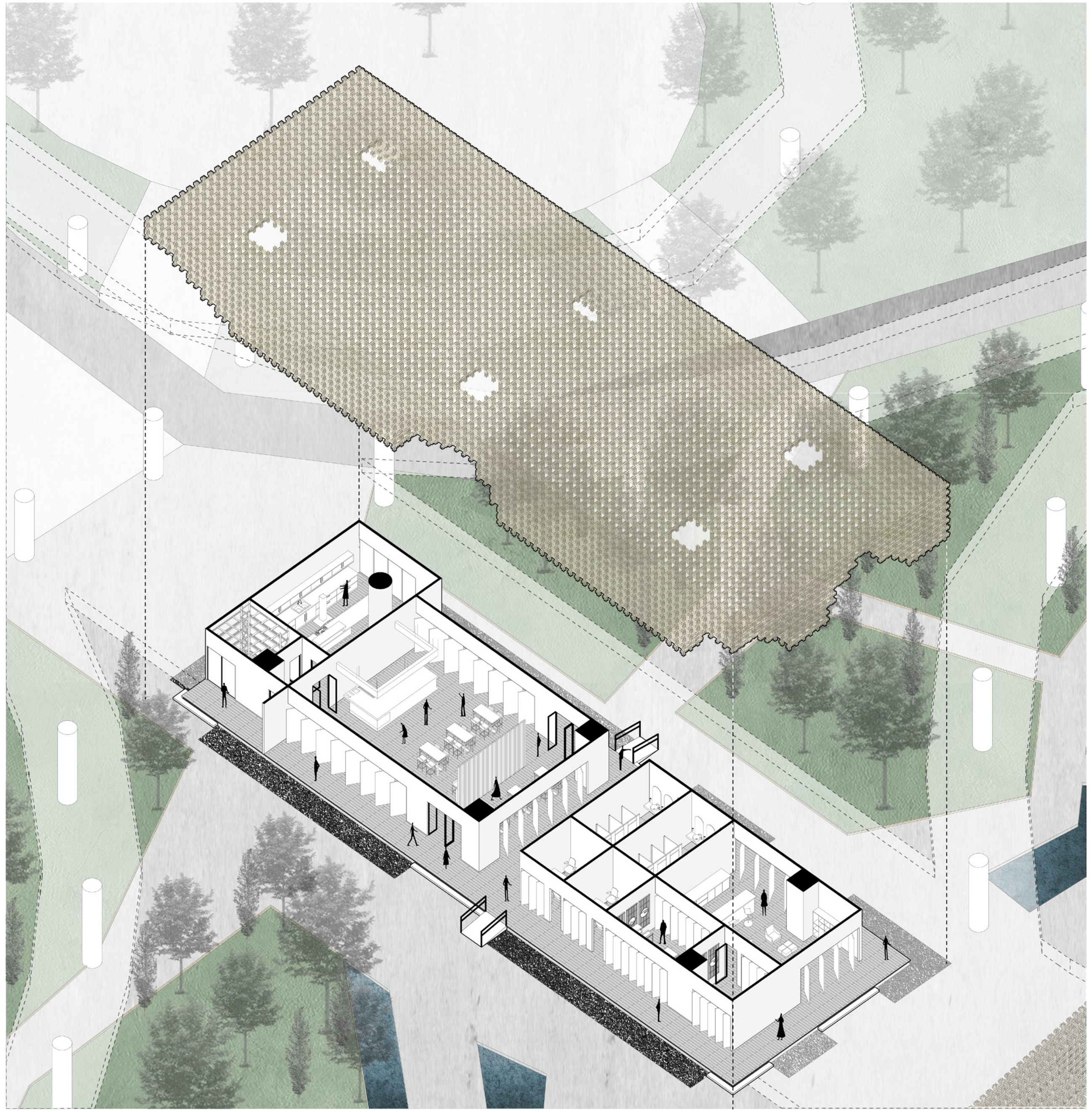

Fig. 100 Exploded axonometric drawings of Main Pavilion 1

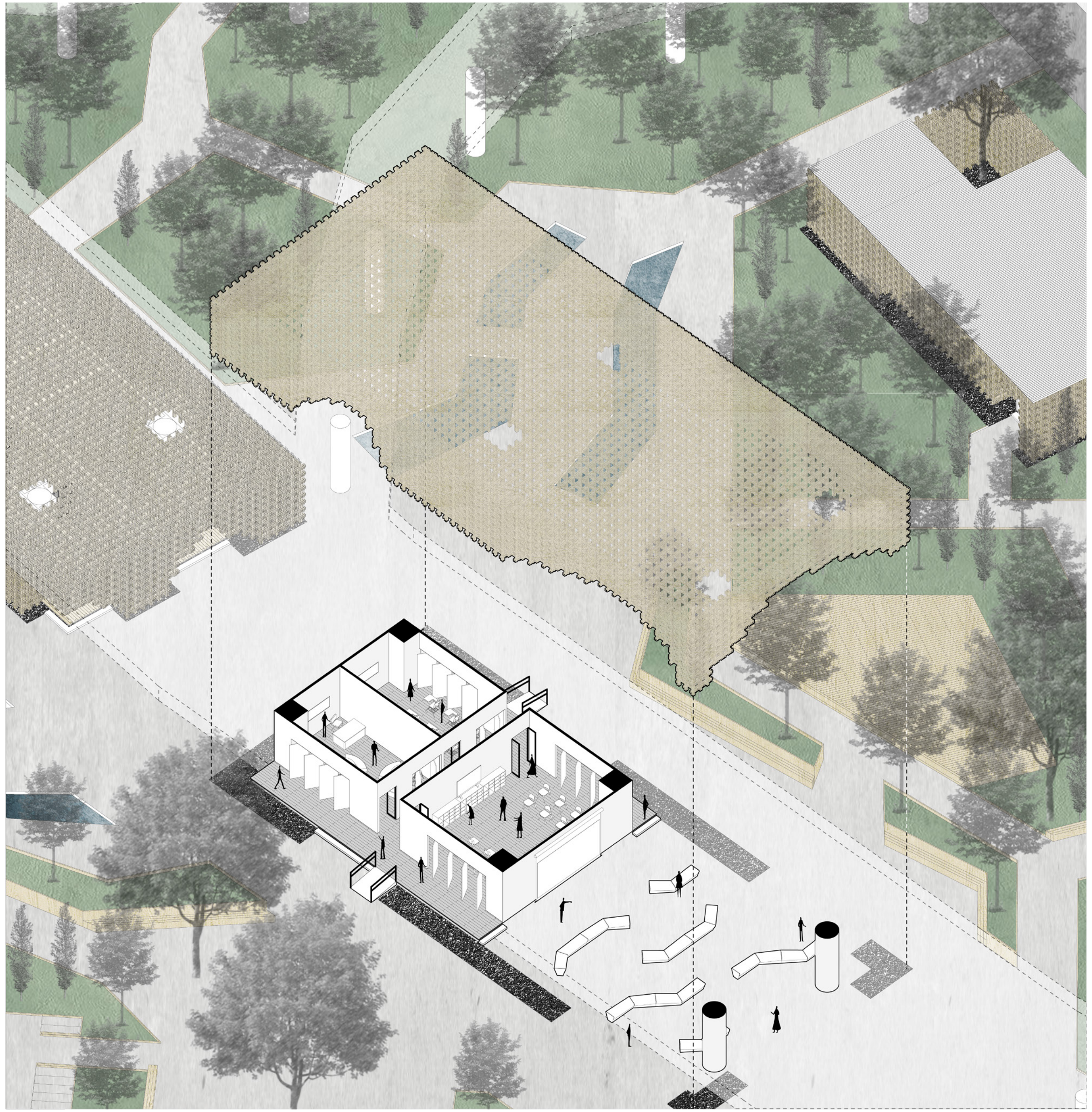

Fig. 101 Exploded axonometric drawings of Main Pavilion 2

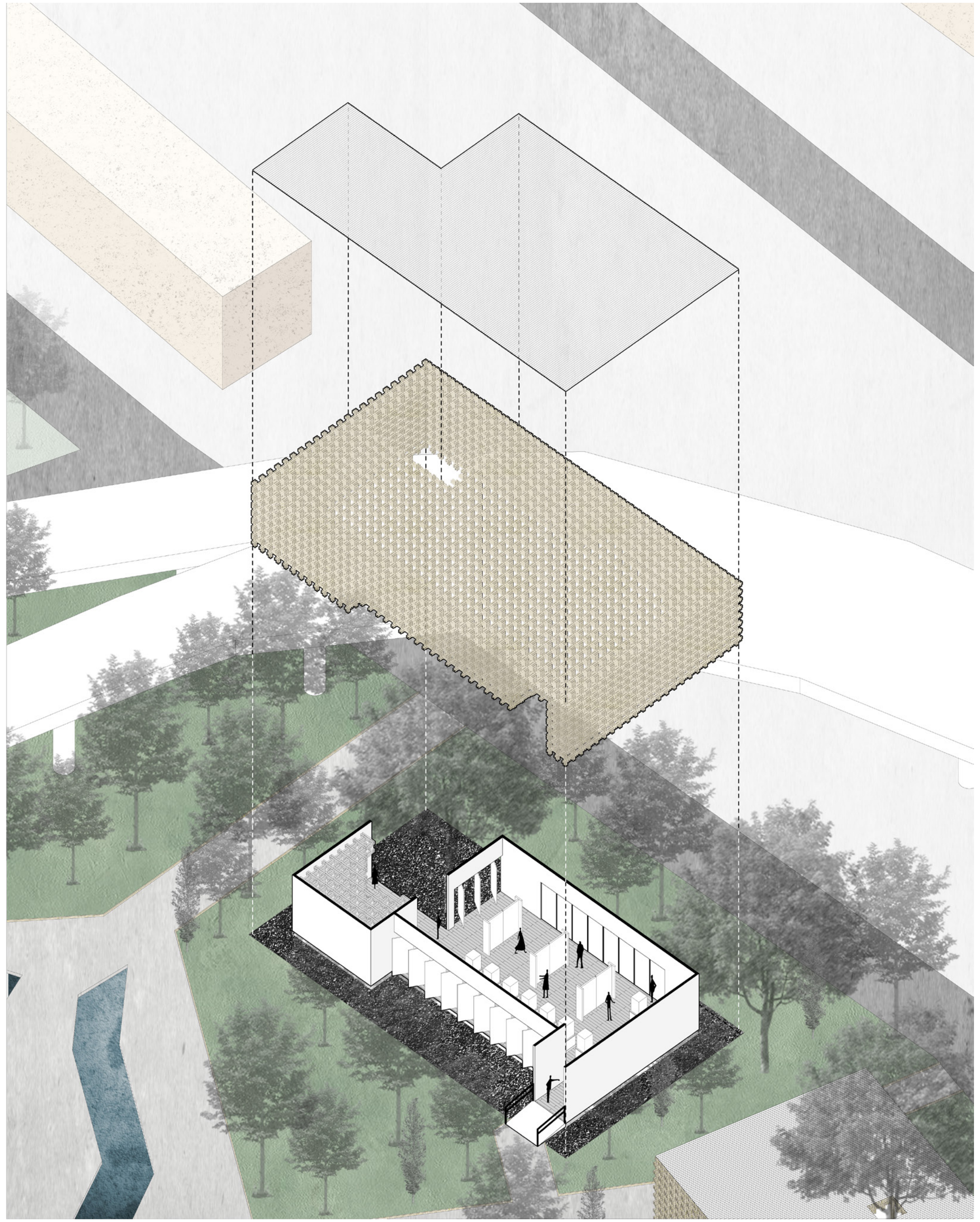

Fig. 102 Exploded axonometric drawings of Exhibition

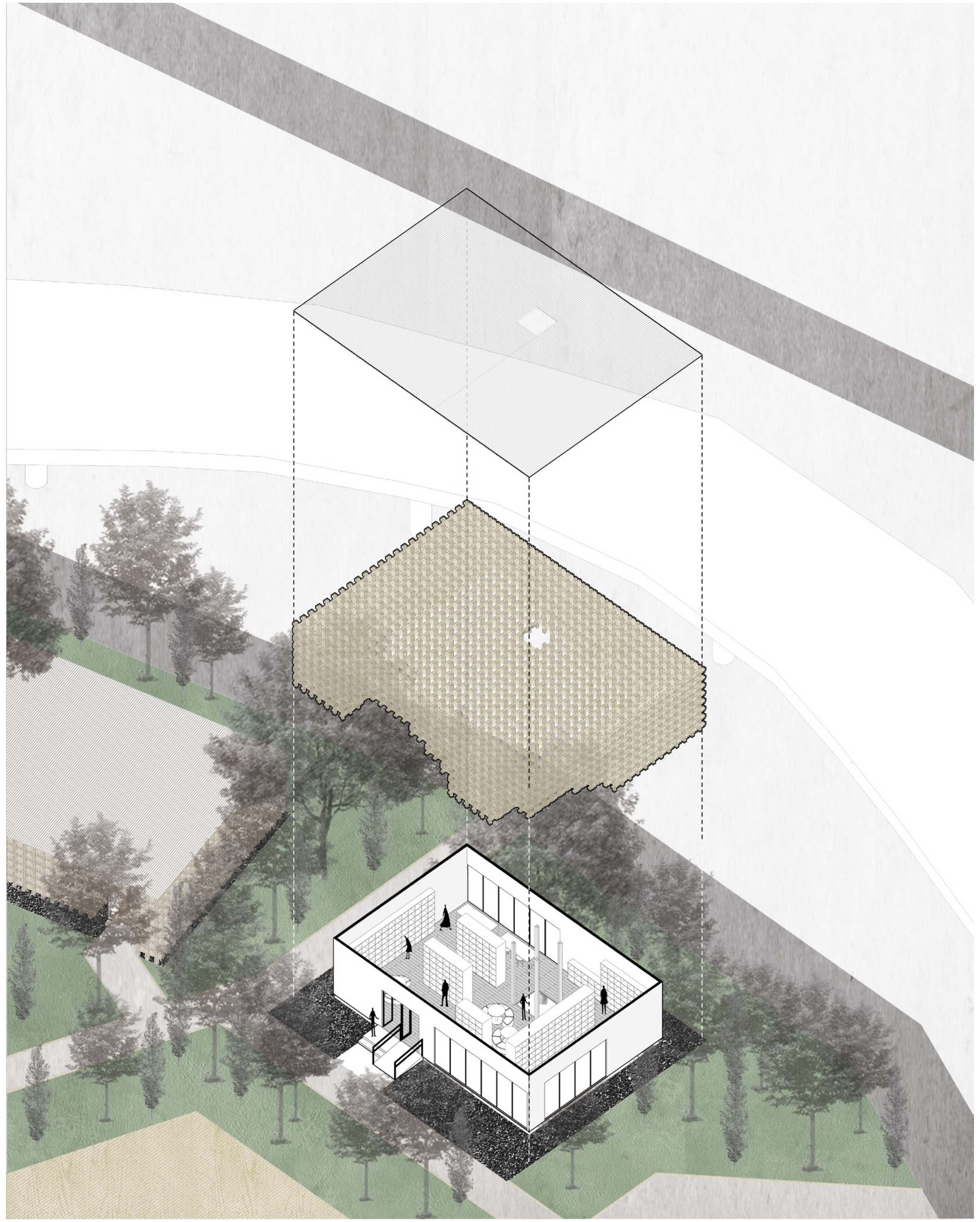

Fig. 103 Exploded axonometric drawings of Reading Room

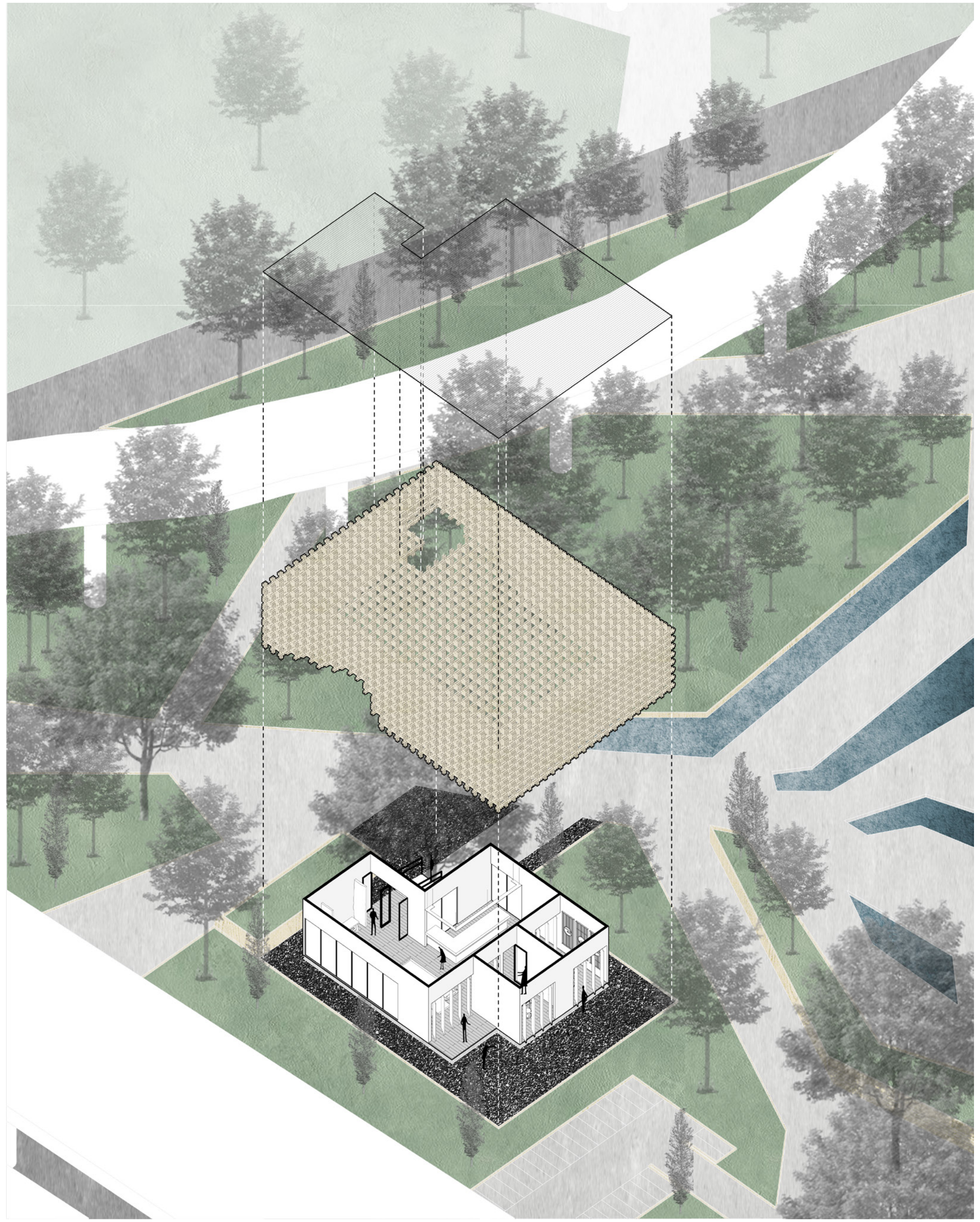

Fig. 104 Exploded axonometric drawings of Teahouse

4.4.6 Elevations

The south elevation of main pavilion 1 is main made of local camphor wood as the main structural