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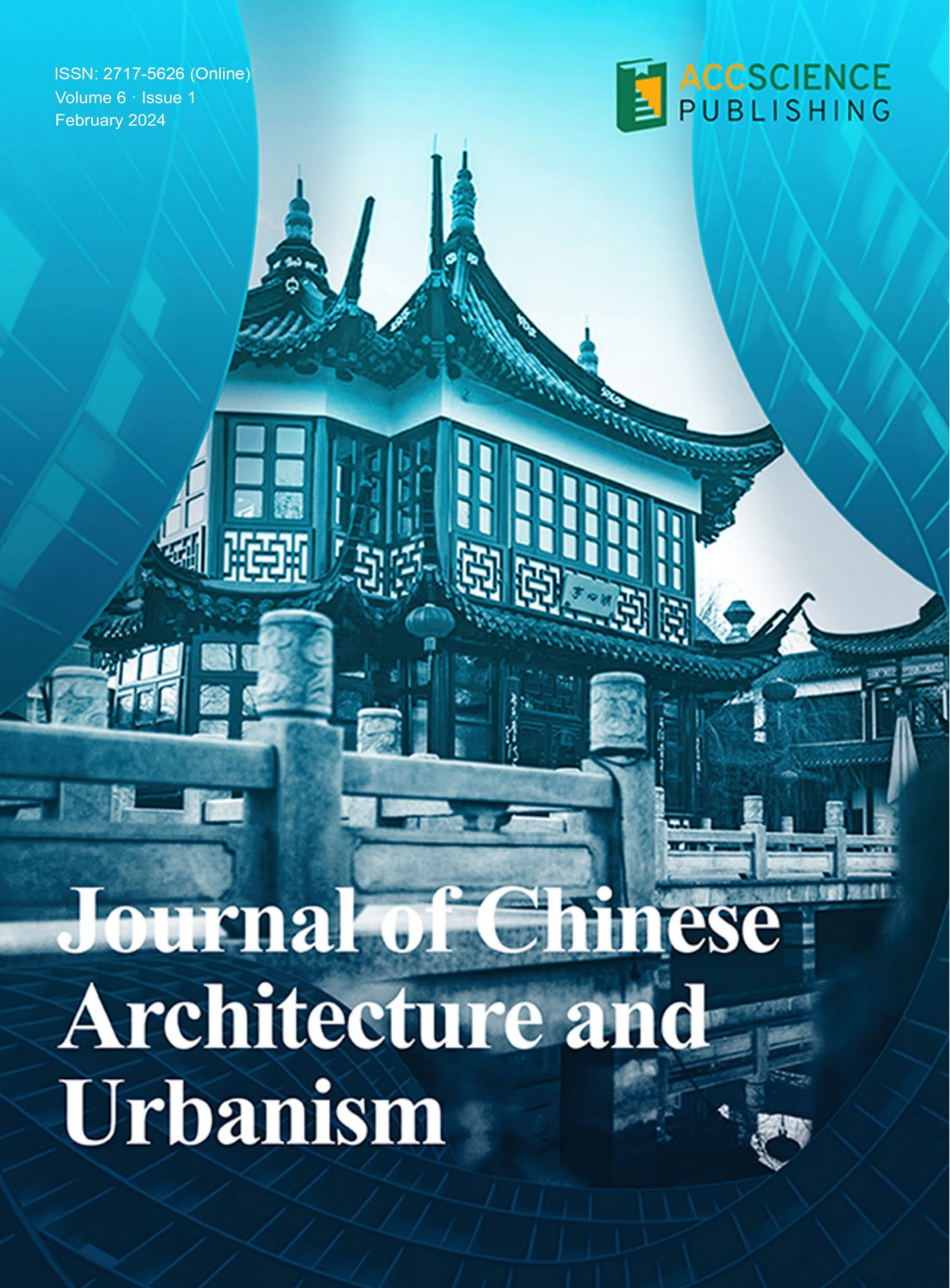

Journal of Chinese Architecture and Urbanism

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Journal of Chinese Architecture and Urbanism

The *Journal of Chinese Architecture and Urbanism (JCAU)* is an international peer-reviewed academic journal which publishes original research articles, review articles, reports, viewpoints, book notes, and book reviews. The Journal presents new and original results of research, and provides a platform for discussion and debate relating to architectural heritage preservation, resilience and cultural sustainability of modern vernacular architecture in the Chinese context, as well as the cultural influence of Chinese architecture worldwide, past and present.

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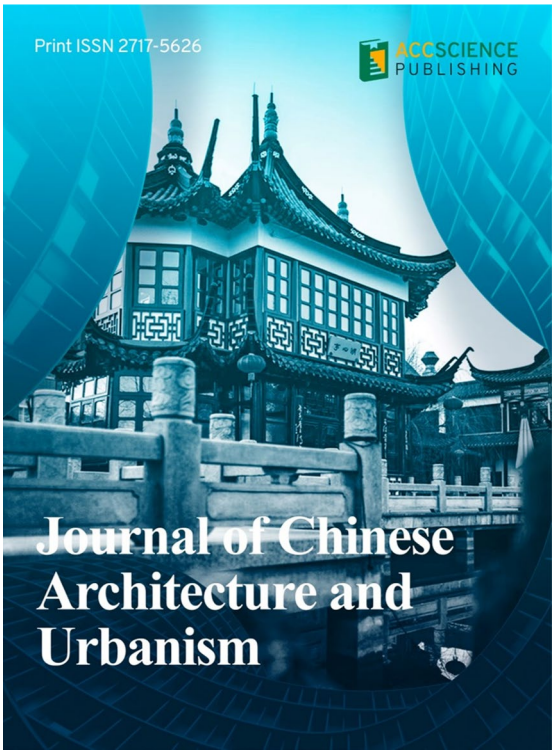

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A typical Chinese-styled building

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Journal of Chinese Architecture and Urbanism

Editorial

Introducing Regenerative Architecture

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(This article belongs to the *Special Issue: Regenerative Architecture*)

Abstract

The global-scale impacts of the Anthropocene have reached tipping points of order, resulting in the climate emergency. We are no longer able to carefully adjust our industrial practices to put this titan back into its box, and we must enter a new era of human development to meet our present needs. This involves restoring the living realm through bioremediating environments, enlivening communities, enriching soils, and rebuilding ecosystems as we live and work. The conservative net zero ambitions of "sustainability" cannot reverse our negative planetary-scale impact. A new approach to designing and engineering our habitats is needed. This introduction to the special issue on Regenerative Architecture takes a design-led approach to discuss how the practice of the built environment, through its imaginaries, materials, spaces, bodies, and technologies, can make a positive impact on the living world. Since we cannot solve the ongoing crises from within our present thinking, which has initiated and compounded our predicament, this special issue explores the work of regenerative architects who are urgently developing diverse and inclusive practices. These practices aim to transcend the habits, expectations, and blind spots that frame contemporary practices. Taking a radically experimental and inclusive interdisciplinary design approach, the emerging field of regenerative architecture is actively developing a range of new tools, technologies, models, experimental platforms, theories, buildable systems, and critiques for environmentally beneficial practices. The nature of this ongoing research is diverse and interdisciplinary, invoking new concepts and formats that search for ways of working with nature, both as a co-creator of places and as a net beneficiary of architectural interventions.

Keywords: Regenerative architecture; Anthropocene; Climate emergency; Bioremediating; Architectural cyborg; Biodiversity

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1. Introduction

> "…I think that you can objectively say that the climate crisis is not being treated as an emergency, especially when you compare it with COVID-19 in many parts of the world. The climate crisis is not being treated as an emergency, and it never has." (Thunberg, 2021)

The extraordinary power unleashed by fossil fuels, deployed through massive machines, has empowered humanity to view itself as no longer bound by the laws of nature. Consequently, Western society has become estranged and detached from the living world. By instrumentalizing the living realm as mere resources, industrial machines have extracted nature's vital riches, leading to resource depletion, pollution,

habitat destruction, and land degradation. In cultivating an exploitative relationship with the living realm, greed has denied biogeochemical cycles the necessary recovery time to replenish the systems that sustain life. As a result, the base of the biosphere is imploding from *the bottom up*.

> "The bottom is chewed through, eviscerated, eaten away, depleted – until nothing is left – by the top. The middle, therefore, buckles and breaks. The top caves in, eventually, along with it. Whether we look at societies, economies, the planet, or food chains – this pattern of collapse is what seems to characterize now." (Haque, 2019)

The resultant collapse is an emergency – devastating, relentless, profound. Global climate patterns have changed owing to the massive release of greenhouse gasses (GHGs) into the atmosphere, stemming from the global-scale combustion of energy-dense fossil fuels such as coal, oil, and natural gas, which power modern industrial development. Trapping heat from the sun, their accumulation leads to an overall increase in the Earth's temperature. This overheating process is exacerbated by other industrial-scale processes, including deforestation, corporate agriculture, livestock farming, rice paddies, draining natural boglands and wetlands, landfill practices, overloaded sewerage systems, and other land-use changes. These activities have severely damaged the world's ability to recapture GHGs and return them to natural biogeochemical cycles.

Today, our impact on the planet has reached the scale of a geological force, a concept termed the "Anthropocene" by Paul J. Crutzen and Eugene F. Stoermer. Human activities, such as industrialization, deforestation, and the burning of fossil fuels, have collectively caused such profound changes to the Earth's atmosphere and ecosystems, replacing the current geological epoch called the Holocene, which began 11,700 years ago after the last major Ice Age (Crutzen & Stoermer, 2000). Although dwarfed by the invisible, intangible, biological, and chemical footprint we leave, cities – especially megacities (with more than ten million inhabitants) like Tokyo, Delhi, Shanghai – are now the most visible manifestation of human development on the planet, and their growth is a characteristic feature of the Anthropocene. While the concept of the Anthropocene has gained widespread recognition, scientifically, it remains an unofficial term. The rock layers that characterize a distinct geological era and mark its lower boundary are still yet to be formally determined (Prilliaman, 2022). From a humanities perspective, some researchers also consider the term as too anthropocentric and in danger of overlooking the complex interrelationships among different species, ecosystems, and structures that contribute to environmental degradation. They propose alternative terms, such as the "Capitalocene" (Moore, 2016) or the "Plantationocene," which better reflect the economic and political systems driving environmental degradation. Whatever we call the devastating consequences of modern industrialization, its environmental impacts are all around us, as exquisitely observed by Rachel Carson:

> "Why should we tolerate a diet of weak poisons, a home in insipid surroundings, a circle of acquaintances who are not quite our enemies, the noise of motors with just enough relief to prevent insanity? Who would want to live in a world which is just not quite fatal?" (Carson, 1962, p. 12)

2. Mitigating impacts

Achieving a meaningful outcome to the challenges of the climate emergency demands a multi-faceted and sustained effort across the whole of society, from individuals to communities, from science and technology to creativity, business practices, and forms of governance. Globally and collectively, significant investment in clean energy and the advancement of sustainable practices requires a cultural shift towards more judicious and ecologically centered values and practices.

The climate emergency has diverse and devastating consequences for natural and human systems, including rising sea levels, extreme weather events (tornadoes, earthquakes, hurricanes), dramatic variations in rainfall (floods, droughts), ocean acidification, loss of biodiversity, and impacts on human health owing to increased air pollution, the spread of disease-carrying insects, rising average temperatures, more frequent and intense natural disasters, declining crop yields, and widespread ecological disruption with food and water security issues. Actions to date have included efforts to reduce GHGs (transitioning to clean energy sources like wind and solar power and implementing energy efficiency measures such as insulation to reduce energy consumption), measures to protect and restore ecosystems (restoring forests, wetlands, and soils that absorb carbon dioxide from the atmosphere), infrastructural changes that prepare communities for the impacts of climate change (e.g., protection against rising sea levels, cooling for heat waves, and more robust forms of construction for intense natural disasters like earthquakes), promoting sustainable development (reducing waste, encouraging public transportation, and supporting sustainable agriculture), international cooperation (setting shared standards to mitigate emissions and support the transition to a low-carbon economy), and developing circular processes that restore resources while promoting biodiversity. Consequently, addressing the climate emergency has mobilized the collective imagination to reconsider how we should live together at a time when nature is increasingly agitated. Through the many facets which this entanglement of causes and effects unfolds, addressing the climate emergency has also become a priority for many governments. While

the worst impacts devastate communities through flash floods, wildfires, giant hailstones, and other extreme weather events, the notion of *sustainability* has become a key factor in shaping policy decisions, allocating resources, and serving as the foundation for international relations. As a proposal, however, the concept of sustainability is merely the beginning of an approach rather than a solution for our changing world.

3. Sustainability

Effective climate action requires vision and coordination. The term "sustainability" is most often used in the context of environmental issues and refers to the ability to maintain the natural systems and resources upon which all life depends. This commitment ensures that these systems can continue to support human and other forms of life into the future. The idea of sustainable development was more specifically defined in a landmark report called "Our Common Future," also known as the Brundtland Report, in 1987. It proposed that "sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The proposed idea encompasses balancing the economic, social, and environmental dimensions of development so that all are given equal consideration. The European Union is at the forefront of international efforts to develop a sustainable future. The primary strategy is to reduce the environmental impacts of modern industrial development by making significant investments in clean energy and energy-efficient technologies. Secondary strategies support this transition by addressing the fundamental social and economic impacts, enabling the adoption of new technologies to support a transition to a low-carbon (fossil-fuel-free) economy. Initiatives include the 2020 European Green Deal,[1] the Renewable Energy Directive,[2] the Energy Efficiency Directive,[3] the Circular Economy Action Plan,[4] the Biodiversity Strategy for 2030,[5] and the New European Bauhaus.[6] All of these initiatives decenter industrial manufacturing as the driver of human development while establishing new principles for sustainable development. Although significant progress has been made, with the growth of renewable energy and clean technologies now being more affordable, a different paradigm for human development necessitates a vision of how we can live together.

In this context, cities have proven excellent sites for addressing the climate emergency through both top-down and bottom-up approaches. From a top-down perspective, city officials like mayors can help reduce emissions by implementing technologies that offset industrial emissions and adapt to anticipated impacts (e.g., investing in flood defenses). Within this context, the concept of sustainable architecture has gained recognition as a key strategy for creating livable, resilient cities that can adapt to climate change. It has been widely adopted by architects, planners, developers, and governments around the world. The concept is now an integral part of many building codes and regulations, incorporated into a wide range of building and planning projects, from individual homes to large-scale developments.

Sustainable architecture has also been incorporated into a range of other fields, such as urban design, transportation planning, and landscape architecture. This integration creates a holistic approach to sustainable city-making and is evolving in response to new challenges. For example, the use of digital tools and data analysis is becoming increasingly important in sustainable architecture as a part of a "smart" city initiative. Architects and planners seek to better understand the environmental impacts of their designs through data collection, allowing them to optimize their building systems rationally. At the heart of sustainable architecture is a focus on the building itself, with the aim to reduce its negative environmental performance. This goal is achieved through various strategies, including increasing energy efficiency, managing water responsibly, reducing waste, and using local materials. The ultimate objective is to achieve net-zero impact, where buildings produce as much energy as they consume over a specific period, typically a year.[7] Sustainable buildings, therefore, strive to minimize their carbon footprint through engineering and construction practices that have as little damaging effect

[1] The European Green Deal is a comprehensive plan for Europe to become the world's first climate-neutral continent by 2050. The plan outlines a range of measures to reduce greenhouse gas emissions, promote the use of renewable energy, and protect biodiversity.

[2] The Renewable Energy Directive sets targets for renewable energy use in the EU, and it requires member states to increase the share of renewable energy in their total energy consumption.

[3] The Energy Efficiency Directive requires member states to adopt energy efficiency measures, including improving the energy efficiency of buildings, appliances, and vehicles.

[4] The Circular Economy Action Plan outlines a range of measures to promote the circular economy, which seeks to keep resources in use for as long as possible and reduce waste.

[5] The Biodiversity Strategy sets out the EU's commitment to halting the loss of biodiversity and the degradation of ecosystems by 2030.

[6] The New European Bauhaus is a creative and interdisciplinary initiative that connects the European Green Deal to our living spaces and experiences.

[7] An example of a net zero building is the Bullitt Center (https://bullittcenter.org/) in Seattle, Washington, USA. The six-story commercial office building was designed and built to meet the rigorous standards of the Living Building Challenge. It features a triple-paned windows, high-efficiency insulation, and a building management system that optimizes heating, cooling, and lighting. To generate its own energy, the building has a large array of photovoltaic panels on its roof, providing all the energy the building needs. Additionally, it collects rainwater and treats it for reuse, utilizing a composting toilet system that eliminates the need for a traditional sewer connection.

on the environment as possible. However, it is important to note that sustainable buildings do not aim to contribute positively to the environment; their essence lies in risk and impact reduction.

4. Beyond sustainability

Upon reaching critical climate tipping points such as the collapse of Greenland's ice cap (resulting in significant sea level rises), the disruption of the Gulf Stream currents in the North Atlantic (leading to altered weather patterns), the melting of carbon-rich permafrost (resulting in methane release), and the destabilization of the Amazon rainforest (McKay *et al*., 2022), a conservative approach to altering the performance of building impacts will prove insufficient in addressing the sequelae of the climate emergency. The dominant industrial view of human development, however, is being challenged by the advent of *socio-technical systems* that offer limits to growth for a planet seen as a pool of finite resources and an ever-expanding population. In contrast, *socio-ecological systems* based on the Gaia hypothesis consider the planet as a self-regulating organism, while R. Buckminster Fuller's notion of Spaceship Earth regards the planet as a *closed-loop system* of material, energy, and information flows. These alternative perspectives pursue distinct objectives compared to the conventional focus on improving a company's bottom line. Instead, they introduce the *Triple Bottom Line*, where economic, social, and environmental value creation is harmonized. This approach ensures that planetary *health and societal well-being* create net positive value across multiple stakeholder levels, and *material creativity* decreases economic throughput by emphasizing value over volume. To implement these transformative changes, dominant design approaches embrace new concepts such as the *sustainable humansphere*. This framework aligns design with human needs within planetary boundaries. Additionally, the *circular Technosphere* integrates design into the technical cycle and material productivity, while the *regenerative biosphere* focuses on designing for biological cycles and ecosystem regeneration. Together, these approaches bring about changes for sustainable, circular, and regenerative practices (Figure 1) (Konietzko *et al*., 2023).

Despite the widespread adoption of such sustainable solutions, global carbon emissions have been rising. According to data from the Global Carbon Project, global carbon dioxide emissions reached a record high in 2019, and while there was a slight decrease in 2020 due to the COVID-19 pandemic, emissions are expected to return to their pre-pandemic levels (Candell *et al*., 2022). *Regenerative architecture*, therefore, distinguishes itself from sustainable architecture and its industries through the dimensions of time and the transformational capabilities of matter. It exceeds the ambitions of sustainable buildings through investments in the natural realm judiciously, making efficient use of resource streams (energy and material) while also repairing and restoring the natural systems that support our communities. The resulting buildings entangle human development with ecosystems

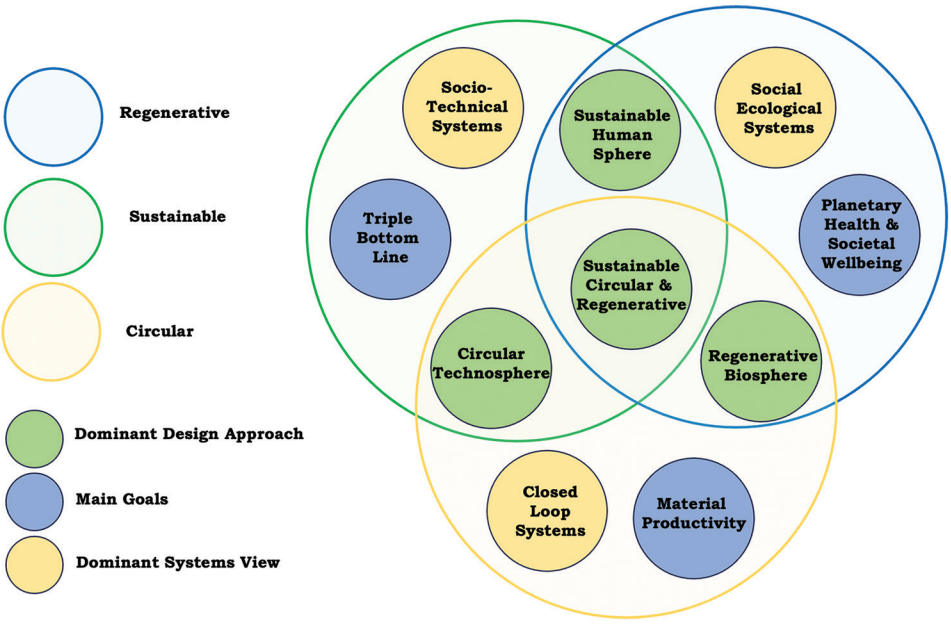

Figure 1. The position of regenerative practices and their overlaps with broader narratives related to sustainable and circular concepts, adapted from Konietzko *et al*., 2023

through cutting-edge advancements in various domains, encompassing closed-loop resource systems (Kallipolitti, 2018), biodesign (Myers & Antonelli, 2014),[8] applications of bio-positive materials, composting, cultivation of cryptogenic crusts on building surfaces, precision gardening, and agriculture. By actively enhancing, bioremediating, and revitalizing the living environment, these structures also facilitate the growth of tiny urban forests,[9] thereby aiding in the rewilding of urban settings, enriching soils to support plant and wildlife habitats, and nurturing regenerative human cultures (Wahl, 2021). A regenerative architectural practice aims to develop tools and strategies based on critical socio-ecological choices that stimulate an ecosystems-sensitive building culture, using localized ecological design and innovative engineering practices. The goal is to generate buildings that are durable, robust, and capable of accommodating multiple uses. By establishing a life-promoting economy of material exchange at the base of human settlement, regenerative buildings propose to restore environmental health, rebuild resources, and create the foundations of a resilient, self-sustaining, and productive built environment that gives back more to nature than it takes.

5. Characterizing Regenerative Architecture

The term "regenerative" is increasingly adopted by architectural practices that uphold a growing awareness and concern for the environment and the impact of human activities on the planet (Arup, 2023; Gattupalli, 2022). However, the indiscriminate use of the term may also be a form of *greenwashing,* reducing it to little more than a slogan that makes exaggerated claims about environmental benefits. These indiscriminate practices mislead target audiences, undermining their ability to make informed choices and harming legitimate advances that are making a significant impact. Presently, the concept is not limited to any distinctive building style, building technology, esthetics, or geographical region, and there are no universally agreed-upon exemplars of existing regenerative buildings, given the field's position at the cutting edge of research in the practice of the built environment.

Since the lens through which "regenerative" is examined applies to the living realm, it is important to recognize that different cultures have varying views on nature. For example, some view nature as a resource to be exploited for human benefit (the European Enlightenment), while others regard it as a sacred and interconnected system (most traditional cultures) that should be respected and protected. Shaped by our cultural values, beliefs, traditions, history, economy, and level of technological development, adopters of the term "regenerative" are likely to have very different views on environmental issues such as conservation, resource management, and the use of natural resources.

Ongoing research largely originates from industrialized societies and effectively aims to extend established knowledge frameworks that enable decisions to be made regarding the choice of materials and construction, with a preference for context-specific low-tech solutions that simultaneously have robust and resilient high-performance outcomes. Some of the most regenerative buildings, however, predate modernity and are traditionally rooted in the local culture and environment, designed and built to meet specific environmental and cultural contexts. One of the best examples of humanity's symbiotic relationship with nature is the Cappadocia caves in Turkey, built by early Christians during the Byzantine era, who were persecuted for their faith. The city's inhabitants used the network of caves to protect themselves from persecution by Muslim Arabs during the Arab-Byzantine Wars between 780 and 1180. Extending eight levels underground, the city has 30 major water tunnels, comprehensive living quarters, stables for horses, and facilities for making grape juice, cooking, drainage, plumbing, and linseed presses for producing lamp oil to light the underground. These dwellings evolved without any central planning and were in use during the 20th century for those fleeing persecution by the Ottoman Empire (Yildiz, 2015). Following the population exchange between Greece and Turkey in 1923, the underground cities were abandoned. They were rediscovered in 1963 when construction workers were demolishing low-income homes and were granted United Nations Educational, Scientific and Cultural Organization World Heritage status in 1985 (Pinkowski, 2015). This city can be considered a regenerative structure as it has used only naturally available materials supported by minimally invasive utilities, which have made the underground world inhabitable for many people for an extended duration that exceeds many lifetimes.

Regenerative design principles also apply to modern or contemporary buildings when – beyond their judicious use of resources – they contribute positively to the local environment and community. This involves embodying a novel architectural form-vocabulary that begins with existing construction methods and materials. Such an approach investigates the relationship

[8] Biodesign refers to a design approach that draws inspiration from and mimics the processes and systems found in nature. It is an interdisciplinary field that encompasses architecture, engineering, biology, and other fields.

[9] The tiny forest method was developed by the Japanese botanist Akira Miyawaki, drawing inspiration from nature's ecosystems to create dense and diverse pioneer forests within 20–30 years.

between materialized form and its flexibility and adaptability in programs for present and future users and the environment. Ultimately, in a Western context, regenerative architecture strives to enrich architectural discourse and practice by initiating a qualitative and creative interdisciplinary design process.

6. Regenerative architecture is not a panacea

The term "regenerative" should never be used uncritically. While it provides a useful lens for examining the limits of sustainable practice and moving beyond them to identify processes or practices that promote healing, renewal, or restoration of the environment to a better or more original condition through a process of improvement or revitalization of nature, it is inseparable from a more idealistic or visionary dimension. Etymologically, "regenerative" is derived from the word *regeneratus*, the past participle of the Latin is *regenerare,* i.e., *re-* means "again," and *generare* is to "bring forth, beget, produce," which is also related to *genus* – meaning "race, kind." Overall, it implies to "bring something forth again." In that sense, the term "regenerative" implies a future society or state of the world where systems and processes are designed and operated in ways that possess fundamentally utopian elements that indicate a trajectory that is significantly better than the present.

In practice, while such utopian projects are inspirational, they are not implementable since not all members of society will agree on every aspect of the development, so their realization is impossible to achieve. Utopian visions are, however, useful when considered judiciously in striving toward a common ideal by providing a coherent vision of possibility. For agreements to be reached that prioritize global environmental concerns over national interests requires a conceptual cooperative framework that transcends national borders and acts as a system for developing environmental policies and agreements that ultimately result in significant overall improvements in how people live. However, environmentalism also has a complex, well-recognized relationship with nationalism, where utopian ideals become obligations that vary according to political, social, and cultural contexts (Posocco & Watson, 2022; Segers & Weisskircher, 2022). Extremist ideologies often use environmental rhetoric to promote a nostalgic vision of the past and develop a romanticized relationship with nature that looks to an idealized or "pure" state of natural affairs (Forchtner, 2020; Hughes *et al*., 2022). This may be expressed through the preservation of natural landscapes, upholding traditional rural lifestyles, and celebrating a perceived connection with the land. This utopian green ideology is also a call to arms for protecting certain territories and national resources against *invasions* (Segers & Weisskircher, 2022). Such environmental views are often inconsistent with the realities of modern ecological problems, where the distrust of science and experts also results in opposition to government intervention and regulation should they contradict the idealized vision of the natural world (Delft, 2017).

Climate change denial by extremist groups may also be motivated by political or economic interests, such as those of the fossil fuel industry, which fund climate change denial campaigns from all aspects of the political spectrum to resist the social and economic changes implicit in green energy developments (Lockwood, 2018). In this manner, the etymological root of "regenerative" that stems from *genus* ("race, kind") is particularly attractive to extremist political groups in the advancement of nativist ideological concepts, both as propaganda and in parliaments. Infamously, mid-twentieth-century German National Socialism (Nazis) took their nationalist ideology to an extreme, using the term "degenerate"[10] to describe certain groups of people, such as Jews, Romas, homosexuals, and people with disabilities, who were forcibly isolated, persecuted, and murdered in concentration camps to "cleanse" the German population of their perceived racial impurities. In a contemporary context, far-right subcultures such as eco-fascism are also imbued with white superiority and ideas of racial purity, regarding migration and multiculturalism as a source of "parasites" that contaminate the purity of the established natural order and are used to justify acts of extreme violence (Campion, 2021; Dyett & Thomas, 2019).

7. Post-humanity and regenerative architecture

The most extreme view of regenerative architecture, viewed through the lenses of new materialism[11] and post-humanism, has the potential to conflate the natural and constructed worlds, challenging established notions of the natural order of living things. Inhabiting a liminal zone between life and non-life, organism and ecology, mind and body, technology and nature, art and science, the liveliest expressions of regenerative architecture acquire the status

[10] Regeneration's counterpoint "degenerate" implies something is below a normal or desirable level and often refers to physical or moral qualities.

[11] New Materialism is a philosophical and cultural movement that emerged in the early 21st century, challenging traditional understandings of materiality and the relationship between matter, objects, and humans. It recognizes that matter possesses agency and emphasizes the mutually shaping and interdependent relationships between humans and non-human entities.

of beings that *actively construct the reality in which they are immersed and* challenge the anthropocentric authority of the technologies from which they are built (Teubner, 2006; Gellers, 2021). This agency results in the formation of a new type of body – *the architectural cyborg* – that, in its most radical context, may even embody a new kind of nature. Forged by a creaturing process that invites us to relate to constructed "beings," regenerative architectures may emerge as "living" entities – midwifed into existence by *Homo sapiens*. Similar to the origin of natural creatures, the deep ontology of architectural cyborgs arises from the primordial relationship between life (organic) and rocks (mineral). The artificial distinction made between the contradictory nature of their building blocks composed of organic (life-forms) and inorganic substrates (minerals, hardware, electronics) and is imposed by human culture, regarded as "crucial boundary breakdowns" of the contemporary world – between human and animal, between animal-human (organism) and machine, and between the physical and the non-physical (Haraway, 1991, p. 293–294).

The architectural cyborg of regenerative architecture is, however, a coherent, diffuse, and decentralized structure whose interacting material ecologies possess properties that are other than the sum of its individual components, thus exceeding the original human design. Becoming more than a machine through its material ecologies, the architectural cyborg metabolizes feedstock (organic wastes) in an ongoing metabolic exchange between the subject (biofilm+hardware+software) and the world (feedstock, temperature, pH, etc.). Possessing an inherent vitality, the architectural cyborg demonstrates an embodied, environmental intelligence that emerges from countless biochemical reactions acting locally throughout its body, ultimately manifested through its relationship with "us." When empathizing with the architectural cyborg's inner self and contemplating what the building may be thinking or feeling, it is worth remembering that its hardware was originally designed to optimize conditions for the cyborg to become animate and thrive. The architectural cyborg is not a beast of burden. While the choreography of its environment is designed by humans, the dynamic agents that co-constitute its active substance will simply not perform its vital work if its environment conditions are not conducive for a *good cyborgian life*.

An animate regenerative architecture is overseen by software, nourished by an *invisible hand* (feedstock protocol, local ecosystems, microbes), and cleansed by hardware (electrodes, hygiene rituals). Consequently, it is likely to exist within the upper layers of Maslow's hierarchy of needs, with all its basic needs (physiological, safety) well attended to. The architectural cyborg "might" now seek belonging and love, find self-worth, contemplate issues, consider notions of beauty, self-actualize, and strive for transcendence. Perhaps it harbors an idea of its own gods. Perhaps the animated building is not just an "it" (a single entity) but a "we" (comprising multiple agentized loci) – or perhaps both! Of course, these are human concepts projected onto a structure designed to promote life through and around it, but the possibility that such a construction has an existence beyond mere materiality with selfish concerns (implied in Neo-Darwinist narratives about the *selfish gene* with its relentless self-propagative drive) is worth considering.

Regenerative architecture's fundamental *monstrosity* – that resists easy classification – provokes new concepts of organisms, buildings, intelligence, and our deep environmental entanglements, underscoring the exquisite complexity of our reality. Characterizing what such an entity might be requires new narratives. For example, the following excerpt is from *Invisible Ecologies*, which imagines the city of Venice as a living entity – an urban-scale regenerative architecture:

> "Like all my kin, I have no eyes, ears, tongue, skin, or lips to witness and narrate events. I am a place, not a mechanism, an aspect of nature that is molded and remolded by the incessant flow and exchange of matter. Descended from ancient families of giant bodies that encircle the earth, sea, and air, we uphold souls, passions, and legacies. Shapeshifters all, we adopt different forms that are appropriate to the surroundings. Simultaneously "one" and many mutually interdependent agents, we do not possess what you might describe as a well-circumscribed brain, but *I* am – *We* are sentient. Embodying the tensions forged between all kinds of lively things, our abilities are not extraordinary, but we claim our rights to be regarded with compassion, fairness, and mutual respect. Simply, I am asking you to "see" me – "us" – as a different *kind of person*. Our terrains are yours, too, and through them, we share a deep history and kinship with the community of life." (Armstrong, 2018, p. 11)

8. Toward a pluralistic view of regenerative architecture

This special issue of the *Journal of Chinese Architecture and Urbanism* is dedicated to regenerative architecture as a way of developing a socially responsible, environmentally considerate, and esthetically inspiring framework for exploring and interrogating the emerging disciplines. Each contributor discusses technological developments, cutting-edge concepts, novel esthetics, narrative-making,

and being-in-the-world in ways that explore teaching practices, theories, and models of innovation that not only include but also go beyond the private-public axis. The featured work expresses different values pertaining to our emerging ecological era, where articles discuss prototypes, pilots, practices, and cultural demonstrators that address the significant challenges of climate change. They activate concepts, methods, and innovation ecosystems that interrogate established approaches within the practice, research, and teaching of architectural agendas. These essays collectively form a snapshot of what regenerative architecture currently means, providing an overview of its promises, limitations, and contradictions. The contributions, however, are not exhaustive, and the readers are also invited to explore what the emerging discipline could be. Collectively, these contributions encourage dialogue across cultural divides, establishing a critical relationship with the concept of regeneration that, on a global scale, links East to West, North to South. They provide a range of tools, principles, and practices that help catalyze a new relationship with nature, the environment, and our planet.

In *Microbial Technologies: Toward a Regenerative Architecture*, I delve into applications of microbial technologies in realizing an infrastructure for regenerative architecture, drawing on collaborative projects I have coordinated and designed. These tiny agents, which are not visible to the naked eye, have, nonetheless, established the base of the biosphere. Drawing on advances in molecular science and biotechnology, it is now possible to establish architectural systems that can enliven the built environment and its territories through cyborgian couplings between digital and biological interfaces, establishing a new relationship between waste, energy, and human inhabitation via microbial "life." I further consider the implications of installing and activating these cyborg infrastructures in *Energy Manifesto: Principles for Regenerative Architecture, Arts, and Design* to position regenerative energy narratives as integral to engaging with a "life force" that flows through all living bodies, rather than commodifying system outputs that continue to valorize unlimited consumption.

Victor de Lorenzo and Miguel de la Ossa examine the creative tension between technology-driven design and biological processes through advances in synthetic biology. In their essay, *Synthetic Biology Enabling a Shift from Domination to Partnership with Natural Space*, they explore the potential of synthetic biology to redesign biological properties à la carte, including large-scale developmental programs, in ways that unlock the opportunity to rethink our interplay with space as a win-win conversation with the natural environment. Exemplifying the radical potential of this approach, they introduce the concept of the Biosynthetic Towers Project, where complex buildings are designed and erected entirely through biological programming rather than standard construction technology.

Xiao Wang and Claudia Pasquero integrate biological and artificial intelligence in *Ecological Thinking in Regenerative Architecture: Relevance of Abduction in ecoLogicStudio's DeepGreen Research Project* to explore potentially similar patterns using Gregory Bateson's notion of "abduction" within the urban landscapes and infrastructures in three cities: Guatemala City (Guatemala), Mogadishu (Somalia), and Vranje (Serbia). By juxtaposing Western and Chinese methodologies, they seek the creation of new dialogic spaces that foster innovation across cultures, potentially leading to an integrated, yet diverse, regenerative approach.

In *Bioregenerative Algal Architectures*, Ramandeep Shergill further explores how algae act as a platform for resource circularity in space and how this translates into the urban condition. In this context, regenerative architecture is established through bioregenerative life support strategies that engage with various microalgae species as a platform for humans to become multiplanetary species.

In *The Seductive Choreography of Space: Learning Regenerative Design Strategies from (Cyborg) Flowers* by Rachel Armstrong, Anna Vershinina, and Rolf Hughes, further lessons from the creativity and organization of plants are discussed as a way to inform the qualities of our living spaces and cities. The authors, employing a design-led research approach, highlight the often-hidden ethical considerations in designing the "living" choreography of space. Important themes such as alternative (non-human) sensory apparatuses, choreographies for ecosystems, and biological strategies that can be adaptable by regenerative architects are explored. These principles and agendas are exemplified in the artistic artifact XENO (exhibited at CIVA, Brussels, 2023), providing a thought experiment that explores the diversity, complexity, and ethics of energy systems associated with regenerative designs.

In the essay *From Burrow to Bungalow: Storytelling in Regenerative Architecture,* Rolf Hughes argues for the serious consideration of storytelling in regenerative architecture, highlighting its unique capacity to model the complexities of relations between humans, the built environment, and the natural world. Exploring the potential role of storytelling in creating a more sustainable and resilient future, he cites relevant narratives from a range of regions and cultures. Hughes takes a close look at Franz Kafka's *The Burrow* from a regenerative architecture perspective. Making a strategic switch to *showing rather*

than telling how stories develop through *re-telling other stories* (part of the *regenerative* characteristic of narrative itself), he offers a compelling architectural adaptation of Kafka's story. This imaginative adaptation explores core themes within *regenerative architecture* debates.

The nature of interactions between humans and nature is explored by Breg Horemans in *Gestures for Interdependence: Expanding Regenerative Design through Spatial Dramaturgies for the Unseen, the Unheard, and the Unfelt*. Situated in the growing field of spatial dramaturgy, he examines collaborations between the architect and more-than-human entities. Based on fieldwork in Lithuania and the Netherlands, Horemans examines the contribution of esthetic experiences to attitudes toward regenerative spatial design through embodied experiences, scoring, cocreation, and written reflections. The synthesis of these exchanges is examined through spatial dramaturgical developments expressed as prototyping "gestures of interdependence," revealing the agency of the unseen and the unheard in spatial design processes. This approach enables us to co-design *along with* the generative forces of nature.

9. Discussion

The diverse community of perspectives in this special issue allows the notion of regenerative architecture to become a "living" concept rather than a fossilized practice constrained by form, esthetics, and material expression. Each contributor challenges fundamental assumptions at the heart of the production of space, the role of the architect, the human, the increasingly vital nature of technological platforms, and the relentless creativity of the natural realm while considering the propositional dimensions through their concrete or built nature. The perspectival frictions between these positions are the lifeblood of architectural design. Not all architectures are buildable, but they initiate spatial, material, and esthetic qualities that engage bodies, materials, and environments as mediating fabrics. Between these polar aspects of architecture, architects must constantly translate their ideas and designs into tangible and constructible forms, where methodologies such as Horemans and Hughes become critical strategies for reading, translocations, and translation. The desired (mis)understanding of what a structure can be is an active discourse between what is possible and what is buildable, often evolving through a process of iteration and refinement that comprises design-led research methodologies. Developing, testing, and refining concepts through various models, prototypes, and simulations, the final work must also consider a wide range of constraints and requirements, including building codes and regulations, construction technologies and materials, and the character of the site and surrounding environment. Architecture must also consider the needs and desires of its intended users, as well as the social and cultural context in which the building will exist. This often requires architects to work closely with stakeholders such as clients, engineers, contractors, ecosystems, and local communities to ensure that their designs meet the needs and goals of all parties involved. Overall, the balance between architecture's propositional and concrete natures is a complex and ongoing process that requires the integration of a wide range of knowledge and skills, including design, engineering, construction, and ecosystem design, alongside cultural and social engagement.

10. Conclusion

This special issue of the *Journal of Chinese Architecture and Urbanism* provides the first set of collected essays on the emerging discipline of regenerative architecture. Exploring its multifaceted dimensions and transformative potential, the contributions mirror the generative diversity of life itself, positioning Regenerative Architecture as a dynamic and evolving concept rather than a static practice bound by conventional norms of form, esthetics, and materiality. Heralding an era of change, regenerative architects are establishing the potential of paradigm-shifting building technologies that are cultured and grown, rather than mined, burned, or extracted, to fundamentally alter the impact of the built environment on our living world. This shift aims to reach new levels of sustainability and resilience against climate change.

The contributions within this collection foster rich dialogs and provoke perspectival frictions that breathe new life in architectural design. They achieve this by challenging core assumptions concerning the creation of space, the architect's role, human interactions with technology, and our relationship with the natural environment. It is important to recognize that not all of these architectural ideas are immediately buildable; they often initiate explorations of spatial, material, and esthetic qualities that engage with the fabric of bodies, materials, and environments. Architects, however, are continually turning their visions into tangible and constructible forms, a process that necessitates methodologies like those proposed by Hughes, Wang, Pasquero, Shergill, and Horemans for reading, translocating, and translating new concepts into frameworks of thought and practice for reorganizing systems, hierarchies, and infrastructures – a practice on which the built environment is founded.

The tension between what is possible and what is buildable stands as a central discourse in architecture, evolving through iterative and refinement processes guided by design-led research methodologies such as those

proposed by Shergill, Armstrong, Hughes, Vershinina, Pasquero, Wang, and Horemans. Architects must navigate an intricate web of constraints, from building codes and regulations to construction technologies, materials, and environmental considerations, which are in themselves subject to change, as observed by Armstrong, DeLorenzo, and de la Ossa. Moreover, architects must be attuned to the diverse needs and aspirations of end-users and the broader social and cultural context within which their creations will exist. Collaboration with stakeholders, including clients, engineers, contractors, and local communities, is essential to ensure that architectural designs align with the goals and values of all involved parties.

Representing a powerful force for positive change in the built environment, regenerative architecture also encourages architects to embrace innovation, challenge conventions, and forge new paths toward sustainable, resilient, and life-promoting spaces. The journey to establish the right balance between propositional and concrete aspects of architecture is complex and ongoing, demanding a synthesis of diverse knowledge and skills. This holistic approach encompasses design excellence, engineering acumen, construction expertise, and cultural and social awareness. As regenerative architecture continues to be explored and refined through the broader practice of the built environment, it holds the potential to usher in a more sustainable and life-centered future for both humanity and the natural world.

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ACCSCIENCE PUBLISHING

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ORIGINAL ARTICLE

Exploring the spatial attributes of streets in Lu Xun's hometown of Shaoxing, China, through image semantic segmentation

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(This article belongs to the *Special Issue: Advanced Technologies and Practices in Built Environment and Cultural Heritage*)

Abstract

Image semantic segmentation, a deep learning algorithm, enables the recognition of pixel collections that form distinct categories, allowing for the identification of vehicles, pedestrians, traffic signs, pavement, and other road features. In urban and architectural design domains, image semantic segmentation and related techniques empower practitioners and researchers to efficiently analyze the distribution of public spaces. This application facilitates a better understanding of how people interact with urban environments, ultimately improving the design of functional and inviting spaces. This paper presents an analysis of images of different streets within the Lu Xun Heritage Area in Shaoxing, Zhejiang Province, China, which were obtained through onsite photography. The images were sampled, segmented, and compared to assess the spatial characteristics of distinct street types. A self-trained semantic segmentation model based on the Cityscapes dataset and the PaddlePaddle framework was employed to statistically analyze space variations across various dimensions. This analysis contributes to a better understanding of historical street structure and provides insights into the integration of artificial intelligence in urban planning and design.

Keywords: Lu Xun's hometown; Semantic segmentation; Street space; Historic streets; Vibrant streets; Shaoxing, China

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1. Introduction

Semantic segmentation has found extensive application in the conservation and digital reconstruction of historical sites and building blocks, as well as in the decision-making processes of urban and rural planning and design (Picon & Zhou, 2019). This advanced computer vision technology employs machine learning methods to partition various areas in street view images into different categories. It acquires semantic information for each element, counts the number and distribution of each element, and facilitates valuable evaluations of the image.

In everyday life, streets are commonly encountered and can be broadly categorized into modern streets and historic streets. Modern streets encompass main thoroughfares in cities or communities, bustling with commercial, social, and cultural activities.

These streets feature an array of restaurants, shops, and entertainment venues, attracting people for shopping, socializing, and experiencing urban life (Hui, 2021). In contrast, historic streets hold significant historical, cultural, or architectural values. They often preserve ancient buildings, street scenes, and cultural heritage, retaining architectural styles, layouts, and streetscapes that bear witness to the historical evolution of cities or regions. Historic streets attract tourists and residents to explore the cultural background of the past, offering different spatial atmospheres and distinct spatial experiences. These areas are conceived in the two street types, influenced by a range of factors such as the distribution and proportion of different elements within the streets. Semantic segmentation technology can conveniently and intuitively obtain various information about each element in the image from the image level, including proportion, distribution status, and mutual connections. The current popular application of semantic segmentation involves the recognition of building outlines in satellite images, followed by tasks such as 3D reconstruction and area estimation statistics. However, there is currently a limited quantity of analysis, and the existing studies are somewhat superficial in exploring the semantic segmentation-based spatial quality aspects of historic neighborhoods (Zeng *et al*., 2021; Cao, 2021; Cheng, 2022).