material, and the elevation design considers both transparency and practicality (Fig. 105). The elevation retains multiple open entrances to meet the travel needs of the elderly, while the sparse arrangement of wooden frame reduces direct sunlight while ensuring natural ventilation. And barrier free ramps have been set up, echoing the overall barrier free design of the site. The overall style is simple and stable, which not only conforms to the usage habits of the elderly group, but also forms a material correspondence with the preserved tree ecological environment of the site.

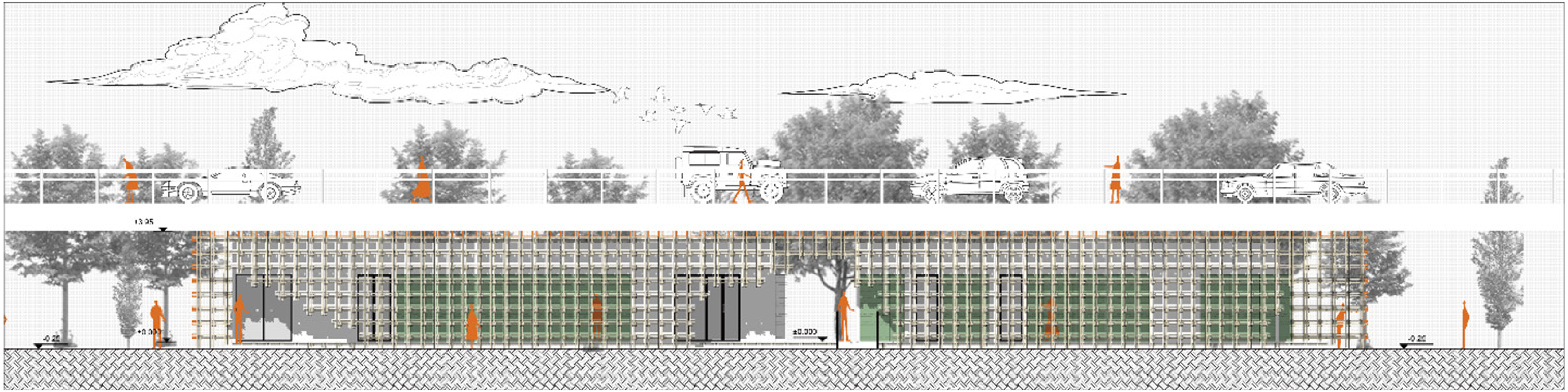

Fig. 105 South elevation of Main Pavilion 1

The south elevation of the exhibition is designed with a combination of semi-transparent corrugated polycarbonate roof and camphor wood frame (Fig. 106). The transparency of the roof allows the interior to obtain soft diffused light, avoiding the visual stimulation of the elderly by strong light. The elevation features a large area of landscape windows, allowing the exhibition space to blend seamlessly with the external green landscape, enhancing the comfort of the space. A wide entrance area is reserved at the bottom for the convenience of elderly people. The overall elevation is light and transparent, which fits the cultural attributes of the exhibition.

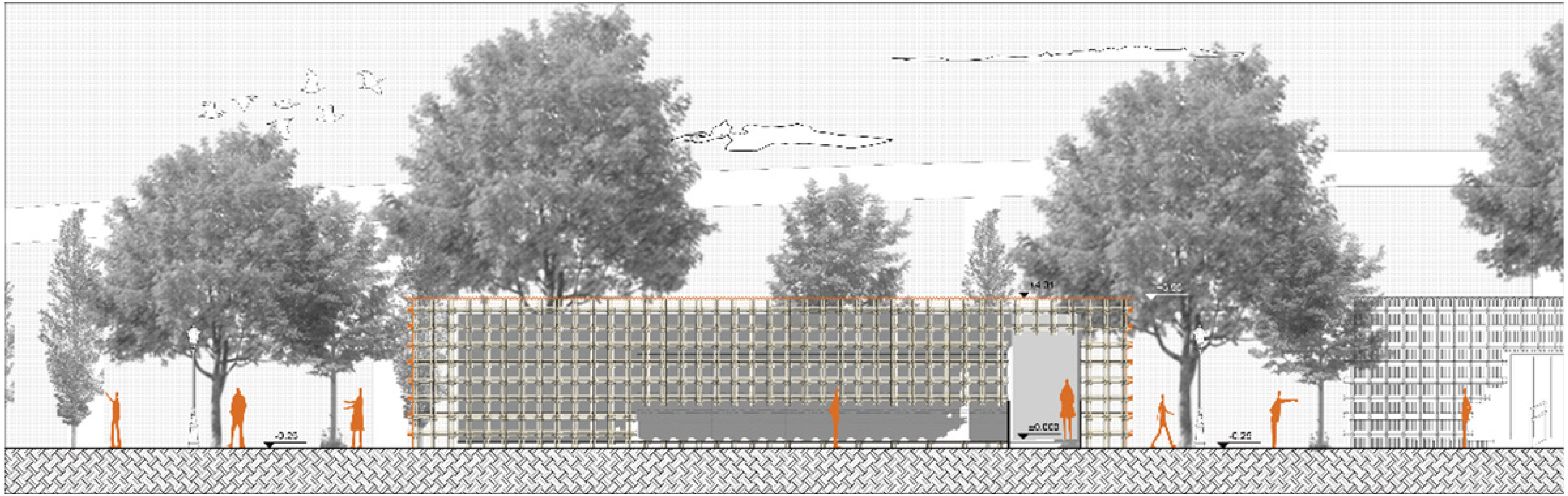

Fig. 106 South elevation of Exhibition

The entrance of the reading room elevation adopts a gentle slope design, combined with the texture of wooden door frames, creating a comfortable and friendly atmosphere (Fig. 107). The elevation material is coordinated with the natural environment under the shade of trees, making the reading room a leisure reading space that combines privacy and ecological sense, meeting the needs of the elderly for a quiet place.