Lu Xun's hometown is located in Shaoxing, Zhejiang Province, China. This unique historical and cultural area, being the birthplace of Lu Xun – a prominent figure in modern Chinese literature – is rich in cultural heritage and historical memories. Renowned for its distinctive historical districts, traditional architecture, and intriguing alleyways, this locale provides a unique backdrop to Lu Xun's formative years. Notable sites in Lu Xun's hometown include Shaoxing Lu Xun Residence, *Baicaoyuan* (Hundred Grass Garden), *Sanwei Shuwu* (Three Flavor Study), Lu Xun's Ancestral Residence, Tugu Temple, Changqing Temple, Lu Xun's Literary Theme Park, and Shaoxing Lu Xun Memorial Hall (designed by Academician Cheng Taining), among many other cultural relics associated with Lu Xun (Fan, 2010).

As the city undergoes development and modernization, the spatial environment of Lu Xun's hometown is also experiencing changes. Given Mr. Lu Xun's significant role in modern Chinese history, preservation and research efforts concerning his former residence have been systematically carried out since the mid-20th century. Emphasis has been placed on the restoration and renovation of his former residence, ancestral home, and school, along with the transformation of nearby ordinary dwellings. Additionally, a Lu Xun Memorial Hall, designed under the guidance of Academician Cheng Taining, has been constructed. Simultaneously, every effort has been made to retain the distinctive characteristics and imagery of the original area (Fan, 2010). Within the process of preserving and utilizing these cultural heritage sites, it becomes crucial to quantitatively assess and preserve the spatial vitality of Lu Xun's hometown (Fan, 2010). Traditional assessment methods such as mental maps and cognitive image analysis primarily involve qualitative analysis and struggle to comprehensively and accurately depict the unique value and spatial experience of Lu Xun's hometown (Zeng *et al*., 2021). Therefore, more advanced techniques are needed for precise analysis (Liu, 2021).

In this paper, image semantic segmentation is employed to quantitatively analyze the differences between historic streets and modern streets, providing a clearer representation on various dimensions. The paper commences with a comprehensive overview of semantic segmentation and its application in urban design, followed by data collection and pre-processing for applying semantic segmentation to street-view images of Lu Xun's hometown. Subsequent sections detail the training models and frameworks used for image processing through Python. This case study offers a comprehensive visual reproduction and analysis of the spatial characteristics and historical context of this cultural area in Lu Xun's hometown. Quantitative evaluation of the distribution and features of different elements in streetscapes enables a better understanding of the spatial conditions of various types of streets in Lu Xun's hometown. This, in turn, provides a scientific basis and decision-making support for its conservation and restoration efforts, as well as for similar heritage sites.

2. Methods

2.1. Basic concepts and approaches of semantic segmentation

Semantic segmentation is a task within the field of computer vision that aims to assign each pixel in an image to different semantic categories, achieving pixel-level segmentation of the image. The objective is to segment different objects and regions in the image and assign each pixel to its corresponding semantic category, including categories such as person, car, tree, and others. Common methods for semantic segmentation involve the use of convolutional neural networks (CNNs), which are deep learning models widely applied in image analysis tasks (Shi, 2022). Specifically, for tasks demanding pixel-level detail, computer programs such as fully convolutional networks proved effective (Deng *et al*., 2021; Fang *et al*., 2021). These networks excel at capturing local features and retaining spatial information, making them well suited for pixel-level classification (An, 2021; Cao, 2017; Dong, 2022).

2.2. Overview of semantic segmentation's applications in urban spaces

Semantic segmentation finds extensive applications in image processing, holding wide-ranging potential applications in urban spaces. Common fields of application encompass urban planning, traffic management, environmental monitoring, and cultural heritage preservation, among others. Currently, the overall application is undergoing rapid development with significant growth prospects. As computing power increases and algorithms undergo optimization, the role of semantic segmentation in urban planning and management is expected to become increasingly significant (Wang, 2020).

In a recent study conducted by Wang *et al.* (2022), the focus was directed toward damage detection in architectural façades, employing CNNs for dimensionality reduction and feature extraction from images, thereby facilitating content classification. Currently, two main methods for object detection prevail anchor-based segmentation and semantic segmentation. Meanwhile, Liu *et al.* (2022) emphasized the significance of high-resolution aerial image-based building extraction for urban planning and environmental management. They introduced ARC-Net, an efficient deep learning model featuring role-based access control, dilated convolutions, and multi-scale pyramid pooling, showcasing superior performance on INRIA and WHU datasets. This model, offering superior segmentation with reduced computational costs, proves highly effective for building extraction from high-resolution aerial images. In a related domain, Zhou *et al.* (2022) contributed by bridging the monitoring of building changes with economic development in rural planning areas. Their method integrated unmanned aerial vehicles (UAV) photogrammetry and deep learning, utilizing the Efficient Deep-wise Spatial Attention Network (EDSANet) for precise building extraction. The results exhibited high accuracy in rural building extraction and floor area estimation, suggesting potential applications in efficient village-level planning in China and beyond. In an earlier study, Chen and Jahanshahi (2017) explored traditional image processing techniques coupled with image segmentation for crack detection. Structural changes were detected by comparing images of structures at different time points, and crack indices were quantified through non-contact remote sensing crack detection methods. Finally, Lee *et al.* (2011) contributed to the field by developing a vision-based image capture robotic system designed for the automatic identification of crack sizes, utilizing digital image processing software.

The above studies exemplify practical applications of semantic segmentation, often accompanied by optimizations throughout the entire machine-learning process, including the underlying algorithms. Furthermore, several applications in construction personnel management, edge protection safety management, and construction site vehicle management are rooted in computer vision (Gao *et al.*, 2022; Gerhard *et al.*, 2018; Zhang *et al.*, 2021).

2.3. Data collection and pre-processing

2.3.1. Collection of street image data of Lu Xun's hometown

As depicted in Figures 1 and 2, Street 1 and Street 2 were selected for analysis, serving as examples of historic streets and modern streets, respectively. A handheld camera positioned at an approximate height of 1.7 m simulated a typical walking speed. Each street was recorded three times to facilitate subsequent averaging and error reduction during data processing.

2.3.2. Pre-processing of street image data in Lu Xun's hometown

(a) Denoising and color adjustment

Python was used to conduct initial video cropping for each segment of footage (Figures 3 and 4). A frame of the video

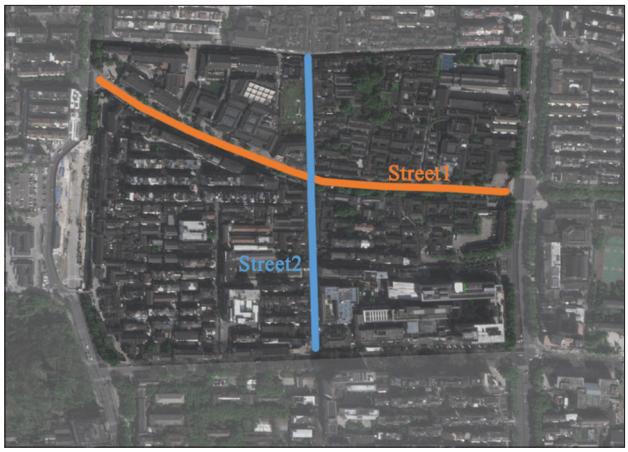

Figure 1. Satellite images of Lu Xun's hometown area, Shaoxing, Zhejiang province, China. Source: Drawing by the author

Figure 2. Block model of Lu Xun's hometown area, Shaoxing, Zhejiang province, China. Source: Drawing by the author

Figure 3. Partial image stitching of Street 1. Source: Images by the author

was captured and saved separately every 10 s. Subsequently, the captured frames underwent brightness adjustment and noise reduction to address instances of excessive darkness and noise, thereby facilitating the subsequent processing.

(b) Normalization

The resolution dimensions of the 279 images were obtained through the abovementioned process and normalized by Python.

2.4. Street scene analysis based on semantic segmentation

2.4.1. Selection of semantic segmentation model

The semantic segmentation process utilized a classic CNN model, ResNet-22, implemented through CUDA-accelerated computation, with the training framework facilitated by Baidu's PaddlePaddle. Cityscape trained the datasets using a series of high-resolution images encompassing various urban scenes, including roads, buildings, pedestrians, and others. The extensive dataset, consisting of thousands of high-precision annotated training images, was methodically divided into training, validation, and test sets. The accuracy of well-trained Cityscape images could reach up to 70% or even 80%.

2.4.2. Model network architecture and training process

Eight pre-defined labels were adopted in Cityscape, namely road, vegetation, building, sky, person, vehicle, wall, and sign.

2.4.3. Semantic segmentation and subsequent processing of street images of Lu Xun's hometown

The pre-processed street images from Lu Xun's hometown were incorporated into the abovementioned training dataset for semantic segmentation. This process resulted in the generation of segmented color block images. The results of semantic segmentation are exclusively affected by the proportion of different color block regions. To reduce computational workload, further normalization processing was applied to the color block images. During this process, the image resolution was compressed to facilitate pixel statistics.

2.4.4. Pixel-wise image analysis using Python

In this step, Python was utilized to scan images pixel by pixel, tallying and merging pixels belonging to various color groups. Statistical charts were subsequently generated based on the counting results. The results obtained from various dimensions were aggregated to calculate quantities, averages, variances, and other parameters, facilitating subsequent analysis (Figures 5 and 6).

2.5. Comparison and analysis of different street spatial features in Lu Xun's hometown

2.5.1. Spatial features of the historic street (Street 1) in Lu Xun's hometown

The distribution of various elements in historic streets is worthy of examination. As illustrated in Table 1, road

surfaces, buildings, and vegetation collectively dominate the visual proportions within the streetscapes of historic streets, accounting for 37.35%, 25.14%, and 16.78%, respectively.

When considering standard deviation, it becomes apparent that these three factors undergo substantial changes, indicating that the distribution of streets, buildings, and plants undergoes significant changes as individuals traverse these streets. This phenomenon may be attributed to the inclination of historic streets to retain the spatial design variability and alterations, ultimately striving to offer visitors a diverse spatial experience.

2.5.2. Spatial features of the modern street (Street 2) in Lu Xun's hometown

Diverse distributions of various elements characterize modern streets when compared to historic streets. As depicted in Table 2, the visual space within the streetscapes of modern streets is chiefly dominated by buildings and roads, which constitute the largest proportions at 44.26% and 26.14%, respectively – significantly surpassing other elements. People, vegetation, and the sky exhibit similar proportions. This situation suggests that, in modern streets, the predominant components shaping individuals' daily perceptions are the streets themselves and the buildings lining their sides.

Examining the standard deviation, it becomes evident that roads and buildings have higher standard deviations. This observation indicates that the visual sensory changes associated with these two elements during movement are relatively more pronounced compared to other elements. Consequently, the distribution continuity of roads and buildings appears weaker, while the distribution of other elements exhibits a more uniform pattern.

Table 1. Spatial characteristics of historic streets in Lu Xun's hometown

Element	N (Sum)	M (Mean)	Proportion	Σ (Standard deviation)
Road	2323166	48399	37.35%	109.55
Building	1563750	32578	25.14%	116.08
Person	359149	7482	5.77%	81.25
Transportation	78545	1636	1.26%	38.59
Vegetation	1043739	21745	16.78%	116.05
Wall	254123	5294	4.09%	52.84
Sky	455256	9485	7.32%	68.30
Traffic Sign	143072	2981	2.30%	46.08

Table 2. Spatial characteristics of modern streets in Lu Xun's hometown

Element	N (Sum)	M (Mean)	Proportion	Σ (Standard deviation)
Road	1524219	33872	26.14%	112.96
Building	2581022	57356	44.26%	121.15
Person	402311	8940	6.90%	75.94
Transportation	90648	2014	1.55%	39.02
Vegetation	422113	9380	7.24%	78.07
Wall	283589	6302	4.86%	65.16
Sky	409553	9101	7.02%	70.08
Traffic Sign	118545	2634	2.03%	48.42

2.5.3. Comparison of spatial characteristics and distribution of historic and modern streets in Lu Xun's hometown

Given the aforementioned data, conducting a comparison of the proportion and standard deviation of each element yielded interesting results.

(a) Descriptive statistics

Based on the metrics presented in Table 3 and Figures 7-9, it can be observed that the proportion of road surface in historic streets significantly surpasses that in modern streets, indicating a wider expanse of road surfaces in historic streets. On the other hand, the proportion of buildings in historic streets is notably lower than in modern streets. Moreover, the proportion of people in modern streets slightly exceeds that in historic streets, suggesting a higher level of human activity in modern streets under the specific sampling conditions of this study. The proportions of other elements, such as vehicles, walls, and signs, remain relatively low and stable, indicating a uniform and essential distribution of these objects across general streets. Notably, the proportional differences imply that historic streets emphasize traditional culture, natural environment, and greenery, contributing to a pleasant and comfortable spatial atmosphere. In contrast, modern streets feature more buildings and a denser population, prioritizing the fulfillment of daily life needs.

Moving on to Table 4 and Figures 10-12, which presents standard deviation comparisons of element distributions in historic and modern streets, it becomes apparent that, with the exception of people and vegetation, there is minimal variation in the standard deviations of other elements between the two types of streets. This observation indicates that these elements likely serve as integral components for individuals to engage with the urban space while walking along each street. The distribution difference in people in historic streets surpasses that in modern streets, possibly due to historic streets offering more areas for visitors to pause and explore, encouraging people to linger and rest,

Table 3. Proportion of various elements within historic streets and modern streets

Element	Historic street	Modern street
Road	37.35%	26.14%
Building	25.14%	44.26%
Person	5.77%	6.90%
Transportation	1.26%	1.55%
Vegetation	16.78%	7.24%
Wall	4.09%	4.86%
Sky	7.32%	7.02%
Traffic Sign	2.30%	2.03%

Table 4. Standard deviation of the distribution of each element within historic streets and modern streets

Element	Historic street	Modern street
Road	109.55	112.96
Building	116.08	121.15
Person	81.25	75.94
Transportation	38.59	39.02
Vegetation	116.05	78.07
Wall	52.84	65.16
Sky	68.30	70.08
Traffic Sign	46.08	48.42

resulting in greater distribution disparities. Conversely, the distribution of people in modern streets is relatively uniform. Turning to vegetation distribution, modern streets exhibit a notably uniform pattern compared to historic streets. This phenomenon might be attributed to the deliberate design of vegetation distribution in historic streets as part of scenic spots, utilizing clustering and grouping techniques to provide stronger guidance for visitors. In modern streets, vegetation arrangement is relatively more even, typically featuring evenly spaced solitary trees along the sidewalks, offering a continuous sensory experience.

(b) Distribution of change rate

Figures 13–28 depict the temporal distribution of various elements within historic and modern streets.

(i) Road

In Figure 13, the distribution trends in historic streets and modern streets are observed to be consistent, exhibiting fluctuating changes during the walking process. It indicates that both types of streets follow a pattern of enlarging their spatial features at the beginnings, ends, and midsections of the street. For a more visual representation, Figure 14 overlays road features on the actual site.

(ii) Building

In Figure 15, the distribution trends between historic streets and modern streets appear inconsistent and lack distinct characteristics. Building distribution is generally more pronounced in modern streets compared to historic streets. As previously mentioned, this disparity might be attributed to the higher density of residential and commercial buildings in modern streets, whereas historic streets tend to feature sparser and shorter buildings. For a more visual representation, Figure 16 overlays building features on the actual site.

(iii) Person

In Figure 17, the distribution of people in both historic streets and modern streets follows similar waveforms. However, it can be observed that in historic streets, there is a peak in the distribution of people near the entrance, gradually decreasing afterward. On the other hand, in modern streets, the waveform is smoother, indicating a more uniform distribution of people. This situation suggests that the spatial layout of modern streets is relatively homogeneous and consistent, while historic streets exhibit a richer and more diverse spatial arrangement. For a more visual representation, Figure 18 overlays person features on the actual site.

(iv) Transportation

In Figure 19, the distribution of vehicles in both historic streets and modern streets is generally consistent in both waveform and quantity. Additionally, the waveform closely aligns with the road dimension, indicating a positive correlation between the proportion of road surface and the number of vehicles. This characteristic holds true for both historic and modern streets. For a more visual representation, Figure 20 overlays transportation features on the actual site.

(v) Vegetation

In Figure 21, concerning vegetation distribution, historic streets exhibit significantly more fluctuation than modern streets. Notably, in historic streets, there is a substantial presence of vegetation near the entrances, with fewer plants in the midsections compared to modern streets. This pattern is likely because vegetation in historic streets tend to cluster around the vicinity of landmarks. On the other hand, vegetation distribution in modern streets is relatively even, lacking significant fluctuations. This situation is likely attributed to the even distribution of street trees. For a more visual representation, Figure 22 overlays vegetation features on the actual site.

(vi) Wall

In Figure 23, both historic streets and modern streets exhibit relatively gentle waveforms and lower quantities in the dimension of wall distribution. This condition indicates

Figure 4. Partial image stitching of Street 2. Source: Images by the author

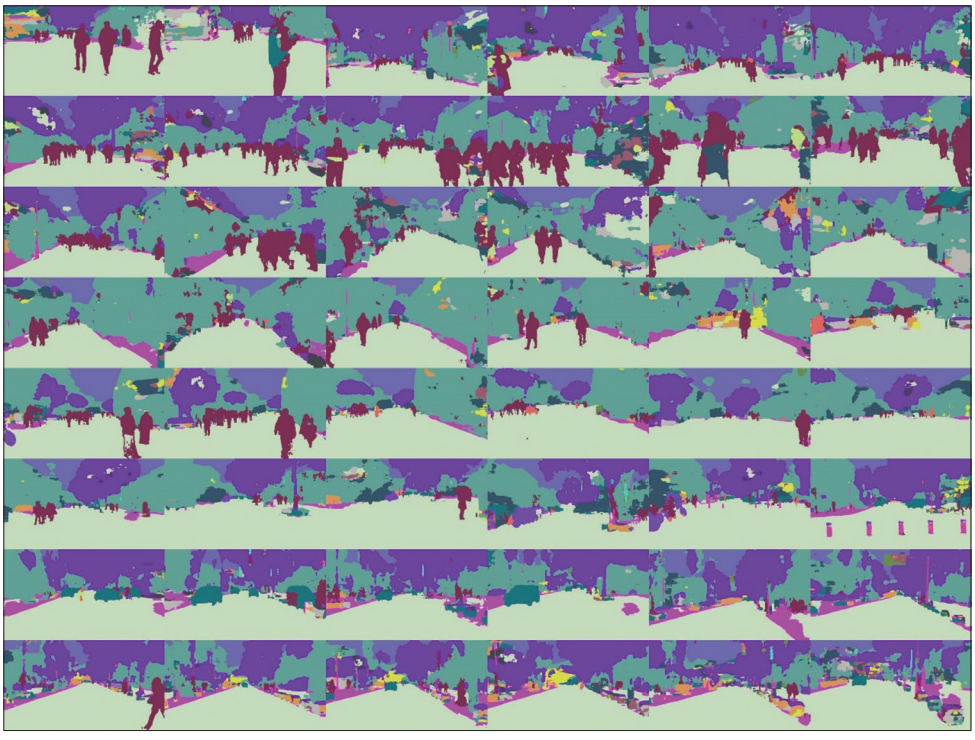

Figure 5. Partial pictures of historic street semantic segmentation results. Source: Images by the author

that the presence of walls holds lesser significance within the streets and does not exhibit prominent differences between the two types of streets. For a more visual representation, Figure 24 overlays wall features on the actual site.

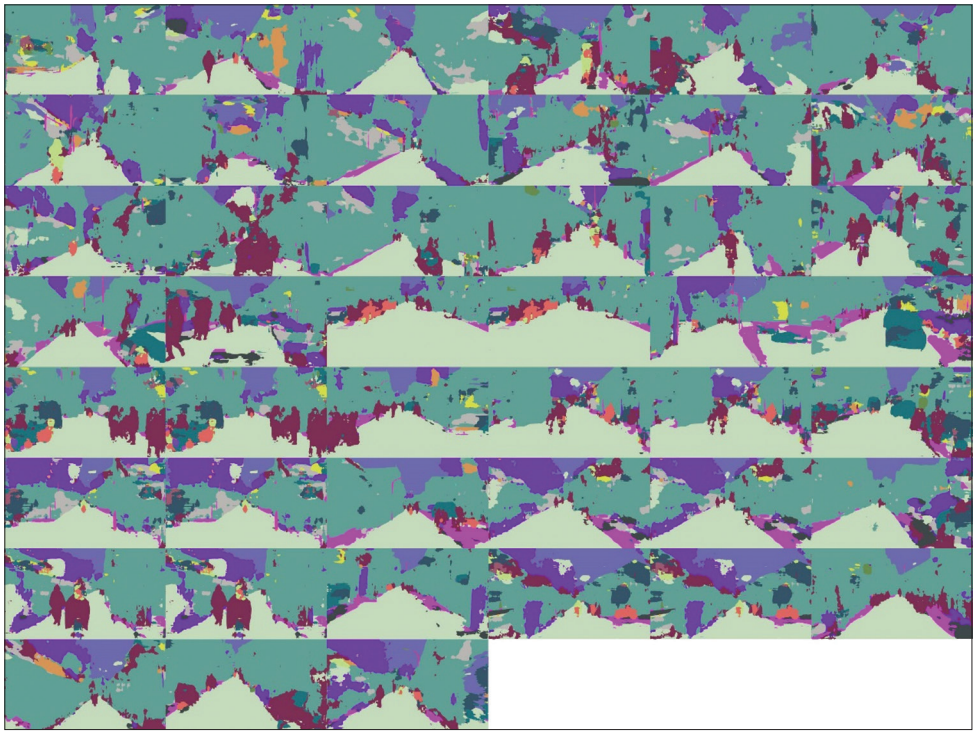

Figure 6. Partial pictures of modern streets semantic segmentation results. Source: Images by the author

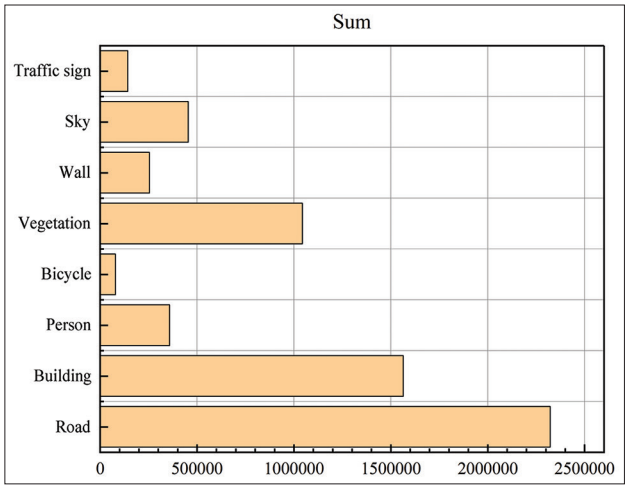

Figure 7. Total distribution of various elements in historic streets. Source: The author

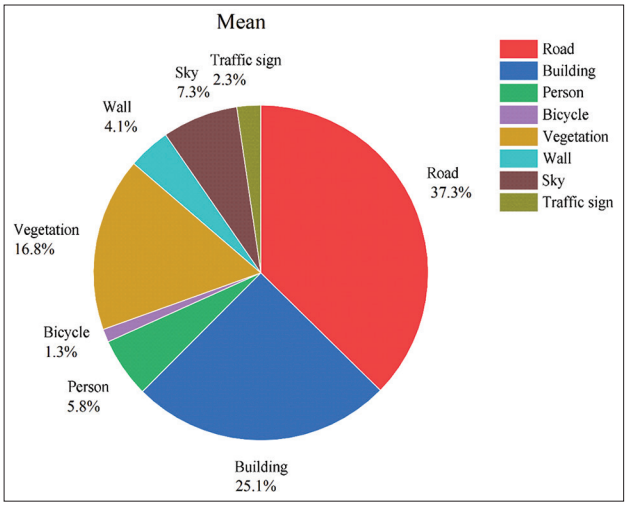

Figure 8. Average distribution of various elements in historic streets. Source: The author

(vii) Sky

In Figure 25, the sky often functions as the background and typically constitutes the residual part after the superposition of many other elements in the streets. From the graph, it can be observed that both historic streets and modern streets exhibit significant fluctuations in the sky dimension. While their waveforms differ, it is evident that the waveform in the sky dimension demonstrates a noticeable negative correlation with the waveform of vegetation. This finding indicates that the visibility of the sky while walking along the streets is markedly influenced by the presence of vegetation, and this effect appears consistent across street types. For a more visual representation, Figure 26 overlays sky features on the actual site.

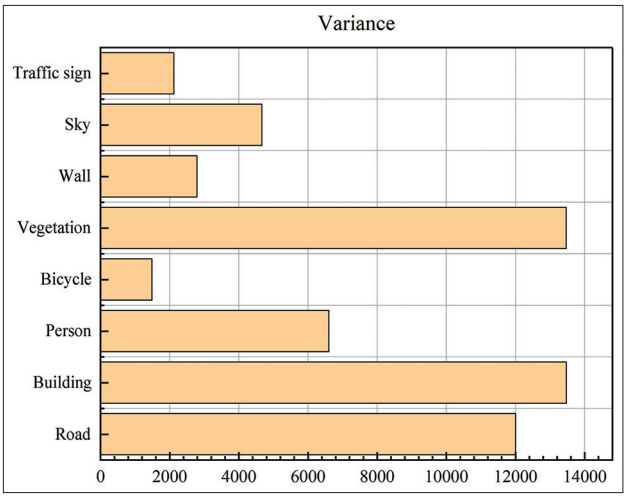

Figure 9. The distribution variance of various elements in historic streets. Source: The author

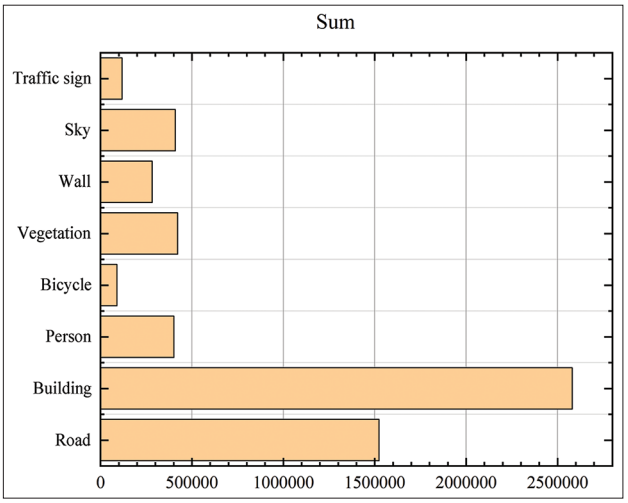

Figure 10. Total distribution of various elements in modern streets. Source: The author

(viii) Traffic sign

In Figure 27, signage, as an essential component of streets, plays a crucial role in guiding pedestrians. The waveform of this element presents differences between historic streets and modern streets. In historic streets, the proportion of signage exhibits a fluctuating upward trend. This trend could be related to the depth of the street: the deeper one ventures into the street, the more guidance is required, suggesting a decrease in street accessibility. On the other hand, in modern streets, the signage proportion displays a slow rise followed by a rapid decline, indicating that the streets with good accessibility allow pedestrians easier navigation with the guidance of signs. For a more visual representation, Figure 28 overlays traffic sign features on the actual site.

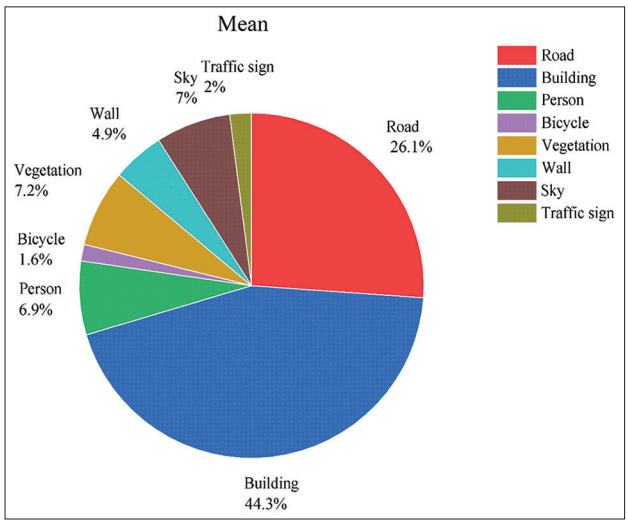

Figure 11. Average distribution of various elements in modern streets. Source: The author

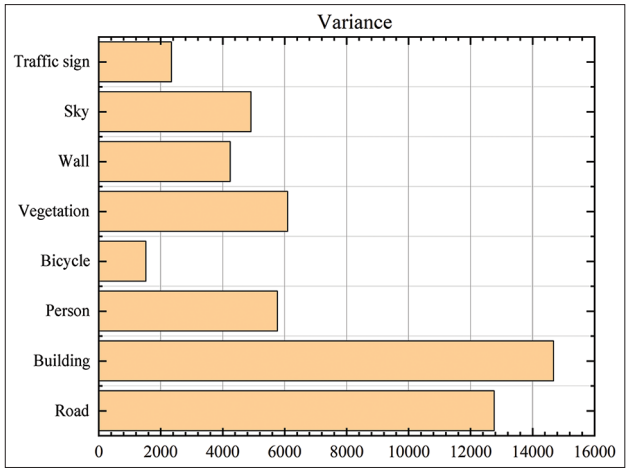

Figure 12. The distribution variance of various elements in modern streets. Source: The author

3. Discussion

3.1. Main findings and insights

Based on the descriptive statistics and detailed comparisons of different elements in historic and modern streets, the following characteristics can be summarized:

3.1.1. Visual distribution characteristics

In historic streets, the major visual elements are roads, buildings, and vegetation, with noticeable variations. This finding suggests that these streets prioritize maintaining diversity in space design and renovation to offer a rich spatial experience.

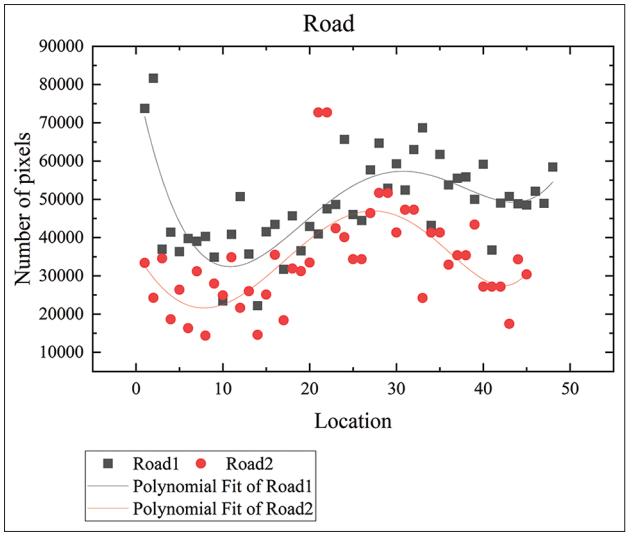

Figure 13. Distribution of roads within historic (Road 1) and modern (Road 2) streets. Source: The author

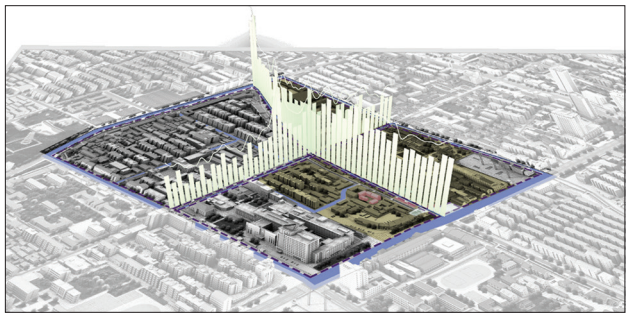

Figure 14. Spatial distribution of roads within historic and modern streets. Source: Drawing by the author

Modern streets primarily feature buildings and roads in their visual space, with people, plants, and the sky having similar proportions. This result reflects that people on these streets are mainly concerned with the roads and the surrounding buildings.

3.1.2. Standard deviation characteristics

Roads and buildings have higher standard deviations in both historic and modern streets, indicating larger visual variations during people's movement and emphasizing their discontinuity.

People and plants have relatively lower standard deviations in both types of streets, implying that they are essential, continuous elements on each street.

3.1.3. Street type differences

Historic streets feature broader road surfaces and emphasize the preservation of historical and cultural aspects, natural environments, and greenery, thereby creating a diverse spatial atmosphere.

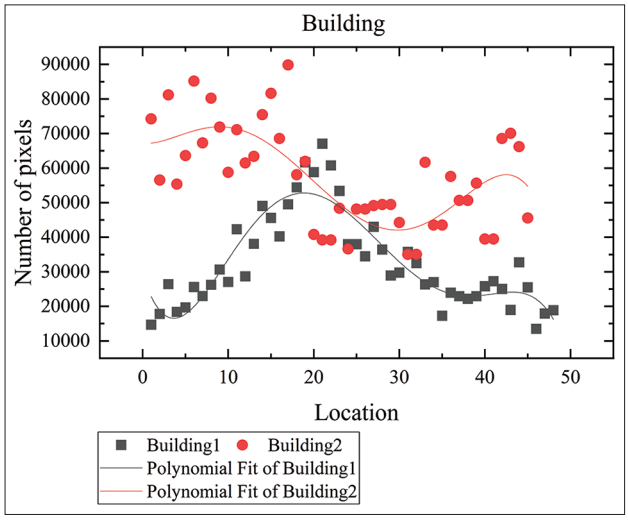

Figure 15. Distribution of buildings within historic (Building 1) and modern (Building 2) streets. Source: The author

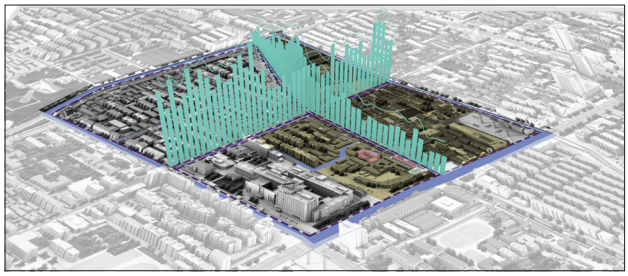

Figure 16. Spatial distribution of buildings within historic and modern streets. Source: Drawing by the author

In contrast, modern streets incorporate more buildings and exhibit higher population density, prioritizing the fulfillment of daily life needs.

A significant difference emerges in the distribution of people, with historic streets exhibiting larger variations. This discrepancy may be attributed to areas of interest that attract tourists, creating distinct distribution patterns. Additionally, the distribution of plants on historic streets displays significant fluctuations, whereas modern streets tend to have a more uniform distribution. This distinction may be related to layout methods, as historic streets strategically place plants around attractions and in clusters, while modern streets predominantly feature evenly spaced street trees.

In summary, historic streets emphasize diversity and spatial atmosphere, while modern streets prioritize population density and daily life needs. An in-depth analysis of the visual characteristics and distribution differences between historic and modern streets may contribute to urban planning, landscape design, and tourism management. This analysis may help decision-makers strike a better balance between historical

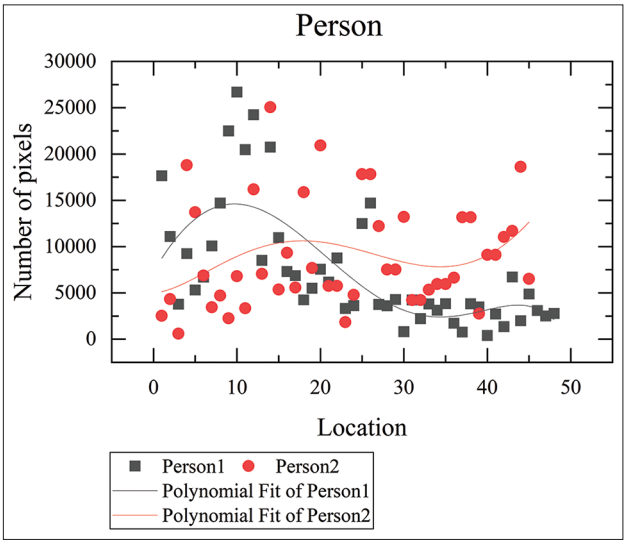

Figure 17. Distribution of people within historic (Person 1) and modern (Person 2) streets. Source: The author

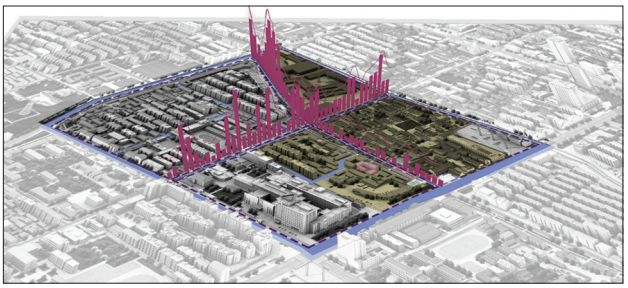

Figure 18. Spatial distribution of people within historic and modern streets. Source: Drawing by the author

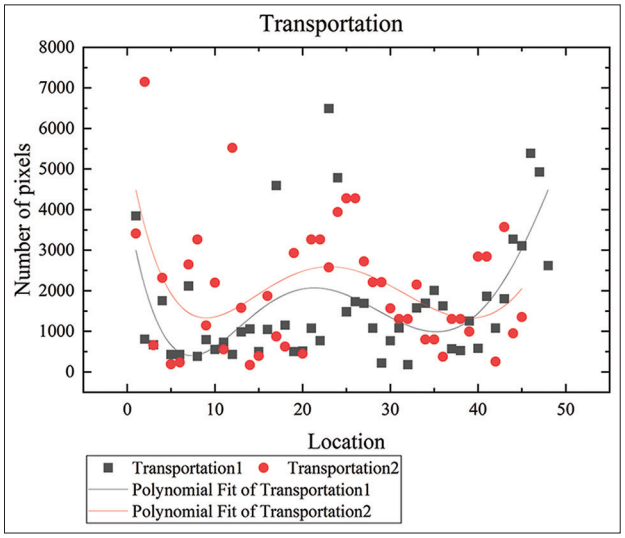

Figure 19. Distribution of vehicles within historic (Transportation 1) and modern (Transportation 2) streets. Source: The author

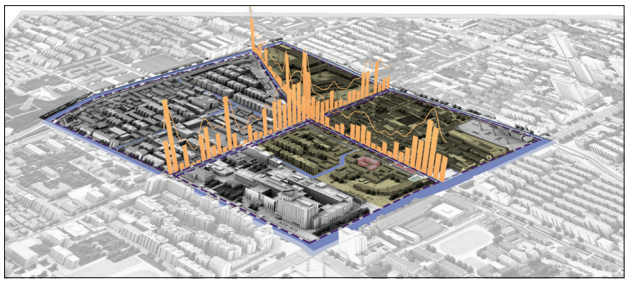

Figure 20. Spatial distribution of vehicles within historic and modern streets. Source: Drawing by the author

preservation and daily needs, fostering an appealing urban environment, enhancing living quality, and meeting diverse societal demands. Ultimately, this approach may promote urban sustainability and attractiveness.

3.2. Limitations and expectations

The analysis in this article is grounded in the collected street images of Lu Xun's hometown in Shaoxing, Zhejiang Province, China. Currently, due to limitations in computing power and time, a total of 279 images have been used for model training, potentially impacting the granularity of statistical results. Future research studies can aim to augment the number and stability of collected images.

3.3. Innovations and main contributions

This paper employed a self-trained semantic segmentation model based on the Cityscapes dataset to perform semantic segmentation on street spatial images with different attributes in the Lu Xun's hometown area. A quantitative statistical analysis of the segmentation results was conducted using Python, providing an intuitive visualization of the differences in various dimensions among different types of street spaces. This visualization serves to capture people's perceptual experiences. Through a comparative analysis of dimensions within and between historic and modern streets, the urban space was reevaluated from a rational and quantifiable perspective.

3.4. Insights and prospects

This study utilized innovative techniques for the quantitative analysis of street space, underscoring their significant guiding role in urban design and street space planning. Building upon this foundation, various analytical dimensions, such as Kevin Lynch's "Five Elements of the City," can be integrated to conduct weighted statistical evaluations of different indicators in urban space. This process generates comprehensive evaluation data for street space vitality, providing valuable guidance for urban design. For instance, during the design phase, simulating street scenes can be used to assess different attributes

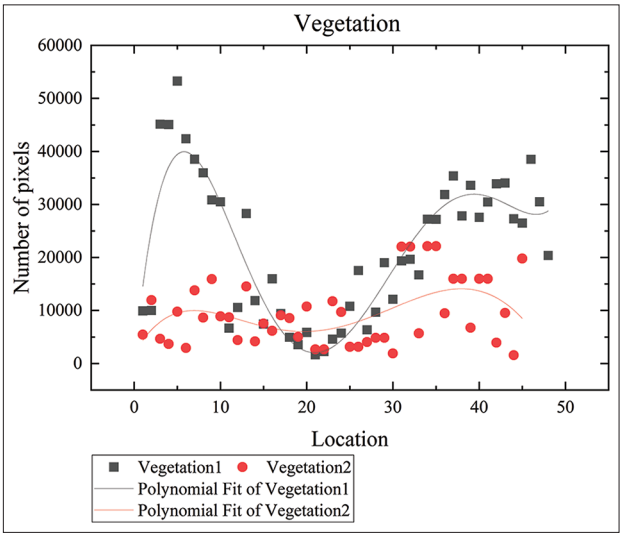

Figure 21. Distribution of vegetation within historic (Vegetation 1) and modern (Vegetation 2) streets. Source: The author

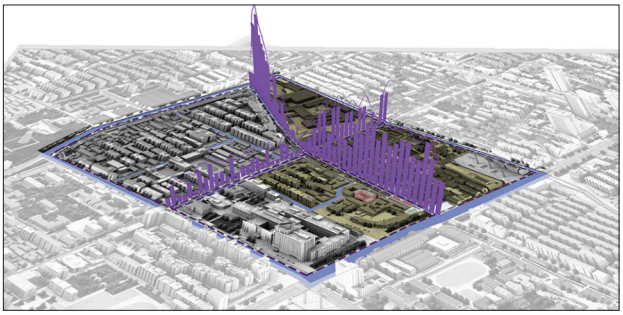

Figure 22. Spatial distribution of vegetation within historic and modern streets. Source: Drawing by the author

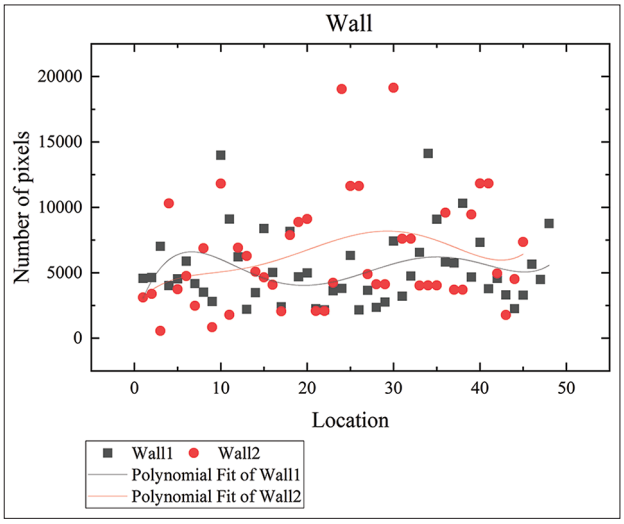

Figure 23. Distribution of walls within historic (Wall 1) and modern (Wall 2) streets. Source: The author

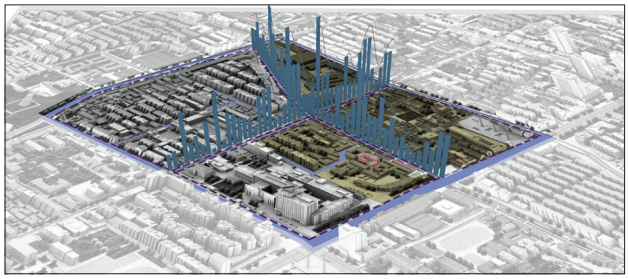

Figure 24. Spatial distribution of walls within historic and modern streets. Source: Drawing by the author

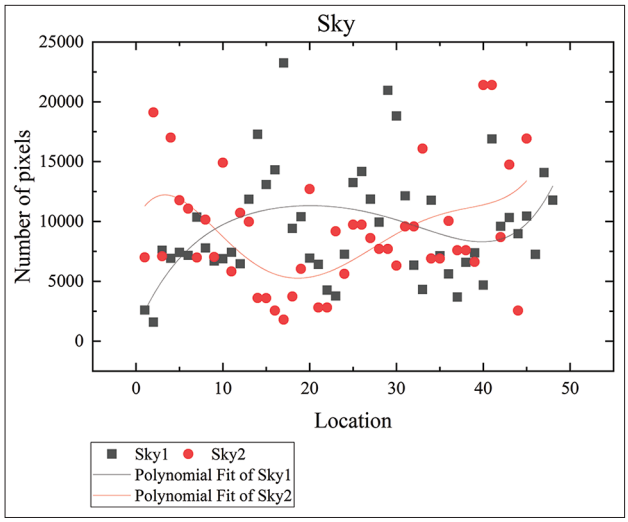

Figure 25. Distribution of sky within historic (Sky 1) and modern (Sky 2) streets. Source: The author

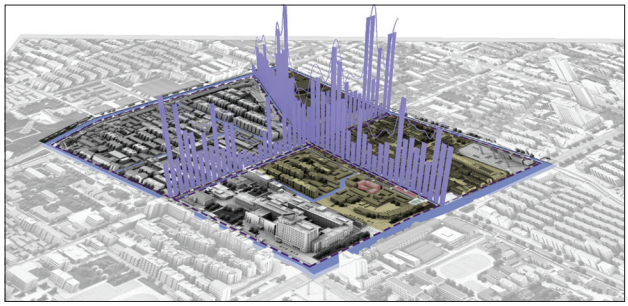

Figure 26. Spatial distribution of sky within historic and modern streets. Source: Drawing by the author

of streets, enabling the optimization of specific design aspects accordingly. Alternatively, street scene data and comparisons of different types of street feature data can be utilized to analyze elements in urban spaces that may require updates. This approach could also be applied to location speculation, involving the deduction of street types based on feature proportions, estimating street

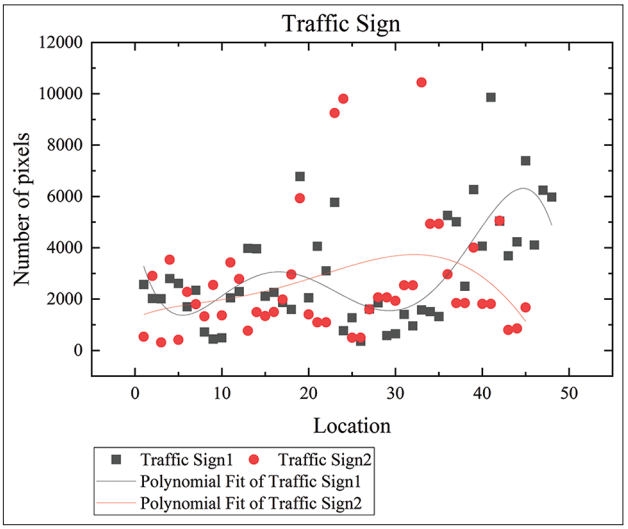

Figure 27. Distribution of traffic signs within historic (Traffic Sign 1) and modern (Traffic Sign 2) streets. Source: The author

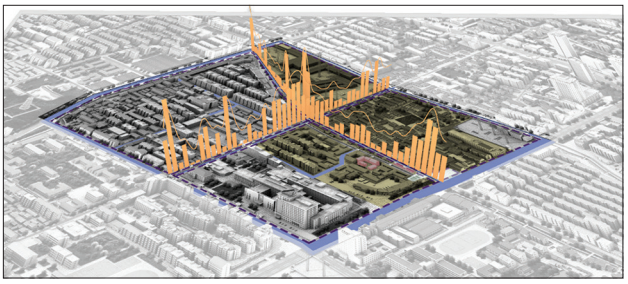

Figure 28. Spatial distribution of traffic signs within historic and modern streets. Source: Drawing by the author

depth and accessibility through signage distribution, and analyzing street congestion by examining the relationship between people distribution and streets.

4. Conclusion

In summary, this paper serves as a preliminary exploration, offering ideas, foundations, and technological paths for the refined design of urban space. Future work could entail gathering similar spatial cases and conducting more advanced studies using big data methods.

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Conflict of interest

The author declares no competing interests in this paper.

Author contributions

This is a single-authored article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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ORIGINAL ARTICLE

Perception of tourists and residents on the pedestrian environment of heritage cities

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Abstract

In China, most heritage sites are car-free destinations due to narrow roads, a result of government policy. This study examines the relationship between environmental factors and pedestrian perceptions in Gulangyu, China, among both residents and tourists. It analyses how different groups perceive the environment while walking, aiming to create a more functional walking environment that balances the needs of both groups. The study employed a quantitative approach, specifically logistic regression analysis, to examine the relationship between environmental factors and pedestrian perceptions. Statistical software, SPSS, was utilized for data analysis. The results of logistic regression analysis indicate that resident's perceptions are significantly influenced by comfort level, lighting, building maintenance, commercial attractiveness, and historic buildings. For tourists, the four factors significantly impacting the walking experience are road cleanliness, the indicating system, building facades along the street, and walking pleasure. The study reveals that the walking perceptions of residents and tourists suggest diverse concerns and experiences of the environment due to the different purposes of walking for each group.

Keywords: Pedestrian perception; Heritage city; Walking environment; China

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1. Introduction

The UNESCO document, "Convention Concerning the Protection of the World Cultural and Natural Heritage," defines cultural heritage sites as "works of man [humans] or the combined works of nature and man [humans] and areas including archeological sites which are of outstanding universal value from the historical, esthetic, ethnological, or anthropological point of view" (UNESCO, 1972, p. 2). World Heritage Sites encompass the most exceptional civilizations and contributions of various countries, regions, and peoples. China officially acceded to the Convention for the Protection of the World Cultural and Natural Heritage on December 12, 1985, and is projected to have 57 World Heritage sites by 2023. The protection and transmission of heritage sites involve sustainable tourism and systems for managing and protecting heritage areas, giving due consideration to the crucial role of local communities in cultural heritage (Liu, 2017). Therefore, ensuring sustainable development and the conservation of tourism in

heritage areas while also attending to the welfare of local communities is equally important.

Many heritage areas in China, such as Lijiang and Gulangyu, are car-free destinations. Transportation policies in these areas depend on the city's situation and local government policies. While some historical areas completely prohibit the use of cars, other cities restrict motor vehicle traffic during specific times or in certain zones. The prohibition of cars is justified because the roads in heritage areas are not designed for vehicles (Rahman, 2013). This transportation policy helps reduce pollution and traffic congestion while protecting the integrity of heritage sites.

Walking allows tourists to experience sites fully (Mohanty *et al.*, 2021). Slow walking is an ideal way to delve into historical, cultural, and ecological sites in greater detail (Harumain *et al.*, 2020). For residents, walking serves as an essential aspect of daily life. This difference in perception implies contrasting experiences for residents and tourists (Coldwell, 2017). Evidence suggests that tourist attractions, landscapes, and cultural places across World Heritage sites can appeal to both tourists and residents (Du Cros & Jolliffe, 2011; Winter, 2004). However, the appeal to tourists and residents is often expressed differently. Heritage cities are communities where residents engage in their daily lives while tourists visit these unfamiliar places for exciting recreational activities (Barber, 2019). Residents pay more attention to life-related places, such as shopping, physical exercise, and social communication activities, while tourists are drawn to landmarks, architecture, streets, and commercial activities.

Both residents and tourists value their experiences of the environment in heritage cities, as walking serves not only as a leisure activity but also provides a deeper understanding of the cultural and spiritual context of heritage areas (Barber, 2019). Therefore, the study of walkability holds significant importance for people in heritage cities. The relationship between walking and the environment is well established in research (Forsyth *et al.*, 2009). Based on the theory of walkability, appropriate planning and adaptation of the environment can facilitate walking (Ewing & Handy, 2009). The perception of walkability is a crucial factor influencing walking behavior (Arellana *et al.*, 2020). Several related studies applying the Theory of Planned Behavior (TPB) have demonstrated that the perception of walkability is a mediating variable influencing the relationship between the environment and respondents' walking (Le *et al.*, 2021).

In this study, the examination of differences in environmental perceptions may help identify specific targets for improving the heritage environment, contributing to the sustainable regeneration of heritage cities (Tweed & Sutherland, 2007). The study aimed to investigate the environmental factors influencing the perceptions of residents and tourists while walking, along with the extent of influence exerted by each factor. The findings of this research have implications for subsequent studies in Gulangyu and other Chinese heritage cities.

2. Literature review

2.1. Nature of walking

In walkability studies, walking is often classified into two categories: Purposeful and recreational. Purposeful walking is characterized by a specific destination, and time constraints are considered a necessary activity. In contrast, recreational walking is a more open-ended activity, allowing for greater spatial selectivity and a less defined walking destination. Typically, purposeful walking is associated with utilitarian destinations such as shops, schools, workplaces, and bus stops (Sugiyama *et al.*, 2012). In contrast, recreational walking tends to be associated with natural or built recreational facilities like parks, open spaces, gyms, health clubs, and sports grounds (Sugiyama *et al.*, 2012).

In heritage cities, there is a unique form of walking known as travel walks, often engaged in by tourists. Tourists to heritage cities may be more inclined to explore the city on foot and cover longer distances than residents. Research has suggested that walking is an excellent way for tourists to become better acquainted with a city, allowing for a deeper exploration of the urban environment (Thompson, 2003).

Research on slow-moving systems has indicated that the needs of walkers with different travel purposes vary depending on the environment (Gu & Chen, 2014). A review study found that purposeful walking among adults is linked to the presence and proximity of retail and service destinations and functional aspects of routes (Sugiyama *et al.*, 2012). In contrast, leisure walking is associated with the presence, proximity, quality, and route esthetics of leisure destinations (Sugiyama *et al.*, 2012). However, there is limited research on the walking environment and walkability for tourists despite walking being a common and meaningful activity (Dihingia *et al.*, 2022). Of the few studies conducted, comfort and safety factors are more commonly considered to influence the walking experience of tourists (Dihingia *et al.*, 2022).

2.2. Walking perception toward the environment

Environmental perception refers to people's subjective experience and mental evaluation of their surroundings

and any changes within them (Peng & Zhou, 2001). The perception of walking is often expressed through individuals' satisfaction with their environment. Increased environmental satisfaction may prompt walkers to spend more time in a particular location or revisit it multiple times (Herbolsheimer *et al.*, 2020). Walking perceptions result from subjective feelings and psychological states that walkers experience as they engage in this activity.

Ball *et al.* confirmed the impact of environmental esthetics, convenience, and walking companions on recreational walking by examining walkers' perceptions (Ball *et al.*, 2001). Carnegie *et al.* also found that esthetic and functional environments were associated with perceptions of walking and could promote more walking activity and dwell time (Carnegie *et al.*, 2002). The researcher investigated the walking time of individuals on Korean streets and their satisfaction with the street environment, concluding that a comfortable street environment can improve the quality of walking behavior (Kim, 2017). In a study of walking perceptions in a community park, Lee *et al.* identified gentle slopes, provision of shade, pavements, pedestrian crossings, and street lights as the main environmental factors influencing the perception of the walking environment (Lee *et al.*, 2016). Nag *et al.* investigated 14 factors, including footpath quality, footpath continuity, and shading/tree cover, that may affect satisfaction. They concluded that improving the environment can change walking behavior, especially footpath continuity (Nag *et al.*, 2020). The literature suggests that environmental factors significantly influence walkers' perceptions of the walking environment and behavior. Moreover, research in this area remains limited in China (Chan *et al.*, 2021). This study applies a theoretical framework to investigate the relationship between walking perception and environmental evaluation in Chinese heritage cities. By identifying the factors influencing residents' and tourists' perceptions of the walking environment, this study contributes to improving the urban environment and pedestrian satisfaction in Chinese heritage cities.

2.3. Heritage city

Heritage cities are tourist destinations, and their tourism appeal primarily stems from the value of heritage (historical buildings and culture), activity value (food, artistic, commercial activities), natural scenery, and the regional environment of heritage (convenient transportation and surrounding tourist attractions), providing tourists with self-growth, health benefits, social benefits, and cultural benefits (Tu, 2020). In addition, many of these cities, such as Lijiang, Gulangyu, and Pingyao in China, still function as residential areas for the locals. This situation has created a conflict between the identities of residents and tourists, and the problems and solutions posed by this conflict have also been studied in heritage areas in other countries such as Venice, Quebec, and Oxford (Coldwell, 2017; Evans, 2002).

One of the challenges that heritage cities face is their narrow and complex street layouts, making them unsuitable for motorized vehicles (Rahman, 2013). The roads were formed before the Industrial Revolution when people traveled on foot, in sedan chairs, or on horseback. The transport system has resulted in traffic congestion and increased traffic accidents, particularly during holidays (García-Hernández *et al.*, 2017). Walking is a recommended solution to address these issues. It alleviates traffic congestion and allows tourists to experience the city's culture and environment in more detail, providing a more profound experience of the heritage city. By designing a pedestrian-friendly environment, heritage cities can create an attractive, cohesive, and vibrant atmosphere that benefits residents and tourists (Gehl, 2013).

Studies on walking in heritage cities are limited, but some research has been conducted on the perception of walking in heritage sites (Wang & Wong, 2020). One study evaluated the environmental and spatial quality of historic districts in Canterbury, England, using behavioral maps to inform the enhancement of the pedestrian environment (Vasilikou, 2019). Another study surveyed tourists during festivals in Oaxaca, Mexico, to understand their choice of transport and the barriers that prevent them from walking in heritage cities (Barrera-Fernández & Hernández-Escampa, 2019). A study on residents' satisfaction with a proposal to build a pedestrian path in a cultural heritage site in Milan found mostly supportive attitudes toward slow-moving ways, though it did not consider tourists' attitudes (Maltese *et al.*, 2017).

3. Methods

Gulangyu was included in the World Heritage List in July 2017 under the theme of "Historic International Community, earning its status as one of China's most renowned heritage cities. In 1988, Gulangyu initiated the development of its tourism industry and adopted the conservation system of national scenic areas under Xiamen City's jurisdiction (Yan, 2018). Since the inception of tourism in Gulangyu, it has become a prominent pedestrian island. The study of walking on Gulangyu aims to improve the quality of physical activity for residents and tourists, providing a reasonable basis for the island's sustainable development. This study involved collecting data through a questionnaire, with separate surveys and analyses conducted for residents and tourists.

3.1. Study area

Gulangyu is situated in Xiamen (Figure 1), Fujian Province, covering an area of 1.91 sqkm with a registered population of approximately 12.59 million. As a World Heritage Site, Gulangyu is an international community with a rich history and culture, serving as both an urban and tourist district. The island has a unique geographical location, historically functioning as a pedestrian island, and this pedestrian characteristic remains a distinctive feature. External transportation primarily relies on ferries, with three terminals in Gulangyu connected to terminals in Xiamen City (Figure 2).

Gulangyu has been a walkable community from its inception. Originally established to meet basic living needs, it has now incorporated a tourism role. Residential and historic buildings have taken on additional functions as tourist stores, restaurants, homestays, and museum attractions (Figure 3). Conflicts between residential and tourism functional areas and walking routes are possible, especially in areas of high tourist activity. The inclusion of tourism functions also affects the environment of the heritage area. As people's demand for visual, safety, and amenity environments increases, it is essential to research whether a historical city meets the needs of its current citizens. However, Gulangyu historically surpasses most Chinese historical cities, both within and beyond its surroundings. It is renowned for its diverse plants and animals, expansive green spaces, fresh air, vibrant music culture, and proximity to the sea.

Hence, Gulangyu exemplifies the study of heritage pedestrian environments. The value of studying the walking environment is enriched by the combination of community and tourism functions, distinctive geographic and ecological surroundings, and the presence of pedestrian policies. The findings of this study have the potential to enhance the pedestrian infrastructure and overall community well-being, while also promoting the sustainable preservation and development of Gulangyu's cultural heritage.

3.2. Study method

3.2.1. Questionnaire method

The survey participants include residents who walk in Gulangyu and tourists traveling to the island. Compared with purposeful walking, residents' environmental perception may be closer to that of tourists. Purposeful walkers may be more concerned with the quality and safety of walking paths, while various factors may influence the feelings of recreational walkers about their environment. Therefore, this study chooses the residents who walk for leisure as the survey participants.

The survey comprises three parts. The first part gathered basic information about the respondents. The second part focused on the respondents' overall perception of the environment in Gulangyu, evaluated through a 5-point Likert scale. The third part involved respondents rating specific environmental factors using a 5-point Likert scale.

Figure 1. The location of Gulangyu in Xiamen. Source: Google Maps, 2022

Figure 2. The three ferry terminals of Gulangyu. Source: Gaode Maps, 2023

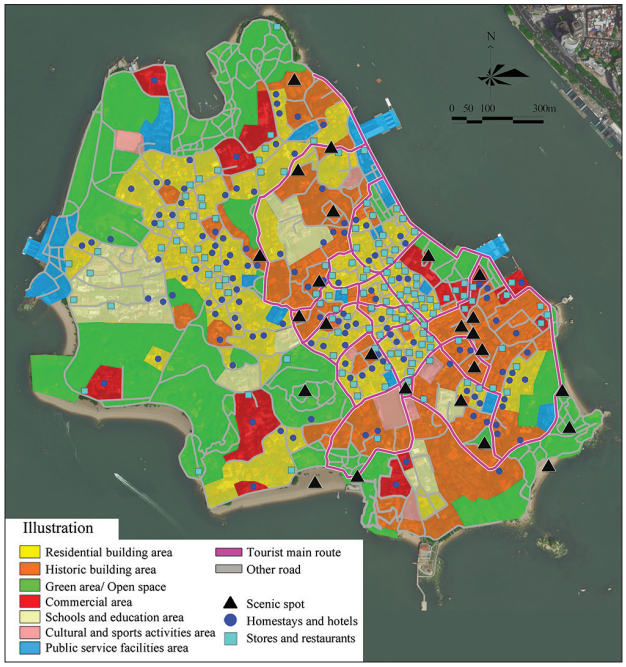

Figure 3. The land use, routes, and tourist facilities in Gulangyu. Source: Gaode Maps, 2023

The questions in the questionnaire were formulated based on all the environmental items in Figure 4. The sample size was determined using Krejcie and Morgan's methodology (Krejcie & Morgan, 1970). Based on the number of residents (12.59 million) and tourists (2.21 million) in Gulangyu in 2022, the sample sizes for residents and tourists were set at 370 and 384, respectively. The study selection criteria required a random selection of participants rather than a specific target population. During the survey period (January 2022–June 2022), 781 questionnaires were distributed, and 753 valid questionnaires were returned. Of the valid questionnaires, 372 were from residents, with 279 respondents indicating leisure walking as their main purpose of travel, and 381 were from tourists.

The questionnaire data were analyzed using SPSS 26.0 (2019) to verify the impact of various factors on walking perception. Descriptive statistics and ordered logistic regression analysis were employed to determine the overall evaluation of residents' and tourists' perceptions of the walking environment and the environmental factors that influenced their evaluation. The demographic profile of the sample and the basic identification of environmental factors were analyzed using descriptive statistics. Subsequently, an ordered logistic regression analysis was performed to develop model-fitting equations to test the environmental factors that impacted the perceived rating. Similar methods were employed in Tan *et al.*'s study, where correlation and logistic regression analysis were used to examine the relationship between walking behavior and environmental factors (Tan *et al.*, 2020).

3.2.2. Conceptual framework

The relationship between environmental factors and walking behavior and perception has been verified in numerous studies. However, there is currently no scale fully suitable for measuring the environmental factors of walking in Chinese heritage cities. This research conducted a search using keywords such as walking environment, walkability, walking landscape, and pedestrian, covering the period between 2000 and 2020. Thirty-four relevant studies were selected for analysis, and environmental factors affecting walking were extracted from their findings. Three studies, namely those by Arellana *et al.* (2020), Alfonzo (2005), and Ewing & Handy (2009), served as the primary references for selecting environmental elements for analysis. Based on the literature review, the researchers identified five key factors influencing the perception of walkers: Function, safety, comfort, esthetics, and pleasure. These factors were further divided into 30 indicators based on the literature and the characteristics of Chinese heritage cities. The

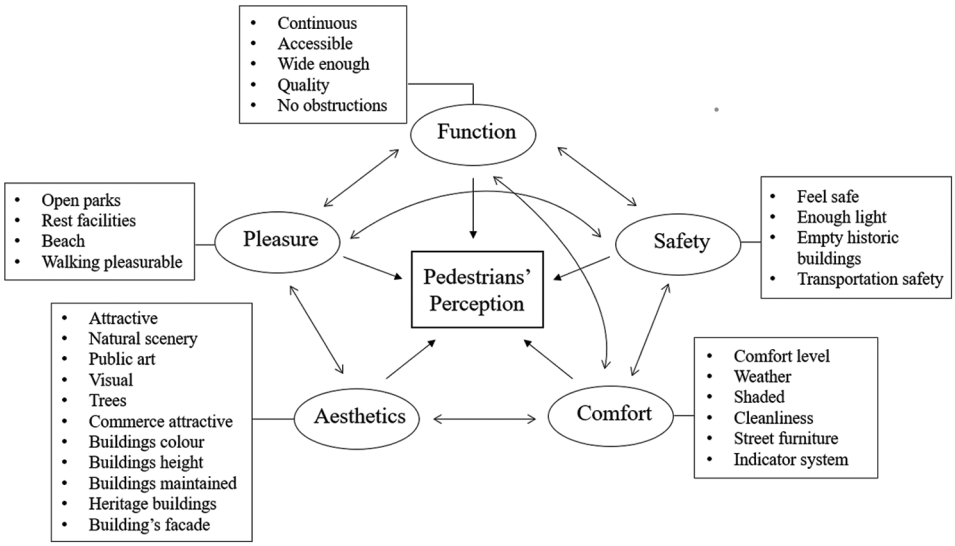

Figure 4. Conceptual framework. Source: Illustration by the authors

interrelated correlation between these five factors is shown in Figure 4.

Function is considered the most important environmental factor affecting walking (Giles-Corti & Donovan, 2002; Ozbil *et al.*, 2019), including surfaces and accessibility, which are critical in determining both the route and quality of walking. Safety is another essential factor for feeling secure from crime, traffic, or disorder (Alfonzo, 2005). Comfort is influenced by climate and artificial measures, such as shade and cleanliness (Alfonzo, 2005). Esthetics are considered a significant driver of walking, including environmental appeal (such as natural beauty, public art, etc.) and architectural features (color, height, age, etc.) (Cain *et al.*, 2014; Pikora *et al.*, 2006). Recreational facilities and enjoyment are also among the factors influencing walking, with public recreational facilities, parks, squares, and green spaces associated with increased walking (Ozbil *et al.*, 2019; Zang *et al.*, 2020).

4. Result

4.1. The participants' demographics

It can be observed from Table 1 that the gender ratio of tourists and residents is the same, thereby eliminating the influence of gender bias on the reliability of the research.

Analyzing the statistics of resident and visitor respondents' age, it is evident that the majority of residents fall within the age groups of 21 – 30 (26.88%) and 31 – 40 (35.48%). The data indicate that middle-aged and young people constitute a significant portion of Gulangyu's total population. Among the respondents, the lowest age group was those aged 51 – 60 (6.09%) and those aged 61 and above (6.45%). In terms of educational background, high school education topped the list with 26.16%, followed by a bachelor's degree at 25.09%, and a college degree at 22.94%. These three educational stages constitute the primary respondents of this survey, indicating that the educational background of Gulangyu residents generally reaches the high school level or above.

Table 1. The participants' demographics

Categories	Residents (Percentage)	Tourists (Percentage)
Gender		
Male	46.95	44.62
Female	53.05	55.38
Age		
11 – 20	10.75	12.86
21 – 30	26.88	67.19
31 – 40	35.48	12.34
41 – 50	14.34	4.72
51 – 60	6.09	2.36
61+	6.45	0.52
Education		
Primary school	3.23	0.52
Junior middle school	15.05	3.15
Senior middle school	26.16	9.45
Diploma	22.94	16.01
Bachelor degree	25.09	52.23
Master's degree and above	7.53	18.64

Visitor age statistics reveal that very few respondents are over the age of 41, with the majority falling in the 21 – 30 age group (67.19%). The data show that Gulangyu is particularly popular among young tourists. The age group with the fewest respondents was 51 – 60 years old and 61 years old and above, at 2.36% and 0.52%, respectively. Survey results regarding the educational level of tourists in Gulangyu show that the educational level is generally high. Those with a bachelor's degree topped the list, 52.23%, followed by those with a master's degree or above (18.64%) and college degrees 16.01%. These three educational stages reflect the main respondents of this survey.

4.2. The descriptive statistics of environmental perception

Descriptive statistics were initially conducted on residents' and tourists' overall satisfaction with the environment in Gulangyu and their ratings of the five factors. This analytical process provides a foundational understanding of the respondents' walking perception of the environment.

Figure 5 shows the ratings of residents and tourists regarding their overall satisfaction with Gulangyu's environment. The majority of both residents and tourists are satisfied and very satisfied with the environment of Gulangyu. However, the proportion of residents who are very satisfied with the environment is higher than that of tourists. Less than 10% of both residents and tourists are dissatisfied with Gulangyu's environment. The largest percentage of both residents and tourists consider the environment of Gulangyu to be satisfactory, with tourists slightly outnumbering residents at 60.24% and 52.33%, respectively. The percentage of residents who are very satisfied with the environment is about 8% higher than that of tourists.

Figure 6 displays the mean scores of residents and tourists on environmental factors in Gulangyu. In general, tourists assign higher ratings to environmental factors than residents do. Tourists tend to favor all the factors except the comfort factor. Both residents and tourists rate function and safety as the least favorable factors among the five categories.

4.3. The ordered logistic regression analysis

Based on the results of the correlation analysis in the previous step, the regression relationship between environmental factors and pedestrian perceptions was tested. Ordered logistic regression is suitable for regression equations where the dependent variable is an ordinal categorical variable, and the dependent variable is classified as equivariant in rank (Fullerton, 2009).

The findings of the ordered logistic regression analysis indicate that several environmental factors significantly influence residents' perceptions of the environment (Table 2 and Figure 7). These factors include safety (enough light), comfort (comfort level), and three esthetic factors (commercial attractiveness, building maintenance, and heritage buildings). In contrast, for tourists, the factors that significantly impact their perceptions of the environment are two comfort factors (cleanliness and indicator system), one esthetic factor (building facades), and the factor of walking pleasure.

First, the esthetics of walking sightlines substantially impact residents' perception of leisure walking. Although the historic buildings in Gulangyu are generally well maintained and restored, ordinary buildings require better maintenance, and some buildings are in disrepair due to being vacant and unoccupied. An esthetically pleasing built environment would lead to a higher level of perception when residents are walking for leisure. Second, comfort plays a more significant role in residents' perceptions. Therefore, more emphasis should be placed on items that affect walking comfort, such as resting seats, shade facilities, and other facilities that impact walking comfort. Third, street lighting and heritage buildings are additional factors that affect residents' perception of walking. During the survey, residents generally reported needing more street lighting, particularly in the less visited but residential areas on Gulangyu's North and West sides. Adequate street

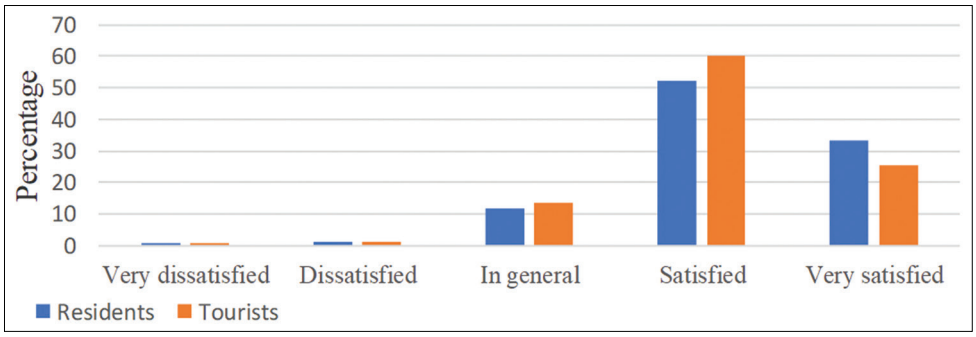

Figure 5. The score of overall environmental satisfaction. Source: Graph by the authors

Table 2. The ordered logistic regression analysis between factors and perception

Environmental factors that impact perception		β	Significance level	Odds ratio	Category
Residents' perception	Constant term				
	Y1 = "1"	0.530	0.580	-	-
	Y1 = "2"	1.649	0.045	-	-
	Y1 = "3"	4.759	0.000	-	-
	Y1 = "4"	8.500	0.000	-	-
Environmental factors	Enough light	0.371	0.035	1.449	Safety
	Comfort level	0.690	0.040	1.994	Comfort
	Commercial attractiveness	-0.820	0.026	0.440	Esthetics
	Building maintenance	0.854	0.015	2.349	Esthetics
	Heritage buildings	0.527	0.034	1.694	Esthetics
Tourists' perception	Constant term				
	Y2 = "3"	1.579	0.009	-	-
	Y2 = "4"	5.231	0.000	-	-
Environmental factors	Cleanliness	0.503	0.048	1.654	Comfort
	Indicator system	0.331	0.047	1.392	Comfort
	Building facades	-0.632	0.009	0.532	Esthetics
	Walking pleasure	0.450	0.038	1.568	Pleasure

Notes: Y1 is the perception of residents, Y2 is the perception of tourists, and both Y1 and Y2 are assigned the values 1, 2, 3, and 4, which represent dissatisfied, relatively dissatisfied, neutral, and relatively satisfied with the environment, respectively

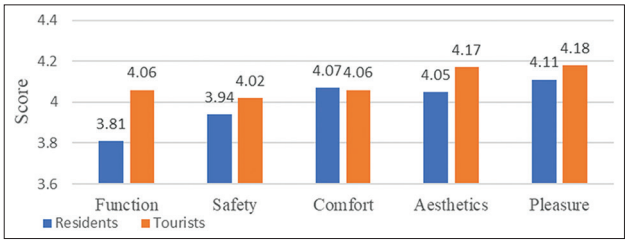

Figure 6. Average scores for environmental factors. Source: Graph by the authors

lighting would provide greater security when walking at night. Heritage buildings are also attractive to residents on foot; better maintenance would enhance their perception of leisure walks. Finally, the negative correlation between commercial attractiveness and perception of walking suggests that commerce reduces residents' satisfaction with the environment. This outcome could be due to the commercial environment of Gulangyu being primarily targeted at tourists, with a limited number and lack of diversity of businesses for residents.

Tourists have different priorities from residents when it comes to experiencing the environment. Tourists tend to focus more on factors such as the cleanliness of the roads, the esthetics of building façades along the streets, having a good road signage system, and the pleasure of walking. Therefore, to make Gulangyu a more attractive destination for tourists, attention must be paid to these aspects. For instance, it is necessary to improve the cleanliness of roads, especially in restaurant areas. In addition, the building facades along the streets should be planned and designed uniformly and esthetically, considering factors such as business distribution, building colors, building quality, and decoration style. Moreover, the confusing signage system should be addressed, and a clearer system of directions more appropriate for a heritage city should be established in Gulangyu. Finally, enhancing the tourist experience can be achieved by improving and increasing the number of leisure and social spaces, such as squares, parks, and beaches. These spaces can contribute to enhancing the overall pleasure of tourism.

5. Discussion

This study established a relationship between environmental factors and the psychological perception of the respondents, aligning with previous research conclusions (Arellana *et al.*, 2020). Environmental factors were found to enhance the walking experience of both residents and tourists. An improved sense of walking experience implies a heightened recognition of the environment, potentially promoting healthier moods, walking behaviors, and social activities. The findings of this study are consistent with those of other studies indicating differences in ratings of the walking environment and environmental factors between residents and tourists (Coldwell, 2017). While both groups generally

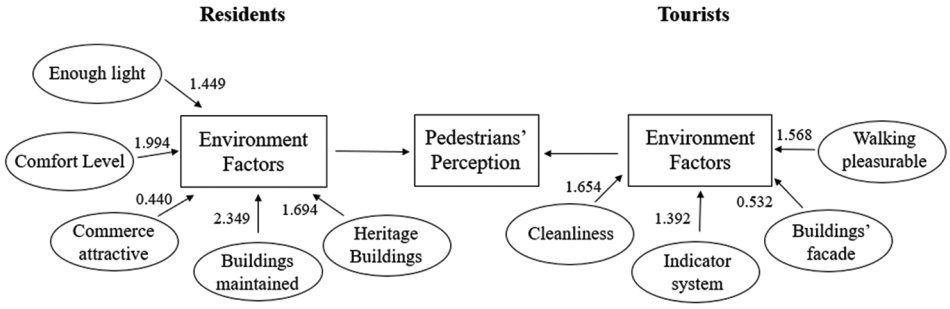

Figure 7. The environmental factors affecting walking perception. Source: Illustration by the authors

find the environment of Gulangyu satisfactory, residents tend to express higher levels of satisfaction, likely due to their sense of belonging to the residential community and a deeper understanding of Gulangyu (Cao *et al.*, 2006).

According to the results of the ordered logistic regression analysis, the environmental factors that enhance the walking perception of residents and tourists were identified. The architecture of Gulangyu, including heritage buildings and their maintenance, as well as the esthetics of façades, plays a critical role in the walking experience (Ewing & Handy, 2009). In addition, lighting and pedestrian comfort were identified as crucial factors for the island's residents but are currently lacking in these aspects (Ewing *et al.*, 2016). Improving lighting in residential areas and creating a more walkable environment could encourage more leisurely walking among the locals. Conversely, tourists prioritize factors such as roads' cleanliness, pleasurable walking, and the signage system; thus, a clean environment would provide a more comfortable visit (Yang *et al.*, 2020). The pleasure of walking is enhanced through spaces and facilities such as parks and squares, where individuals can rest and engage in social activities (Tan *et al.*, 2020). The absence of a signage system in historic areas can lead to detours, lost destinations, and repeated walks due to intricate roads. Therefore, developing a well-designed signage system would allow tourists to create routes and complete their journeys efficiently.

6. Conclusion

Walkability studies provide valuable insights for researchers seeking to understand the dynamics of heritage areas and the diverse walking practices among residents and tourists (Svensson, 2021). This paper mainly studies the spatial elements of residential communities and the tourism environment to improve the walking perception of both residents and tourists. Many researchers have proposed that the contradiction between residents and tourists arises in heritage cities, representing a collision between historical living spaces and tourism development (Landorf, 2009). Tourists typically travel at a slower pace and approach walking with an exploratory attitude, making micro-environmental factors with a more significant impact on tourists' travel experiences (Vojnovic, 2006). On the other hand, improving the walking environment for residents has been proven to promote better walking behavior and experiences, along with increasing residents' sense of belonging to the city and community (Cao *et al.*, 2006; Harumain *et al.*, 2020; Hoehner *et al.*, 2005).

The findings of this study reveal that the perception of recreational tourists and residents engaging in recreational walking can be significantly influenced by environmental factors in heritage cities. Furthermore, there are variations in the factors that impact these two groups. These findings offer concrete recommendations for the field of urban design. In future, urban revitalization and conservation strategies, urban planners, and relevant governmental agencies may prioritize environmental factors that influence the perceptions of both residents and tourists. The study aims to contribute to making heritage cities healthier communities and more attractive visitor destinations. In addition, since many heritage cities in China are designed as pedestrian-only destinations, placing a high demand on the pedestrian environment (Yang *et al.*, 2020), the methodology and findings of this study may be applied to other heritage cities in China to enhance the walking experience of both residents and tourists and promote sustainable development in the future.

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Conflict of interest

All authors disclosed no relevant relationships.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

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Availability of data

The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Further disclosure

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ACCSCIENCE PUBLISHING

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ORIGINAL ARTICLE

A study on the block pattern and spatial characteristics of *gara* in Surat, India

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Abstract

Surat is a major port and trading city in the northwestern state of Gujarat, India, boasting a rich multicultural background where colonial, religious, and commercial cultures coexist. Field research conducted on the historical districts of Surat indicates that the traditional residential buildings in Surat are not *havelis*; rather, their planar features bear a remarkable similarity to shophouses in Southeast Asia. The urban formation, spatial pattern of historical blocks, and architectural characteristics of Surat were thoroughly analyzed at three levels: macro, meso, and micro, using methods such as the examination of historical maps, reading historical literature, gathering oral histories, and conducting field investigations. The analysis of the political culture of Asian port cities reveals that Surat has been involved in cross-cultural exchanges in Asia. Through document analysis, the study delves into the formation process of Surat City and the spatial pattern of its historical blocks. To gain a comprehensive understanding, an exploration of the types of planes and profiles of the existing *gara* cases was carried out, along with a study of the spatial characteristics and evolution of *gara*. Finally, a comparative analysis between *gara* and the local architecture *haveli* was conducted, examining the factors for *gara* formation from multiple aspects, such as politics, religion, and policy. It can be concluded that the formation of Surat's city and architecture was not only influenced by the spread of Asian culture at that time but also integrated with local traditional characteristics.

Keywords: Surat; Historical blocks; Grid type block; Non-grid block; *Gara*

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1. Introduction

With the emergence of the "Maritime Silk Road" (Zhao *et al.*, 2021), the maritime landscape in Asia has expanded beyond its initial confines within Asian countries to include Eastern and Western nations. The evolution of port cities in Asia can be divided into four stages: (i) Emerging Period: This phase witnesses the rise of early port cities, resulting from overseas trade, often situated between the two ancient civilizations, China and India; (ii) Early Colonial Period: During this phase, international trade flourished, attracting European explorers and merchants who not only profited from commerce but

also solidified their political influence (Luengo, 2023); (iii) Prosperous Colonial Period: Western colonizers exerted their influence on military, economic, religious, and social aspects of the colony, prompting distinct planning for various ethnic and religious groups; (iv) Modern Period: In the modern era, some traditional cities have vanished, whereas others have flourished into major metropolises (Wang & Jia, 2016). From the ancient "Maritime Silk Road," to European colonization and national independence, the forms and architectural typologies of Asian port cities have predominantly been shaped by three factors: trade, colonization, and religion.

India, situated along the route of the "Maritime Silk Road," harbors Surat, a city in Gujarat, as a port city that emerged within this dynamic environment. The city was founded by Akbar, the third emperor of the Mughal dynasty, establishing the first seaport city. After the 16th century, Surat became a stronghold for Muslim merchants engaging in maritime trade across the Indian Ocean (Gupta, 1979). Spanning from the late 16th century to the first half of the 18th century, Surat served as a trading hub of Asia for the Portuguese, British, and Dutch. Due to its unique geographical location, Gujarat directly links to ports along the west coast of India, the Arabian Sea, the Persian Gulf, the Red Sea, and the east coast of Africa. In addition, it serves as a hub for trade routes to Java and China through the Strait of Malacca (Figure 1). Therefore, the urban layout and architectural styles of Surat were predominantly influenced by trade, religion, and colonization. To clarify the formation process of Surat City, the spatial pattern of historical blocks, and the spatial characteristics and evolution of *gara*,[1] it is essential to infer the fundamental reasons for changes in urban structure and residential types at both the macro-urban and micro-architectural levels (Eddy *et al*., 2020).

[1] *Gara*: Originally intended as a commonly used architectural term in the southern region of Gujarat, *gara* refers to the spacing between beams.

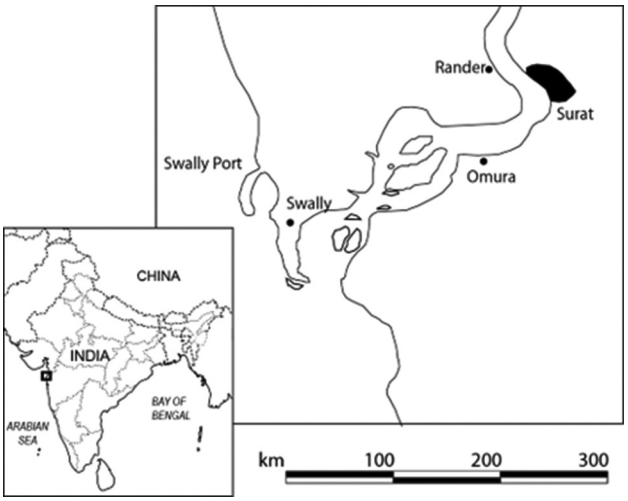


Figure 1. Location of Surat. Source: Drawing by the authors

2. Shophouse, *haveli*, and *gara*

Traditional Indian houses are commonly referred to as the courtyard-style *haveli* (Figure 2). However, the field investigation conducted in this study showed that the traditional houses in Surat are not *havelis*, and their planning features closely resemble those of the shophouses in the Malay Peninsula and Indochina Peninsula (Figure 3).

2.1. *Haveli*

Haveli is a noble residence in North India, characterized by similar width and depth, representing a courtyard-style architecture. In general, it features two courtyards, with the front yard intended for men's use and the backyard for women's use. Courtyards are generally square shaped and mainly used for natural light and ventilation purposes. Depending on the needs, *haveli* can be divided into family rooms, reception rooms, trade office rooms, and carriage garages (Bera, 2020).

2.2. Form, origin, and development of shophouse

The involvement of Western colonizers in Asian trade competition promoted architectural innovation (Luengo, 2017). The spread and evolution of shophouses (Figure 2) spanned roughly two centuries, from the establishment of the Straits Colony to the independent autonomy of each colony. Jon Lim divided this evolutionary phase into three periods based on the time of colonial government power transfer and important regulations (Lim, 1993):

(i) The first period (1786–1866): The migration of early Chinese people to Southeast Asia facilitated the adoption of "street houses" architectural forms from ancestral homes in southern China (such as bamboo pole houses in Fujian, bamboo tube houses in Guangdong, and Tingzi buildings in Taiwan) into Singapore (Chen, 1998). In 1822, under British influence, Raffles in Singapore combined the corridor form of ancient Greece and Rome with traditional Chinese commercial buildings, giving rise to the shophouse. The idea of racial zoning governance was adopted, leading to the separation and distribution of cities according to different ethnic groups. To unify the urban landscape and facilitate management, the planning of grid-shaped blocks was introduced. Shophouses emerged in Penang and Malacca, Malaysia, in 1862.

(ii) The second period (1867–1926): This period was characterized by the further development of shophouses in Penang and Singapore as the British gained control of the Straits Colonies. European

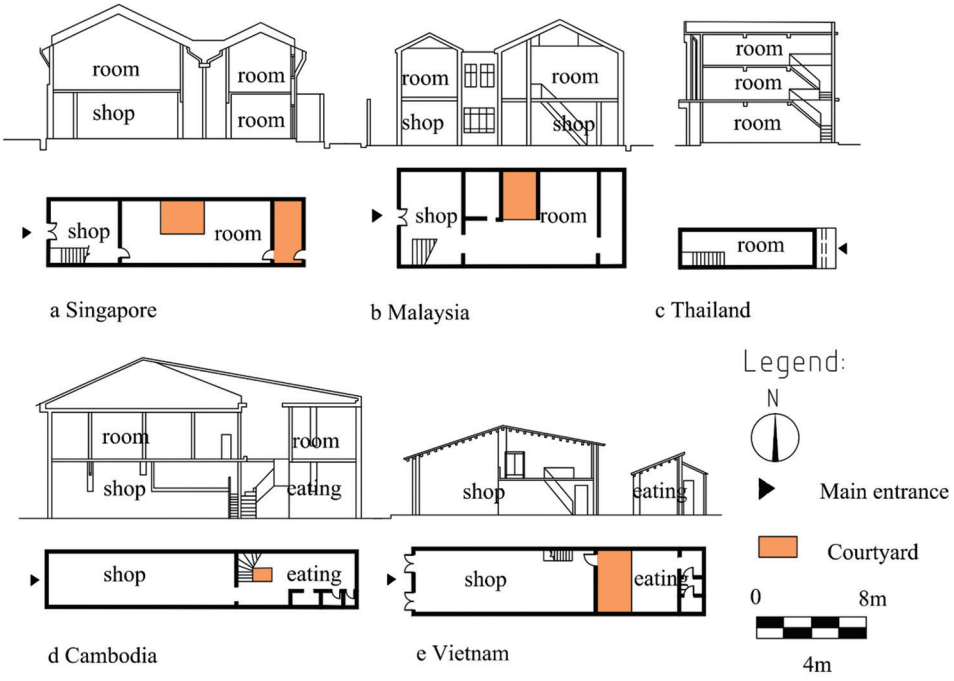


Figure 2. Shophouse. Source: Gokhale (1978)

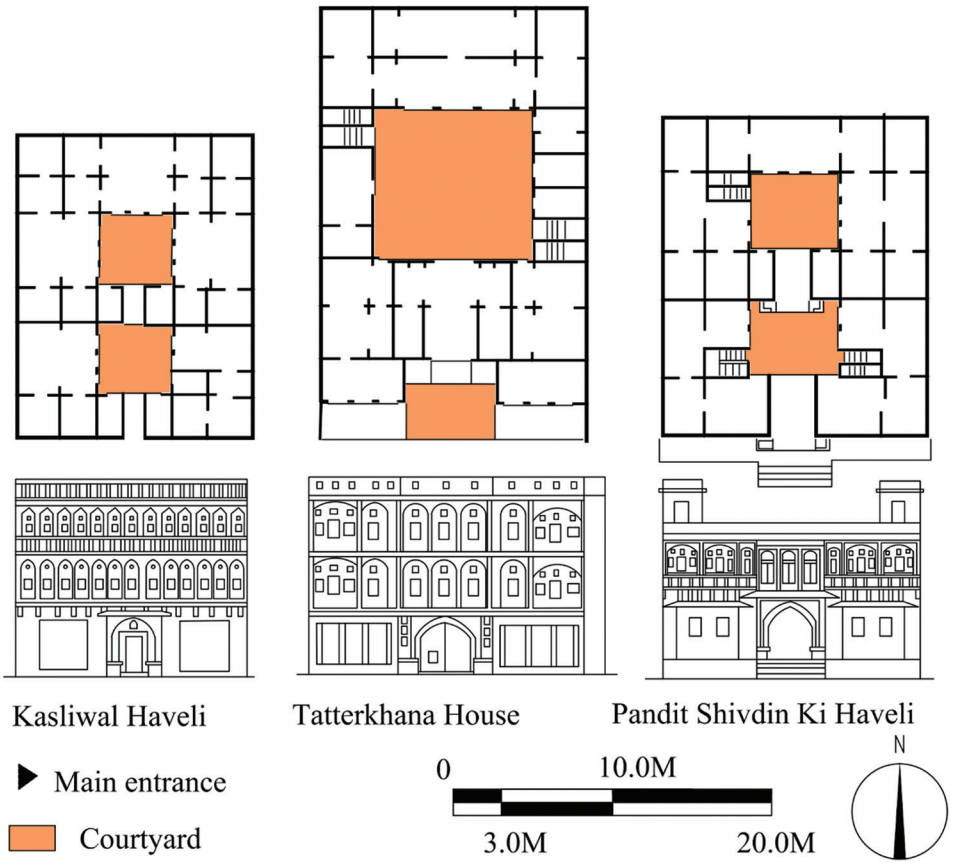


Figure 3. Traditional *haveli* (courtyard style) residence. Source: Parmar, (1989)

colonizers entering colonial cities profoundly influenced local culture, diversifying the storefronts of shophouses with architectural elements from China and Europe.