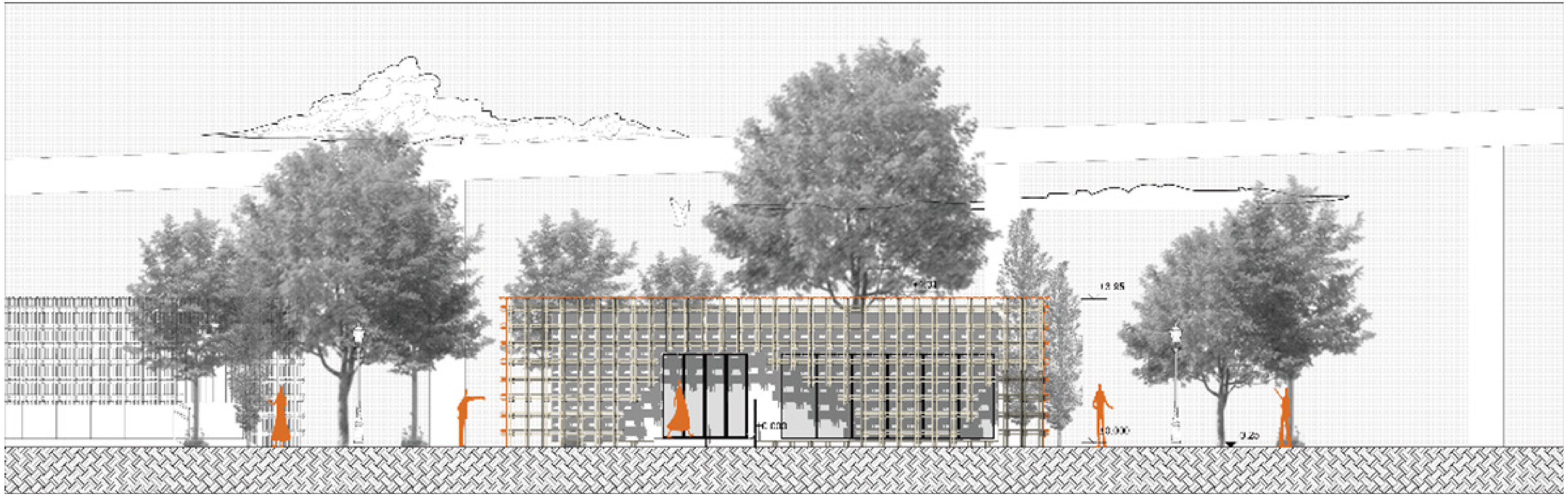

Fig. 107 South elevation of Reading Room

4.4.7 Sections

The sections show the spatial structure of the main pavilion and the minor pavilion, clearly presenting the support system of the camphor wood frame, the construction of the semi-transparent corrugated polycarbonate roof, and the functional layout of the ground floor (Fig. 108, Fig. 109 and Fig. 110). As can be seen from the sections, for the minor pavilion, the roof adopts a lightweight structural design to reduce structural loads while ensuring transparency. The ground level of the pavilion has been raised by 250mm, and the net height of the indoor space is controlled at 3.25m to ensure air circulation, reduce stuffiness, and fully consider the activity comfort of the elderly.

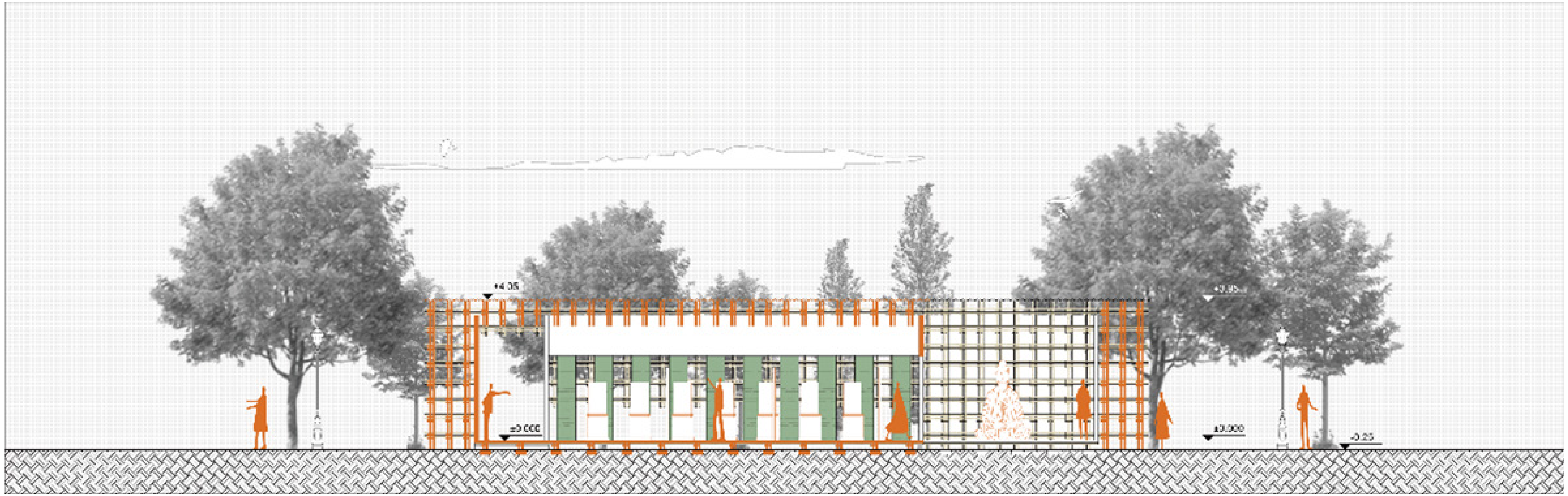

Fig. 108 Section A-A

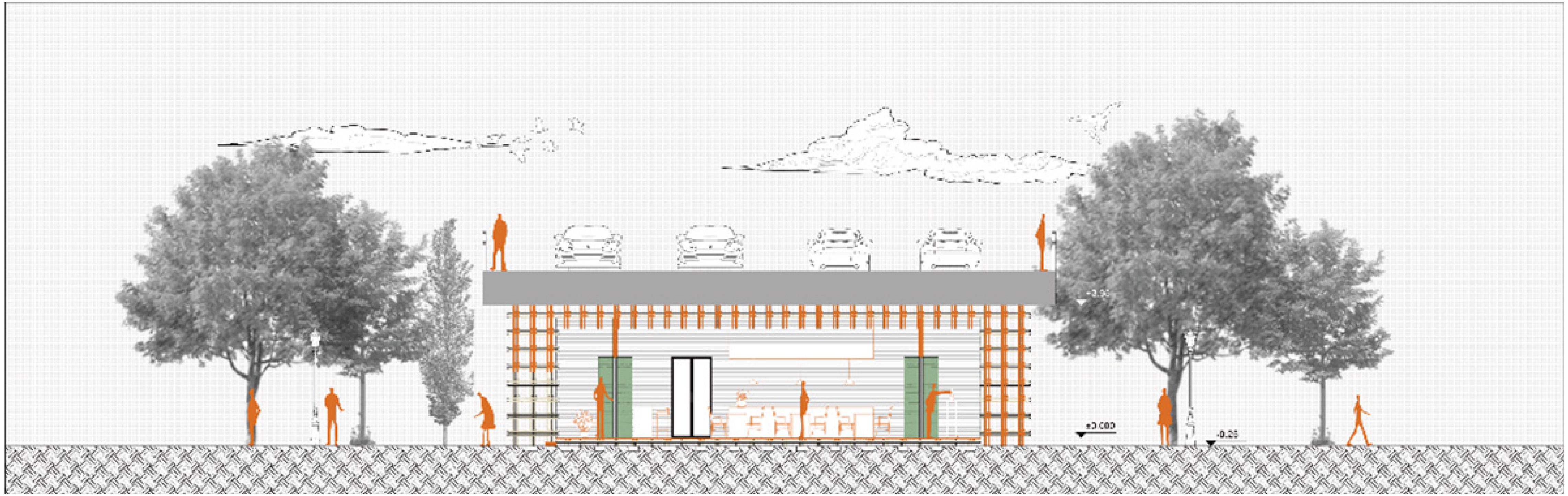

Fig. 109 Section B-B

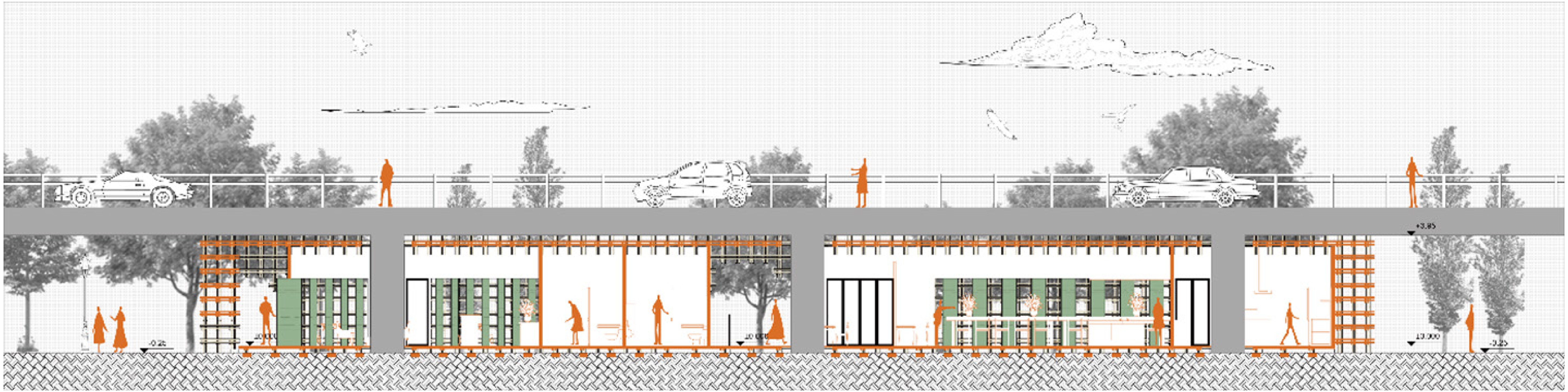

Fig. 110 Section C-C

4.4.8 Detail

Fig. 111 shows the connection between the wooden frame, enclosure structure, and foundation. In vertical support, a wooden mullion with a cross-sectional size of 50mm×80mm is used as the loadbearing component, and its outer side is covered with 20mm thick wooden boards to enhance aesthetics and protection. Horizontally, it is fixed with multiple layers of bolts using 50mm×50mm wooden strips, significantly enhancing the structural integrity and stability of the component. In the design of connection nodes, the upper part of the wooden mullion is connected to the wooden frame through bolts, and the bottom is fixed to the cement foundation with column base connector combined with U-channel. At the same time, reliable anchoring with the wooden joist and wooden floor is achieved through connectors. In terms of barrier free design, there is a standardized barrier free ramp with a slope of 1:8 and a height of 250mm, and safety railing are installed to comply with the barrier free access regulations, ensuring that wheelchair users can safely and conveniently pass through the area. The area paved with laying stones in the figure is a drainage ditch, which combines aesthetic and practical functions.