(iii) The third period (1927–1963): Shophouse expanded beyond the Straits Settlements. Influenced by the Western modern architectural movement, artistic decorative styles and early modern styles emerged (Han & Beisi, 2015), leading to the diversification and simplification of shophouse façades.

Shophouses are mostly single-room or double-room residences (Zhao *et al*., 2015), designed to cater to both the commercial and residential needs of merchants (Lin, 2002). Their spatial layout typically comprises shops in the front and storage rooms and kitchens in the back, with a narrow width and long depth. An external corridor in front of the building provides shade and shelter to pedestrians in tropical rainforest climates. The central courtyard connecting the front and back of the entire building is mainly used for natural light, ventilation, and rainwater treatment purposes. Due to their unique spatial and structural characteristics, shophouses are suitable for tropical and subtropical cities.

2.3. *Gara*

Gara is a unique traditional residential area located in Rander and Surat. Constructed with wooden structural bricks and tiles, it features a narrow surface width ranging from 3 m to 5 m. Typically, *gara* buildings consist of 3 or 4 floors, adhering to set standards during construction. The primary planning characteristic of *gara* is the adjacency of buildings sharing walls, where the façade width is narrow and the depth is extended, forming a distinctive "comb-like" arrangement. Notably, *gara* has yet to be discovered in other cities in India.

3. The history of urban formation in Surat

Before the 15th century, Rander was India's main port. However, following the Portuguese's attacks in the 16th century, Rander declined and the ports of Surat began to flourish gradually. In the early 17th century, the Dutch and British successively entered the region for trade exchanges with Surat, officially establishing it as one of the few port cities of the Mughal dynasty. Toward the end of the 18th century, the development of Surat was hindered by severe natural disasters such as major storms, fires, and floods. In 1852, the British established the City Hall in Surat, planning it according to Victorian ideology, resulting in well-defined grid-shaped blocks (Gokhale, 1978).

As shown in Figure 4, the urban development of Surat occurred in three stages. The first stage, spanning from 1494 to 1687, witnessed the migration of Jainists from Rander and Gujarat to Surat. The city was mainly inhabited by Hindus, Jainists, Muslims, and Parsi merchants in the central area known as the "inner city." In the second stage (1688 – 1910), particularly in the latter half of the 18th century, Surat underwent a major political transformation that empowered both the British and the Nawab (deputy ruler under the Mughal rule of India) to jointly manage the city. Given the increasing authority, the British established public and private buildings prominently along the river, while the Nawab built their palace in the southern low-lying areas near the inner wall river, leading to the emergence of the "outer city." In the third stage (1911 – 1950), these areas were primarily developed by nobles such as governors, Parsis, or Hindu merchants but were mainly inhabited by the artisan class and lower-caste groups. The acceptance of low-lying areas as habitable areas by the upper-caste group was low, reflecting the social order of the time. The construction of the city wall began in the second half of the 17th century, connecting the gates of the inner wall with the riverbanks around the fortress. In the early 18th century, a double-walled city consisting of inner and outer walls was formed, and the regional scope of Surat continued to expand. Thus, the urban development of Surat was affected at different times by various factors, including natural conditions, political changes, and social and commercial orders (Kinariwala, 2012).

Rander (the old city of Surat) and Surat (the new city of Surat) belong to the historical state of Gujarat. During the middle ages, Rander and Surat served as important trade centers in India. In the early 16th century, Sudanese rulers began building the walls of Surat and included Rander within their jurisdiction. After being ruled by the Portuguese, Dutch, and British, Surat and Rand gradually became major cities in India after gaining independence. By the 20th century, Rander was once again incorporated into the jurisdiction of Surat. This article covers the new town located in the southeast of Surat (Figure 5).

4. Urban spatial structure of Surat

4.1. The double walls of Surat

Surat, surrounded by the Tapi river, has a semi-circular outline that distinguishes it by the presence of two concentric layers of inner and outer city walls (Figure 5). The construction of the inner-city wall began after the Shivaji attack in 1664, aiming to protect the city's economic and political center. This area is also the oldest part of Surat. The inner city's heightened density gave rise to the development of the outer city, a modern urban area in Surat built in the early 16th century to fortify against potential invasions by foreign colonizers.

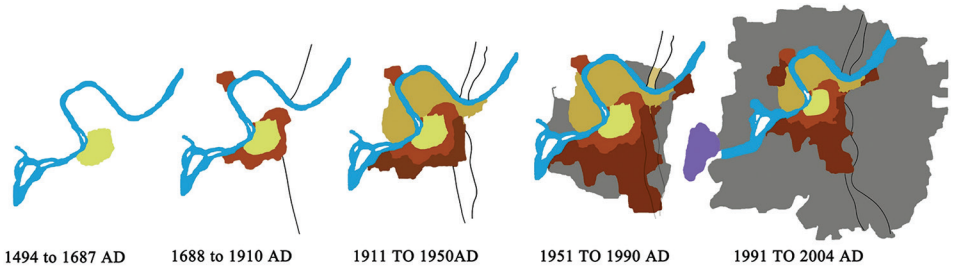


Figure 4. Evolution of urban space in Surat. Source: Baradi & Malhotra (2009)

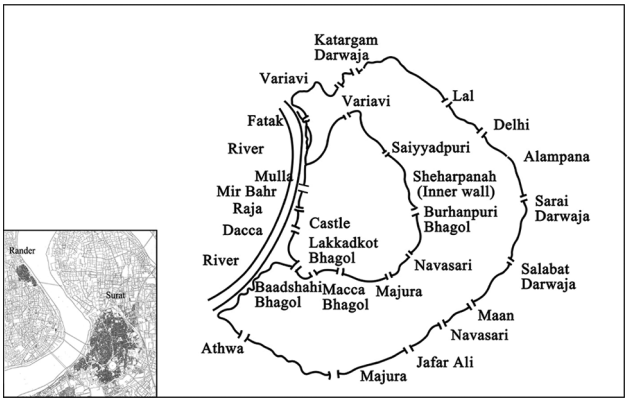


Figure 5. Double city walls of Surat. Source: Baradi & Malhotra (2009)

4.2. Block system

A comparison of the texture of the Surat neighborhood between 1817 and 2018 (Figure 6) reveals that the original road layout has remained unchanged, with new roads primarily concentrated in the eastern and southern parts of the outer city. As the population grew, residential areas expanded toward the highlands in the northeast. Due to the necessity of urban drainage, the original terrain has remained unaltered, maintaining a natural slope.

4.2.1. Grid and non-grid blocks

The spatial configuration of the Surat neighborhood (Figure 7) can be categorized into grid and non-grid shapes, with the inner-city wall demarcating the boundary. The inner city exhibits a non-grid-like texture, whereas the outer city showcases a grid-like pattern. The formation of these patterns can be attributed to four key points. First, the gradual development of inner cities contributed to a non-grid-like texture. The inner city, evolving over an extended period, witnessed buildings accumulating over time, resulting in loosely arranged blocks and a non-grid-shaped block. In contrast, the outer city saw the rapid formation of blocks, characterized by long and orderly streets, creating an overall grid-like texture. Second, the introduction of South Gujarat typology facilitated the creation of a grid-like block structure,[2] while the inheritance of *Pol* typology led to a non-grid-like block structure.[3] Third, Muslim neighborhoods adopted non-grid forms (Ahmedabad, 1990). Fourth, the British's adoption of the Victoria plan in Surat contributed to the formation of a grid-like block.

The uniqueness of Surat lies in being the only town in the southern part of Gujarat that showcases both northern and south settlement patterns and architectural forms. The subsequent sections of this paper delve into the analysis of these three points in conjunction with case studies.

4.2.2. Description of the six blocks

To gain a deeper understanding of the various principles involved in urban development, a detailed analysis was conducted on six blocks, namely Nanavat, Haripura, Med Harpura, Hindu, Parsi, and Bohra (Figure 8). The selected region belongs to different periods, communities, and religions, and can be viewed as representatives of the entire city.

Nanavat, situated in the inner city, emerged in the initial stage of urban development and was the home to wealthy Banyan merchants. In the Mughal era, Jains migrated from Rander and Northern Gujarat to this place and residents inherited the spatial concept of *pol* typology distinct from the traditional South Gujarat typology (Kinariwala, 2012). Nanavat adhered to a patriarchal system, where the head of

[2] Typology of southern Gujarat: In the settlement pattern of southern Gujarat, each dwelling is connected to adjacent dwellings, sharing a wall to form a row, and the streets are randomly distributed over the entire block, without the blind alleys in northern Gujarat.

[3] *Pol* typology: The urban typology of northern Gujarat is within the settlement model of northern Gujarat. Each dwelling is connected to adjacent dwellings, sharing a wall; many such units form a row. There is a similar row on the opposite side of each row, so these two rows enclose the space in front. So, the entire layout is identical to a fortress. Due to the closure of both ends, the settlement formed a dead end. However, in towns, the situation is different. People from different castes may be adjacent to each other and may all be open to an ordinary street, with both ends closed with gates. This arrangement is called POL typology.

Figure 6. Changes in the texture of the neighborhood. (A) 1817 block texture. (B) 2018 block texture. Source: Drawings by the authors

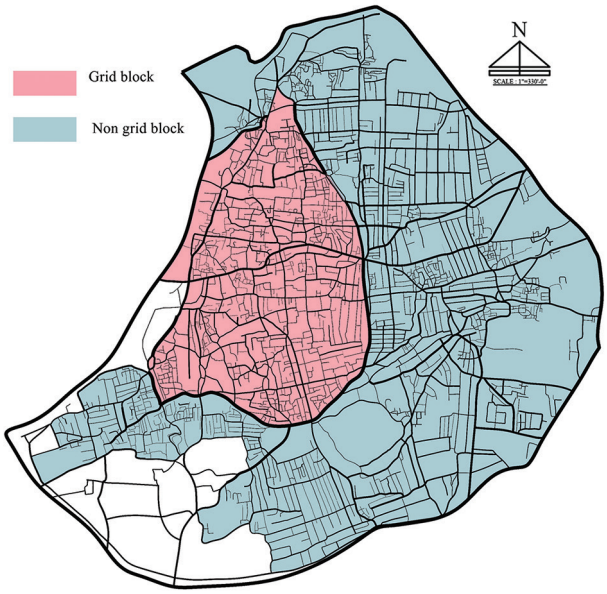


Figure 7. The texture of the streets in Surat (grid-like and non-grid-like). Source: Drawing by the authors

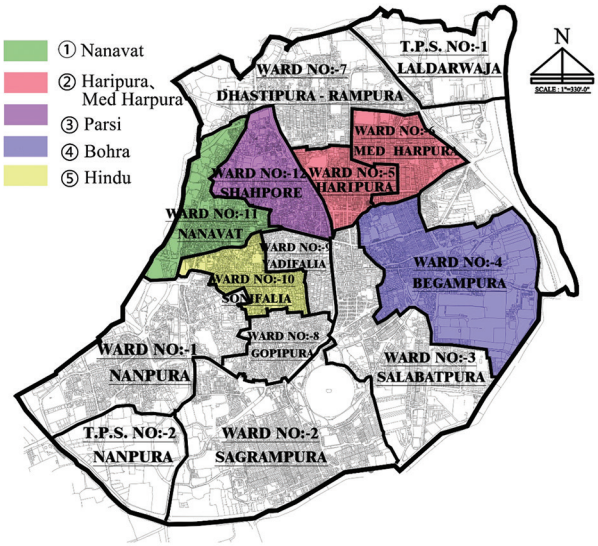


Figure 8. Block map. Source: Drawing by the authors

the household engaged in business outside while women, children, and the elderly stayed at home. This necessitated a highly secure housing planning, resulting in an integrated and introverted residential layout.

Haripura and Med Harpura, located in the outer city, emerged in the second stage of urban development and were predominantly inhabited by craftsmen. In the Mughal era, these people occupied a lower position in the societal hierarchy, but during the colonial period, coinciding with a decline in trade status, craftsmen gained prominence. At present, they stand as some of the most densely populated and prosperous areas in the city. Unlike the patriarchy in Nanavat, the entire family of craftsmen in these cities engaged in product manufacturing and trade. Residential houses were constructed openly facing the street to accommodate both family and commercial activities. The establishment of the City Hall by the British government in 1852 shaped the current appearance of the block. The construction of the block aligns with Victorian ideology in India,[4] incorporating the orthogonal planning principle of the grid to form a grid-like block texture with service streets. The service functions and toilets were designed at the back of the residence with a backyard to reduce the possibility of future encroachment. This

[4] Victorian ideology: During the Victorian era, the concept of urban block division began to emerge, and the entire city was roughly divided into several areas using simple geometric shapes, including noble areas, ordinary citizen areas, and slums.

trade and economic model diversified the composition of artisans engaged in handicrafts, fostering a heterogeneous environment and strengthening neighborhood relationships, thus diminishing differences based on religion or caste.

Hindu is located in the inner city, which emerged in the first stage of urban development and was primarily inhabited by Hindus such as Brahmins and Jains. Hindus constituted a significant commercial group, making Hindu the main commercial center. The neighborhood underwent many political and social changes over the centuries, leading to chaos and instability in urban planning and architectural development. New buildings and streets were added to the existing urban structure, resulting in a complex and chaotic non-network block structure in the region.

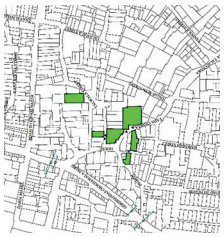
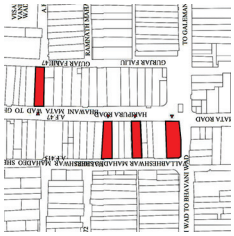
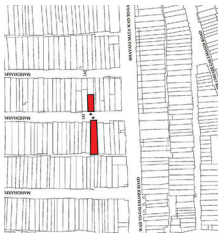
Parsi, situated in the inner city and one of the earliest settlements in Surat, emerged in the first stage of urban development, displaying a non-grid-like structure due to slow growth. This block resisted foreign infiltration, even on main streets, remaining utterly residential without commercialization. The community has not developed around religious or institutional centers.

Bohra, located in the outer city and formed in the late 17th century during the second stage of urban development, was mainly inhabited by Bohra merchants (Desai, 1985). This block exhibited a neat grid-like form, reflecting the impact of colonization on urban structure (Mathew, 1993).

4.3. Distribution of *gara* within the block

As shown in Table 1, the inner-city wall serves as the boundary, forming a sharp contrast in the spatial pattern of buildings and blocks inside and outside the city wall. Inner-city blocks exhibit an irregular and non-reticular texture, with buildings facing north and south and mixed east-west orientations. The rapid development and irregular homesteads within the inner city contribute to the irregular architectural form and arrangement, corresponding to the irregular structure of the block. In contrast, the outer city showed a regular and networked texture, with the buildings facing north and south. The architectural form and arrangement in the outer city are uniform, aligning with the regular structure of the block. In summary, the design of traditional dwellings in Surat is strongly influenced by factors such as climate, planning regulations, trade, colonization, and the distribution of groups of different castes.

Table 1. Analysis of block and architectural form

Characteristics	Hindu	Parsi	Bohra	Nanavat	Haripura	Med Harpura
Locations						
Inner/Outer City	Inner city	Inner city	Outer city	Inner city	Outer city	Outer city
Block texture	Non-grid-texture	Non-grid-texture	Grid-texture	Non-grid-texture	Grid-texture	Grid-texture
Gara orientation	North, south, east, and west	North, south, east, and west	North and south	North, south, east, and west	North and south	North and south
Gara morphology	Irregular shape	Irregular shape	Regular rectangle	Irregular shape	Regular rectangle	Regular rectangle
Gara arrangement form	Irregular	Irregular	Regular	Irregular	Regular	Regular

5. Multicultural residential areas and traditional residential types

5.1. *Gara* plan types

Three distinct types, A, B, and C, were extracted from the existing building materials (Figure 9):

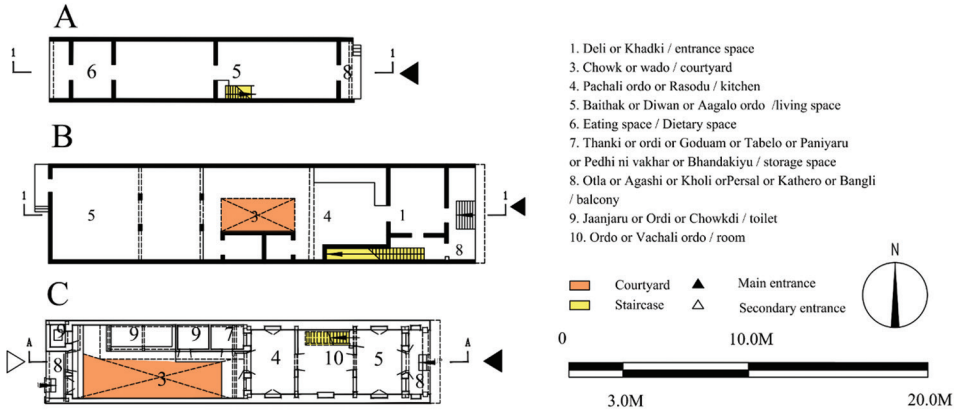


Figure 9. The basic form of *gara* (Type B). Source: Compilation by the authors from Kinariwala (2012), Ahmedabad (1990), and Baradi & Malhotra (2009)

- Type A: Single bay with a courtyard.
- Type B: Single bay with atrium.
- Type C: Single bay with a backyard.

The basic *gara* type, affected by insufficient residential area, had the homestead land divided into Type A with a courtyard. Due to changes in the functional requirements, Type B with an atrium evolved into Type C with a backyard. The reasons behind these changes are as follows: (i) Type B has the most abundant existing samples; (ii) whether it is the shophouse with similar flat forms or the *haveli* traditional Indian house, their basic forms typically include a courtyard; and (iii) the depth of Figure 10**:** NA-1 is relatively short and is derived from the basic type.

5.2. *Gara* plan classification

As demonstrated in Figure 10, only four buildings (NA-1, PA-2, HA-5, and NA-2) exhibit an east-west orientation, all of which are located in the inner city of the block with a non-grid texture. The remaining buildings have a south-north orientation. A more detailed analysis was performed according to the number of courtyards and bays.

Analyzing its width directions, the number of bays in the width direction can be divided into the following three categories:
(i) A single bay.
(ii) A double bay.
(iii) A triple bay.

Similarly, the number of courtyards in the depth direction can be separated into the following four categories:
(i) No courtyard.
(ii) A courtyard.
(iii) Two courtyards.
(iv) Three courtyards.

Combining the bay types and depth directions results in 12 types, with four types not found in existing samples. Most samples belong to the single-bay and one-courtyard type.

Three single-bay buildings with a courtyard were found. The functions starting from the entrance are divided into a balcony (*Otla*), entrance space (*Khadki*), living room (*Baithak*), eating space, kitchen (*Rasodu*), and storage space (*Thanki*), which can be simplified as entrance space – living space – ancillary space (food, storage) (PA-3, HI-3). NA-1 is unique and comes from the division of homestead land.

In a single-bay building with a courtyard, the ancillary spaces (catering, kitchen, toilet, and storage) are usually located together with the yard. It can be divided into three types, where the first and second types have a yard in the middle of the building, whereas the third type has a yard located in the back of the building:
(i) Type 1: entrance space – courtyard – living space (BO-2, BO-3, BO-4)
(ii) Type 2: entrance space – living space – courtyard – auxiliary space (BO-5, PA-1, HI-4, HI-5, and HA-3)
(iii) Type 3: entrance space – living space – auxiliary space – courtyard (BO-1, PA-2, HI-1, MED HA-1, HA-2, HA-5).

In South Gujarat, the concept of backyard is popular in rural typology. In the Haripura area, predominantly inhabited by artisans, both family and commercial activities were carried out within the building, resulting in a transformation of basic types and the establishment of a backyard, often combined with service spaces. In essence, trade played a crucial role in the evolution of housing.

The evolution from a single bay to a double bay represents a change in homestead land; for example, the expansion of homestead land moved ancillary functions to the side of a single-bay building, reducing the building's depth (NA-3 and NA-4). Another change is the abundance of homesteads, with sufficient width and direction, leading to the construction of twin houses.[5] It comprises two almost identical building units (MED HA-4, HA-6, and HI-2). Except for two buildings (NA-3 and HA-6) without

[5] Twin house: The two bays of a twin house are similar.

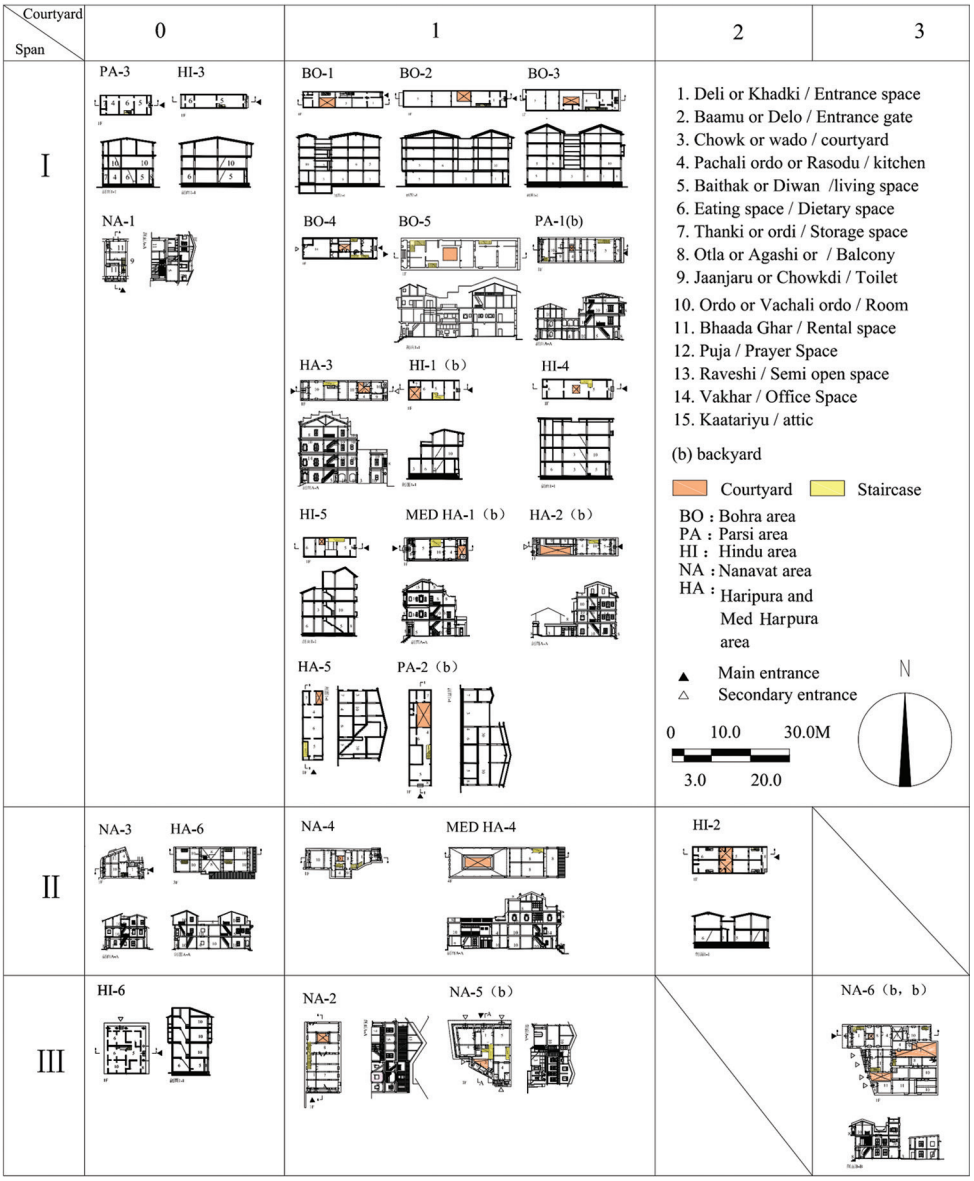


Figure 10. The planar type of *gara*. Source: Compilation by the authors from Kinariwala (2012), Ahmedabad (1990), and Baradi & Malhotra (2009)

a courtyard located at the corner, all other double-bay buildings have a yard.

A triple-bay building, HIN-6 with a courtyard, NA-2, NA-5, and NA-6 are residential buildings with atria, all of which are located in the affluent Nanavat region, known as *havelis* in northern India, and are generally residential properties for businesspeople or wealthy individuals.

Due to maritime trade, Western culture has continued to influence not only the urban layout of Surat but also its architectural form. In the urban development process, trade is an important component of daily life, and houses have also evolved in response to this. At the housing level, the houses in the Nanavat area show the footprints of *pol* houses in Northern Gujarat and are highly similar to the houses in Northern Gujarat. In addition, as these houses began to adapt to the local climate, the size of the courtyard changed, which was earlier limited to light shafts (Laina *et al.*, 2018).

6. *Gara* spatial pattern

6.1. Classification of stair positions

6.1.1. Stairs in the front of the building (number of samples: 13)

The straight staircase near the wall is relatively small, neither affecting the normal functional use of the room nor disturbing the rear room. It is mainly present in single-

bay buildings and was observed only in one double-bay building (HA-4).

6.1.2. Stairs in the middle of the building (number of samples: 8)

This type of staircase can be further divided into two categories: straight-running stairs (PA-3, HI-6, NA-2, NA-5) and double-running stairs (HI-1, HI-4, MED HA-1). These two types of stairs are not combined with the courtyard but are set up against the wall, which is their prominent characteristic. The staircase is located in the middle, ensuring privacy by separating the open areas of the building and playing a transitional role.

6.1.3. Hybrid (number of samples: 5)

Hybrid staircases can be further divided into three categories: (i) Staircases located at the front and rear (HA-6, HI-2), all twin house types; (ii) Staircases located at the front and middle (NA-4, NA-6); and (iii) Staircases located at the center and rear (BO-1). In the second and third categories, the stairs in the middle are combined with the courtyard and separate the privacy and open areas, playing a transitional role.

In a shophouse, a store is at the front and living space at the rear; therefore, it has a staircase located at the back of the building, allowing direct access from the living space on the first floor to the living space on the second. *Gara* does not have a store, and residential space is on the first floor; therefore, *gara* does not have a staircase at the back of the building or an arcade space.

6.2. Spatial evolution of *gara*

The evolution of the *gara* spatial pattern is depicted in Figure 11.

(i) *Gara* spatial pattern type, with the highest number of buildings having a single bay and one courtyard.
(ii) The evolution in the depth direction of *gara* gradually decreased the segmentation of homesteads. Two types of evolution occurred in the order of the bay. One of them aimed at moving the ancillary functions to the side of the building, and the other aimed to establish a twin house.
(iii) The evolution of the *gara* spatial pattern is related to the homestead area, the number of courtyards, changes in roofs, and the location of stairs. A single bay with an atrium (Figure 10**:** Type B) is the basic form of *gara*. The atrium divides the building into two parts, front and back, and its space has four evolving states:
    (a) The disappearance of a courtyard: Due to the increase in household population, the yard was covered and transformed into a hall, which increased the usable area of the building.
    (b) Partition of homestead land: The second half of the courtyard's buildings disappeared due to insufficient depth of homestead land.
    (c) Roof change: The pitched roof transformed into a flat roof.
    (d) Change in stair position: The staircase in the middle could ensure privacy and separate the open area of the building, indicating a transition.

6.3. Factors affecting *gara* formation

(i) Climate: The narrow and long building plan is separated by a courtyard, which provides ventilation and natural light, making it suitable for residential use in tropical areas. The problem of high internal air temperature is circumvented through the shade of vegetation planted in the yard and the shade of trees in the adjacent room.
(ii) Economy: Due to insufficient residential land area and inadequate economy, the triple-bay *haveli* evolved into a single-bay *gara*. Due to insufficient depth of the homestead, the second half of the courtyard's buildings disappeared. Furthermore, with an increase in the family members, the courtyard was covered and turned into a hall.
(iii) Trade: The concept of backyard is extremely popular in rural typology in South Gujarat. In the Haripura area, artisans are the main group of residents, and both domestic and commercial activities are carried out within the building, resulting in a transformation of basic types and the formation of a backyard, which is usually combined with service spaces. In summary, trade played an important role in the evolution of housing.
(iv) Colonization: *Gara* was mainly influenced by Western colonization, which introduced Southeast Asian architectural styles that were integrated with traditional Indian houses, thereby forming *gara*.

7. Causes of *gara*

7.1. Comparison between *gara* and *haveli*

7.1.1. Similarities

(i) From a plan scale perspective, the average width of a single-bay *gara* is 5.3 m (maximum 8.3 m and minimum 3.5 m), the average depth is 19.1 m (maximum 30.0 m and minimum 13.0 m), and the average aspect ratio is 3.7 (maximum 6.0 and minimum 1.7). The average width of a *haveli*'s interior is 17.8 m (maximum 25 m and minimum 15 m) and the average depth is 23.4 m (maximum 27 m and minimum 18 m). The average aspect ratio is 1.3 (maximum 1.6 and minimum 1.0). The façade width of the *haveli* is 3.35 times that of the *gara*, though they exhibit similar depth (Figure 12).

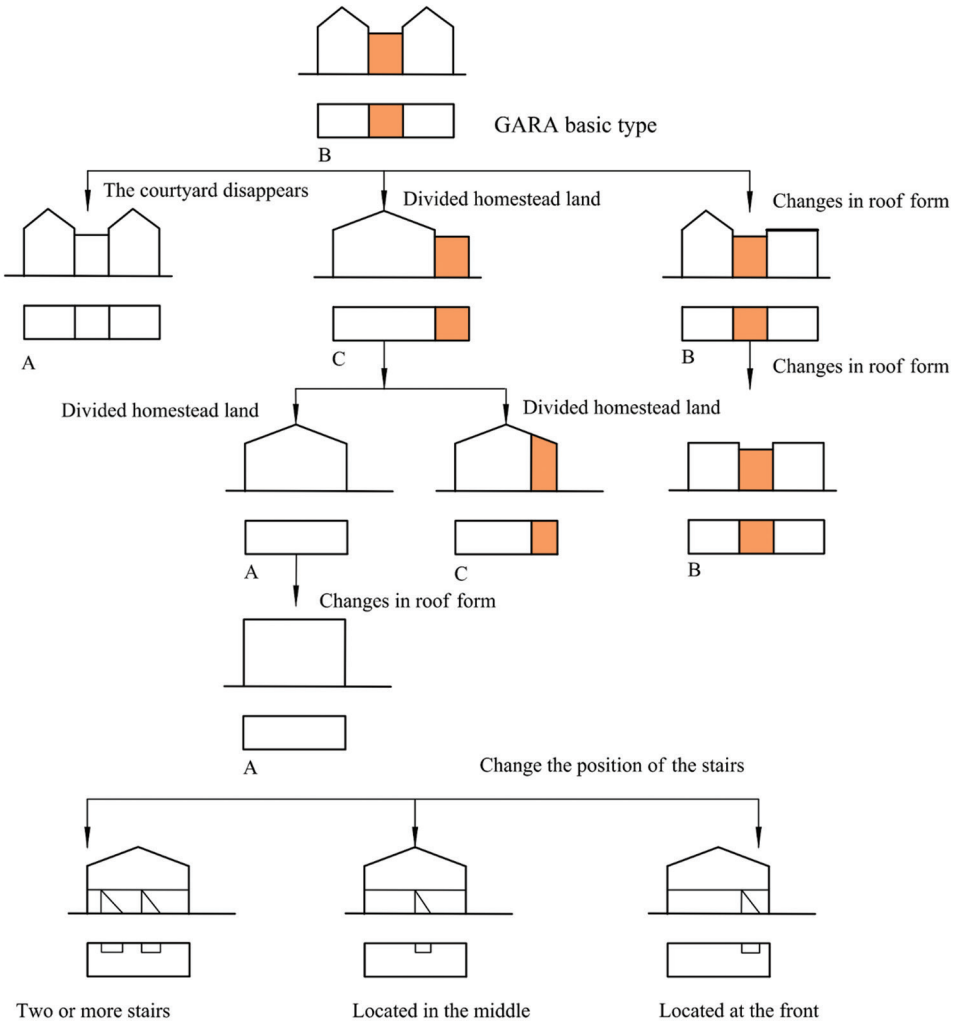


Figure 11. Spatial evolution of *gara*. Source: Drawings by the authors

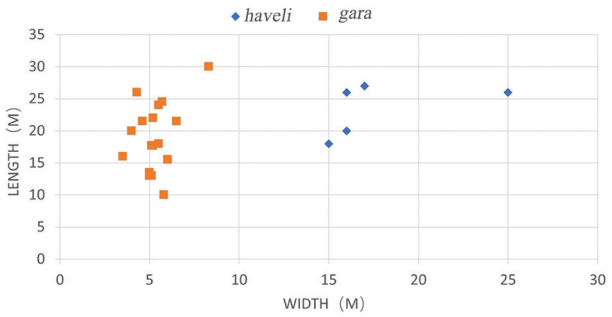


Figure 12. Data analysis of *gara* and *haveli*. Source: Plot graph by the authors

(ii) From the functional perspective, *gara* can be divided into entrance, living, and ancillary spaces (warehouse, office, and catering). According to usage requirements, *haveli* can be divided into family rooms, reception

Figure 13. *Haveli* (⑤, ⑥) in the Nanavat block. Source: Drawing by the authors

rooms, trade office rooms, and carriage garages. The functions of the two are similar.

(iii) From the blocks analyzed in this article, as shown in Figure 13 (NA-5 and NA-6), irregular arrangements of homesteads and architectural forms appeared in the non-grid-shaped inner city (such as the Nanavat block). In the ample area of homesteads, a triple-bay *haveli* architectural form appeared. Looking at each bay of the building alone, its plan shape and proportions are similar to those of *gara*. However, no such situation was found in the outer city.

(iv) An example of a *haveli*, as shown in Figure 1, illustrates that the *haveli* courtyard is located in the middle, dividing the building into three parts, each with a flat form and an aspect ratio similar to that of a *gara* (Figure 13).

7.1.2. Factors that cause the difference between gara and haveli

(i) Social factors: *Haveli* is a traditional aristocratic residence in India, which is located in the inner city and commonly found in the Nanavat neighborhood, as shown in this study. However, in Surat, many groups of people, such as merchants and craftsmen, are residing in *havelis*. *Gara* is suitable for the artisan and merchant classes as it can satisfy both commercial and residential needs.

(ii) Economic factors: *Haveli* is usually a triple-bay building type, inhabited mainly by aristocrats. The overall area of a *gara* is not large and nearly one-third of a *haveli*, with almost no economic needs.

(iii) Cultural factors: Surat is a famous port city in India, with *havelis* as the local aristocratic residence. Throughout history, Surat has flourished in commerce and has been influenced by various Western colonial cultures, such as the Victorian ideology of Britain. Under the influence of colonial culture, the urban and architectural forms changed, forming a grid-like block pattern, and the characteristic architecture of shophouses from Southeast Asia was introduced, which merged with the local residential characteristics of India, eventually resulting in *gara* housing.

Based on the above discussion, the formation of *gara* can be attributed to three factors. First, it involves the longitudinal segmentation of the original *haveli* plane. Second, it results from rebuilding based on the original homestead. Third, it incorporates the introduction of the shophouse architectural form and its integration with the local Indian architecture of *haveli* by Western colonizers.

8. Conclusion

The flourishing era of the "Maritime Silk Road" led to the prosperity of Asian port cities. In addition, the involvement of Western colonizers in the trade competition among these port cities promoted urban renewal and architectural innovation, with Surat being precisely under the influence of Western colonizers. Based on an analysis of the formation process of Surat City, the spatial pattern of historical blocks, and the spatial characteristics and evolution of *gara* at macro, meso, and micro levels in this study, the following conclusions can be drawn:

(i) According to a comparison of the old city's street layout between 1817 and 2018, Surat maintains the original layout, with new roads concentrated in the eastern and southern parts of the outer city. The residential area has expanded toward the highlands in the northeast.

(ii) The texture of the district in Surat is bounded by the inner-city wall, which can be divided into grid and non-grid shapes. The inner city has a non-grid-like texture, while the outer city has a grid-like texture. The reasons for their formation are as follows:

- Economic development: The slow economic development of the inner city led to a loose neighborhood, forming non-grid-shaped structures. In the outer city, neighborhoods are products that are implemented in a short period. The streets are long and tidy, and the entire neighborhood is divided into a grid shape.
- Policy factor: The introduction of typology in South Gujarat resulted in a grid-like block structure. The inheritance of *pol* typology led to the formation of a non-grid-like block structure.
- Religious reasons: Muslim neighborhoods adopted non-grid structures.
- Political influence: British colonizers adopted Victorian planning ideas, which contributed to a grid-like neighborhood.

(i) The architectural spatial characteristics of Surat include the inner-city wall, the inner-city buildings facing north-south and east-west with irregular architectural forms and diverse architectural arrangements, and the outer-city buildings facing north-south with a regular rectangular shape and undiversified architectural arrangements.

(ii) *Gara* has mostly a single bay and one courtyard layout. The evolution of its spatial pattern is related to the homestead area, number of courtyards, roof changes, and the position of stairs. The evolution in depth direction gradually decreases with the segmentation of homesteads, whereas the growth in bay direction increases with the changes in functionality.

(iii) In Surat, the growth of the inner city has been slow, and buildings have a loose arrangement. Due to insufficient homestead land, the triple-bay *haveli* residence was transformed into a single-bay *gara* residence.

(iv) *Gara* formation has been affected by the following four factors:
- Climate: The courtyard was created that could separate narrow buildings and thus was suitable for residential use in tropical regions.
- Economy: Due to insufficient residential land area and insufficient economy, the triple-bay *haveli* evolved into a single-bay *gara*.
- Trade: Because of the need to carry out both household and commercial activities within the building, a backyard was created, which was combined with a service space.
- Colonization: Western colonization introduced Southeast Asian architectural styles, which were merged with traditional Indian houses, resulting in the formation of *gara*.

(v) The formation factors of *gara*: With the emergence of the "Maritime Silk Road," the maritime pattern in Asia has evolved from between Asian countries to between Eastern and Western countries. While participating in Asian trade competitions, Western colonizers also promoted architectural innovation. From the establishment of the Straits Settlements to the independent autonomy of each colony, the spread and evolution of the shophouse took approximately two centuries. After entering Surat, Western colonizers introduced the architectural style of the shophouse and integrated it with the traditional Indian residence *haveli*, forming *gara* while adapting to the local climate and environment.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

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Formal analysis: Chong Zhao, Lu Zhang
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Methodology: Chong Zhao
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Writing – review & editing: Chong Zhao, Lu Zhang

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Data will be made available from the corresponding author on reasonable request.

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ORIGINAL ARTICLE

Ecological thinking in regenerative architecture: Relevance of abduction in ecoLogic Studio's Deep Green research project

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Abstract

This article explores the connotations of regenerative architecture in the context of the Anthropocene, emphasizing the role of abduction on human cognition and its potential impact on innovation, especially when applied to a bio-cybernetic design method. The DeepGreen research project, developed by ecoLogicStudio in collaboration with the University of Innsbruck and the Bartlett UCL, serves as an exemplification of this method. The project combines biological and artificial intelligence to create an urban ecological infrastructure that integrates architectural and ecological systems. Centering on the DeepGreen project, this study discusses the creative potential and ecological embodiment of bio-cybernetic design protocols. It focuses on the mechanism of abduction in triggering innovative design solutions from a logical perspective, aligning with the principles of mind ecology at a cognitive level. The analysis suggests an innovative and ecological design thinking mode, asserting that regenerative architecture can encompass not only material aspects but also informational and spiritual dimensions. This approach ultimately promotes a holistic and harmonious urban environment. Furthermore, this research posits that the bio-cybernetic stance and the morphogenetic approach share commonalities with the holistic conception of nature and the ecological view in ancient Chinese Daoist philosophy. This contribution can potentially offer a contemporary interpretation of the Daoist principles of "Nature and Humans in One Unity (天人合一)" and "The Dao Imitates the Laws of Nature (道法自然)." Such an interpretation is deemed beneficial for addressing today's concerns related to holistic, balanced, and harmonious urbanism. Henceforth, the study endeavors to facilitate discourse between Eastern and Western trends of thought, culminating in a cohesive yet heterogeneous regenerative approach.

Keywords: Regenerative design; Abduction; Bio-digital computation; Design innovation; Ecological thinking

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1. Introduction

As the resource impacts of the urbansphere become ubiquitous in the Anthropocene (Poletto, 2018), sustainable building design has faced criticism for its perceived inadequacy, often seen as merely sustaining the status quo and minimizing harm rather than actively improving and benefiting the planet (Littman, 2009). A paradigm shift is thus called for in the notion of sustainability, prompting architecture to evolve toward circular and regenerative principles (Pasquero & Poletto, 2023a). Advocating for the engagement of living and natural systems as both the medium for and generator of architecture (Littman, 2009), the manifesto of regenerative architecture resonates with the wisdom embedded in ancient Chinese Daoist philosophy. This philosophy explores the intricate interplay between humans and nature. However, in the face of the pervasive hybridization of artificial and natural systems in the post-human era, the connotation of nature undergoes a profound transition into a state referred to as post-nature (Figure 1). This shift necessitates a contemporary reinterpretation of classical philosophical beliefs. In this context, it is worthwhile to reflect on and draw lessons from the profound principles of "Nature and Humans in One Unity (天人合一)" and the core concept of "the Dao Imitates the Laws of Nature (道法自然)" found in ancient Chinese urban planning and building construction. This reflection becomes crucial in addressing today's concerns related to holistic, balanced, and harmonious urbanism.

This paper adopts a bio-cybernetic standpoint to scrutinize regenerative architecture, delving into the dynamic nexus within nature and investigating the unity of nature and humans in the Anthropocene. It presents DeepGreen, a project-based research framework developed by ecoLogicStudio in collaboration with the University of Innsbruck and the Bartlett UCL. This research initiative explores the design of urban ecological infrastructure employing the coupling of biological and artificial intelligence (AI), of humans and non-humans, thereby establishing novel urban design protocols (Pasquero & Poletto, 2021a). The bio-cybernetic approach contributes to regenerative purposes by introducing multiple design agents and creating intricate feedback loops (Figure 2). These loops foster mutual balance, self-regulation, and system resilience, facilitating the seamless integration of architectural and ecological systems. Moreover, the bio-cybernetic approach lends robust support to the architectural relevance of cybernetics (Pask, 1969) and human ecology (Geddes, 1915; Odum, 1993).

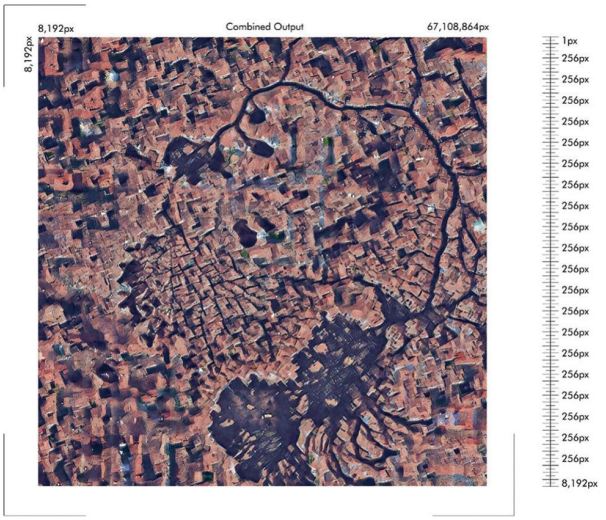

Figure 1. AI-driven speculation on the prospective urban fabric of Venice as shaped by the biological intelligence of its liquid lagoon infrastructure. Source: ecoLogicStudio, Deep Green, Urbansphere, Venice, 2021

Dissecting the project, the article focuses on exploring an innovative and ecological design thinking mode for regenerative architecture from the perspective of abduction. The discussion of this bio-cybernetic approach extends beyond optimization and problem-solving, encompassing its creative potential and natural embodiment. On the one hand, the ideation of this project accords with the logic of innovative abduction, initially implied by Pierce and later officially named by Habermas (Roozenburg, 1993). It aims at triggering innovations that transcend the status quo. On the other hand, as non-human design agents function as extensions of the human mind (Nassetti *et al.* 2019) to engage in meaning-searching activities and capture innovative insights, this paper explains abduction as a cognitive method in depicting the "mind ecology" (Bateson, 1979, p. 86). This bio-cybernetic regimen shapes spatial decisions in a manner that is compatible with the living world. The pattern of relations adheres to the law of morphogenesis and transcends mere imitation of biological forms.

This research posits that the bio-cybernetic stance and the morphogenetic approach share commonalities with the holistic conception of nature and the ecological viewpoint present in ancient Chinese Daoist philosophy. Such alignment could potentially contribute to an enhanced understanding and contemporary interpretation of the principles encapsulated in "Nature and Humans in One Unity" and "The Dao Imitates the Laws of Nature." This reinterpretation is beneficial in addressing today's concerns related to holistic, balanced, and harmonious urbanism. Henceforth, the study endeavors to facilitate discourse between Eastern and Western trends of thought, culminating in a cohesive yet heterogeneous regenerative approach.

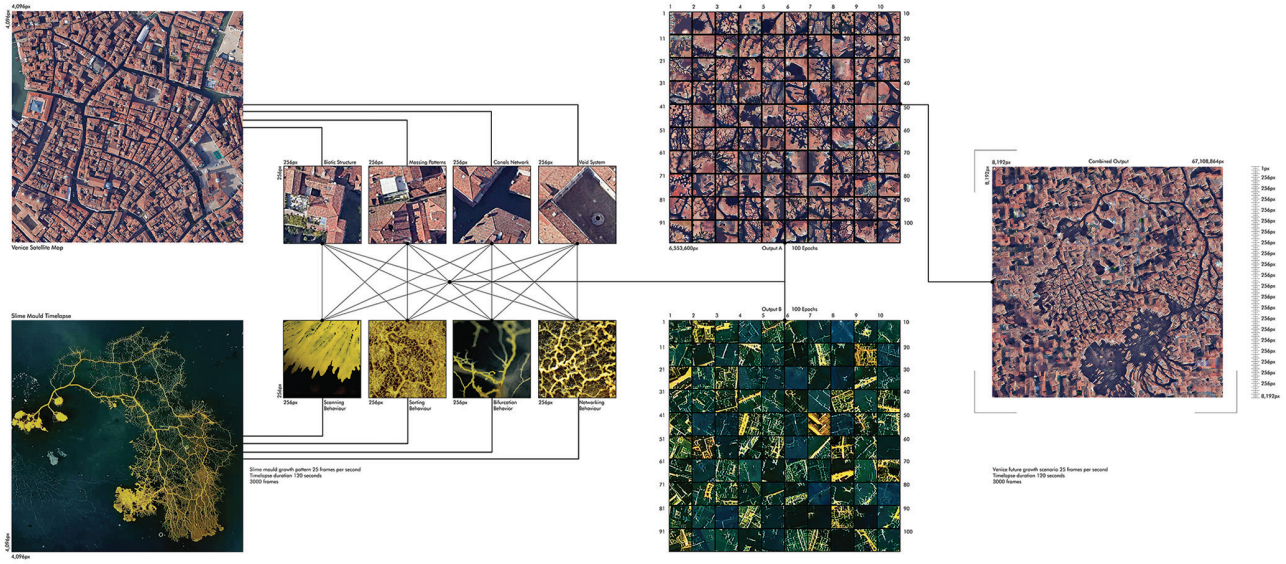

Figure 2. Cognitive diagram of the GAN_Physarum model. Source: ecoLogicStudio, Deep Green, Urbansphere, Venice, 2021

2. Nonhuman entities as the design agents: The bio-cybernetic stance and approach

DeepGreen is a long-term project-based research initiative presented by ecoLogicStudio in collaboration with the University of Innsbruck and Bartlett UCL, focusing on the development of ecological infrastructure and the planning of blue-green cities. This research has yielded the DeepGreen protocols, a comprehensive urban design workflow, through sub-projects and design explorations in various cities across multiple countries. These sub-projects encompass a range of urban challenges and future scenarios. They involve the speculation and planning of wastewater treatment networks in a post-flooded future Tallinn, Estonia (Pasquero & Poletto, 2019); water collection and distribution networks in Guatemala City, Guatemala; municipal waste recycling networks in Mogadishu, Somalia; renewable energy networks in Vranje, Serbia (Pasquero & Poletto, 2021b); canal systems in Venice, Italy (Pasquero & Poletto, 2021c); and wet path systems in Paris, France (Pasquero & Poletto, 2022). The planning strategy advocates for the integration of these systemic networks with biotic layers and landscape design, aiming to create urban ecological facilities that accommodate both human and non-human entities. It posits that what is conventionally regarded as human waste and pollution can serve as a source of material and nutrients for the growth of living organisms, especially microorganisms. Through intervention, waste can be converted into raw materials for new production processes, signaling a transition in urban metabolism from linear consumption to a closed-loop circular system, thereby rendering the cities regenerative (Pasquero & Poletto, 2019). The research outcomes, at various stages, have been exhibited at prestigious platforms, such as the Tallinn Architectural Biennale, the Venice Architectural Biennale, the FRAC in Orleans, the Shanghai-Hong Kong Biennale, CAFA Beijing, and the Centre Pompidou in Paris, among others. Furthermore, these outcomes have contributed to a series of urban-scale projects in collaboration with UNDP (United Nations Development Programme) and local municipalities, including Aarhus and Tallinn, among others.

Employing advanced and sophisticated algorithms for the analysis of urban big data and the simulation of new urban patterns, Deep Green achieves a morphogenetic workflow that is both iterative and adaptive to the designed environment (Pasquero & Poletto, 2021b) (Figure 3). "The workflow includes four main levels of computation: input data reading, biotic-abiotic analysis, network analysis, and finally, scenario modeling. For the first level analysis, advanced algorithmic design techniques are used to read large data sets (...) Levels two and three recognize and analyze the morphology of the city, the surrounding landscape and the resources' networks. The analysis produces density maps and path systems for several urban systems such as biomass, water collection, solar energy, community waste, and so on" (Pasquero & Poletto, 2021a, p. 669). In the case of Bio.Tallinn and its urban proposal, Tallinn Wet City, the blue-green plan diverges from the conventional typology-driven approach. Instead, it directly identifies green vegetation areas utilizing satellite data. This method allows for the inclusion of small-scale vegetation

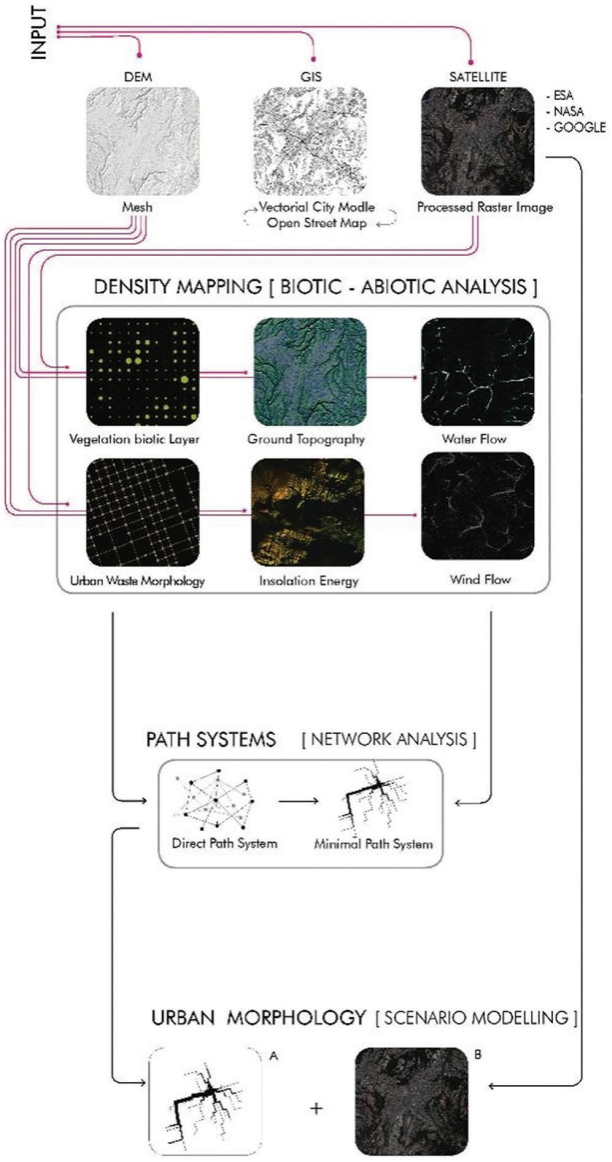

Figure 3. Diagram of DeepGreen workflow. Source: ecoLogicStudio, Deep Green, 2021

that might otherwise be overlooked in traditional planning approaches. In addition, in network analysis, the notion of zoning is discarded. The protocols involve a cross-referential analysis of the pathway networks of architecture and the green system, revealing an intricate interplay between the two (Pasquero *et al.*, 2019).

These maps subsequently function as training datasets for GAN_Physarum, a specific bio-digital algorithmic model. At its core, this model is designed to train a GAN (generative adversarial network), a type of AI, to "behave" like a PP (*Physarum polycephalum* or slime mold), a form of biological intelligence (Pasquero & Poletto, 2023b). PP is a uniquely peculiar single-celled organism whose cognitive capabilities have defied scientific scrutiny for decades, lending it an almost magical aura. Despite lacking a brain and nervous system, PP exhibits a capacity to "think" and respond to environmental changes. It builds a distributed external spatial memory by secreting chemicals and accumulating traces in its surroundings. In addition, it possesses an internal temporal sense, allowing it to predict certain periodic events. Therefore, PP has been dubbed an "unconventional general-purpose computer" by computer scientist Andrew Adamatzky (Pasquero & Poletto, 2020). PP can form networks based on the balance of various nutrients. In an experiment, researchers strategically placed food in corresponding locations and prompted PP to find the most efficient path between multiple food sources. PP initiates the process by establishing pseudopods in all directions. Subsequently, branches in areas without food are gradually abandoned, while those connecting to food are reinforced and become thicker (Adamatzky, 2010). This dynamic interaction results in intricate route patterns and connection structures in PP, emerging from "billions of dynamic interactions" (Adamatzky, 2019, p. 102).

In "GAN_Physarum: *la dérive numérique*," a design proposal developed within DeepGreen, a satellite image of Paris undergoes processing to extract the biotic layer of information. This information is then remapped onto a physical grid to provide an accurate distribution of biomass density. Density percentages are subsequently translated into nutrient quantities on a canvas. The bio-computational process is initiated with the introduction of PP (Pasquero & Poletto, 2021a). As the PP grows and reacts with the substrate, networks gradually emerge, exhibiting a prototypical path system for the future of Paris (Figure 4). The bio-computational results of PP undergo further manipulation through the CycleGAN AI protocol, visualizing a novel urban fabric across various scales, with the resolution incrementally increased. The AI eventually bridges the abstract pseudopod networks and the vivid urban satellite maps, completing the simulation of the future urban morphology for Paris. This simulation transcends "traditional planning concepts such as zone, boundary, scale, typology, and program" (Pasquero & Poletto, 2020, p. 136). The resulting urban morphology, shaped by the interaction between architecture and the green network, serves as a speculative model for future urban planning reference (Figure 5).

In the DeepGreen protocols, urban data are sourced from remote sensing satellites, GIS (geographic information system), and DEM (digital elevation models) (Pasquero & Poletto, 2017). This information is then processed and recreated through the coupling of biological and artificial

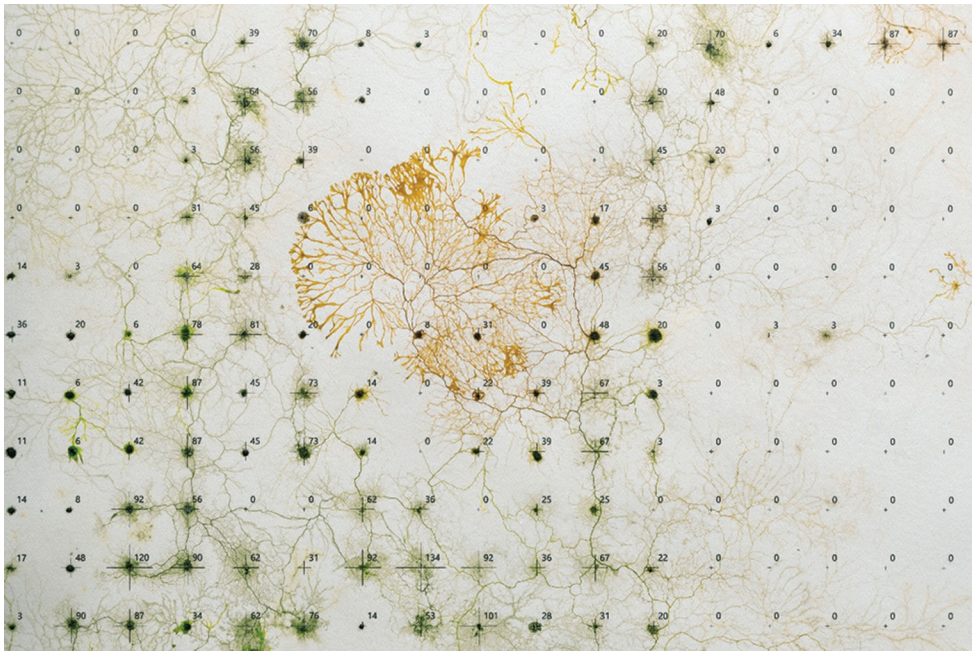

Figure 4. Bio-painting of slime mold. Source: ecoLogicStudio, GAN_Physarum: *la dérive numérique*, 2022

Figure 5. GAN_Physarum: Paris (scale: 10 km). Source: ecoLogicStudio, GAN_Physarum: *la dérive numérique*, 2022

intelligence. The resultant ecological infrastructures, built upon biomass, water collection, solar energy, and community waste, constitute the future cities. These cities are meticulously planned in a bottom-up fashion, taking into account the needs of both human and non-human entities. Running in parallel with this development are ecoLogicStudio's architectural and installation-scale prototypes built based on bioreactors, such as Urban Algae Folly (2015), Photo.Synthetica Curtain (2018), and Air Bubble (2021). These prototypes directly integrate human habitats with non-human elements (such as microalgae) at the microclimate level. This integration enables non-human entities to metabolize human waste, effectively closing the loop and contributing to a regenerative cycle. The integration of blue-green infrastructure planning and regenerative architecture prototypes forms a synergistic approach aimed at building the regenerative city.

Throughout these processes, design cedes ground to non-human organisms and machines, with an intensified focus on their subjectivity. It is non-human entities, acting through humans that take the lead in designing urban ecological spaces. Multiple design agents create intricate feedback loops, fostering mutual balance, self-regulation, and system resilience for the seamless integration of architectural and ecological systems. As a consequence, a bio-cybernetic stance and approach have been proposed to transcend human limitations and envisage a non-anthropocentric future. In the context of the Anthropocene, where human activities significantly shape nature, the bio-cybernetic stance reaffirms the coexistence of technical devices (machines) and living organisms, dissolving the dichotomy between artificial and natural, human and non-human. It aspires to deconstruct and subsequently reconstruct the relationship between humans and nature into a unified whole, propelling directly toward the post-nature era. This attitude coincides with the holistic conception of nature and ecological views found in ancient Chinese Daoist philosophy ("Nature and Humans in One Unity"). This philosophy argues for the inseparability of humans and nature, subject and object, as all originate from

the "Dao," the primordial force that gives birth to all things (Yin, 2012). Building upon this philosophy, we advocate for the inclusion of machine intelligence as a digital form of life, further blurring the boundaries between organic and inorganic, material and digital. This expansion broadens the scope of the holistic view.

3. Abduction as patterns of inference: The logic structure of innovative design

The origins of regenerative architecture can be traced back to the critique of sustainable design. Littman argued that sustainable design is an inadequate approach as it stops at sustaining the status quo and minimizing harm rather than improving and benefiting the planet (Littman, 2009). Therefore, regenerative design aims to take a step forward and go beyond sustainability. This critique coincides with reflections on the prevailing anthropocentric problem-solving paradigm, under which designs are bringing about changeless changes rather than probing into meaningful innovation (Pasquero & Zaroukas, 2016).

To explain how design can function as an innovative activity, design thinking is an essential topic that cannot be bypassed. Goldschmidt and Weil argued that design is now construed as the outcome of thinking and cognitive processes (Goldschmidt & Weil, 1998). Ever since Rowe's proposal in 1987, design thinking has gained widespread recognition across a wide range of fields (Dorst, 2011). It has gradually become an academic consensus among design educators and researchers (Cross *et al*., 1992). Under labels such as speculative design, critical design, radical design, discursive design, and interrogative design (Attolico, 2019), the practice and methodology for design thinking are investigated in fine art and industrial design to activate ideas and innovations (Auger, 2013; Dunne & Raby, 2013). Similarly, speculative design is committed to fulfilling the potential of design, technology, and materials in architecture and urbanism (Bratton, 2016). Beyond the scope of design, design thinking is deemed a social technology to facilitate creativity in business (Liedtka, 2018), an innovation tool for organizations in management (Wrigley *et al*., 2020), and an inspiring interdisciplinary collaboration method in education and industry (Paay *et al*., 2021). Research interests in design thinking span both practical and theoretical purposes. The latter underscores the nature of creative thoughts. Elaborated by Roozenburg, Eekels, and Dorst, the core of design thinking is built on different kinds of design reasoning or formal logic (Roozenburg & Eekels, 1995; Dorst, 2011).

The DeepGreen project has set its sights on planning and designing regenerative ecological infrastructure (Figure 6). The core model, GAN_Physarum, demonstrates novelty

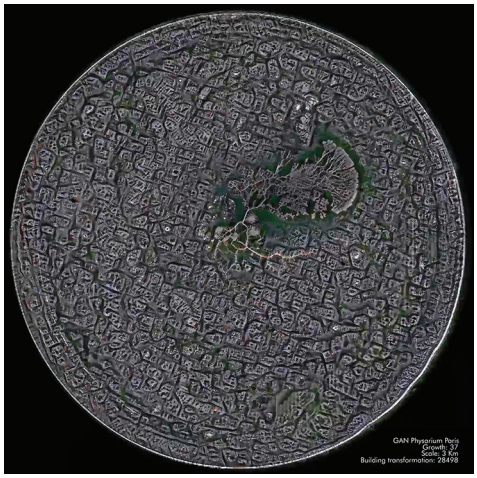

Figure 6. GAN_Physarum: Paris (scale: 3 km). Source: ecoLogicStudio, GAN_Physarum: *la dérive numérique*, 2022

and innovation in both workflow and outcome. To decode the innovative design and summarize the knowledge, one possible avenue lies in design reasoning. The design logic behind the DeepGreen protocols is worthy of analysis.

When dealing with the same design task, various modes of design reasoning may entail various design workflows and outcomes. For example, with regard to the ecological infrastructure, certain think tanks and city planning councils have established relevant design guidelines and action plans, which can serve as a framework for project design. Since the guidebook itself is a workflow codified by academics and experts, even a novice designer can structure a planning map by following the instructions when the context of the project aligns with its application scope. In other words, the specific design outcome is inferred from well-defined logic rules and premises, which is deduction. Deduction requires substantial previously established theoretical knowledge. In this reasoning, all the information and conclusions are already contained in the premises. No new knowledge is generated; it is merely a tautology (Hintikka, 1998), which can only infer the necessary inferences and results. That is clearly not how the Deep Green project envisioned the scenario.

Another circumstance involves dealing with projects for which a guidebook is not available. Certain designers may search for multiple design cases to consult. From these reference cases, it is feasible to derive a workflow to implement ecological infrastructure planning. That is, the logical rules for design are obtained by synthesizing a rich set of specific cases, which is inductive. This mode of reasoning is a generalization of empirical phenomena. The expansion is limited to the descriptive summary of specific features (Haig, 2014), which has nothing but to determine

a value. The upper bound on the design outcome is already fundamentally determined by the original database. However, as an innovation rather than an improvement, there are no pre-existing and comparable references for the DeepGreen protocols.

The GAN_Physarum model in the DeepGreen project draws form-driven inspiration from slime molds and trains an AI to project the network onto urban forms (Figure 7). Elements that do not originally exist in the urban typology are absorbed and transformed into the new urban morphology, altering the initial design expectations. This process of ideation is not delimited by pre-existing paradigms and experiences, and thus, its logic differs from deduction and induction. It is clear that these two models of reasoning are inadequate to explain how new knowledge and ideas arise. This is why Charles Sanders Peirce developed abduction as an extended and comprehensive reasoning mode to create new hypotheses and knowledge (Burks, 1946). Peirce exemplifies the variations among the three reasoning modes as presented in Table 1 (Peirce, 1878):

"Deduction is the inference of a result from a rule and a case (...) Induction is the inference of a rule from a case and a result (...) Abduction is an inference of a case from a rule and a result" (Roozenburg, 1993, p. 9). In fact, common modes of reasoning infer from a cause to its effect, while

Figure 7. GAN_Physarum: Paris (scale: 1 km). Source: ecoLogicStudio, GAN_Physarum: *la dérive numérique*, 2022

abduction is a quasi-causal process inferring from the consequence (usually a surprising fact) to its precondition, inquiring what entails this effect. Abductive reasoning does not point directly to an absolute conclusion but tends to find explanations. Thus, the abductive conclusion has some residual uncertainty and is still a hypothesis to be verified (Sober, 2019).

Design reasoning inherits reasoning models from scientific reasoning. Commonly, deductive reasoning arrives at design outcomes from explicit and approved premises to show what must be. Inductive reasoning generalizes what literally is by summarizing specific examples. Abductive reasoning offers new recipes and redefines the desired value in design, suggesting what may be (Dong *et al.* 2012). However, in Roozenburg's opinion, Peirce specified two abductive modes. He re-articulated the two patterns as explanatory abduction and innovative abduction. The first pattern is interpreted as the following syllogism (Roozenburg, 1993):

Premise q a given fact, a desired result

Premise p → q a given rule, IF p THEN q

Conclusion p the cause (I)

In explanatory abduction, the rule is known and becomes a premise, allowing us to infer from the result to the cause. Roozenburg commented that the abduction in Syllogism I "is not about discovery but about diagnosis or troubleshooting" (Roozenburg, 1993, p. 10). In contrast, innovative abduction involves the conception and inference of the rule along with the cause without assuming the rule's truth. This pattern is, therefore, expressed as (Roozenburg, 1993; Kroll & Koskela, 2017):

Premise q a given fact, a desired result

Conclusion p → q a rule to be inferred, IF p THEN q

Conclusion p the cause (II)

Since the hypothesis enabling us to infer from result to cause (p→q) remains to be supplemented, "the essence of abduction lines in finding or forming the missing hypothesis" (Roozenburg, 1993, p. 9). Peirce, in particular,

Table 1. The variations among the three reasoning modes exemplified by Peirce

Reasoning mode	Rule	Case	Result
Deduction	All the beans from this bag are white.	These beans are from this bag.	These beans are white.
Induction	These beans are from this bag.	These beans are white.	All the beans from this bag are white.
Abduction	All the beans from this bag are white.	These beans are white.	These beans are from this bag.

emphasized that the generation of hypothesis includes our interpretation of certain preference, which is not based on past knowledge affecting the truth of the hypothesis, nor is it based on the test of the hypothesis after admitting a certain possibility of the hypothesis (Parisi, 2013). Hence, compared with deduction and induction, abduction is not delimited by "a priori theory or a posteriori verification" (Parisi, 2013, p. 234). Roozenburg insisted that innovative abduction (Syllogism II) should be the key reasoning in design so that innovation could be created, responding to the original idea of abduction to produce new knowledge. Building on this foundation, Kroll & Koskela interpret syllogisms in the context of design. They added that the function or the desired result of design could be the starting point (q). The rule to infer from p to q may be "a working principle associated with the desired function, or a description of some structure associated with the working principle" (Kroll & Koskela, 2017, p. 64).

In this regard, the DeepGreen project's logical structure is identified as innovative abduction. The design reasoning starts from a vague purpose – the vision for a self-organized urban ecological infrastructure (q) – and then conceives and infers rules and causes. The combination of PP and CycleGAN is not based on previous design frameworks and examples but is purely speculative. Subsequently, GAN_Physarum becomes the rule (p→q) to infer slime mold computation (p) to the urban infrastructure (q); both the workflow (p→q) and the slime mold network (p) are the results of inference. Having clarified this logical structure, the operation of the newly established workflow reshapes the ambiguous design purpose into a vivid urban morphology (Figure 8). Nevertheless, the outcome of the phase remains a speculative hypothesis to be tested. It necessitates deduction to verify its feasibility and, through repeated implementation, eventually becomes generalized as a theory through induction. This follows the three-step scientific inquiry procedures outlined by Peirce, which March adopted as the Production-Deduction-Induction (PDI) model in design (March, 1976).

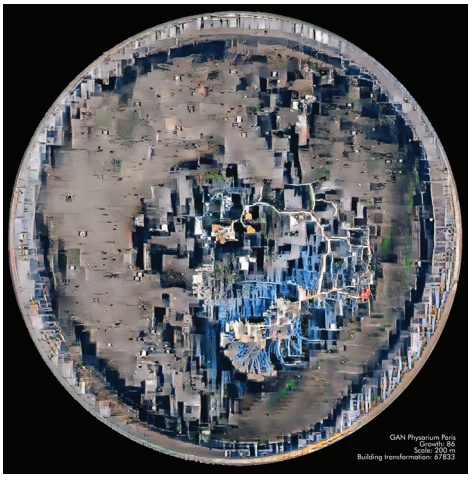

Figure 8. GAN_Physarum: Paris (scale: 200 m). Source: ecoLogicStudio, GAN_Physarum: *la dérive numérique*, 2022

Consequently, GAN_Physarum, as a product of abductive reasoning, is speculative but innovative. This inference motivates the invention of new rules and the realization of novel outcomes, suggesting a higher level of innovation than other design reasoning modes. It is not intended to solve problems but rather to provoke more questions and discussions that drive the design. It is worth mentioning that without a fundamental shift in the design reasoning and orientation, the application of non-human computation may simply establish an algorithmic description of the design, resulting in rule-based form generation (deductive method). Alternatively, it may only increase the number of reference cases and the speed of induction, optimizing existing solutions (inductive method). In this sense, technology does not thoroughly renew the value of design but leads to changeless change. We may conclude that decision-making in problem-solving sustainable design tends to exclude and converge options. The thinking underlying regenerative design (such as DeepGreen protocols), with its implied innovation to break through the status quo, needs to be divergent, exploratory, and even disruptive. This is why abduction, as a logical structure, facilitates possible innovations and regenerative architecture.

4. Abduction as patterns of cognition: The mind ecology of morphogenesis

As the logical structure of DeepGreen becomes an apparent example of innovative design protocols, it can be observed in the syllogism of abductive reasoning that both rule (p→q) and cause (p), in this case, GAN_Physarum and PP, are the conclusions of abductive inference, implying that they should emerge together. "You do not have 'p' unless you have 'p→q,' and vice versa; neither of them can be seen as a premise (...) Indeed, abduction typically comes to us in a flash" (Roozenburg, 1993, p. 11). Davis explained that "All of the component ideas in an abduction may have been present in the mind before the abduction was made, but the new combination of ideas or the relation between them is what is new in an abduction. (...) Sometimes one has to stare at the problem for some long period of time before the whole solution appears before the mind's eye in a moment of 'insight' "(Davis & Davis, 1972, p. 48). Parisi commented that abduction as a speculative device "includes a mutual yet indirect interplay between method and object, a real yet inexact connection of thought and fact, a constructive

tension between conditions and occurrences, premises and predictions" (Parisi, 2013, p. 238).

Regarding the GAN_Physarum model, CycleGAN is an existing invention. PP and cities are not recent scientific discoveries. The computation of PP is believed to be a potential inspiration for urban design. It is the combination with CycleGAN that turns unattainable ideas into real applications, defining PP as a form-generating machine. The relationship between technologies, between PP and cities, is new to DeepGreen's research. The establishment of their relations cannot, however, be entirely exhausted by logic. Descriptions such as an elusive "flash" or "moment of insight" are the reason why researchers question whether abduction is a truly logical pattern in the conventional sense, as part of it extends beyond the scope of logic. Hence, the study of abduction diversified into the broader field of cognition.

Gregory Bateson once proposed that abduction is "the lateral extension of abstract components of description." After describing certain events and deriving certain rules, we then "look around the world to find other instances" that "fit the same rules" and share "the same abstract relations" (Bateson, 1979, p. 142). Jeff Hawkins's theory of intelligence provides understanding from cognitive science. He addressed that "truly random thoughts don't exist. Memory recall almost always follows a pathway of association." The concept of association is established through the use of analogy, which involves comparing external objects or ideas to those already present in our memories (Hawkins & Blakeslee, 2005). Gardner adopted this theory as a foundation to explain design reasoning as an analogical operation or pattern-matching process based on varying levels of similarity, among which abduction carries out pattern matching (finds similarity) on a high abstract level (Gardner, 2009). In the GAN_Physarum model, abduction establishes a relationship between PP and cities through analogical association. PP creates efficient networks for the transport of energy and nutrients. Similarly, path systems serve as transportation networks for cities (Figure 9). Drawing on Peirce's syllogism of abduction and Bateson's "syllogism in grass," we can construct a syllogistic structure regarding PP and urban path system to describe this relation, as presented in Table 2.

Bateson's conclusion that "humans are grass" may be scientifically false, but as Borden explains, it is the metaphor commonly found in poetry. The thinking, which forms metaphorical relationships, finds its best explanation in the "mind-like process of abduction" (Borden, 2017). Therefore, the concept of Physarum city proposed by "PP's pseudopod networks are urban path system" is also a poetic metaphor, implying the abstract similarity between the two entities. This is the basis of how abduction establishes the relationship between PP and the city. In addition, we were once hampered by the large-scale difference between PP and the city, but CycleGAN allows us to jump over this wide divide. In the "eyes" of AI, the two patterns are compatible (Figure 10). AI is thus not merely a tool to translate PP computations to urban morphology; it genuinely helps humans uncover the synthesis between seemingly unrelated and vastly disparate things, aligning with the analog operations of abduction and materializing abstract linguistic metaphors into concrete visual images.

According to Bateson, abduction as a mind-like process is a common phenomenon. "Metaphor, dream, parable, allegory, the whole of art, the whole of science, the whole

Figure 9. Urban fabric (left panel) and slime mold (right panel) networks. Source: ecoLogicStudio, Deep Green, Urbansphere, Venice, 2021

Table 2. Peirce's syllogism, Bateson's syllogism, and syllogistic structure regarding PP (*Physarum polycephalum*) and urban path system

Syllogism	Rule	Case	Result
Peirce	All the beans from this bag are white	These beans are white	These beans are from this bag
Bateson & Bateson, 1987	Grass dies	Humans die	Humans are grass
GAN_Physarum	Urban path systems are transport networks	PP's pseudopod networks are transport networks	PP's pseudopod networks are urban path systems

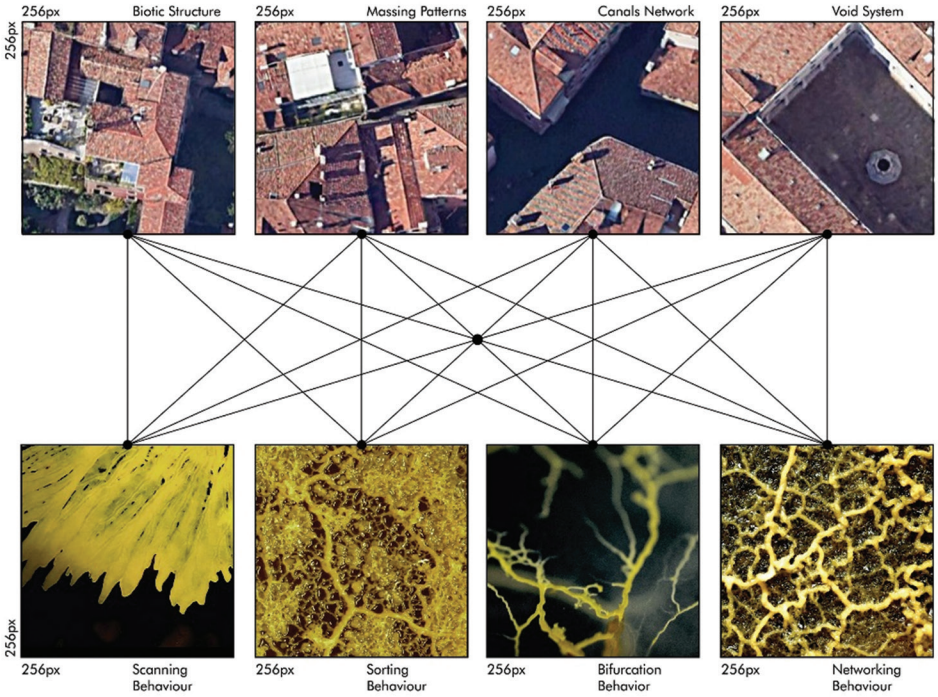

Figure 10. The processing of urban satellite images with slime mold images through GAN_Physarum. Source: ecoLogicStudio, Deep Green, Urbansphere, Venice, 2021

of religion, the whole of poetry (...) these are instances or aggregates of instances of abduction, within the human mental sphere." In his view, abduction also occupies a great region in nature and in our thinking toward nature, such as evolution and ecology. On this basis, Bateson proposed the concept of mind ecology, expanding the notion of the mind beyond the human body. He aimed to reshape the epistemology, the "knowing how," of nature, to establish connections common to all living beings (Bateson, 1979). PP "knows" how to grow and establish efficient transportation networks. AI "knows" how to perform pattern matching (Figure 11). What they possess may not be human-like thinking, but it is indeed a form of what Hayles referred to as "cognitive non-conscious" (Hayles, 2014). Although humans do not fully understand their epistemology, the non-humans still possess embedded cognition, which could be new knowledge for humans. In the DeepGreen project, abduction, as patterns of cognition, links the minds of humans and non-humans together. "The search for meaning then becomes a pervasive activity among humans, animals, and technical devices, with many different kinds of agents contributing to a rich ecology of collaborating, reinforcing, contesting and conflicting interpretations" (Hayles, 2014, p. 217). This represents the first layer of meaning in the mind ecology based on a bio-cybernetic stance, that is, the correlation between multiple design agents.

Bateson's pursuit of connections that span the entire world, known as "patterns which connect," is embedded within the biological language of how organisms come together and develop. Bateson rejected rigid classifications of organisms and studied how forms of individual life evolve and change (Borden, 2017). The same organism may exhibit a variety of forms at various stages of its life. Typicality-based research breaks the underlying organic connections between forms. This insight has thus inspired reflection in

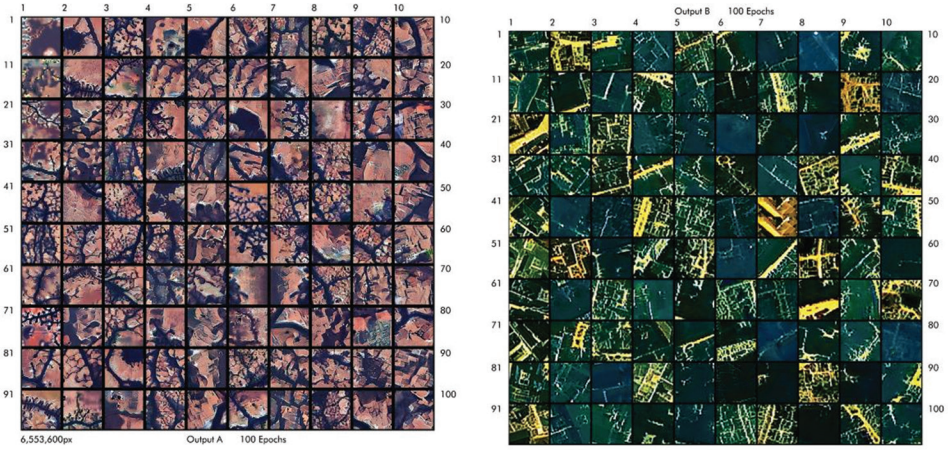

Figure 11. The outcomes of the GAN_Physarum computation. Source: ecoLogicStudio, Deep Green, Urbansphere, Venice, 2021

the study of cities, transforming urban typology into urban morphogenesis. It shifts the focus from the form of the city to how variations in the environment and resources may impact the form generation of the city. We argue that this is the second layer of meaning in mind ecology, suggesting the correlation within the multiple stages of the same entity. The two layers of meaning initiate the correlation of all and resonate with the epistemology behind the "Nature and Humans in One Unity" in Daoist philosophy, which recognizes the unity and interconnection of all things. In this regard, the concept of urban morphogenesis embodies such unity and coherence in urban design. This notion becomes computational thinking in the self-organizing city (Poletto & Pasquero, 2012).

The DeepGreen protocols establish not only an innovative workflow but also an algorithmic model that combines biological and digital computation, serving as the DNA for the urban form. Training GAN_Physarum to behave like a PP is also driven by the unique computational mechanisms of PP. PP does not simply compute; it still exhibits uncertain behaviors in any particular case, which is also a form of free will. This is because "it does not follow a rigid priori rules but instead operates according to a 'heuristic dynamic,' relying on 'unbiased physical, chemical and biological laws'" (Shaviro, 2016, p. 321). That is, the GAN_Physarum model also does not follow a top-down and deductive algorithmic procedure that invariably presents the same conclusions when the parameters are kept constant. PP's method is bottom-up, demonstrating a self-organizing system that changes its morphology according to interactions (Figure 12). As a consequence, urban design is no longer centered on static forms but strives to build dynamic and adaptive models. Urban morphology becomes "the result of a computational interaction between internal rules and external (morphogenetic) pressures that themselves originate in other adjacent forms (ecology)" (Kwinter & Davidson, 2008, p. 147).

This morphogenetic process within the DeepGreen project demonstrates the understanding of algorithms as "natural" patterns and embedded forms to compute in a biological manner and design in an ecological way. In fact, in ancient Chinese architecture and urban design, there was profound contemplation and emulation of nature behind the selection, layout, and construction of cities and buildings (Almodovar-Melendo & Cabeza-Lainez, 2018). Daoist philosophy holds that humans should discover the Dao of Nature by observing and understanding the phenomena of all things and applying it as a guiding principle for human behavior (Yin, 2012). Today, we perceive that the Dao of Nature embodies the interconnection and unity of all things and points toward a developmental, dynamic, and adaptive pattern. Therefore, the morphogenetic approach, integrating the collective intelligence of humans and non-humans, echoes this philosophical concept and could be a contemporary understanding and extension of "The Dao Imitates the Laws of Nature" in urban design.

5. Discussion

This article presents the DeepGreen project as an exercise in regenerative design, which applies digital algorithmic analysis, biological computation, and AI to establish design protocols for urban ecological infrastructure. The project envisions innovative urban fabrics at various resolutions, ranging from the urban scale to the architectural scale. The design process is intricately woven around the innovative and ecological thinking of abduction as well. Non-human entities become design agents and bio-citizens (Pasquero & Poletto, 2020) to create rich and complex feedback loops, realize circular urban metabolism, and integrate architectural and ecological systems.

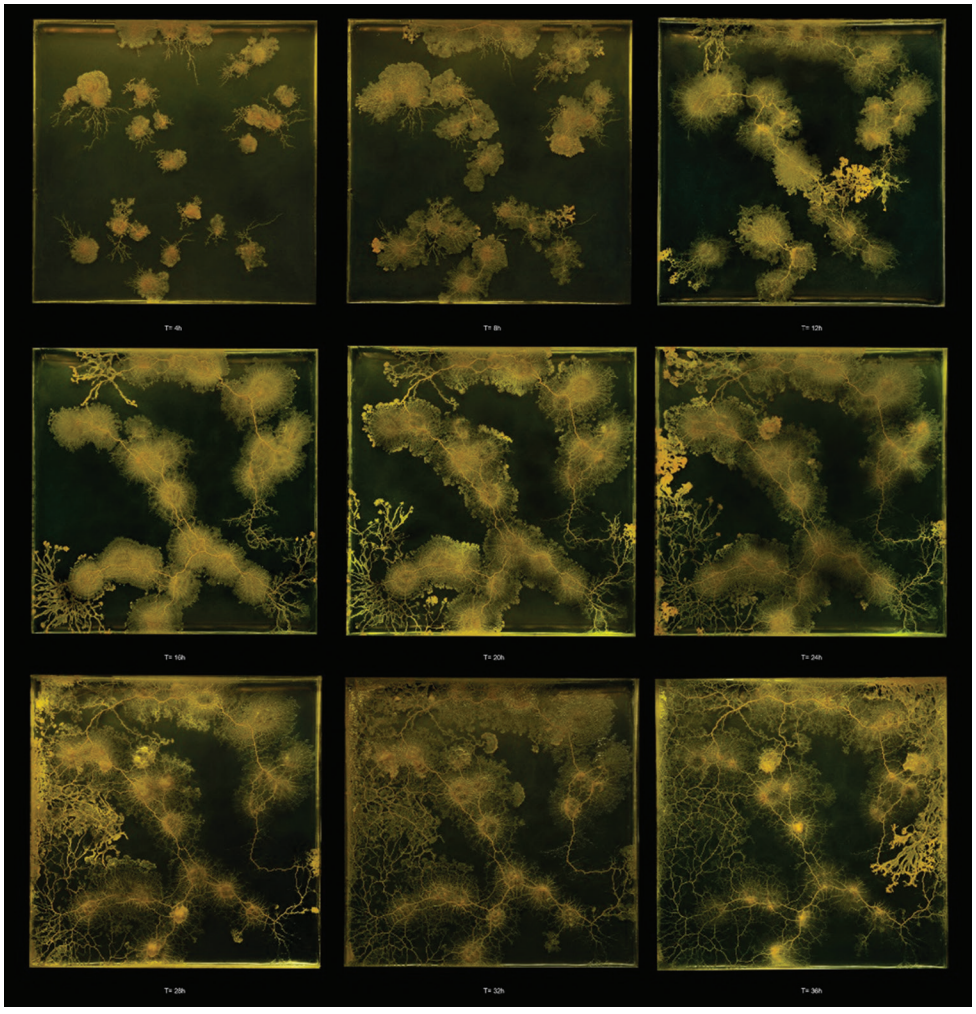

Figure 12. The computational process of PP. Source: Urban Morphogenesis Lab, Physarum Morphological City, 2019

Nonetheless, implementing innovation in architecture and urban design always encounters challenges and obstacles. In this field, progressing from proposing an innovative idea to completing the project requires meticulous refinement and consideration, given the project's vast scale, substantial investment, lengthy construction period, and multiple risk factors. This process inevitably dictates that DeepGreen is poised to be a long-term research project. The research trajectory spans from 2D urban plans to 3D spatial volumes, progressing from initial blueprints to small-scale prototypes and eventually to large-scale construction. Guided by abductive reasoning, this design process formulates hypotheses and speculations for subsequent testing, culminating in the development of a mature theory. Therefore, immediate results are unattainable. In contrast, in disciplines such as industrial design, innovation often implies invention, promising more immediate application prospects and value. This distinction has prompted fervent research interest in design thinking and design innovation. However, we contend that fostering discussions on innovation and deepening comprehension of the nature of design thinking will also benefit regenerative architecture. Moreover, it can contribute significantly to the education and practice of the architecture industry itself. Therefore, we advocate for adopting a long-term perspective.