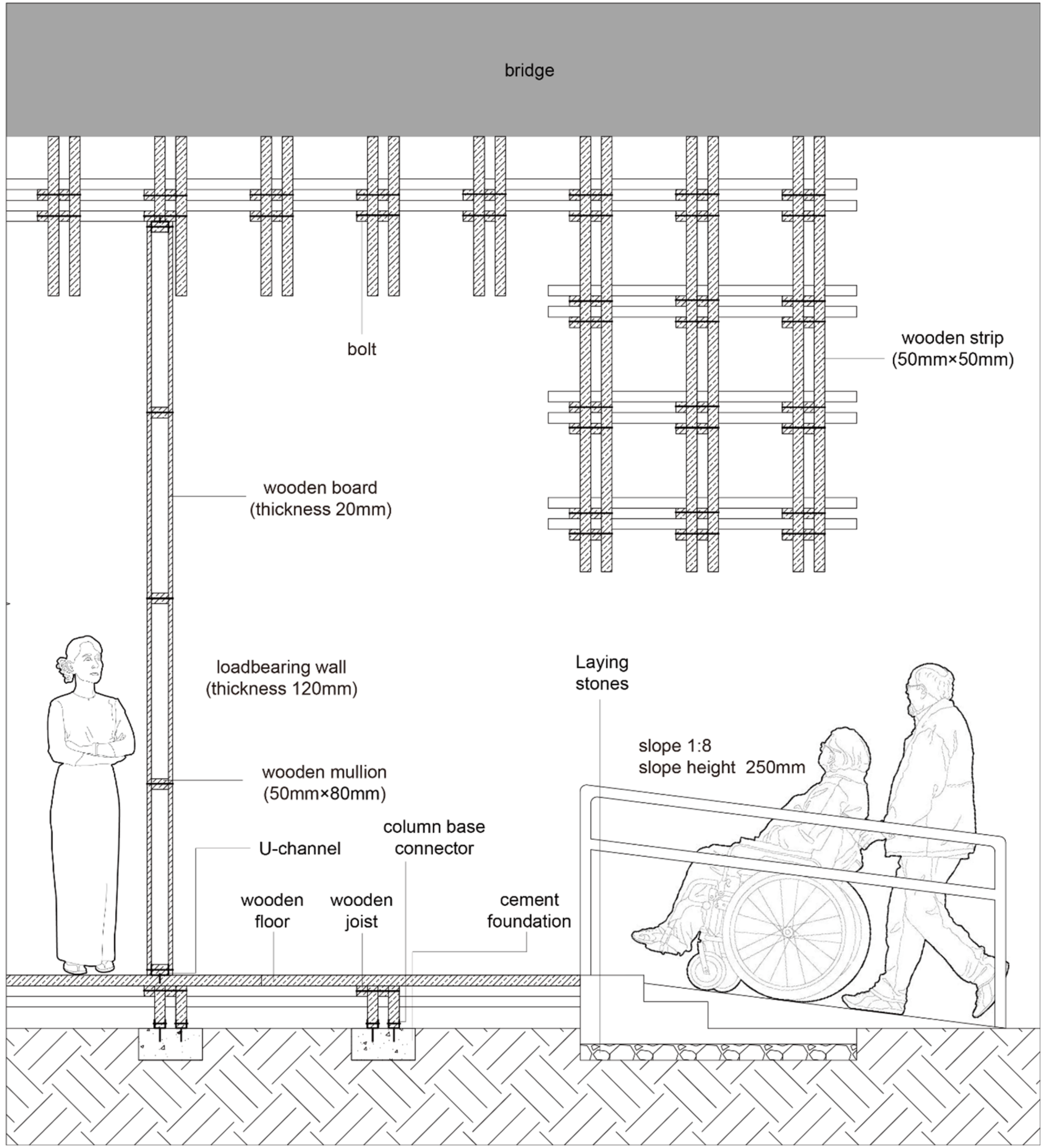

Fig. 111 Detail

4.4.9 Scenario

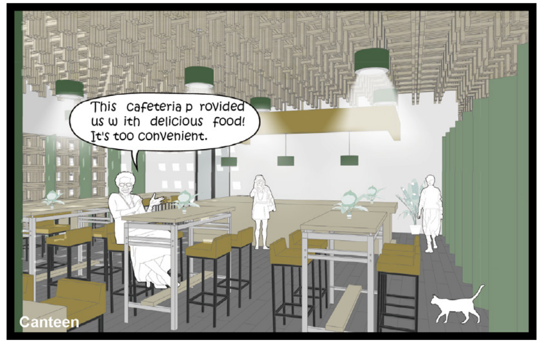

Fig. 112 Canteen

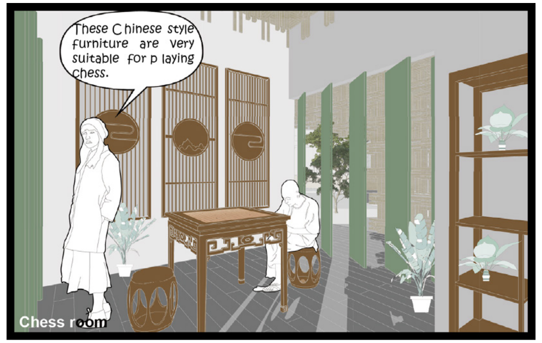

Fig. 113 Chess room

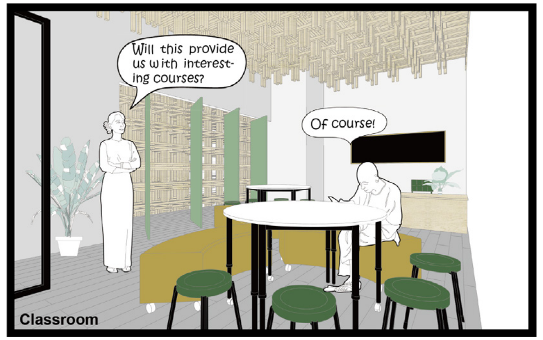

Fig. 114 Classroom

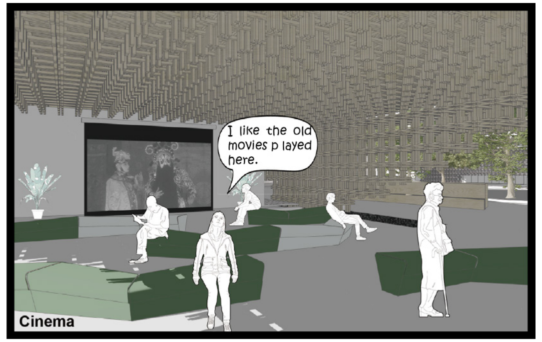

Fig. 115 Cinema

Fig. 116 Waterscape

Fig. 117 Gymnasium

These scenarios present the activity status of elderly people in the site, focusing on the spiritual culture and leisure function, demonstrating the compatibility between the functional layout and actual usage needs, as well as the relatively quiet activity atmosphere (Fig. 112, Fig. 113, Fig. 114, Fig. 115, Fig. 116, Fig. 117, Fig. 118, Fig. 119, Fig. 120, Fig. 121, Fig. 122, Fig. 123, and Fig. 124). Allowing the elderly to have comprehensive activity experience in a comfortable environment.