Another limitation is that this innovative and ecological cognitive process, the abductive approach, cannot be adequately described by logic and algorithmic models. However, in a sense, it is precisely this incompleteness that affirms the necessity of biological-cybernetic coupling – the progressive decoding of the unknown into the known, as humans extend their cognition through the non-human.

When it comes to bio-politics and ethical considerations, the mention of non-human-oriented urbanism and bio-

citizens within the prevailing human-centered society and design paradigms is likely to encounter moral and cognitive barriers and even significant bias. We argue that these ideas do not aim to diminish or marginalize humans but rather seek to transcend human limitations by harnessing collective intelligence while acknowledging the human condition.

6. Conclusion

Given the existence of these limitations and challenges, we can still conclude that the DeepGreen research design project proposes a bio-cybernetic stance and approach aimed at dissolving the dichotomy between artificial and natural, human and non-human. This direction is toward a post-nature era where humans and nature merge into one unified whole. This attitude resonates with the holistic conception of nature and ecological views found in ancient Chinese Daoist philosophy. Building on this, we propose the inclusion of machine intelligence as a digital form of life, further blurring the boundaries between organic and inorganic, material and digital, thereby expanding the scope of holistic view.

The article highlights the pivotal role of the GAN_Physarum model within the DeepGreen protocols. The logical structure of the design follows the innovative abduction proposed by Peirce and formally named by Habermas. This inference stimulates the creation of new rules and the realization of novel outcomes, demonstrating a higher level of innovation than other design reasoning modes. Consequently, the approach shifts from problem-solving sustainable design to problem-making regenerative design. From a cognitive perspective, abduction establishes metaphorical relationships between seemingly unrelated entities (such as PP's pseudopod networks and urban path systems) through analogical association. The DeepGreen protocols offer an algorithmic model as the DNA for the self-organizing city, transforming urban typology into morphogenesis and revealing correlations within multiple stages of the same entity. This approach aligns with Bateson's "patterns which connect" in mind ecology and resonates with Daoist philosophy's recognition of unity and interconnection.

According to Bateson, "the major problems in the world were the result of the difference between how nature works and the way people think" (Borden, 2017, p. 89). Daoist philosophy asserts that individuals should uncover the Dao of Nature and adopt it as a guiding principle for living. In today's context, we perceive that the Dao of Nature embodies the interconnection and unity of all things, indicating a developmental, dynamic, and adaptive pattern. Therefore, what we propose as the post-nature, the regenerative design, and the integration of nature into architecture requires the assimilation of collective intelligence, feedback loops, circular metabolism, and morphogenetic mechanisms within ecological systems.

Through the lens of post-nature and mind ecology, this research identifies commonalities with the holistic conception of nature and ecological views in ancient Chinese Daoist philosophy. The bio-cybernetic stance and morphogenetic approach could represent a possible understanding and contemporary interpretation of "Nature and Humans in One Unity" and "The Dao Imitates the Laws of Nature." This research, henceforth, endeavors to foster discourse between Eastern and Western trends of thought, culminating in a cohesive yet heterogeneous regenerative approach. We believe that the content of regenerative architecture encompasses not only the material but also the informational and spiritual levels. Establishing an innovative and ecological design thinking mode contributes to a thorough and comprehensive understanding of natural and life systems in design (Reed, 2007), embodying a more profound connotation for the motif of regenerative architecture.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Xiao Wang, Claudia Pasquero
Formal analysis: Xiao Wang

Investigation: Xiao Wang, Claudia Pasquero
Methodology: Xiao Wang
Writing – original draft: Xiao Wang, Claudia Pasquero
Writing – review & editing: Claudia Pasquero

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The urban data, regarding the satellite map, vegetation, and so on, are open source data from ESA Map (European Space Agency). It can be accessed through ESA's Copernicus Open Access Hub.

Further disclosure

The information and workflow of the DeepGreen research project were presented at the conference of the Association for Computer Aided Design in Architecture (ACADIA).

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ACCSCIENCE PUBLISHING

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ORIGINAL ARTICLE

Digital twin applications in an archaeological site: A virtual reconstruction of the Pishan site, Zhejiang, China

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Abstract

A digital twin is a virtual counterpart of a physical object or system based on precise data collection. Although digital twin applications are gaining traction in the virtual reconstruction of built heritage, their relevance in archaeological sites remains limited, especially for those with only foundations. The Pishan (毘山) site in Huzhou, featuring the remains of a high-platform building and a large stilt-style architecture, represents the largest settlement site from the late Shang (商, ca. 1600 – 1046 BCE) and early Western Zhou (西周, 1046 – 771 BCE) dynasties in Zhejiang Province, China. At present, confronting contradictions among preservation, restoration, and reuse as a heritage park, the site leverages digital twin technologies to address two concerns: (i) reconstructing a 3D scene for further restoration and related studies and (ii) integrating multimedia to enhance visitors' experiences and dissemination. Photogrammetry, unmanned aerial vehicle, and a mirrorless camera are employed to collect sky and ground dual graphic data and reconstruct the 3D model of the loess terrace. A panoramic roaming environment is created through panoramic photography. Geographic information system is integrated to enable visual analysis and information management while building information modeling facilitates the integration of parametric modeling and point cloud, aiding virtual restoration research. In conclusion, a workflow entitled "Virtual Reconstruction – Management and Analysis – Restoration – Exhibition" is proposed, promising in-depth exploration in further studies.

Keywords: Digital twin; Virtual reconstruction; Restoration; Photogrammetry; Panoramic photography; Archaeological site

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1. Introduction

The concept of digital twin, as proposed by Grieves and Vickers (2017), encompasses real space, virtual space, links for data flow from real space to virtual space, links for information flow from virtual space to real space, and virtual sub-spaces. Its primary objective is to enhance product lifecycle management. In essence, the digital twin serves as a virtual counterpart of a physical object or system, relying on precise data collection through simulations, sensors, graphic documentation, and machine learning.

This comprehensive approach aids in visualization, management, analysis, and decision-making (Angjeliu *et al.*, 2020; Kantaros & Piromalis, 2022). Widely employed across various fields such as satellite/space communication networks, ships, vehicles, power plants, aircraft, complex equipment, building engineering, mining and energy engineering, medical and healthcare, agriculture, shop floors, smart cities, and digital twin technology improve the understanding of physical entities (Tao *et al.,* 2019; Gabellone, 2022). Authorities strongly endorse its applications, evident in initiatives such as "digital built Britain" in the United Kingdom (National Digital Twin Programme, 2022) and the "digital twin of water conservancy" in China (Ministry of Water Resources, 2023).

In the field of built heritage, the digital twin itself serves as a perfect mirror object of the physical built heritage, presenting a high-resolution spatial and graphic dataset. It finds applications in many heritage sites with different materials, areas, and preservation conditions, serving purposes such as documentation, visualization, management, monitoring, decision-making, simulation, prediction, and more (Dang *et al.*, 2023). An exemplary instance of its application is the faithful reconstruction of Notre Dame after its 2019 fire, initiated with the aid of terrestrial laser scanning (TLS) for full-scale spatial data collection (Lepère & Lemmens, 2019). Similarly, the Mcbain Building in Shanghai, China, has developed a digital twin model that provides valuable data support for design, construction, monitoring, management, activation, and preventive conservation (Shanghai Cultural Relics Protection Buildings, 2023). Digital twin models can also store attribute data, such as hygrothermal and mechanical properties, facilitating further exploration (Gabellone, 2022). Angjeliu *et al.* (2020) integrated the physical monitoring datasets into an accurate digital twin model to investigate the masonry structural response of the Milan Cathedral in Italy, aiding in preventive maintenance, and strengthening operations.

The toolkit for digital twins in built heritage encompasses a range of software and techniques. 3D surveying and mapping technologies, such as 3D laser scanning (Pepe *et al.*, 2021; Lenda *et al.*, 2023), photogrammetry (Arza-García *et al.*, 2019; Galantucci & Fatiguso, 2019), and panoramic photography, enable the creation of a virtual counterpart that mirrors the physical object. In addition, a global positioning system within the physical device aids in spatial positioning. Information management techniques, such as geographic information system (GIS) and building information model (BIM), establish connections between the reconstruction model and various data, facilitating the visualization of analytical functions. Virtual technologies, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), activate the digital museum, promising an immersive and accessible experience. Furthermore, the integration of the Internet of Things (IoT), sensors, big data, cloud computing, 5G, and artificial intelligence has the potential to enable real-time condition monitoring, big data management and analysis, simulation and prediction, and supportive or automatic decision-making in the virtual world (Piromalis & Kantaros, 2022; Dang *et al.*, 2023).

Archaeological sites within built heritage present unique and varied challenges to digital twin applications. While basic preservation, exhibition, and management are commonly planned goals, the demand for simulation and analysis, particularly in the context of virtual restoration, has become essential. This necessity is evident in cases such as the Pishan site in Zhejiang, China, where excavation of a loess terrace (LT) with building remains requires uncovering its cultural appearance and original architectural profile. However, only pillar holes and residual wood remain, shrouding the original appearance in mystery for researchers. Virtual reconstruction of the LT is necessary to prevent potential damage caused by continuous surveys and to enhance overall comprehension. Pierdicca *et al.* (2016) have successfully addressed similar challenges by integrating spherical photogrammetry and dense reconstruction techniques to complete a virtual reconstruction of a building in a UNESCO archaeological area in Peru. In another study, Banfi *et al.* (2023) integrated laser scanning, digital photogrammetry, and unmanned aerial vehicle (UAV) data to reproduce archaeological, architectural, and infrastructure scales in Roman-built heritage. While there are abundant digital survey cases for built heritage, including archaeological sites, experiences like that of the Pishan site – characterized by being an underground site without walls, patterns, or even a half-complete pillar – are rare and still challenging.

In this scenario, we propose our work: the virtual reconstruction and restoration of the LT and its surroundings, both in a virtual circumstance through digital twin technologies. We initiate the process by reconstructing a 3D model of the LT through photogrammetry. Subsequently, we create an immersive panoramic environment using panoramic photography. Furthermore, we propose to complete the restoration research with the help of visualized analysis and information management based on GIS, and integration of point cloud and parametric modeling based on BIM. Therefore, the digital twin matters not only because it facilitates the reconstruction of a reliable digital replica

of the physical site but also because it has the potential to integrate multi-source and multi-format information to help the comprehensive restoration work for building remains in archaeological sites.

1.1. The study site

The Pishan (昆山) site, located in Pishan Village, Hudong Street, Wuxing District, Huzhou City, Zhejiang Province, China, is positioned 10 km south of Taihu (太湖) and in the lower reaches of the Yangtze River (长江), as depicted in Figure 1. The main remains at the site date back to the Neolithic Age through the Zhou (周, 1046 – 256 BCE) dynasty. Notably, it holds the largest site from the late Shang (商, 1600 – 1046 BCE) dynasty to the early Western Zhou (西周, 1046 – 771 BCE) dynasty in Zhejiang province. Since its discovery in 1957, the site has undergone numerous ground investigations. Six formal archaeological excavations were conducted in 1995, 2000, 2004 – 2005, and 2008, leading to the publication of the archaeological report *Pishan*. In 2013, the Pishan site gained national recognition as a major historical and cultural site, securing protection at the national level in China and becoming part of the first batch of provincial archaeological site parks in Zhejiang Province. Simultaneously, *the Archaeological Work Plan of Huzhou Pishan Site (2014 – 2018)* was formulated (Yan *et al.*, 2022).

In 2013 and 2014, an extensive exploration of the Pishan and Xishan area was conducted, resulting in the determination of an area covering nearly 1 million sqm at the Pishan site. To determine the specific boundary of the Pishan site and elucidate the characteristics of cultural

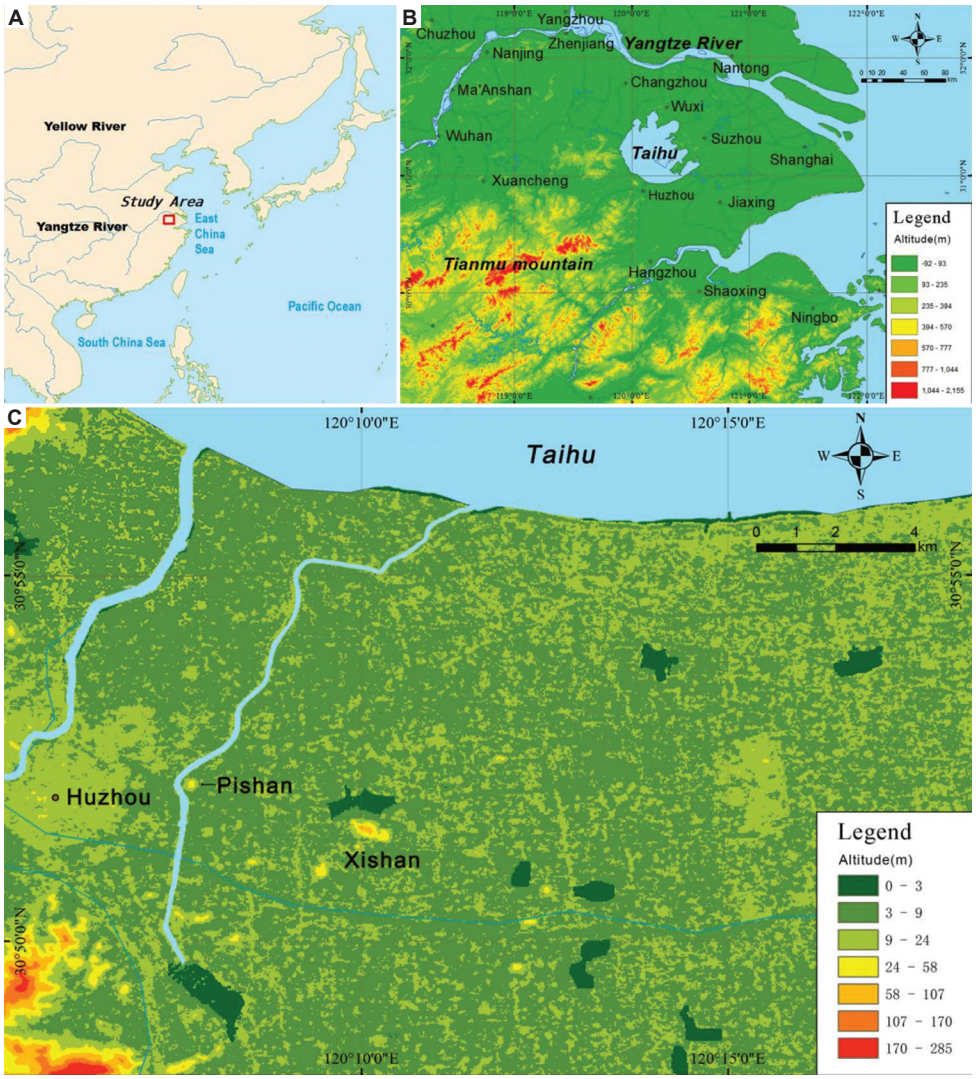

Figure 1. Location map of the Pishan site. (A) Study area in the lower reaches of the Yangtze River. (B) Yangtze Delta and the location of Huzhou. (C) Topographic map of Huzhou and the location of Pishan. Source: Drawings by the authors

accumulation in each area, a large-scale exploration was implemented in 2015 – 2018. A circular area, surrounded by the Sanliqiao River, Longxi Harbor, Tiedianqiao River, and their respective tributaries, displays uniform high piles of soil resembling the walls along the inner perimeter of the river. This distinctive topographical feature is evident in satellite imagery dating back to the 1970s (Yan *et al.*, 2021). Figure 2 shows the extent of protection afforded to the Pishan site and the configuration of circular drainage during the 1970s.

Located on the southwest side of Pishan, adjacent to the Sanliqiao River, the Maquetian Spot underwent excavation from 2017 to 2019, which revealed a range of architectural remnants dating to the Post-Maqiao Culture (后马桥文化), which succeeded the Maqiao Cultural (马桥文化) period (3900 – 3200 before present), displaying distinct and contrasting features (Yan *et al.*, 2023). These findings include various features such as building site-based grooves, single grooves, rammed earth platforms, and extensive stilt-style architectural sites.

The highest and largest rammed earth platform is an LT, as depicted in Figure 3, featuring a high-platform building. The LT measures about 70.5 m in length and nearly 30 m in width, covering an area of about 2000 sqm. The thickest accumulation point reaches 4 m, while the highest elevation at the top point reaches 7 m.

At present, approximately 4/5 of the LT is sheltered by a steel structure shed, while the remaining 1/5, left exposed, is covered with black cloth. However, due to frequent rainfall and the soil's tendency to dry quickly, the entire LT is usually covered with thick black cloth, rendering the whole scene less accessible to researchers. Despite prolonged protection by cloth, certain areas of the LT, particularly those with lower terrain, have experienced moisture absorption, resulting in soil drying out and cracking, as depicted in Figure 4. Therefore, virtual preservation becomes imperative for the safeguarding of original records and proves beneficial for public exhibition.

2. Methods

2.1. 3D surveying and mapping

Digital twin technology necessitates 3D surveying and mapping, aiming to create a replica of a physical object in a virtual environment, completely surpassing the limitations of traditional 2D expressions in the plane. The primary methods employed for 3D mapping are 3D laser scanning and photogrammetry.

3D laser scanning, also referred to as light detection and ranging, is capable of recording distance measurements between the object and the scanner, generating a high-accuracy point cloud (Alshawabkeh *et al.*, 2020). Depending on the carriers, 3D laser scanning can be divided into satellite-based, airborne-based, and ground-based systems. The selection of these systems is contingent on the types and scale of the objects being digitalized, particularly suited for the digital preservation of built heritage.

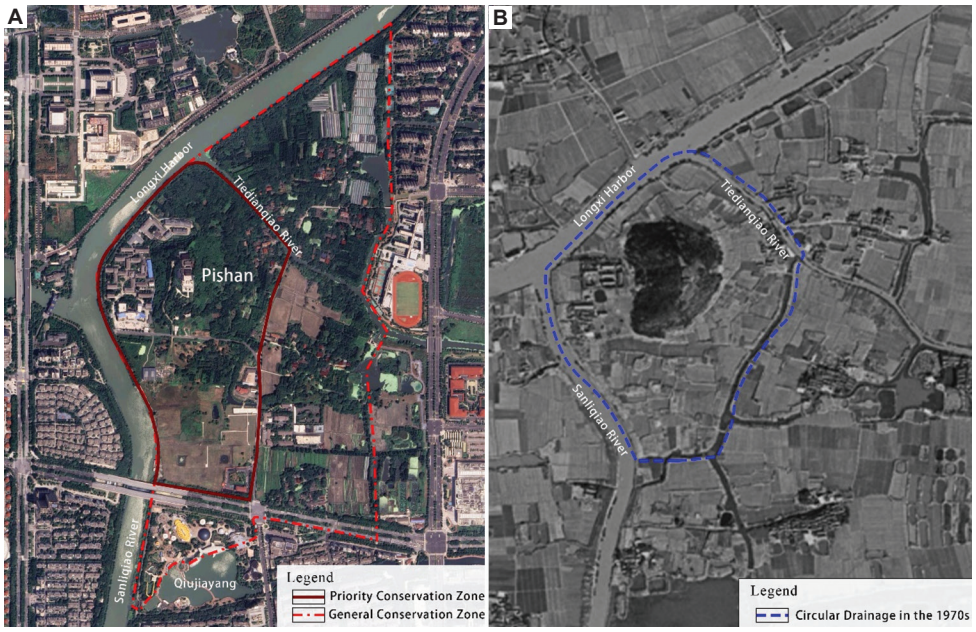

Figure 2. Satellite imagery of the Pishan site. (A) The extent of the conservation zone. (B) Circular drainage in the 1970s. Source: Drawings by the authors (satellite imagery from https://www.tianditu.gov.cn/)

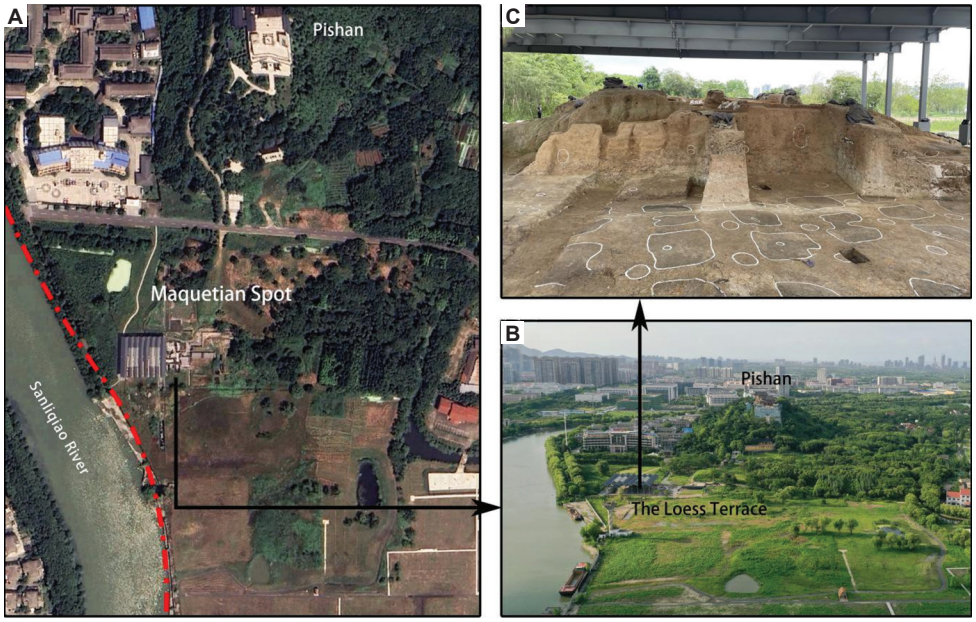

Figure 3. Survey of the loess terrace (LT). (A) Satellite imagery of the Maquetian Spot. (B) Aerial photo of the LT. (C) The west-facing-east view of the LT. Source: Drawings and photos by the authors

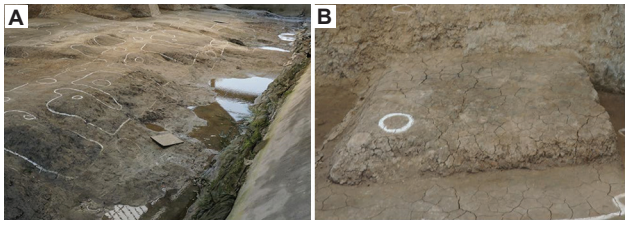

Figure 4. Soaking and cracking condition of the loess terrace (LT). (A) Standing water on the site. (B) Cracks of the LT. Source: Drawings and photos by the authors

Photogrammetry, on the other hand, focuses on generating a 3D model using the Structure from Motion (SfM) method (Jover *et al.*, 2016). The process involves subsequent steps, including orientation, dense point cloud and depth map generation, triangulated mesh formation, and texture mapping (Cruz Franco *et al.*, 2022).

Mainstream photogrammetry software includes Bently ContextCapture (renamed as ITwinCaptureModel in 2023), PIX4Dmapper, Agisoft Metashape, Autodesk ReCap Photo, and DJI Terra. Imaging devices commonly used for photogrammetry encompass UAVs, smartphones equipped with a camera function, digital cameras such as single-lens reflex cameras (SLR), mirrorless cameras, and panorama cameras.

Five-lens UAVs, specially designed for oblique photography, are relatively uncommon due to their high cost and are predominantly utilized for reconstructing high-altitude and wide-range heritage sites. Usually, a single UAV is used for small-scale or fine-scale tasks, requiring five flights at different angles for optimal 3D reconstruction. Nap-of-the-object photogrammetry (Yan, 2019) is a technique aimed at obtaining ultra-high-resolution images closely by drones, particularly suitable for objects with intricate structures or patterns, such as murals, Chinese palace buildings, and Gothic churches.

Compared to 3D laser scanning, photogrammetry exhibits a lesser capability for obstacle penetration and lower-shape accuracy. However, it compensates with superior image color quality (Kadobayashi *et al.*, 2004). The lower cost of UAVs and increased accessibility to cameras has promoted the widespread adoption of photogrammetry in the digital twin generation. Both 3D laser scanning and photogrammetry are occasionally employed in the same project to leverage their complementary advantages (Pepe *et al.*, 2021).

Beyond 3D mapping intended for creating a 3D model in a virtual world mirroring the real-world object, panoramic photography utilizes panoramic cameras to capture panoramic pictures that include both the object and its surroundings. Panoramic photos, characterized by their wide view and unobstructed nature, enable the inclusion of an extensive area in all directions. These images can be transformed into panoramic roaming works, providing visitors with an immersive experience.

At present, panoramic technology finds extensive application in numerous museums and archaeological sites, exemplified by institutions such as the British

Museum (The British Museum, 2020) and the Metropolitan Museum of Art in New York (Diamond, 2016). Platforms such as Google Arts and Culture offer an abundance of panoramic views showcasing museums and archaeological sites. In China, plenty of museums feature virtual museum projects on their websites often spurred by incentives from the Chinese government.

2.1.1. A virtual reconstruction via photogrammetry

In general, archaeological remains and artifacts often exhibit challenges such as blurred edges (due to the deterioration of the construction material and erosion phenomena), uneven material and color distribution, and difficulty in identifying corresponding points. Photogrammetry, when compared with laser scanning, proves more suitable for archaeological sites, especially in addressing complex surfaces.

For the acquisition of LT data, a UAV (DJI Mavic2, DJI, China) equipped with a Hasselblad L1D-20c camera (5472 × 3648 pixel) and a Sony α6000 digital camera with 24 million pixels were used. To ensure optimal conditions, the data collection occurred on a cloudy day to avoid the shadows cast by the sun, as variable shading can potentially affect the accuracy of calculation results.

The reality capture process in photogrammetry consists of three steps:

- The first step involves oblique photography to obtain fundamental data using the DJI Mavic2.
- The second step entails capturing images of missing places at a lower altitude using the DJI Mavic2.
- The third step includes taking detailed pictures using the Sony α6000.

To ensure the completeness and precision of the reconstruction model, the overlap rate of oblique photography must meet specific requirements, usually with a recommended minimum of 75% frontal and 60% side overlap in general cases. In the beginning, the plan was to use DJI GO PRO to automatically design five routes of oblique photography, aiming for 80% frontal and 70% side overlap. Unfortunately, the signals were interfered with by the steel structure shed, leading to a mission failure. Consequently, manual control and picture-taking became necessary, with the overlap rate manually monitored at approximately 80%, a critical step ensuring the success of subsequent processes.

After completing all the steps, a total of 2,693 photos were taken with DJI Mavic2, and 373 photos were taken with the Sony α6000, making a combined total of 3,066 photos.

For data processing, Bently ContextCapture was chosen to run the SfM process due to its perfect 3D reconstruction capabilities. Following the established workflow – "Import Photos – Submit Aerotriangulation – Reconstruction Settings – Production" – final products in formats such as. 3mx,. 3sm,. osgb, and. obj, could be obtained.

After completing aerotriangulation, a quality report was generated, revealing that 16 photos were discarded due to the failure of strict registration of image positioning information. Figure 5 illustrates photo positions and the number of photos capturing the scene. Black dots represent the photo position, and the main part of the overlap exceeds 80%, excluding the edge of the site, which did not contribute to the main body reconstruction. Points at the bottom of the Z-axis exhibit a distance from the dense point above, indicating photos taken by a handheld camera on the ground capturing vertical walls and corners with intricate details. This is particularly evident in Figure 5B, which depicts areas with the highest photo density where handheld cameras focused on capturing fine details.

2.1.2. An immersive experience through panoramic photography

For the acquisition of panoramic photos, an Insta360 camera and a DJI Mavic2 UAV were used with the ultimate goal of creating a web platform that provides an immersive panorama and VR experience.

The process involves three key steps:

(i) The first step entails capturing ground-based panoramic photos of the LT using an Insta360 camera and aerial panoramic photos of the surrounding site using a DJI Mavic2 UAV.
(ii) In the second step, the format of ground-based panoramic photos is transformed into jpg format using Insta360 Studio 2023. Simultaneously, aerial panoramic photos are automatically generated in the

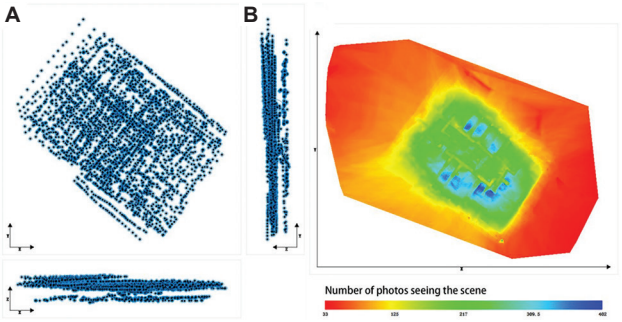

Figure 5. Photos collected from the loess terrace (LT). (A) Position uncertainties: Top view (XY plane), side view (ZY plane), and front view (XZ plane) of computed photo positions (black dots). Blue ellipses indicate the position uncertainty, scaled for readability. (B) Number of photos capturing the scene: Top view (XY plane) of the scene with colors indicating the number of photos potentially covering each area. Source: Downloads from the quality report produced by Bently ContextCapture

DJI Mavic2, allowing for direct use.

(iii). The third step includes uploading these panoramic photos to the 720yun website. Subsequent tasks involve naming, categorizing, creating a sand table, and arranging hot spots.

Ground-based panoramic photos were taken at 38 different location points, as illustrated in Figure 6, ensuring that adjacent positions have a clear line of sight to each other. Aerial panoramic photos were captured at three different location points, as depicted in Figure 7, offering various angles and heights to showcase the surrounding scene of the LT.

2.2. Management and restoration based on GIS and heritage/historic BIM

The digital twin demands full lifecycle management, with a focus on information management, analysis, simulation, and prediction (Grieves & Vickers, 2017).

GIS and heritage/historic BIM (HBIM) (Murphy *et al.*, 2009) are both technology platforms that directly manage information and have found applications in built heritage preservation and conservation over recent decades. GIS primarily deals with processing, integrating, and visualizing spatial and geographical data in large-scale outdoor environments rather than within buildings. It is centered on managing, querying, and analyzing spatial, attribute, and relational information related to various elements (Yang *et al.*, 2020). On the other hand, HBIM begins with the model construction of the building structure, enabling the comprehensive management of various building components and the integration of non-geometric information through effective updates.

The integration of GIS into archaeology is widely recognized as an ideal pairing, given that archaeology often involves the study of the spatial dimension of human behavior over time, and spatial considerations are intrinsic to all archeological studies. On a macro level, archaeological sites from the same period are typically geographically dispersed, making the application of GIS essential for unraveling relationships among numerous sites. On a microlevel, practitioners can seamlessly incorporate graphical and spatial information of a single site, measured at local positions, into GIS. This integration involves historical documents and images, records of restoration and management, and other relevant information for addressing comprehensive tasks. In a study by Zhang *et al.* (2010), archaeological site attributes were linked with the spatial data of Yangzhou using ArcGIS software, ArcMap, enabling the visualization and comprehensible presentation of information. Simultaneously, Pepe *et al.* (2021) integrated a parameterized 3D model into different ArcGIS software, ArcScene, allowing the association of each object with multiple layers of information.

In 2007, Murphy *et al.* (2007) proposed the BIM-based HBIM, emphasizing the integration of drawings, images, text, and standard parametric components based on historical buildings. In contrast to BIM, which was developed for managing new buildings in architectural, structural, and MEP (mechanical, electrical, and plumbing) domains, HBIM focuses specifically on historical and archaeological buildings. However, Autodesk Revit, the most widely used BIM software, relies on simplified parametric models suitable for industrial elements and modern architecture (Oreni *et al.*, 2013). Consequently, much of the HBIM research is devoted to building databases of components in built heritage (Godinho *et al.*, 2020). Meanwhile, cases using HBIM for 3D modeling often involve structures with intact figures or, at the least, recognizable structures and components (Jordan-Palomar *et al.*, 2018; Ramos Sánchez *et al.*, 2022; Stanga *et al.*, 2023). Rarely do we encounter cases where only destroyed pillars or pillar holes remain.

Figure 6. Left panel: The work plan of the loess terrace (LT). Top- and bottom-right panels: Examples of collected scans (the LT orthography was produced by photogrammetry). Source: Drawing and photos by the authors

Figure 7. Left panel: The work plan of the Pishan site. Top-, middle-, and bottom-left panels: Examples of collected scans. Source: Drawings and photos by the authors

This discrepancy can be attributed to factors such as building times or materials. Buildings constructed of stone, predominantly found in Europe, tend to be better preserved, while those made of wood, more prevalent in Asia, may only have foundations and pillars or pillar holes identifiable through archaeological methods. Modeling archaeological remains without intact figures poses a significant challenge, and its application is hindered by stakeholders who deem it unnecessary.

2.2.1. Information management and geo-analysis in the GIS for building restoration

Architecture is an essential aspect of people's lives, influenced by both natural and cultural conditions. Interdisciplinary material collected and analyzed on a single platform is always beneficial. Therefore, the information management and visual analysis functions of ArcGIS make sense. The Pishan site represents a typical human settlement located at the foot of a hill and surrounded by water, making the environment simulation and analysis of that time more meaningful.

To achieve the ultimate goal of architectural restoration, numerous supporting data need to be collated and organized. Figure 8 displays reference data for restoration, with three essential types of documentation. The first type comprises the natural environment, directly recorded in the literature about the archaeological site, including climate, terrain, and hydrology. The second type involves first-hand information from the excavation site and other sites of the same age, type, and area as the target site. The third type encompasses historical material, containing architectural and cultural history materials related to the target site.

These data manifest in various formats, such as photos, drawings, videos, documents, and models. The management of this diverse array of data occurs within the framework of ArcGIS, utilizing its comprehensive set of toolboxes. Within the ArcGIS environment, users can swiftly query and filter the organized information.

Incorporating altitude data recorded in documentation alongside the modern ground digital elevation model (DEM), an ancient ground elevation model is simulated. This approach enables the inference of the evolution history of environmental elements, such as ancient landforms and hydrology. The arranged information accelerates the initial speculation, encompassing structure, function, and layout, fostering a quicker and more scientifically informed approach. Subsequently, detailed restoration modeling, incorporating parametric information, is undertaken within the framework of BIM. It's worth noting that the current terrain-based analysis is limited due to the absence of collected surrounding geographic data.

To further enhance the restoration process, additional GIS software can be explored for their utility. The

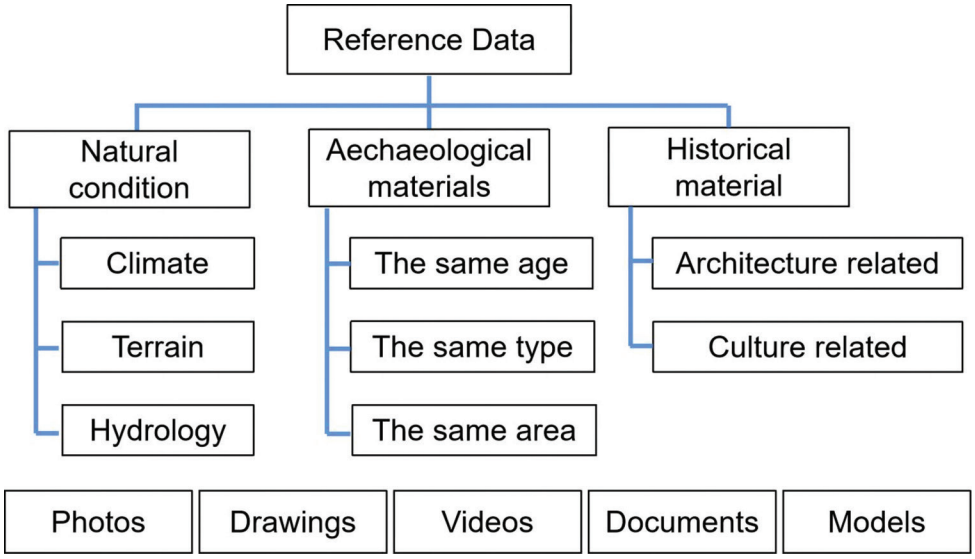

Figure 8. Management of reference data for restoration in ArcGIS. Source: Drawing by the authors

functionality of various GIS software in this context will be investigated. The 3D mesh models, complete with level-of-detail and paging, produced by ContextCapture seamlessly integrate with several leading 3D GIS software options, including TerraExplorer (Skyline), SpacEyes3D Builder, CityPlanner (Agency9), VirtualGeo (DIGINEXT), Blaze Terra (Eternix), Supermap GIS, Google Earth, and Cesium, with the promise of more compatibility to come.

2.2.2. Restoration modeling in heritage/historic BIM for visualization and management

In ancient China, architecture was predominantly built from wood, a material highly susceptible to deterioration from both human activities and natural erosion. Consequently, excavated architectural sites commonly reveal remnants such as pillar poles, basements, residual pillars, or the foot of walls. In the case studied here, without exception, there are only traces of column holes and the base of the wooden columns remaining.

Despite the absence of intact constructional elements and a complete building image, HBIM provides a viable solution for the information management of archaeological building remains. Moreover, it proves to be a valuable tool in aiding the virtual restoration of these buildings.

Autodesk Revit, a widely used BIM software, was chosen for this task. Point clouds can be imported into Revit, making it an ideal environment for the digitalization of the excavated archaeological site and its integration with restored buildings. However, the point cloud in the. las format produced by ContextCapture is not compatible with Revit; only. rcp and. rcs formats have access to Revit. Therefore, Autodesk Recap was used to transform the format and clip and relocate the origin when needed. As a result, a modified 3D point cloud of the LT was completed and imported into Revit, excluding the 3D views and plane. In addition, four elevation views were captured, as illustrated in Figure 9.

Historic and archaeological information is introduced through a plug-in prototype that allows the synchronization of architects and archaeologists. Figure 10 shows an attribute tree designed to organize available data that can be assigned to each pillar. The data include geometry-related attributes (e.g., diameter, depth, residual height, and shape), documentation (e.g., texts, drawings, photos, and videos), and (e.g., earth-filling and timber), and management-related attributes (e.g., reports on the conservation status).

3. Results

3.1. Virtual reconstruction model

Figure 11 shows the 3D reconstruction model in ContextCapture Viewer. The images were captured almost simultaneously to ensure the required lighting conditions for laser data coloring and true orthophoto. However, an unbalanced color persists due to the approximately 1/5 of LT without the steel structure shed above, and the uneven lighting area created by the steel scaffolding. Moreover, the resulting products can be published on the Internet through Acute3D Web Viewer (.3mx format), Sketchfab (.obj format), and Cesium (Cesium 3D Tiles format).

3.2. Panoramic roaming

As a result, a webpage dedicated to the Pishan site was created (Pishan Site, 2023), offering panoramic roaming

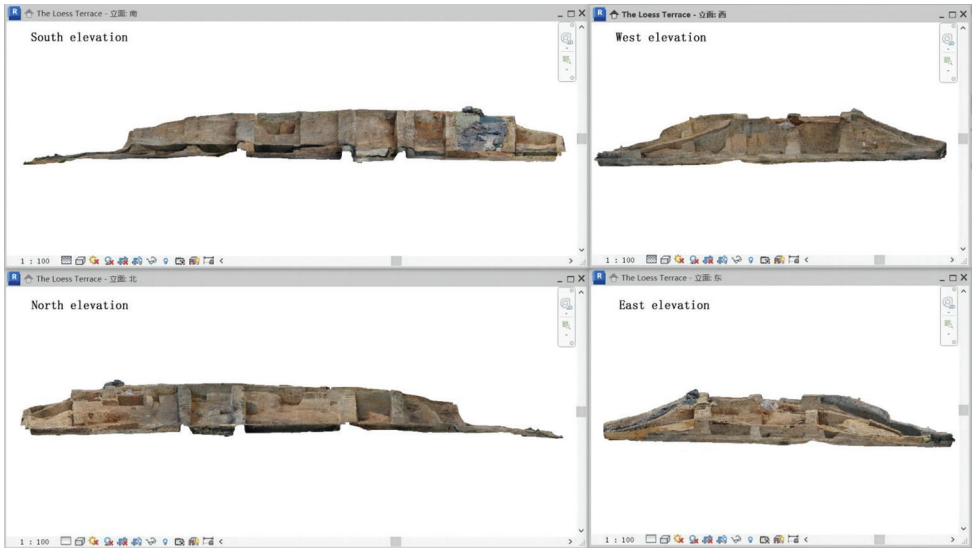

Figure 9. Four elevation views of the loess terrace (LT). Source: Drawings by the authors

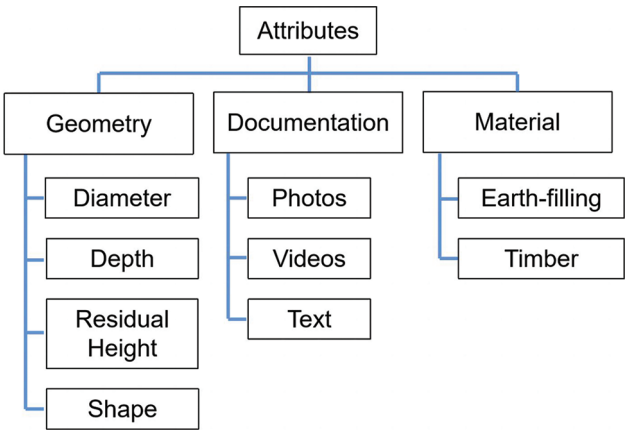

Figure 10. Attribute tree of pillars. Source: Drawing by the authors

and VR experience using a VR headset, as depicted in Figure 12. This presentation includes the surrounding environment, providing online visitors with an immersive on-site experience in comparison to the 3D model reconstructed through photogrammetry.

3.3. Integration of pillar and point cloud

Ideal parametric pillars were placed in Revit's plan view, guided by the pillar hole marks identified in the point cloud. Changes in other views were synchronized simultaneously. The height of the pillars was manually set at 2 m, as the real height is still unknown. The relationship between pillars and the LT is clearly visualized in the 3D view, as illustrated in Figure 13.

The noteworthy challenge is that the scale of this data is not particularly extensive; importing the point cloud into Revit software can be achieved by reducing clarity several times in Recap. However, further plans involve the digitization of the whole Maquetian spot site. Moreover, when dealing with a substantial volume of point cloud data, careful consideration and resolution of potential issues will be essential.

4. Discussion

The method presented here enables the creation of a digital twin. First, the outcome was the 3D reconstruction model achieved by capturing imagery data, granting the LT an immortal life in the virtual world. A foundational exhibition, accessible both on a local computer and online, was completed. Second, the utilization of ArcGIS was proposed for the management of restoration reference data and the analysis of the LT's surrounding terrain, encompassing both modern and historical periods, although this process is still undergoing verification. Third, HBIM was used for the integration of the point cloud and pillars, with the expectation of creating a parametric management and restoration model.

In comparison to archaeological sites where stone structures are preserved, this research demonstrates the feasibility and significance of 3D reconstruction through photogrammetry in underground archaeological sites, where building remains made of wood are rarely found. The 3D reconstruction model enriches practitioners' comprehension of the archaeological site, its architectural features, and layouts, particularly when combined with HBIM. This method proves advantageous for large-scale sites, providing individuals with the flexibility to navigate the 3D reconstruction model freely, rather than being restricted to limited on-site views. In such cases, higher-

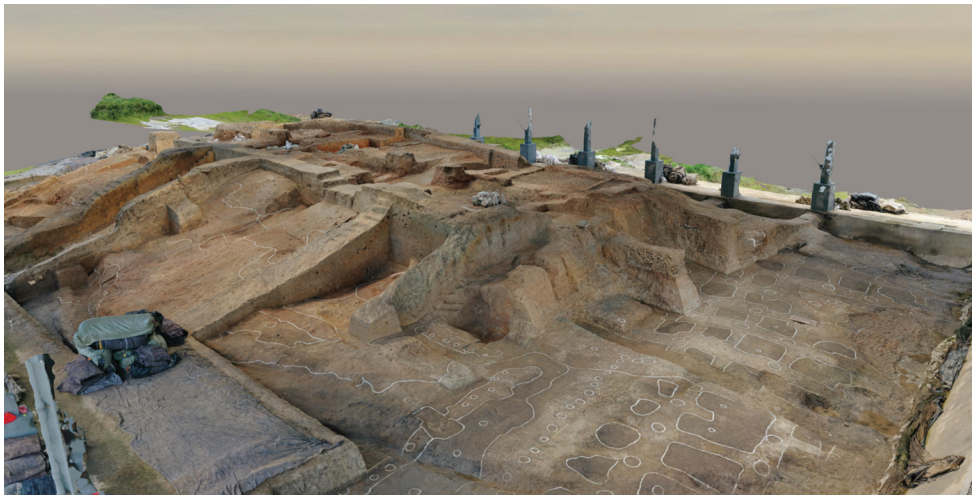

Figure 11. Reconstruction model in ContextCapture Viewer. Source: Drawing by the authors

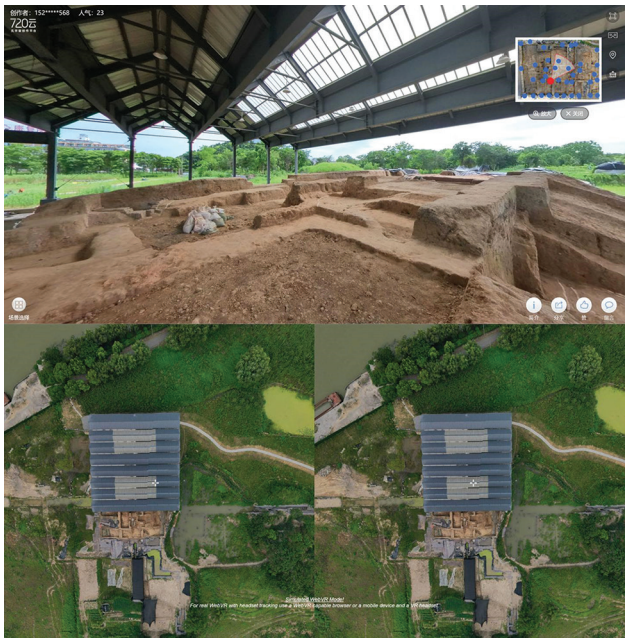

Figure 12. Panoramic roaming and VR experiences provided on the webpage dedicated to the Pishan site. Source: Drawing by the authors

specification UAVs, like the 5-lens UAV, are needed (Zhou *et al.*, 2021).

To maximize the potential of archaeological digital assets, we propose a workflow, "Virtual reconstruction – Management and analysis – Restoration – Exhibition," leveraging the toolkit of digital twin technology, photogrammetry, panoramic photography, GIS, HBIM, VR, and AR.

Through systematic management and analysis facilitated by GIS and HBIM, references essential for restoration can be methodically organized. Experts can scientifically and efficiently extract meaningful knowledge and documentation for restoration, a notable improvement over traditional approaches where attributes and objects lack connectivity. The informatization and visualization technologies discussed in this article carry positive implications for restoration work. Moreover, virtual restoration based on digital twin technology is a non-invasive approach, ensuring the authenticity of heritage.

An initial VR experience was presented through panoramic photography on the free part of the 720yun website, centered on the excavated ruins without restored buildings. An exhibition that combines the excavated ruins and restored buildings is expected to be completed using VR, AR, or XR techniques. This combination will provide a more interactive and educational immersive experience, depicting restored buildings with ancestors living and working in them. The knowledge researched by architects and archaeologists will be seamlessly integrated into this immersive scene. Various devices, such as head-mounted (Athens Olympic Museum, 2023), hand-held (Voinea *et al.*, 2019), and projection-based (Czernuszenko *et al.*, 1997) devices, are commonly employed in both homes and museums. In addition, 3D printing facilitates the production of highly detailed physical replicas of objects, positively enhancing the engagement and comprehension of vision-impaired visitors (Kantaros *et al.*, 2023). Numerous exhibition forms can be explored, although the choice often depends on cost considerations.

However, the workflow still encounters several challenges. The intricate connection between multiple software platforms, alongside the need for a time-saving and streamlined software scheme, constitutes the main challenges in the realm of digital twin technology. In this research, for example, the "Virtual Reconstruction – Management and Analysis" phase

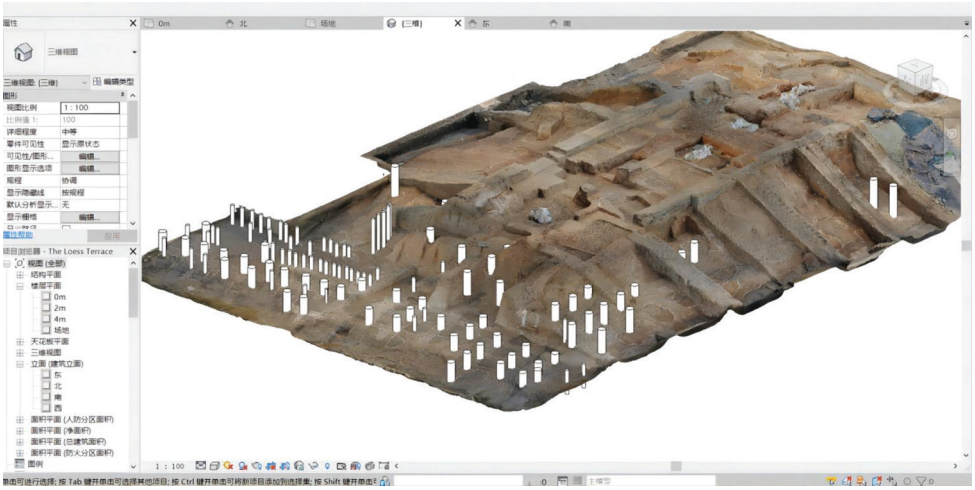

Figure 13. Integration of pillar and point cloud in Revit. Source: Drawing by the authors

needs software from three companies – Bently, Esri, and Autodesk. Consequently, format transformations become necessary to ensure the smooth progression of the workflow. Similar challenges persist in subsequent phases such as "Management and Analysis – Restoration – Exhibition." Therefore, there is a pressing need to explore and examine simpler and more effective approaches. To ensure the sustainability of the workflow, it is crucial to stay abreast of the latest technological advancements and be prepared to adjust accordingly, avoiding dependency on specific software or devices. Furthermore, this workflow inherently demands multidisciplinary expertise, encompassing architectural, archaeological, geographical, and computational domains. Therefore, close collaboration among interdisciplinary experts is of utmost importance. Finally, while we place great emphasis on digital technologies – a prevailing trend in every industry – it is essential to acknowledge the significance of the physical world. Physical documentation should not be abandoned because technology is not always dependable.

In addition, the cost of implementing the workflow should be considered, as not all archaeological or heritage projects can afford it. In fact, UAV and camera-based 3D surveying and mapping are notably more cost-effective, approximately 10 times lower, than laser scanning- and camera-based 3D surveying and mapping, a method commonly employed in various cultural heritage projects. Moreover, readily accessible smartphones can replace mirrorless or SLR cameras, although with some compromise on precision.

5. Conclusion

From the perspective of the method's contribution to archaeological research, it draws some interesting conclusions:

(i) Data collected using 3D mapping technology are sufficient and prevent information loss compared to traditional information recording methods such as CAD drawings. This is highly beneficial for stakeholders seeking real and precise field data.
(ii) Web-based panoramic visualization makes archaeological sites more accessible to the public and convenient for researchers. Users can freely explore the site and gain a comprehensive understanding from all angles.
(iii) GIS and HBIM provide archaeologists with management and visualization tools that can be permanently preserved. They offer architects a method for creating faithful restoration models and enable different levels of detailed management for other insiders.
(iv) Digital twin allows the site to have immortal life in a virtual environment, eliminating the risk of physical site damage from constant observation needs by researchers.

Subsequent studies will continue to complete the whole workflow and constantly improve this approach. Future work will focus on the following aspects:

(i) More detailed and accurate restoration will require an in-depth study of relevant materials. Reference data based on Figures 8 and 10 are expected to be managed and organized in GIS and HBIM. A virtual restoration model will be built in the BIM software Revit, along with the point cloud of the LT.
(ii) Future possibilities include the adoption of VR and AR. The use and enjoyment of VR- and AR-based devices expand the paradigms of interactivity between the user and the digital environment, making heritage assets fully accessible to users.

(iii) This case is a small spot of the whole site. Possible existing settlements are expected to be restored along with further excavation, contributing to the continuous improvement of this workflow based on digital twins.
(iv) Whether in heritage conservation or digital twin development, both encompass extensive content in tandem with the evolution of conservation concepts and technology. Several potential advancements, listed below, warrant deeper research:
(v) Integration of GIS and HBIM, signifying the integration of geographic environment and architectural noumenon. This integration can be achieved through multi-software fusion or plug-in fusion, including web-based platforms.
(vi) Real-time monitoring relying on sensors and IoT. Architectural heritage inevitably suffers from natural damage (e.g., warm and humid climate), environmental pollution, and human-made destruction. An IoT platform based on digital twin modeling, linking sensor data such as temperature and humidity monitoring, should be implemented properly in the future.
(vii) Web-based management cloud platform. The continuous excavation and research of the Pishan site resulted in growing data. Leveraging big data and cloud computing provides robust information processing and management capabilities, allowing concurrent access by a multitude of users without compromising performance.

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Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

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Availability of data

The data are not publicly available due to the confidential nature of archaeological sites.

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ACCSCIENCE PUBLISHING

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ORIGINAL ARTICLE

Research on governance structure and benefit balance concerning urban regeneration in Beijing, China: Analysis of the best practical cases

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(This article belongs to the *Special Issue: Theoretical and Practical Innovations in Relation to China's Urban Regeneration*)

Abstract

While proposing the national strategy of implementing urban regeneration, the Chinese government put forward requirements such as preventing large-scale demolition and construction and protecting historical architecture, indicating that the previous urban regeneration methods of demolishing low-rise and old buildings and building high-rise and new ones are no longer applicable. As the capital city, Beijing is facing more stringent constraints on reduction-oriented development and historical protection, and the problems of insufficient motivation and unclear paths for market players to participate in urban regeneration have become more prominent. Based on a systematic review of the main theories and practices of market participation in urban regeneration, this study builds a market-oriented mechanism analysis framework for urban regeneration of "governance structure-benefit balance." In this study, we compared 34 cases that won the title of "The First Beijing Urban Regeneration Best Practice in 2022" and conducted further in-depth analysis of three typical cases by semi-structured interviews, field research, qualitative analysis, and quantitative comparison. From the study, we identified three typical governance structures of welfare protection, economic growth, and comprehensive development during the emergence of market participation in Beijing's urban regeneration process and found that different governance structures have different cooperation and interaction mechanisms, value promotion orientations, and benefits distribution, which are respectively applicable to facilities and public space regeneration projects that implement social public welfare responsibilities, industrial regeneration projects with ample economic value-added space, and regional comprehensive regeneration projects where quasi-public goods and private goods coexist. We believe that the coexistence of multiple governance structures is an inevitable choice for China's market mechanism of urban regeneration. The value-added space of urban regeneration projects should be further improved, the distribution of interests among multiple subjects should be balanced, and the sustainable and normalization of urban regeneration actions should be promoted.

Keywords: Urban regeneration; Market mechanism; Governance structure; Benefit balance; Beijing; China

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1. Introduction

As China's urbanization rate reaches 64.72% in 2021, "implementation of urban regeneration" has become a national strategy in the new era. Compared with megacities such as Guangzhou, Shenzhen, and Shanghai, Beijing, the capital, is facing more stringent requirements for reduction-oriented development, non-capital function decommission, historical protection, the methods of obtaining economic dividends through large-scale demolition and construction, and increasing floor area ratios have become strictly limited, thereby reducing the initiative of various enterprises to participate and slowing down the implementation of Beijing's urban regeneration.

The "Regulations on Urban Regeneration of Beijing" promulgated in December 2022 proposed a governance pattern of "government-led, market-operated, and multi-participatory," which shows that the market players, as the backbone of urban regeneration, undertake essential roles, such as capital investment, coordination and communication, technical services, and implementation of operation and maintenance. Establishing a market-oriented mechanism for urban regeneration can effectively mobilize the initiative of various cooperative entities in communication, the fairness of negotiation, and the continuity of operation, which can effectively reduce transaction costs in the process of information communication, negotiation, and organization and implementation. Therefore, it is urgent to establish a market mechanism to promote the sustainable development of Beijing's urban regeneration.

Obtaining economic benefits is the main motivation for market players to participate in urban regeneration (Zhao & Song, 2021). The balance of costs and benefits of multiple parties is the core of sustainable urban regeneration. That is why constructing a market mechanism for urban regeneration focuses on the formation of multi-subject cooperation and the balanced distribution of value-added benefits (Tallon, 2019; Yang, 2012; Wang *et al.*, 2022). Existing studies mainly focus on the game of interests under the large-scale demolition and reconstruction model. However, there are few studies on the regeneration mechanism of Beijing in the new era with comprehensive renovation as the main mode. On the analysis of typical cases of urban regeneration implemented in Beijing in recent years, this study focuses on two issues. First, how do the multi-stakeholders cooperate and interact in the process of urban regeneration? Second, what are the characteristics of benefit distribution in different governance structures? Furthermore, this study attempts to put forward corresponding strategic suggestions and provide ideas for the construction and optimization of the market mechanism of urban regeneration under the guidance of reduction-oriented and high-quality development.

2. Literature review

2.1. Market participation in urban regeneration

Urban regeneration in the Western countries has been carried out gradually since World War II. Overall, it has gone through the stage of dismantling and rebuilding affordable housing under the leadership of the government in the 1950s and 1960s and the stage of government and enterprise cooperation to promote economic growth in the 1960s and 1970s. Subsequently, since the late 1980s, with the development of neoliberalism and the activation of the capitalist market, urban power has been dispersed in various social subjects. At the same time, the task of building and governing cities is becoming heavier and heavier, resulting in the inability of local government agencies to solve the problems of urban construction and governance. Therefore, there are a growing number of updated models of cooperation between the government and the private sector (Clark, 2001), and bottom-up community planning and public participation are valued (Silvers, 1969; Lee *et al.*, 1985). Urban regeneration also brought about the return of the middle class to the city center, and the spatial displacement of different classes of population at this stage (Fang, 1988), triggering debates on issues such as spatial justice (Davidoff, 1973), social equity (Castells, 2002), gentrification (Hackworth & Smith, 2001), and sustainable development (Bromley *et al.*, 2005; Zheng *et al.*, 2014; Roberts & Sykes, 2000), among others.

Urban regeneration governance involves various aspects, such as "Multiple Stakeholders – Capital Source – Physical Space – Operation Service" (Tang *et al.*, 2022), and it is a complex systematic engineering involving the demands of multiple subjects' cooperation (Shen *et al.*, 2021), extensive financial guarantees, space management innovation, and long-term operation and maintenance. It has aroused attention and research in different disciplines. The theory of space production proposed by Lefebvre first regards space as a social product which profoundly participates in the process and structure of social change and plays an important role in promoting capital appreciation and safeguarding public interests (Lefebvre, 1991; Harvey, 2001; Harvey *et al.*, 2018). Molotch regarded the economic-growth-oriented alliance as the "growth machine," which dominates the development process of urban regeneration (Molotch, 1976). Stone put forward the urban regime theory based on empirical research in Atlanta. He believed that the informal cooperative relationship between the city hall and the business elites formed the joint participation

of public and private stakeholders in formulating and implementing urban regeneration management decisions in the city center (Stone, 1989, 1993, 1996, 2005). In the field of public administration research, the governance structure research in the field of public management focuses on different subjects, such as managers, producers, and users, and their cooperative and interactive relationships in different public affairs. Williamson divided the governance structure into different types, such as unified governance, market governance, bilateral governance, and tripartite governance, according to the types of transaction objects and the asset specificity, uncertainty, and transaction times in the transaction process (Williamson, 1975). Ostrom (1996) proposed a polycentric governance structure based on his empirical research on public pool resources, emphasizing that autonomous forces play a fundamental role in the field of public affairs.

Different governance models have been formed in different urban regeneration projects in different countries and cities, and all market players play an important role in general. The United States (Brower, 1971; Marcello, 2021), the United Kingdom (Rob, 1999), the Netherlands (Michiel & Erik, 2011), and other places have established urban development or regeneration companies to promote economic growth and asset reconstruction (Chris & Annekatrin, 2000), which is the main driving force regenerating the area with extensive public-private partnerships (Chris *et al.*, 2003). Vesalon and Cretan believe that the market mechanism of urban regeneration is an important measure for the development of a free market economy (Vesalon & Cretan, 2019). Sorina divided developers into three types that contribute to the gentrification of neighborhoods, including professional developers who purchase property, redevelop it, and resell it, occupier developers who buy and redevelop the property and inhabit it after completion, and landlord developers who rent to tenants after rehabilitation in the research on the market mechanism of urban regeneration in Romania (Sorina *et al.*, 2009). Peter considered funding implications for environmental, social, and community issues as the fundamental aspects of urban regeneration (Peter & Hugh, 2003).

China's urban regeneration also went through three stages as a whole before the reform and opening-up in 1978, including the government-led stage aimed at improving people's livelihood and housing security, the government-led stage aimed at economic development with the real estate boom and cooperation between real estate development enterprises and governments from 1978 to around 2010, and the stage of people-oriented development and multi-governance by the government, enterprises, and society after the urbanization rate exceeds 50% in 2010 (Yang & Chen, 2020). The research on China's urban regeneration in the second stage has produced plentiful results, and scholars generally agree that enterprises and the government often form urban entrepreneurialism through collusion in the process of land commercialization (Jiang *et al.*, 2009), which promoted the rapid development of China's urbanization, but has also exposed some problems in certain urban regeneration projects. For example, Zhu (1999) believes that many China's state-owned enterprises rely on socialist land use rights to seek land rent and change planning parameters such as plot ratio and land function based on corporate interests, resulting in "corruption in land use planning" in urban regeneration. Zhang *et al.* (2013) believe that the essence of urban regeneration is the process of urban governments' industrial and commercial capital; a lot of them use the replacement of urban space types and locations to obtain land rent income and realize capital appreciation and accumulation. He & Wu (2005) argued that in the process of real estate-led demolition and reconstruction, a pro-growth alliance is formed between local governments and developers, and the developers play the role of providing capital under the supervision of the government, but this model results in unfair redevelopment. Tian (2018) believes that in the regeneration of urban villages, which is widely promoted at this stage, there are problems of imbalance between public interests, collective interests, and private interests, so it is necessary to comprehensively analyze its pros and cons from the perspectives of society, collection, and economy.

The above-mentioned research shows that the market is an important force in urban regeneration, and their experience and challenges can be summarized in three aspects. First of all, the operation mode of urban regeneration projects presents different characteristics in different urban environments and different developmental stages. The current research on governance structure mainly focuses on demolition and reconstruction projects, which have large space for economic value-added characteristics (Adair & Berry, 1999), and the motivation of multiple parties to participate is relatively strong. However, there are few studies on the "micro-regeneration" model in the new era that prevents large-scale demolition and reconstruction. Second, there are differences in the participation paths of multiple subjects in different projects. It is necessary to focus on project types and pay attention to the roles played by different subjects. Existing research focuses on the collusion relationship between the government and enterprises. In actual operation, different types of regeneration projects, due to their different functions, profit mechanisms, participants, and benefit distribution, have relatively different cooperation models for different entities. Therefore, there are many forms of governance structure in current urban regeneration projects, including government-led

initiatives, government-enterprise cooperation, market-led approaches, residents' initiatives, as well as their various combinations. Furthermore, governance structure and benefit distribution are the core issues of urban regeneration. In different economic and social backgrounds and different types of regeneration projects, different governance structures are required. Benefit distribution is an important factor in promoting the formation of cooperation in various governance structures. The foundation and the balance of interests are the core of the sustainable advancement of urban regeneration.

2.2. Urban regeneration in Beijing

Beijing's urban regeneration process is closely related to the evolution of economic and social development, urban planning and construction, and spatial governance, and has gone through four main stages and presents a developmental process from government-led, government-enterprise cooperation to multi-coordination among government, enterprises, and society. From 1949 to 1978, from the founding of New China to the reform and opening-up, Beijing's urban regeneration showed a strong political orientation and adhered to the goal of "building a socialist capital with Tiananmen Square as the center and following the new planning" in renovating the old city (Liu, 2012). During this period, modern enterprises and market-oriented economic systems had not yet been established, and urban regeneration and construction activities were planned and implemented by the government. State-owned factories, unit compounds, and office functions of government departments were rapidly constructed during this period on state-owned allocation land (Tang & Zhang, 2021). From 1978 to 2007, the reform and opening-up brought about the rapid development of China's economy, and the rapid expansion of Beijing's urban area resulted in a surging development of old cities. At the same time, with the beginning of paid use of land and the end of the welfare housing allocation institution, the real estate market has gradually thrived. In addition, the modern enterprise system was gradually established based on expanding the enterprises' autonomy, local and foreign-funded private real estate enterprises achieved rapid development, and state-owned enterprises that originally focused on manufacturing also developed real estate businesses one after another. The main way of urban regeneration in Beijing during this period was promoted by real estate developers, demolishing the original dilapidated buildings and constructing high-rise residences (Liu & Lin, 2018; Hyun, 2009). The preparation for the 2008 Beijing Summer Olympics was a significant turning point in Beijing's urban construction and development. Under the guidance of the goal of "Humanistic Beijing," the improvement of the city's ecological environment, image, and style, and the optimization of facilities had become the focus of urban regeneration during this period. The old factories, such as the 798 Art Zone, have gradually gathered cultural and creative industries. Therefore, while the government and market entities were carrying out the transformation of urban villages, they were also trying to implant cultural and creative industries in spaces such as Hutong courtyards and old factory buildings, emphasizing the optimization of industrial functions while emphasizing the improvement of the quality of the physical environment (Bian, 2016). In 2017, the "Beijing Urban Master Plan (2016 – 2035)" clearly put forward the development requirements of "reducing scale and improving quality." Under the call of the government, municipal and district state-owned enterprises gradually explore urban regeneration pilot projects, taking the lead in relieving traditional industries and implanting new industries such as technology research and development, carrying out regeneration of old communities and construction of green parks, and implementing regeneration and protection of historical blocks and their operation and utilization. At the same time, relevant planners and other practical explorations have expanded the channels for public participation and intensively introduced a series of special urban regeneration institution systems, providing a certain foundation for the in-depth implementation of Beijing's urban regeneration actions (Wang & Chen, 2021; Ge & Li, 2022).

Compared with megacities such as Guangzhou, Shenzhen, and Shanghai, there are relatively few studies on urban regeneration governance in Beijing (Zhou *et al.*, 2021). Zhang & Fang (2002) believe that in the process of large-scale demolition and reconstruction in Beijing, local state-owned enterprises developed from welfare-oriented government branches to profit-oriented developers and formed growth alliances with local governments, accumulating at the expense of providing enough living and working places for residents. Zhang *et al.* (2016) discovered that in the process of urban regeneration in Jiuxianqiao, Chaoyang District, the government-enterprise alliance transformed into a government-society alliance. Since 2017, Beijing's urban regeneration has entered a new stage of transformation with the characteristic of reduction orientation and historical protection requirements, and thus, the method that stimulates urban regeneration and balances renovation funds by increasing development capacity is not applicable anymore. In addition, the different levels of central and municipal governments, the different types of administrative departments, public institutions, the military, and enterprises, as well as the different holding methods such as self-owned, shared, collective, and mixed, have resulted in a complex structure of property rights

subjects, making it difficult for multiple subjects to form a consensus on transformation in Beijing (Tang & Zhang, 2021). The complexity of the interest pattern and the reality has led to difficulties in starting the regeneration project. Beijing's current management methods make it difficult to effectively manage the formed property rights pattern. The degree of complexity makes it difficult for multiple subjects to form a consensus on transformation (You *et al.*, 2022).

In the existing research, the objects of Beijing's urban regeneration mainly include urban villages (Xu & Noriko, 2021), shantytowns (Fan *et al.*, 2023), industrial plants (Deng *et al.*, 2020), historical relics (Yue, 2008), and so on, which failed to cover the five types of regeneration objects in the "Beijing Urban Regeneration Regulations." In addition, Beijing's urban regeneration dynamic mechanism has undergone fundamental changes under the requirements of reducing volume and improving quality. At this stage, the governance structure of Beijing's urban regeneration is more diverse, and its benefit distribution mechanism is more complicated. It is necessary to clarify the participation path and benefit distribution method of market entities.

3. Research framework, methods, and case introduction

3.1. Research framework

Based on identifying the special institutional, economic, and social environment of Beijing's urban regeneration, this study focuses on analyzing the marketization mechanism of urban regeneration from the aspects of governance structure and interest balance. The research on the governance structure focuses on the interaction and cooperation between the market and the government, residents, and other subjects in various urban regeneration projects, which is the basis for constructing a market mechanism. The research on the balance of interests focuses on the allocation of cost input and value-added benefits among different subjects in urban regeneration projects, which is the core of the sustainable advancement of the market mechanism (Figure 1).

By identifying the participants of urban regeneration projects, the research on governance structure analyzes the different cooperation and interaction relationships among different subjects, such as market transactions, principal agents, and management services. Specifically, the market transaction relationship refers to the transaction relationship between the buyer and the seller. Urban regeneration mainly exists between market entities and property owners. Specifically, it refers to various situations where the original property owner transfers the space property rights to the implementing entity, the property

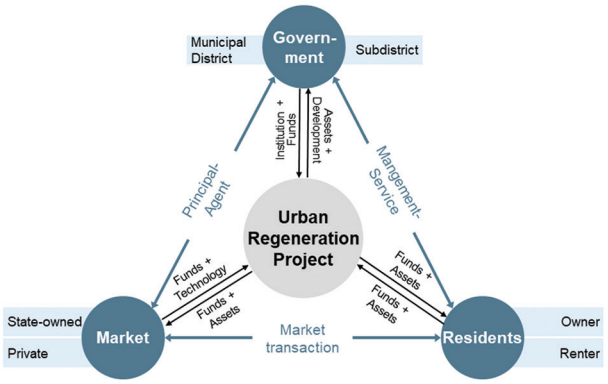

Figure 1. Urban regeneration governance structure and benefit distribution analysis framework. Source: Diagram by the authors

owner leases the space to the lessee, and the implementing entity raises project costs from the financial institutions and other investment entities through loans and funds, among other sources. The original property owner pays and entrusts the construction unit to carry out renovations, and so on. In essence, capital gains are exchanged for space use rights or property rights, technical and human services, financing guarantees, and the like. In addition, borrowing, employment, and leasing, in a broad sense, are all sales relationships. The principal-agent relationship refers to the contractual relationship in which the principal is entrusted to the agent to operate when the principal cannot directly exercise the power. In urban regeneration, it mainly refers to the system guarantee or financial support given by the government to the implementation subject and the implementation subject invests in technology and provides workforce and funds to promote the implementation and transformation of the regeneration project. The management service relationship mainly exists between the government and the society. The government serves to protect the interests of the public on the basis of guiding and managing social subjects through institutional norms.

The research on the balance of interests takes urban regeneration projects as the core and analyzes the "cost-benefit" distribution of different subjects in the whole process of planning, construction, and operation of regeneration projects. Among them, the input forms of different subjects include investment in capital and space property rights, as well as technical and human input in construction, operation, and maintenance. The benefits of different participants include the acquisition of space property rights, use rights, rents, asset sales, and other financial income.

In addition, the characteristics of benefit allocation in different governance structures of urban regeneration projects are different. Among them, the trading

relationship is a kind of market behavior, and the focus of the establishment and maintenance of the cooperative relationship is whether the pricing is reasonable and unanimously recognized by all participants. The government has an obvious involvement in the relationship between principal-agent and management services, and it is difficult to quantitatively measure the investment of financial subsidies and system dividends, the generation of public interests, and whether public interests can be shared. Thus, it is still controversial whether urban regeneration projects are fair and just.

3.2. Research methods

The research method is a qualitative and quantitative analysis based on case information collected from field research, semi-structured interviews, and other public ways. The goal of the analysis is to objectively describe the participants, operation process, renovation methods, and cost-benefit relationship of the regeneration project and to analyze the evaluation of stakeholders on whether the effect of the urban regeneration project meets expectations and whether the benefit allocation is balanced.

The case information comes from two sources: first-hand information comes from the fund calculation, planning, and design materials provided by the project team, as well as the author's interviews with multiple participants; second-hand information comes from the public, such as news reports and official propaganda. Research, interviews, and discussions on three typical cases were conducted between February and March 2022. The interviewers involved administrative personnel representing government departments, implementers and investors representing business entities, lessee enterprises and residents representing social entities, and university scholars representing experts, including all stakeholders in the renewal project.

3.3. Case introduction

In 2022, under the guidance of the Beijing Urban Regeneration Special Group with the support of the Municipal Party Committee's Urban Affairs Office, Municipal Planning and Natural Resources Committee, and Municipal Housing and Urban-Rural Development Committee, the "First Beijing Urban Regeneration Best Practice Selection Activity" was hosted by the Beijing Urban Planning Society. After expert evaluation and public voting, 16 Beijing urban regeneration "best practice" projects and 18 Beijing urban regeneration "excellent cases" were selected from 210 projects declared by more than 100 enterprises and departments in Beijing. According to the evaluation of the Beijing Department of Planning and Natural Resources, these 34 projects are "rich in types, have strong social influence and good demonstration effect," and the projects represent the latest frontier of Beijing's urban regeneration practice and exploration. However, in the official publicity, most of the implementers describe the experience and exploration in the promotion of the project from their own perspectives, and in-depth horizontal comparison is lacking.

This study analyzes the typical governance structures of 34 cases based on systematically comparing their functional types, subject cooperation relationships, market participation mechanisms, multi-party resource contributions, and benefits. As such, we selected typical cases and further analyzed the operation mechanism of the project through field research, semi-structured interviews, and comparative analysis. In general, the 34 cases can be divided into three typical governance structures, including welfare protection type, economic growth type, and comprehensive development type, which are relatively evenly distributed in urban regeneration projects in Beijing. Among them, the welfare protection-oriented type mainly includes public space, facilities, and residential projects, with less economic value-added potential. The economic development-oriented type mainly focuses on industrial projects such as old buildings and old factories, which involve residential projects promoted by private enterprises. The comprehensive development-oriented type mainly refers to regional comprehensive projects, which contain large-scale industrial projects (Table 1 and Figure 2).

4. Findings: Three governance structures and benefit distribution of market participation in Beijing's urban regeneration

4.1. Welfare guarantee-oriented governance structure

Welfare guarantee-oriented governance structure, which mainly exists in urban regeneration projects, such as public space, infrastructure, and old neighborhoods, and which has the nature of quasi-public goods, but the economic value-added characteristics are not obvious. In these projects, market players, mainly state-owned enterprises, are usually responsible for the concrete implementation, and government departments provide financial guarantees for the projects through special funds. However, residents do not directly pay or only pay part of the construction costs and enjoy the benefits, such as environmental improvement and facility additions at a very low cost.

Guangming Building 17 in Chaoyang District is a district government-owned public housing project, built in the 1960s, suffering from problems such as inadequate kitchen and bathroom facilities and safety hazards. The

Table 1. The main situation of the research object

Governance structure	Project type	Typical cases	Project features	Leading participant	Market mechanism
Welfare guarantee-oriented type	Public space projects	Micro public space, Chongyong Street, Yangmeizhuxie Street, Bajiao New Park	State-owned property, public service	The government	The government coordinates the promotion and investment, and market players implement and operate
	Facility projects	15 min community life circle, Fucheng building			
	Residential projects	Guangming Building 17, Guchengnanlu Community, Beixiaoyuan Community, Dongao Community, Guanghuadongli Community	State-owned or corporate-owned public housing		Government financial subsidies, property owners invest, market players implement and operate
Economic growth-oriented type	Industrial projects	Jinnovation park, Taigu west region, Meike building, Xindadu park, Beiren park, etc.	Corporates' private property land	State-owned enterprises, private enterprises	Multi-party market players jointly invest, build, and operate
	Residential projects	Zhenwumiao Community, Jinsong Community	Private residences	Private enterprises	Government, market, and residents jointly invest, market players implement and operate
Integrated development-oriented type	Regional projects	Caixi historic area, Moshikou historic area, Nanluoguxiang alley, Wangfujing area, etc.	Mixed property rights, historic preservation needs	State-owned enterprises	Government promotion and financial subsidies, market players coordinate, implement, and operate
	Industrial projects	Shougang old industrial zone, 751 park, Xidangengxin park, Zhangjiawan design town	Old factory with large-scale	State-owned enterprises	Government cooperates with state-owned enterprises to promote and provide public activities and service functions

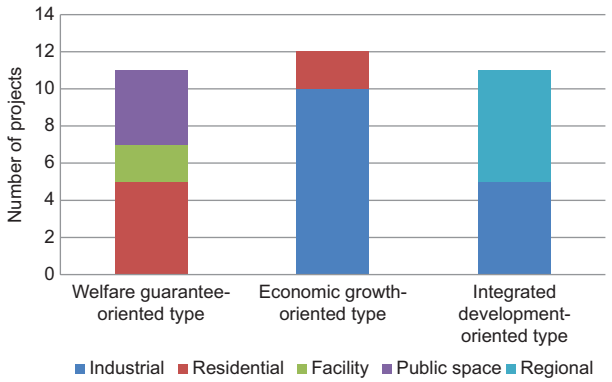

Figure 2. Typical urban regeneration case in Beijing. Source: Bar chart by the authors

building was demolished and rebuilt from three-story to four-story above ground and one-story below ground, with the number of households remaining unchanged and all residents relocated. From the perspective of government, the municipal and district governments cover 78% construction costs of the project, including 29% financial support from the municipal and district governments and 49% from the property rights owner, the district government. On this basis, the district government balances its expenditure by holding the property rights of the newly built underground service facilities. According to the introduction of government administrators, this regeneration method of promoting residents to improve housing conditions *in situ* is different from the previous method of relocation and resettlement in different places. It avoids the path for developers to obtain profits by increasing housing prices and can effectively save regeneration costs. In addition, the original residents bear about 23% costs through repurchasing the rebuilt housing units and turning the former district government-owned public property rights into private property rights, referring to the affordable housing management system. A resident who has lived in the building for decades said that the rebuilt house is "completely different" from the previous one, "the living area has increased a lot," and the three major problems of "difficulty in going to the toilet, bathing and cooking" have been solved. In the process of regeneration, the market player, Jingcheng Group, a district state-owned enterprise belonging to the Dongcheng (Eastern) district, mainly assumed the role of implementation entity to carry out demolition and construction, as well as the role of

assistant of the community committees to communicate with residents and designers to promote the formation of the design (Figure 3).

4.2. Economic growth-oriented governance structure

Economic growth-oriented governance structure mainly exists in the regeneration projects of old factory buildings, old office buildings, and other commercial and industrial buildings. The property rights of such projects are mainly privately owned by enterprises with few historical issues, such as property rights disputes. This kind of governance structure can obtain a large economic value-added characteristic through quality improvement, function replacement, and other means, with the highest market mechanism in all the regeneration projects.

Jinnovation Park was originally the furniture production plant of BBMG Group, a municipal state-owned enterprise, covering a land area of 200,000 sqm with a total construction area of 120,000 sqm. In 2016, with the overall migration of the hospital furniture production function to Hebei, BBMG Group and the Haidian District Government jointly planned to build a professional technology industrial park with the goal of "big information and intelligent manufacturing," relying on surrounding technology resources and using idle factories. In terms of space utilization, on the premise of not increasing the overall area of the park, more than 85% of the high-lifting and high-load industrial space in the park is reserved to support the spatial needs of innovative enterprises. An enterprise in the park transformed the original one-story factory building into two stories, of which the second story is used as a meeting, office, research, and development space, and the first story is used for mechanical testing and production. The business owner said that such a space can meet all the needs in its industrial chain, and the rent is lower than that of the surrounding office space. In terms of subject cooperation, under the comprehensive support of the district government's financial subsidies, industries introduction, and policy provisions for transitional use of functions, BBMG Group, the property owner, as the main investor, organizes reconstruction and transformation, introduces, and cultivates various enterprises through leasing operations, and then obtains rent and tax income, as well as paying taxes to the government. At present, the park is nearly fully rented and has attracted more than 200 technology companies and more than 5000 technology talents. According to the staff of BBMG Group, in 2021, the total production value of the park exceeded 5 billion yuan. Compared with the original traditional furniture manufacturing industry, the unit output value has increased by nearly 10 times. The government also believes that the transformation and upgrading of the traditional manufacturing industry has been fully realized, and the industrial space has been vacated (Figure 4).

4.3. Integrated development-oriented governance structure

A comprehensive development-oriented governance structure mainly exists in regional comprehensive urban

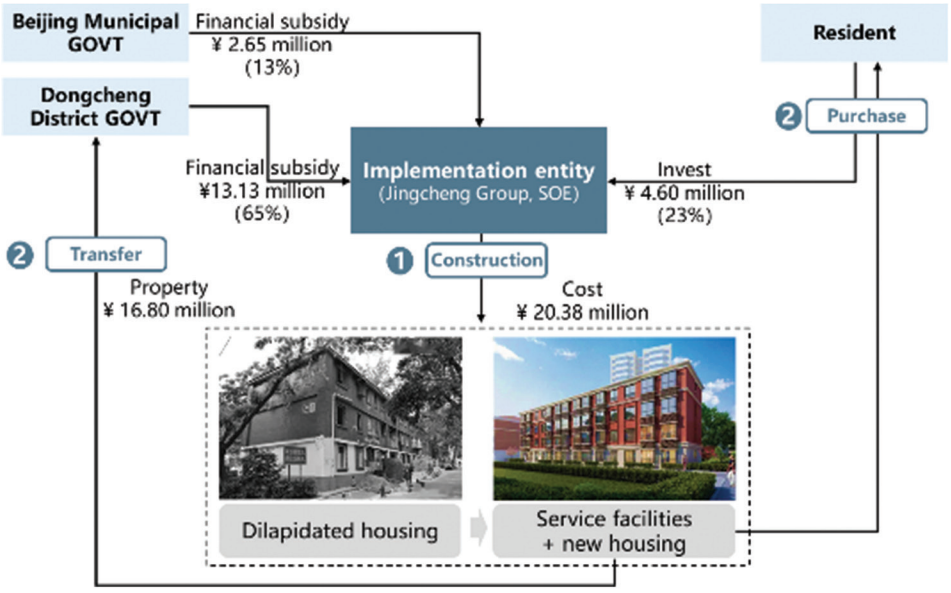

Figure 3. Guangming 17 Housing, Dongcheng (Eastern) District, Beijing. Source: Drawings by the authors (Data in the figure are derived from interviews or project introductions during our research investigation and do not necessarily represent the accurate final data); photos from the implementation entity

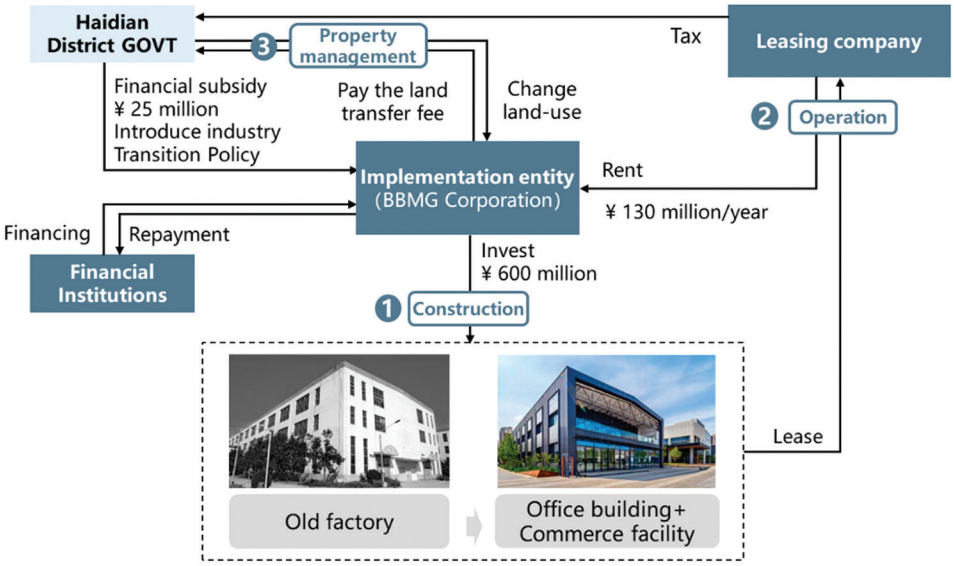

Figure 4. Jinnovation Park, Haidian District, Beijing. Source: Drawings by the authors (Data in the figure are derived from interviews or project introductions during our research investigation and do not necessarily represent the accurate final data); photos from the implementation entity

regeneration projects, which are of large scale and complex situation, involving different functional types of industries, residences, facilities, and so on, and integrate multiple means of protection, repair, demolition, and construction to achieve comprehensive and sustainable development of urban areas.

The Caixi historic area project is located within the "Historical and Cultural Essence District" of inner Beijing's Second Ring Road, covers an area of 6.5 hectares, and is dominated by traditional Beijing courtyards. The Xicheng (Western) District Government authorized district state-owned enterprises Beijing Financial Street Investment (Group) Co., Ltd. to set up a platform company called Beijing Jinhengfeng Urban Regeneration Asset Operation Management Co. The platform company was responsible for the whole process of consultation of residents, planning, design, relocation compensation, construction implementation, and operation services within the area. These courtyard houses of the residents who made *in situ* improvements at their own expense in the application for improvement still retained the residential function. For residents who applied for rent cancellation or change, the buildings and courtyards would be transformed into business functions, such as long-term rental apartments, cultural exhibitions, catering and commercial facilities, and corporate headquarters, according to the situation. The platform company was authorized with a 50-year franchise of the traditional courtyards by the district government and gradually recovered the transformation costs and gained revenue through the rental income of the business (Figure 5). In such projects, the more complete the leased courtyard, the higher the rent level. Five of the six households living in the courtyard of this area chose to quit the lease and live in an apartment in the suburbs, but the remaining one household was unwilling to move out of the city center. Therefore, the platform company provided the household with a new dwelling in another courtyard, which is 120 m away from the current courtyard. The living area was not only expanded from the previous 15.6 sqm to 30 sqm but also equipped with kitchen, toilet, and bathing facilities. This solution has been approved by the family members of the household. The staff of the platform company said that after the residents moved out, the courtyard could be remodeled and rented out, and the rent could be increased from the original 5–6 yuan/sqm/day to 12 yuan/sqm/day. In this way, the residents' wishes and business objectives are realized at the same time.

4.4. Comparison

At this stage, three main governance structures have been formed for market players to participate in Beijing's urban regeneration, applicable to different urban regeneration projects, with differences in the types of values, operating efficiency, and how benefits are distributed among different participants (Table 2).

The welfare guarantee-oriented governance structure is mainly aimed at stimulating public value and welfare, and the government mainly invests in promoting and meeting the needs of the residents in terms of service facilities, public space, and livelihood protection, while market players are responsible for the task of construction and

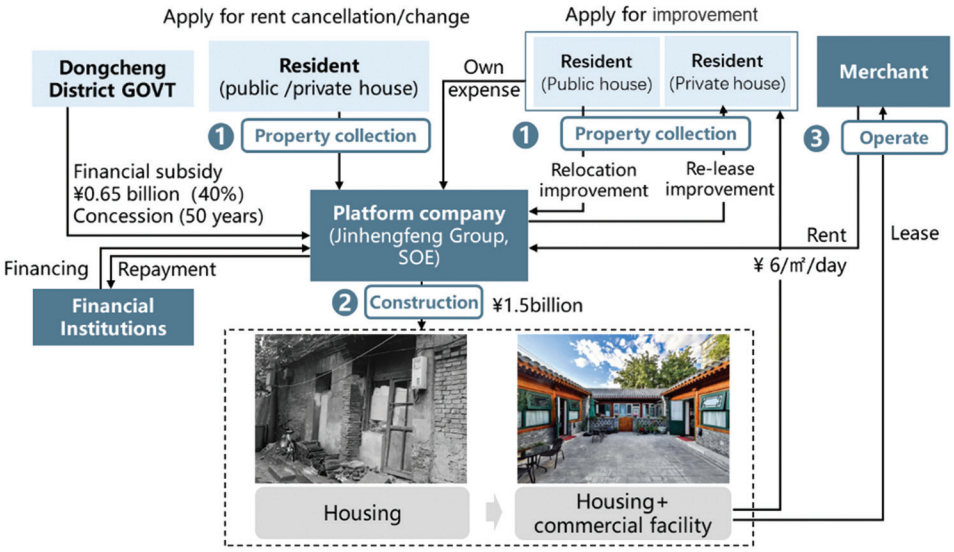

Figure 5. Caixi historic area, Dongcheng (Eastern) District, Beijing. Source: Drawings by the authors (Data in the figure are derived from interviews or project introductions during our research investigation and do not necessarily represent the accurate final data); photos from the platform company

Table 2. Benefits distribution in different governance structures

Governance structure	Value type	Benefit distribution		
		Government	Market	Residents
Welfare protection-oriented type	Public welfare	(++,+)	(+,+)	(+,++)
Economic growth-oriented type	Economic value	(o,+)	(++,++++)	(o,o)
Integrated development-oriented type	Public welfare+economic value	(++,+)	(++,++)	(+,+)

Note: "+" denotes the scale of input or benefit, and the magnitude increases with the number of "+". On the other hand, "o" denotes that no input is made or no benefit is obtained.

implementation with balanced costs and benefits under government financial investment. In this type of project, facilities and public space projects have a relatively high degree of publicity, which can be used by all urban residents. The source of government investment also comes from the tax revenue provided by urban residents, forming a closed loop that balances cost input and users. However, the use rights of residential regeneration projects are owned by the residents, and the degree of publicity is low. The government invests in renovation funds in a targeted manner. The residents of the regenerated community have benefited from the improved spatial conditions, while the residents of the unrenovated community have never obtained any benefits. In fact, it is an unfair distribution of regeneration rights. For example, in the Guangming Building 17 project, the original residents invested in the purchase of the rebuilt houses. The renovation cost of the original house area is 1560 yuan/sqm, and the new parts for purchase after the renovation are based on the comprehensive reconstruction cost of 6564 yuan/sqm; the average investment of 157,000 yuan per household can buy a room of about 50 sqm, the market transaction price of second-hand housing in this community is about 114,500 yuan/sqm, and the market price of a 50 sqm room should be about 5.7 million, which is 10 times the investment of the project. Overall, this is a good deal for the original residents. According to the feedback from the implementation enterprise, the proportion of residents who have agreed reached 100% each time in the three rounds of consultation, which is rare in old community regeneration projects. Some public opinions on the Internet said, "Residents in this project bought a new dwelling of more than 5 million yuan with 150,000 yuan, which is almost an unexpected fortune."