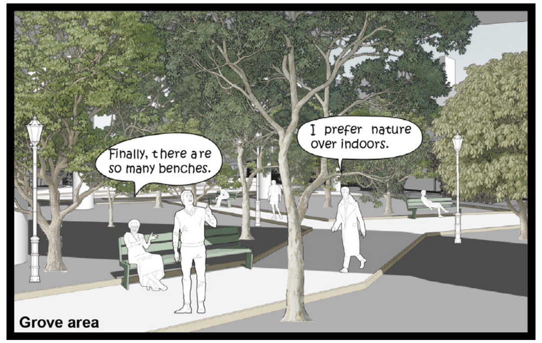

Fig. 118 Grove area

Fig. 119 Market

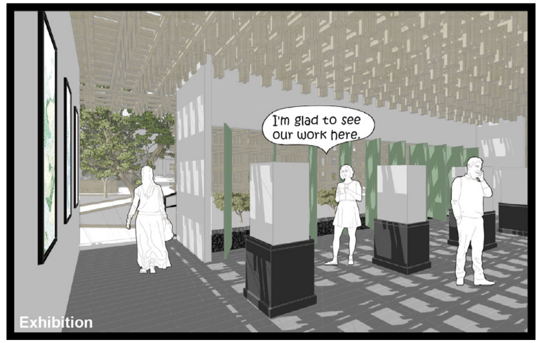

Fig. 120 Exhibition

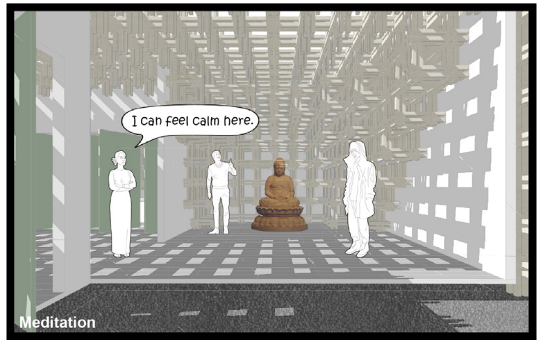

Fig. 121 Meditation

Fig. 122 Yard

Fig. 123 Reading room

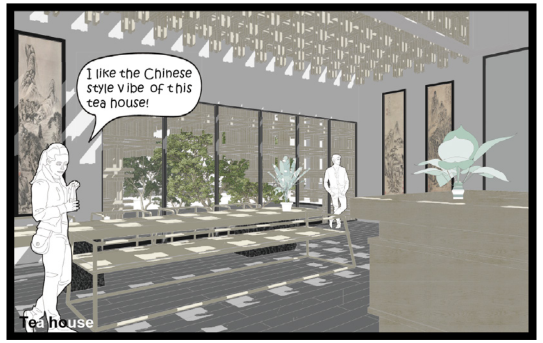

Fig. 124 Teahouse

5. Conclusion

This study focuses on the spatial renewal of the space under the Bayi Bridge in Nanchang, focusing on two core issues: the utilization of idle gray spaces in cities and the construction of aging friendly public spaces. The research is conducted through multidimensional methods such as site research, questionnaire analysis, ENVI-met microclimate simulation, and case studies.

Research has shown that the elderly population, as core users, urgently needs basic facilities such as seat and restaurant, and the shaded area under the bridge has become a key reason for their preference for clustering due to its more favorable thermal comfort and shorter heat stress time. Based on case studies from around the world, as well as the questionnaire outputs, the research proposes design strategies such as preserving large trees, demolishing idle buildings, dividing functional areas according to thermal environment distribution, and creating semi-open pavilions made of camphor wood.

This update achieves the transformation of idle space into a vibrant aging public space through microclimate regulation and user demand orientation, alleviating the contradiction between insufficient urban open space and the shortage of elderly activity venues. And the elderly will also have comprehensive experience in terms of physiological comfort, daily needs, safety, and spiritual life, and truly feel the convenience brought by space renovation.

In terms of physiological comfort, the renovated site has improved the thermal environment comfort through planning. The shadow space under the bridge and the shade formed by the preserved trees create a low thermal stress duration area. The evaporative cooling effect of the central waterscape area and the transpiration effect of the western grove area can further reduce the temperature of the site, shorten the duration of heat stress, and effectively reduce the potential risks of high temperature to the health of the elderly. At the same time, the pavilion built with a semi-transparent corrugated polycarbonate roof and camphor wood frame not only maintains the transparent structural characteristics, promotes natural ventilation to avoid stuffiness, but also softens strong light, reduces the stimulation of the elderly's vision.

In terms of daily needs, the renovation accurately meets the core needs of the elderly, not only adding a large number of seats, toilets equipped with armrests, and convenient canteens to solve the shortcomings of existing facilities, but also specially sets up low intensity sports fields such as chess rooms and table tennis, which meet the preferences of elderly people for low-frequency activities. In addition, the site is equipped with convenient facilities such as Wi-Fi, free drinking water points, and mobile phone charging areas, as well as supplementary services such as barrier-free path, so that elderly people do not have to worry about basic needs for their daily activities.

In terms of safety assurance, the renovation has achieved the separation of people and vehicles through planning, prohibiting electric motorcycles from freely passing through and reducing collision risks. At the same time, increase the lighting facilities on the site to solve the problem of insufficient nighttime light and ensure the safety of elderly people's nighttime activities. The newly added security office can promptly resolve conflicts that may arise during activities, especially adding security to the elderly.

In terms of spiritual and cultural life, the renovated site has added exhibition space, cinema, and meditation area. Regular interest classes such as calligraphy and teaism will also be held, as well as cultural lectures, health consultations, and other activities. This not only enriches the spiritual and cultural life of the elderly, but also fills the gap in community elderly services. The layout design of the main pavilion (under the bridge) and the minor pavilion (under the shade of trees) provides a fixed social space for the elderly, allowing them to spontaneously gather and communicate, especially meeting the social needs of the elderly.

Overall, this renovation has transformed the original space under the bridge into an elderly friendly, comfortable, safe, and warm community activity center. It not only alleviates the contradiction of insufficient urban public space, but also meets the physiological characteristics and living needs of the elderly, making their daily activities more convenient, comfortable, and of high quality.

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