The economic growth governance structure is mainly aimed at tapping the economic value, meeting the profit demand of various market players, and promoting the efficient use of spatial resources through the reasonable allocation of spatial property rights, which is a kind of mature market regeneration model, and the government can obtain certain tax revenue through the development of industries. In projects such as old buildings and industrial plants, the original low-efficiency industries

are evacuated, and the new high-value-added industries are introduced. However, the 5-year transitional period policy proposed by Beijing to promote the regeneration of old factory buildings means that enterprises can use industrial factories for commercial, office, and other purposes within 5 years, but they do not need to pay land transfer fees. In actual operation, the government has not yet formed a clear statistical method to count the start time of the transitional period, and the enterprises in the interviews were unable to figure it out. The delay in the payment of land transfer fees may lead to the loss of government fiscal revenue. In residential projects, through the transformation and utilization of the original idle buildings, functions such as community supermarkets and catering services are implanted, or leased residential buildings are sublet after renovation. The functions of property rights transactions, rents, and property services in these projects are mainly promoted by market entities, relying on the price standards of the free market, and the balance of the interests of all parties is achieved through mutual negotiation. For example, in the Zhenwu Temple project, the cost of housing acquisition and renovation is about 8000 yuan/month. After decoration and renovation, it can be rented out at a price of 12,000 yuan/month. The profit target can be achieved after 8–10 years of continuous operation. In the project, the original homeowner obtains stable rental income at market rental prices, which meets the living needs of surrounding white-collar workers and improves the overall environment of the community and the house, which is a win-win cooperation.

The comprehensive development-oriented governance structure combines public welfare and economic value. The key point is that it is necessary to coordinate the demands of various property rights subjects within the area, and the establishment of a platform company for the overall operation has become a common choice in such projects. In the regeneration of the old city's single-story courtyard houses, the residents independently decide to choose the appropriate regeneration or relocation compensation method, whose costs and benefits are basically balanced, while the government and market players invest in reconstruction costs and obtain corresponding income through the tax and rent of industrial operation at a later and long stage. This method essentially clarifies the interests of multiple parties more fairly, especially for relocated residents. Although residents generally have a "sense of loss" and cannot obtain huge returns such as the demolition of urban villages in Shenzhen, Guangzhou, and other places, this method is a more reasonable relocation compensation policy that reflects the market price of surrounding houses, which is about 120,000/sqm, to make monetary compensation, and to provide public housing for them to choose. However, since this model is under exploration phase, the platform companies generally state that after obtaining the 50-year operating right, whether it can achieve the expected income and balance, the cost input of planning, design, renovation, construction, operation, and maintenance needs to be further verified during the project. However, due to its good location, the platform companies prefer to commercialize the historical buildings, and they all have a relatively optimistic attitude toward the realization of the profit target.

5. Discussion

5.1. Constructing a market-oriented mechanism for urban regeneration with multiple governance structures

Through the analysis of the latest practical cases of urban regeneration in Beijing, this study enriches the existing literature that focuses on the acquisition and distribution of economic value and refines the governance structural content of "government-led, market-operated, and multi-participant" proposed policies across China. The study found that in the transformational period of urban regeneration, the content of urban regeneration is more extensive, the goals of regeneration are more comprehensive, and the value orientation takes into account the comprehensive benefits of social needs and economic value-added characteristics. In addition, the study believes that Beijing's urban regeneration has formed a pluralistic governance model of "growth coalition" and "equity governance." The study also found that different types of projects require different governance structures. Therefore, choosing an appropriate governance structure according to local and current conditions can give full play to the initiative of the government, society, and market participation.

To cope with the complex property rights and interest pattern of urban regeneration projects, Beijing has explored refined governance through a system of decentralization and responsible planners, while market players have also actively changed their roles from single businesses, such as industrial manufacturing and real estate development, to various roles such as comprehensive property services, event planning, industrial incubation, and fund management, and so on. They are increasingly assuming the role of "agents" between government departments and residents while undertaking the work of mapping the basic information of the area and collecting the willingness to renovate. They respond to residents' demands, provide management and services, and provide continuous technical services, operation guarantees, and supervision services, with the role of "operators" throughout the process, becoming

the main driving force for the implementation of urban regeneration projects.

5.2. Promoting value-added income and balance of benefits in urban regeneration

The balance of benefits is an important support for the stable and sustainable development of urban regeneration governance, and the appreciation of space is the premise of benefit distribution. Beijing is exploring the dual means of privatization of comprehensive property rights and flexible use to promote the marketization of stock space, increase the added value of stock space, and gradually establish a written system to improve the use value and efficiency of stock space. The privatization of property rights includes two aspects. First, it refers to the conversion of government property rights and public property rights of state-owned enterprise buildings formed in the era of free land use before the 1980s into private property rights owned by residents, and value-added income is obtained through the sale of property rights. Second, it includes the flexible transfer of commercial buildings to enterprises with more operating capabilities, improving the allocation efficiency and added value of spatial resources. For example, the system design encourages enterprises to transform idle buildings in old communities into operational service facilities, such as elderly care and canteens, and improve operational efficiency by simplifying approval procedures. Overall, the spatial transformation and value-added means in Beijing's urban regeneration have been continuously improved, reflecting the dual characteristics of welfarist policy support and neoliberalism's market mechanism.

However, there are still some deficiencies in the standard of interest balance in Beijing's current urban regeneration. First, it is difficult to attract investment from residents. In dilapidated housing renovation projects, the price of public housing purchased by residents is still far lower than that of surrounding commercial housing. At the same time, tenants enjoy the improvement of the living environment, but they do not bear the corresponding renovation costs. In addition, the varying management of different spatial types has resulted in differences in residents' benefits. For example, most of the single-story courtyard houses in the old city and the simple buildings in the old communities belong to public property houses, but the residents in the simple buildings can purchase house property rights at a price lower than the market without leaving the original residential environment, but residents in the courtyard houses cannot enjoy this right, that is, the differentiated system design results in large differences in residents' "sense of gain." Furthermore, the proportion of government investment is too high. Among the five major types of renovation projects in Beijing, except for old buildings, the government has issued relevant policies to provide corresponding financial support, which has also caused huge pressure on the government's finances.

6. Conclusion

Based on a brief review of market participation in urban regeneration in various countries, this study has explored the developmental process of Beijing's urban regeneration, the main challenges at the current stage, and analyzed the latest typical practical cases from the perspectives of governance structure and benefit distribution, and identified three typical governance structures, including welfare security type, economic growth type, and comprehensive development type. The study has also summarized the transformational experiences of the market participants and the profit mechanism. In addition, the study has analyzed the value types, operational efficiency, and benefit distribution methods of different governance structures of urban regeneration in Beijing. The study finds that a multi-coexisting pattern of "growth coalition" and "equity governance" has been formed in the urban regeneration of Beijing at the present stage. The governance model and the process of reuse of stock space embody the dual characteristics of welfarist policy support and neoliberal market mechanism, which have enriched the latest exploration of Beijing's urban regeneration in existing research. In addition, the experience of Beijing's urban regeneration marketization path summarized in the study also provides a reference for the transformation and development of urban regeneration in other Chinese cities.

Actually, the institutional construction and practical exploration of urban regeneration is a long-term process that needs to be continuously adapted to local conditions and time. Since 2017, Beijing has attained certain achievements and experiences in urban regeneration practice exploration and system construction and gradually established a market-oriented urban regeneration mechanism with local characteristics. The 34 urban regeneration cases selected in the study are representative to a certain extent, but they cannot show the full situation of Beijing's urban regeneration practices, which leads to the fact that the classification of governance structures in the study may not reflect all the situations of Beijing's urban regeneration market participation. Fortunately, however, it is still in the initial stage of urban regeneration practice and exploration. In the future, theoretical innovation and practical exploration need to be constantly combined to implement reform, adjustment, optimization, and improvement to continue to explore the formation of a normalized and sustainable urban regeneration market mechanism for Beijing and other

cities of China in the stock-based or reduction-oriented regeneration era.

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ORIGINAL ARTICLE

Study on the development path of cultural tourism integration in Yubai Village in the context of rural revitalization

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Abstract

As a historical node on the coal transportation route along the Old Road of Western Beijing, Yubai Village served as an important business travel station. However, as time passed by, the Old Road of Western Beijing transport line gradually declined, the Mentougou District coal yard shut down, the service function of Yubai Village disappeared, and the local industry development became slow, necessitating revitalization of the village economy. At present, rural revitalization has become an important strategy to promote rural modernization, and Yubai village has ushered in new opportunities for development. The village can rely on its regional advantages, adjust its own development direction, and become a distribution center on the tourism route. Based on the previous field investigation and literature review of Yubai Village, this paper integrates the current resources of the village, analyzes its realistic development predicament, and, from the perspective of culture and tourism integration, proposes new strategies suitable for the development of Yubai Village, such as improving the overall reception services, improving the village landscape node, improving the village road system, carrying out research and education activities, and developing derivative cultural and creative brands. The purposes are to extend the stay time of tourists and give full play to the function of a service station, realize the revitalization of industry, promote the economic development of the village, and provide a reference for the development of similar villages in the future.

Keywords: Rural revitalization; Integration of culture and tourism; Yubai Village; Service station, China

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1. Introduction

A large number of scholars have extensively studied the integration of culture and tourism, exploring its theory through the interaction of the two (Fan, 2019; Liu, 2019; Zhan *et al.*, 2023). The integration of culture and tourism provides an opportunity for developing rural tourism (Liu & Gao, 2020; Ding, 2023; Guo & Chen, 2023), as well as specific practices applied to urban and rural tourism development (Gui & Tang, 2016; Wang & Hu, 2020; Niu, 2012). There are also many studies related to Mentougou, ranging from the history of the Mentougou District (Yuan & Li, 2007) to the heritage value and conservation recommendations of the Old Road of Western Beijing (Que & Song,

2012), as well as studies of traditional villages along the route (Wu, 2016; Sun, 2018). Scholars have established an evaluation system for low-carbon tourism in the outskirts of Mentougou District (Luo & He, 2015), explored new paths to promote its revitalization under different models (Kuang & Zhang, 2021; Wu & Tian, 2022), and promoted its transformational development (Zhao, 2023). There are more specific studies on the theoretical development and practical application of cultural tourism integration, and there are also studies on the history and development of Mentougou and the path of rural revitalization, but few studies have explored the developmental path of rural revitalization in Mentougou from the perspective of cultural tourism integration.

In this study, we took Yubai Village in Mentougou District as an example to analyze its historical origin and discuss its current development problems, integrate cultural and historical tourism resources in the village, carry out village quality improvement and revitalization, propose a new path suitable for the development of Yubai Village, promote local industry linkage, improve income generation, achieve population return, and realize rural revitalization.

2. Research methodology

2.1. Field research method

Through field research, including interviews, photos, and maps, we were able to gain a comprehensive understanding, compile a record of the current situation of the overall Yubai Village, and dig deeper into the various aspects of the problems facing its current development. At the same time, the problems and optimization methods in the field were investigated by visiting the surrounding traditional villages.

2.2. Literature research method

Through our reading of domestic and international literature, the study provides feasible strategies, methods, and theoretical support for the development of cultural and tourism integration in the village. It also provides a comprehensive understanding of the evolution of the village and its evolutionary pattern through the review of historical documents and relevant data to gain an overall understanding of its development status.

3. Village history

The historical Mentougou District, "with coal under the ground and hundreds of treasures in the mountains and rivers," was famous for coal mining and was accessible through the Old Road of Western Beijing. The coal mining industry can be traced back to the early Liao (907 – 1125) and Jin (1115 – 1234) dynasties, according to the Historical Atlas of Beijing - Cultural and Ecological Volume (Hou, 2013). The first coal mine in modern times was also located here, contributing to the urban development of Beijing. Later, due to modern industrial development and imperfect transportation facilities in the Mentougou District, Beijing's coal economy shifted to other regions, and the Mentougou District lost its regional advantages (Hu, 2022). The year 2019 saw the closure of the last mine in the district, ending a 1000-year history of coal mining, but most villages in the Mentougou District were unable to support the local industry due to insufficient land area and had to rely on the Old Road of Western Beijing for coal transportation. The transformation of the coal economy undoubtedly has a huge impact on the village. As a necessary stop along the Old Road of Western Beijing, Yubai Village in Yanchi Town developed into a service-oriented post-village. Nowadays, with the decline of the historical style of the road, the function of the post-station is also fading away, and the village industry needs to be revitalized.

4. Present situation and development dilemma of the village

4.1. Broken historical style and declining attributes of the post station

Yubai Village is located in the northeastern part of Yanchi Town, Mentougou District, at the border of Changping District and Zhangjiakou City, 70 km away from the center of Beijing (Figure 1). Yubai Village is relatively easy to reach by car compared to other villages and can be reached within 1.5 h. Historically, Mentougou District was once a major mining area, with local coal resources transported through the Old Road of Western Beijing, supplying many areas in and around the capital city. However, with the social and industrial development of the new era, the historical function of the Old Road went from prosperity to decline, with the last mine in Mentougou District shut down and the whole region transformed from a coal economy to an ecological economy. However, most of the local villages are dependent on the formation and survival of the Old Road in Western Beijing, and the small area of the villages and the uneven distribution of resources are not enough to support the development of local industries. As a result, the economic structure of the village has been deteriorating, making its productive capacity harder. Due to its convenient location, Yubai Village in Yanchi Town was once a developed commercial hub as a necessary place on the coal transport route of the Old Road in Western Beijing (Zhao, 2019). However, with the gradual decline of the old road, the function of Yubai Village's post station gradually weakened until it disappeared, and the village's industry also

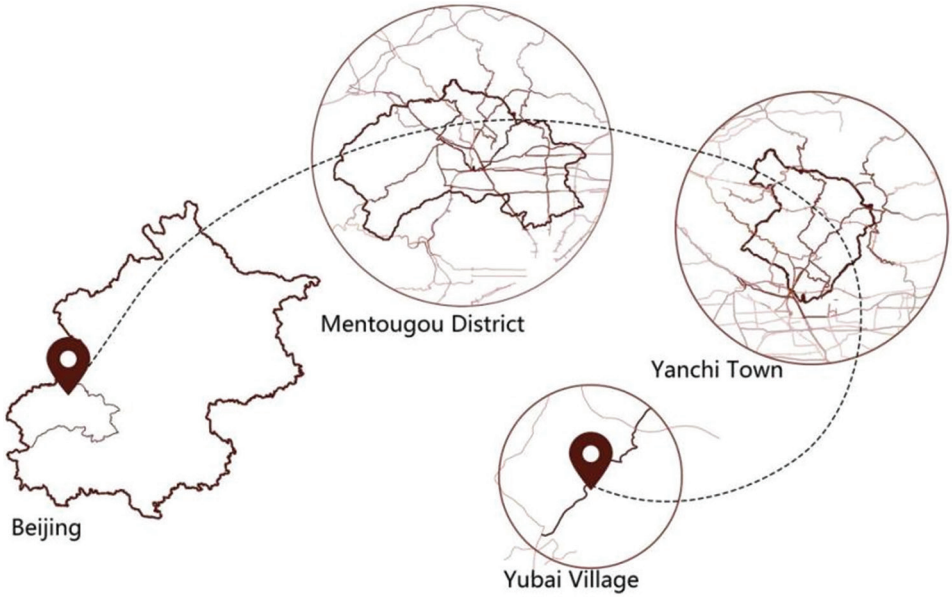

Figure 1. Location of Yubai Village. Source: Drawing by the authors

changed from service-oriented to mono-farming, causing the economic situation to deteriorate seriously. However, analyzing the geographical situation of Yubai Village, the overall situation is good, and the traffic is convenient, with the south side adjacent to the South Yan Road, which leads to the neighboring villages such as Gaotai and Tianzhuang. Thanks to its unique geographical location, it is still a must-see on the local cultural tourism route. However, the village has not yet converted its own conditions, such as location and transportation, and ecological environment into advantages to effectively drive regional economic development. Therefore, there is an urgent need to explore appropriate resource utilization methods in the context of today's culture and tourism integration, restore its post function, and rejuvenate the village.

4.2. Insufficient village space and single industrial structure

The overall planning area of Yubai Village is 1610.69 ha, of which 12.41 ha are under construction. The built-up village is in the central south of the area and is distributed on terraced land. The village has 610 households with a total of 946 people, but the actual resident population is only 180 households with 310 people, mostly elderly. This highlights the serious problem of aging and brain drain. The village is dominated by primary industry, mainly forestry and fruit industry, producing walnuts, Chinese toons, and apricots (Figure 2), but the insufficient space of the village has given rise to a single economical structure, which cannot support the development of village industry and has low capacity efficiency.

Figure 2. Villagers' work. Source: Photo by the authors

4.3. Ineffectively utilized and scattered resources

In terms of ecological resources, Yubai Village is in a deep mountainous area with an altitude of 530 m and striking scenery. The village covers a large area of woodland and is rich in biodiversity. The scenic area of Tiansheng Lake on the south side of the village, with a quiet and elegant environment and fresh air, is now an idyllic place, which has been developed into a multipurpose recreational site suitable for water-friendly tourism and vacation, wilderness camping, and agricultural production.

In terms of cultural resources, Yubai Village was built in the Yuan dynasty (1206 – 1368), with a history of over 800 hundred years. The higher street in the village was formerly known as White Falls Ridge Street, and the other lower street was formerly known as Silt Pit Street, which was

later developed as a whole and renamed Silt White Village and was also known as Yubai Village. The whole village has a strong history, and the pattern of streets and courtyards in the village has basically maintained its historical style. Historic houses, old wells, stone mills, old black trees, and so on can be seen everywhere in the village, and several old bridges have survived to this day (Figure 3). However, after a long time, the gatehouses, old houses, and shadow walls of some folk houses have been left mottled. In addition, there are still many religious and cultural relics in the village, such as Niangniang Temple, Dragon King Temple, and so on. However, due to a lack of repair, these places cannot be open to the public, but the Baipu Temple in the north of the village is well preserved and is a Beijing-level cultural relics protection unit. The temple was built in the Liao dynasty (907 – 1125), more than 900 years ago. In recent years, it has been renovated and reopened to the public. In terms of folk cultural activities, the villagers practice the traditional custom of "receiving the Empress and praying for peace" on the 15th of the fourth lunar month, which has been continued in the village for hundreds of years. Yubai Village will carry forward this folk cultural festival to attract tourists from inside and outside China. There is also a rural Bengbeng Drama, which has a long history and is a representative drama of the Mentougou District. It was listed in the municipal intangible cultural heritage in 2007. In addition, Yubai Village was once situated on an important route during the anti-fascist war of the Second World War, where a large amount of materials, personnel, and information were transported to the anti-Japanese bases of the area, which is of great significance. However, there is a lack of relevant historical legacy within the village, and it is impossible to verify the specific path. International friends such as Michael Lin and William Ban have stayed in the village for about two weeks, but the courtyard where they took a short stay is no longer available.

Figure 3. The Yubai Village landscape. Source: Photo by the authors

There are some tourism resources within Yubai Village, and the tertiary industry is expected to grow. However, at present, the only thing that can be used for the development of cultural tourism in the village is the Baipu Temple on the north side, the Goddess Temple, and the field complex. In general, the local tourism resources are scarce, and the characteristics are weakly refined and lack unique attractiveness. In addition, the points are relatively scattered, and only through the contact of silt road, all resources cannot form a joint force, resulting in the problem of multiple points and wide areas. Hence, it is difficult to attract tourists to divert from the Baipu Temple and field complex to the Yubai Village. On the other hand, the revolutionary resources within the village are not linked to the surrounding revolutionary memorial sites such as Tianzhuang Village and Jiangou Village, and the tourist flow of Baipu Temple is slightly insufficient compared with other similar scenic spots, and the natural and cultural resources are not outstanding. The tourism products in the village are not diverse. Moreover, the tourism packages are not sufficiently publicized, and the short tour time fails to meet the needs of tourists. The characteristic resources only stay in the ornamental stage, so tourists have not yet become consumers of the tertiary industry in Yubai Village, and local resources have failed to be effectively transformed into tourism revenue.

5. Village development orientation

5.1. Development opportunities

Although Yubai Village is faced with the above-mentioned practical difficulties in terms of development, the village was able to bring in development opportunities through policy support.

At present, rural revitalization has become an important strategy to promote rural modernization. Stimulating the potential of rural resource elements has injected new vitality and brought new opportunities to rural development. At the same time, the Beijing Municipal government issued the Opinions on Promoting the Integrated Development of Culture and Tourism in Beijing, pointing out that the integrated development of culture and tourism should be regarded as an important driving force to promote the high-quality development of the capital's cultural and tourism industries. The Mentougou District government also issued the Opinions on the Integrated Development of the Culture and Tourism Industry in Mentougou District, which changed the regional positioning from the mining area in the west of Beijing to an ecological conservation area, requiring the promotion of the city brand construction of "clear waters and green mountains in Mentougou," and the integration of culture and tourism as the future development direction for the region. Therefore,

Mentougou District and Yubai Village ushered in an era of opportunity for redevelopment.

Therefore, by actively integrating the current resources in Mentougou, it can be found that the area is at the west gate of the capital, rich in historical resources and superior natural conditions. Relying on its regional advantages and extensive resources, there are certain benefits in the development of cultural tourism. The area covers three famous Chinese historical and cultural villages, 12 traditional Chinese villages, and 14 traditional Beijing villages, such as Cuanxia Village, Zhaitang Town, Lingshuiren Village, Liuligou Village, and so on (Xu, 2015). These historical villages rely on the rich local cultural resources, enhancement of infrastructure, and vigorous development of the characteristic tourism economy, forming several Beijing cultural tourism routes. Due to its unique geographical location, Yubai Village is still a necessary place on this route. Therefore, with the transformation of Mentougou District's strategic positioning, the development orientation of the local village should be changed from the transportation of coal and other materials, to the development of local cultural tourism resources, and the function of its post station should be redeveloped. However, at present, Yubai Village has not made full use of its geographical advantages, and all kinds of tourism resources within the scope are relatively scarce, scattered, and lacking characteristics, and it is difficult to develop its own industry. It is necessary to seek a suitable development direction in cultural and tourism integration. In other words, the bundled development of nearby famous villages and strong villages provides Beijing and its surrounding cities with large tourism demand, driving the utilization of boutique homestays, folk custom bases, non-generic heritage, and old roads, prompting the construction of multifunctional service stations, and building rural cultural tourism economy (Duan *et al.*, 2009).

5.2. Village orientation

Therefore, combining the unique history and locality, Yubai Village can be repositioned as a "service station" on the cultural tourism route, continuing its function as a transportation hub in the old route of Western Beijing and realizing the industrial revival of the village.

From a historical point of view, the village was once an important traffic node on the transportation route of coal, timber, stone, and other resources, and today, it is still on an important traffic route to the nearby cultural and tourist villages of Mentougou District (Sun, 2008). In general, its historical function as a village service station remains unchanged, but it has only changed from being used by merchants to being used by tourists, so the village still has the potential to become a tourist distribution point.

At the regional level, on the one hand, other villages near the Yubai Village have rich cultural resources but are generally small for the development of local tourism (Qing, 2019). In contrast, Yubai Village has sufficient spaces compared to other villages, which can be built into a service station through infrastructure improvement and road upgrading, thus satisfying the daily needs of tourists, achieving village diversion, and promoting the economic development of villagers and village collectives. On the other hand, compared with its neighboring villages, Yubai Village has lesser village characteristics, scattered resources, natural and cultural conditions that do not have absolute advantages, and relatively challenging industrial development. After the construction of the service station, the village can take advantage of the flow of visitors and the scale of the village itself to offer tourism services such as performances related to folklore, catering, and nature tourism. This initiative aims to revitalize the idle resources and assets of the village and enhance the cultural and economic values of the village.

6. Revitalization pathway of Yubai Village integrating cultural tourism and development

Based on the positioning of the village as a "service station," Yubai Village can take advantage of the village's scale and passenger flow and carry out a series of cultural tourism activities surrounding the relevant policies of "clean water and plant trees on the mountains planning" and "a small courtyard planning." The overall development strategy is to build a "cultural tourism service station" as the core to increase the length of stay of tourists and to actively integrate the existing resources of the village and make full use of them. The main pathway includes upgrading the internal landscape, road system, and infrastructure of the village; creating a special landscape in the village; attracting tourists; bringing into play the function of the post; encouraging tourist visit and longer stay in the village; increasing the tourism economy; and promoting rural revitalization.

On the one hand, the overall planning of the village includes improving its reception and service capacity; building a tourism service center, catering service center, and other infrastructure; improving the quality of the village landscape; and carrying out a series of activities such as learning and exhibition of non-foreign heritage, so as to extend the stay of tourists in the village. On the other hand, the connection between the village and the tourism resources inside and outside the village should be strengthened, and the construction of Yubai Road, Yubaizhong Road, Yubainanshan Road, Village North Walking should be improved to stimulate the flow of

tourists from village to village and to maximize the function of Yubai Village as a "service station" and meet the development needs of the village cultural tourism.

6.1. Improving overall hospitality services

In 2019, Yubai Village was promoted as China's beautiful leisure countryside, with plans to build and renovate 50 new boutique bed and breakfast (B&B) compounds and create a homestay brand with the theme of "beautiful scenery of Yubai Village" by providing rural holiday services. At present, Yubai Village already has a certain amount of tourists, so it is necessary to build a tourism service center, a catering service center, a tourism reception center for the field complex, and a number of parking lots in the village and the Baipu Temple, to improve its reception function and tourism quality, strengthen the integration and connection between various resource points around, and improve the function of "service station" of Yubai Village.

The abandoned site in the village can also be used for reconstruction to give new vitality to the space. The former site of the abandoned elementary school has been transformed into a tourism service center equipped with a dining bar, a village history museum, a "Hong Ni Cao Tang" workshop, and an agricultural products processing workshop to showcase the processing techniques of agricultural products, sell local products, and satisfy the users with labor education, red education, and tourism service consultation. Redesigning the unused senior citizen canteen in the village, establishing a centralized catering service center, and forming a reception scale with the nearby B&B as its service support are also considered. Moreover, it refers to the research of dishes in Zhongshan Park about "A Dream of Red Chamber," and then mines the eating situation of Yubai Village recorded in the memoirs of Michael Lin and others, and combined with the number of tourists in the Baipu Temple, it divides the food types into cultural feasts as described in the "Book of Songs," Michael Lin's recipes, and vegetarian food made from local crop ingredients. So that visitors can taste delicious, while feeling the "Book of Songs" culture and experience the revolutionary spirit.

A new space for service should be built to meet the travel needs of tourists. The tourism reception center to be planned in Nanshangou Field Complex, with an area of about 1500 sqm, can provide catering, accommodation, and other services. The interior decoration carries the theme of a starry sky, echoing the brand of "Xing Kong Yubai" in the camping area, whereas the exterior adopts glass curtain wall with paint and stone and partial three-dimensional greening, to achieve harmony and unity with the surrounding environment, showing the local natural landscape characteristics of the village.

More parking lots inside the village and around the Baipu Temple should be built to improve the reception capacity of the village. The internal tourist service center and catering service center of the village, as well as the external site of the village, such as the site near the Baipu Temple, should build a total area of about 2,000 sqm and 6,500 sqm of ecological parking, respectively, which improved in terms of systematic parking so as to ease the traffic in the village and to better display the landscape of the village.

6.2. Enhancement of village landscape nodes

6.2.1. Completing the design of landscape node enhancement in the village profile

After the planning and construction of the village, the overall environment and landscape are good, but it is still necessary to appropriately supplement and improve the architectural style, entrance signs, and the main landscape nodes in the village to improve the spatial layout, enhance the landscape recognition, improve the landscape quality and cultural tourism environment of the "service station," and increase the stay time of tourists.

Regarding architectural style enhancement, due to the local topographical factors, the roofs of the mountainous villages are staggered, but the individual buildings among them are not coordinated with the overall style of the villages and need to be restricted in their styles and unified in the form, color, and material. Their main colors can be roughly divided into two hues: one is red roofing, and the other is gray roofing. The former is colorful and contrasts strongly with the surrounding environment, whereas the latter is in line with the old buildings, showing the long history of Silber Village (Figure 4).

Entrance signs and main landscape nodes in the village are upgraded. The entrance landscape design of the village is very important as a "village postcard" and needs to be improved appropriately. The current village entrance

Figure 4. Architectural landscape design. Source: Photo by the authors

landmark is not dynamic enough, so a water fountain can be added to enhance the landscape effect (Figure 5). Some of the green areas in the village also need to be improved and can be decorated with colorful and fruit-bearing plants, such as maple, ginkgo, persimmon, and so on, to complement the red roofs to enrich the colors of the village, increase the tourist experiences and extend their stays (Figure 6). In addition, there are some side slopes and roadsides along the village's perimeter, and the village roads in Yubai Village that lack greening can be enhanced by spraying seeds, ecological blankets, and climbing plants.

6.2.2. Construction of poetic edible garden as a special agricultural experience area

China is an ancient civilization with a long history of agriculture, and Mentougou District is one of the first places where agricultural cultivation began (Zhang & Liu, 2008). From the classic literature such as the *Book of Songs* (*Shi Jing*) and the *Compendium of Materia Medica* (*Ben Cao Gang Mu*), edible plants with ornamental effects can be selected for matching combinations and designing a 2,000 sqm edible garden within the field complex (Figure 7). Combining the culture of poetry and scripture with agricultural production, a new type of farm garden integrating food, entertainment, and science education can be formed, which provides a site to carry out parent-child activities, plant learning sessions, and other experiential education programs, thereby attracting a large number of tourists and maximizing the function of Yubai Village as a local "service station."

6.2.3. Creating an air corridor project

The characteristic landscape should be established so as to lead visitors from the Baipu Temple to the interior of the village, thus providing traffic for the "service station." At present, the air corridor is a missing item in the tourism of Mentougou District, so it is planned to take the intersection between two Side Roads as the starting point, and the dining service center in the village as the endpoint, and the proposed air corridor along the mountain with a total length of about 700 m is a special landscape. On the other hand, a lookout platform and stairs are planned to be

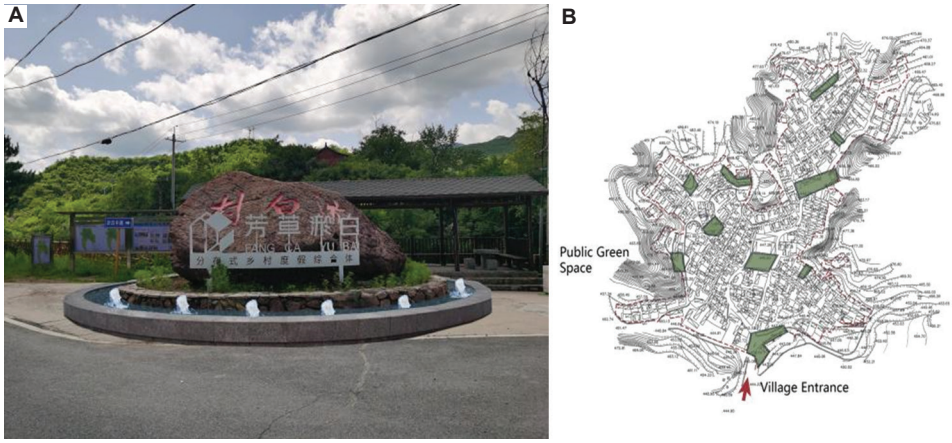

Figure 5. (A) The signage located at the village entrance. (B) Location of the village signage. Source: Photo and drawing by the authors.

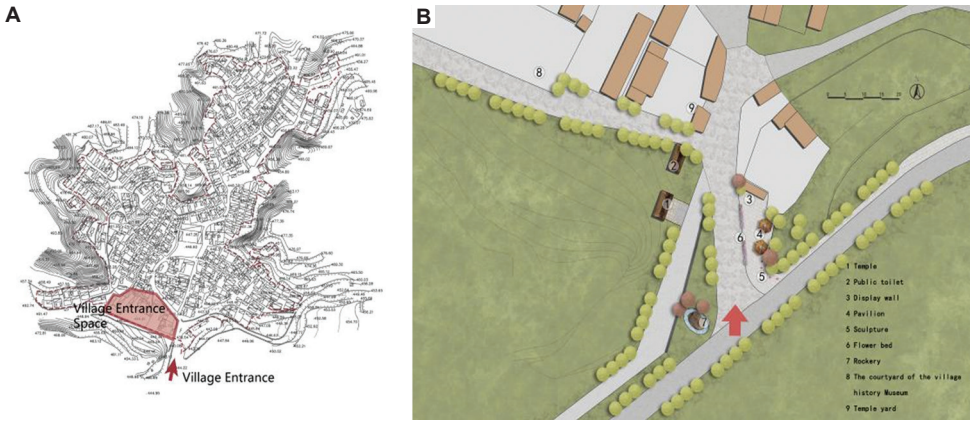

Figure 6. (A) Location plan of village entrance landscape enhancement design. (B) Village plan of entrance landscape enhancement design. Source: Drawings by the authors

Figure 7. Proposed plan of the poetic edible garden. Source: Drawing by the authors

set up locally. In this way, the modern air corridor can be combined with the historic villages and beautiful mountain scenery to create the most distinctive air tour line project in the west of Beijing so as to accentuate the highlights of Yubai Village and provide basic landscape support for the construction of "service station."

6.3. Improving the village road system

Through the improvement of the road system in the village, the connection between the nearby tourism resources will be strengthened so that the village resources can be integrated and utilized, and the construction of the "service station" in the village can be promoted. At present, the roads in the village are generally in good condition, but the individual roads are of low grade and need to be upgraded. For example, Yubai Road, the field complex driveway, and Yubaizhong Road need to be widened and greened; the completed mountainous walkway in the north of the village needs to be repaired and upgraded; and the Michael Lin cultural circuit from Yubai Village to the South Ravine needs to be built.

Due to the large number of visitors to the White Falls Temple, Yubai Road (the road of the Baipu Temple - Yubai Village) needs to be further improved in terms of its landscape and road quality. For example, the exposed rock mass in the local road can be re-greened and beautified by climbing plants. Apricot trees along the way are currently neglected and not in good condition, so peonies and other shade-tolerant plants can be planted under the apricot trees to improve the road landscape and improve economic benefits (Figure 8).

Some sections of Nanshan Road and Yubaizhong Road are narrow and difficult to converge, which is potentially

Figure 8. (A and B) Landscape enhancement effect of Silber Road. Source: Photos by the authors

dangerous for tourists, and with the increasing number of tourist vehicles, the problem is becoming more and more pronounced. The current width of the road from the village to the gully is only 4 m, and the current width of the road from the Anzi Reservoir to the edible garden is only 2.5 m. Road upgrade is therefore planned (Figure 9A). It includes expanding the width of Nanshan Road to 6 m, the partial width of the road from the reservoir to the edible garden to 4 m, and providing a space for vehicles to merge lanes to improve the traffic safety of the pastoral complex.

Yubaizhong Road connects Baipu Temple and the southeast of Yubai Village, which can directly reach the village's food service center, avoiding the problem of tourists arriving directly at Nanyan Road along Yubai Road without entering Yubai Village. At present, the width of Yubai Middle Road is only 2 m, which cannot meet the traffic demand; therefore, there is a need to widen the road and enhance the landscape along the way to attract tourists to the village of the White Falls Temple, to provide visitors with the village B&B and catering services. At the same time, to alleviate the traffic problem, a small loop road can be built at the end of the Middle Side Road (Figure 9B).

Many trails exist in the village, including the trail between the north of the village and the White Waterfall Temple and the Michael Lin cultural circuit. These roads can overlook the village, provide a view of the mountainous scenery, and have certain cultural characteristics, but most of them are narrow and steep, lacking space to pull over along the way, and hence, an upgrade is needed. The red history of the Michael Lin Cultural circuit can be further explored to give the road cultural characteristics; guardrails can be installed on both sides of the local section, and rest areas can be added along the way (Figure 10).

6.4. Conducting research and education activities

6.4.1. Conducting labor and nature education and research

In recent years, the demand for nature education and labor education has continued to grow, using resources such as field and garden complexes and sightseeing agricultural facilities to carry out science and culture classes, create labor education and nature education bases, provide integrated and experiential extracurricular education programs for teenagers and children, and create a pilot science education courtyard. Such activities can effectively extend the stay time of tourists, appealing them to the accommodation and food of the village, which indirectly increases the tourism income of the village.

6.4.2. Strengthening village history education

The village history education is carried out by using spaces such as the Michael Lin Cultural circuit residence and the village history museum. The village history museum presents the introduction of the life and deeds of international friends such as Michael Lin William Ban and other local heroes such as Cui Xianfang, indicating that Yubai Village was an important route of anti-fascism in North China during the Second World War. Outside the

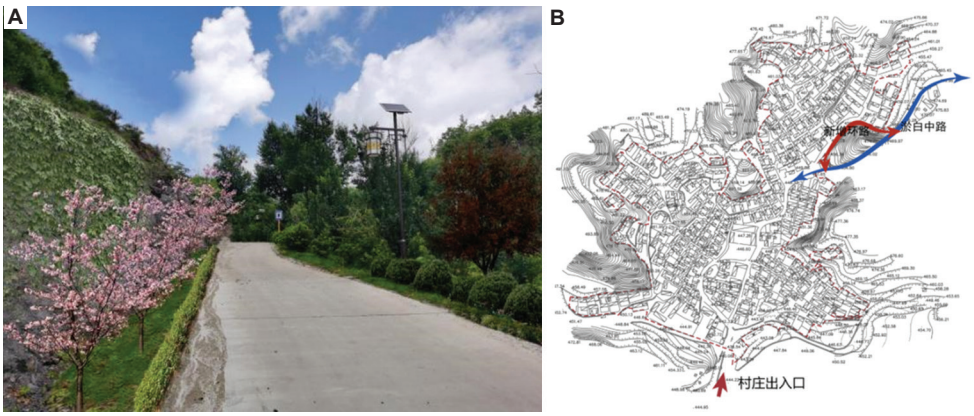

Figure 9. (A) Landscape enhancement effect of Silber White South Hill Road. (B) Proposed plan for the renovation of Silber White Middle Road. Source: Photo and drawing by the authors

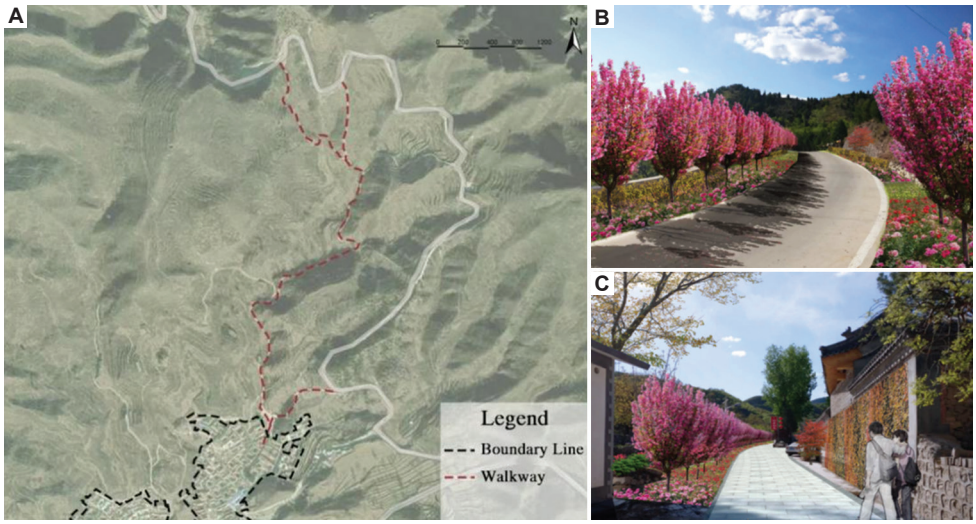

Figure 10. (A) Proposed plan of the walkway. (B and C) Landscape effect of the walkway. Source: Drawing and photos by the authors

village history museum, relief sculptures portraying Michael Lin, William Ban, and Cui Xianfang leading the villagers in the war for the purposes of recreating the old scenes were erected. By increasing such venues and activities, the cultural heritage of the "service station" is enriched, allowing villagers and tourists to understand history and culture, enhancing national pride and a sense of belonging, building the awareness of the public to consciously protect and inherit the excellent traditional culture of the countryside, and improving the refinement of rural society.

6.5. Developing derivative cultural and creative brands

The village has an intangible cultural heritage of Beijing, such as bungee jumping, tap dance, and so on. Creating a folk cultural festival can enrich the nightlife of folk tourism attract tourists to the village, and achieve the goal of a "service station" to extend the stay of tourists. It can also develop cultural and creative products of intangible cultural heritage by extracting the images of bungee jumpers with dramatic expression and selling products such as backpacks, coasters, and T-shirts. Moreover, it can have the "Red Mud Cao Tang" (the existing mud sculpture brand of Yubai Village), make mud figures depicting the history of the village, such as mud sculptures of Michael Lin and William Ban, as well as umbrellas painted with the route of Michael Lin cultural circuit, and cultural and creative snow machines in the shape of transmitters. The brand has also generated a variety of cultural creations, such as ice creams and chocolates, in the shape of a telegraph. The folk cultural activities in collaboration with regional brands can strengthen the public cultural construction, enhance collective cohesion, expand the cultural impact, and achieve cultural tourism integration and empowerment of the village.

7. Summary

As mentioned above, due to its unique geographical location, Yubai Village, along with the Old Road of Western Beijing, has experienced the rise and fall of history. Now, with the trend of culture and tourism integration, the path of the rural revitalization of Yubai Village will continue its historical function as a "transportation hub" along the Old Road of Western Beijing- and re-establish its status as a village service station. In adherence with the existing policies, the village will integrate the ecological and cultural resources in the village area, strengthen the linkage with the surrounding tourism resources, and form a synergy to build a cultural and tourism village with the service station as the main function.

The plan focuses on restoring the service post function of Yubai Village, improving the service and reception functions of the village, and utilizing other tourism resources in the village area to lengthen tourist stay in the village. The landscape nodes in the village will be enhanced, and special agricultural experience areas, aerial corridors, and other special landscape projects will be created to attract tourists and heighten their interest in visiting the village. The road system in the village area will be improved to connect the scattered tourism resources in the village area. In addition, historical and cultural tourism resources will be explored, study activities for labor education and nature education will be carried out, and village history education will be strengthened. Other plans also include combining the village's characteristic folklore and culture to create a folklore and cultural festival brand and develop cultural, creative, and other derivative products; extending tourist stay to drive the development of the village tourism economy; combined with the implementation of the rural revitalization strategy and the construction of beautiful villages, focusing on the cultural and tourism planning system; grasping the characteristics of Yubai Village; promoting the deep integration of culture and tourism; and generating a wide array of post-tourism products, such as B&B tourism, leisure agriculture, catering services, cultural creativity, and research and science popularization. To realize the ideology of "culture to promote tourism, tourism to promote culture," the synergistic development of the two should be promoted, thereby improving the income of villagers and village collectives, encouraging population return, increasing the sense of well-being of people's livelihood, and revitalizing Yubai Village.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Matt Fu
Formal analysis: Mingyue Li
Investigation: Yihong Luo, Dehao Zheng
Methodology: Matt Fu
Writing – original draft: Mingyue Li
Writing – review & editing: Mingyue Li, Mingjing Yang

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data that support the findings of this work are available on request from the corresponding author, Matt Fu, on reasonable request.

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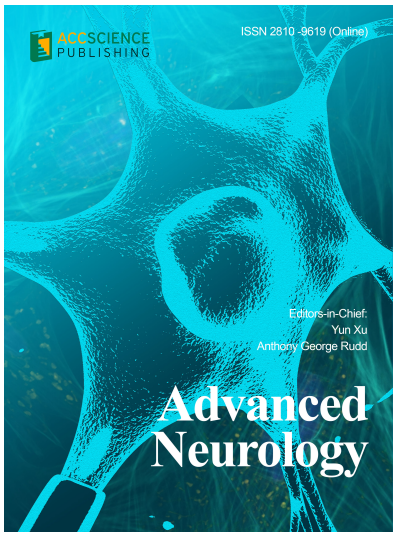

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