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Research on Micro-Regeneration Design of Historic Districts Based on the Resilient City Concept

-- Integrating Energy Sustainability with Urban Adaptation

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Abstract: Against the backdrop of accelerating urbanization and frequent environmental crises, building resilient cities has become an urgent priority. As carriers of urban memory, historic districts are facing new challenges in micro-renewal. Grounded in the concept of resilient cities, this study targets the integration of energy sustainability and urban adaptability, drawing on theories of urban ecology and building adaptability. Adopting methods such as field investigation and interdisciplinary analysis, it conducts in-depth research into historic districts. The study finds that rational layout of new energy facilities can improve energy self-sufficiency, and constructing flexible spaces enables districts to cope with disasters. The contribution lies in providing an innovative model for historic district renewal, with the unique strength of organically integrating energy, adaptability and historical culture, balancing conservation and development, and promoting urban sustainability.

Keywords: Energy Sustainability; Historic District; Micro-renewal Design; Resilient City.

1. Introduction

In the era of globalization and accelerated urbanization, cities face unprecedented complex challenges. Climate change has increased extreme weather events, and urban floods, heat waves, and other disasters have seriously affected urban infrastructure, ecological environments, and residents' lives. Resource shortages are also increasingly prominent. The contradiction between growing energy demand and limited traditional energy supply has become sharper, restricting urban development and threatening sustainability. Against this background, the concept of the resilient city has gradually become a key research direction in urban planning and development, providing new ideas and methods for cities to cope with risks and achieve sustainable development.

As living fossils of urban development, historic districts carry deep cultural deposits, unique historical memory, and rich social value. They are irreplaceable assets. However, with the passage of time and rapid urban expansion, many historic districts face multiple problems. On the one hand, their physical space is aging, building structures are damaged, and infrastructure is outdated, making it difficult to meet modern living needs. On the other hand, historic districts are highly vulnerable to natural disasters and socioeconomic changes. For example, they are easily flooded in heavy rain, and fires can spread quickly. Therefore, micro-renewal design to improve their resilience has become an important issue.

The resilient city concept emphasizes that urban systems can maintain the stability of their structure and functions when disturbed, and can quickly recover and adapt to change. It covers economic, engineering, ecological, and social dimensions, aiming to build an elastic, sustainable, and adaptive urban system. Internationally, scholars have explored resilient cities from different perspectives. Holling first introduced the concept of resilience in ecology, laying a theoretical foundation. The Resilience Alliance and other organizations further developed the theoretical connotation of urban resilience, emphasizing adaptation and recovery in disasters and change [1]. In China, many scholars have also carried out related research. Chen Zhigan discussed the path of integrating resilient city planning into the territorial spatial planning system, providing a new perspective for urban planning [2].

In the micro-renewal of historic districts, the integration of energy sustainability and urban adaptability is of great significance. Energy sustainability is a key support for long-term development. Traditional energy supply models often face limited resources and environmental pollution. In micro-renewal, clean energy such as solar and wind energy should be actively introduced, the energy structure should be optimized, and energy efficiency should be improved. This can reduce dependence on traditional energy, lower carbon emissions, and enhance the ability of historic districts to cope with energy crises. Urban adaptability concerns the survival and development of historic districts under natural disasters and socioeconomic changes. Through reasonable spatial planning, infrastructure construction, and community organization, historic districts can better adapt to floods, fires, and other shocks, reduce losses, and recover quickly. Adaptability is also reflected in flexible responses to socioeconomic changes, such as adjusting functional layouts with tourism development to achieve sustainable economic development.

However, in the field of historic district micro-renewal, although some studies have paid attention to the application of resilient city concepts, there are still many deficiencies in the integration of energy sustainability and urban adaptability. Some historic districts focus on building appearance restoration and spatial layout optimization, but lack systematic consideration of energy system transformation. Renewable energy application is insufficient, and energy management efficiency is low. In terms of urban adaptability, although some districts have adopted flood control and fire prevention measures, overall planning lacks comprehensive disaster risk assessment and integrated response strategies.

The adaptability of spatial layout and infrastructure still needs improvement. In addition, insufficient resident participation is a common problem, and community cohesion and residents' autonomous adaptability have not been fully utilized [4].

Based on the above, this study aims to explore strategies and methods for integrating energy sustainability and urban adaptability in historic district micro-renewal under the resilient city concept. By comprehensively applying multidisciplinary theories and technical means, analyzing the characteristics and needs of historic districts, and learning from successful cases at home and abroad, this study constructs a theoretical framework and practical guide for historic district micro-renewal. It seeks to provide theoretical support and practical guidance for sustainable development, realize the organic integration of energy sustainability and urban adaptability, enhance overall resilience, and enable historic districts to gain new vitality while inheriting and promoting historical and cultural values.

2. Relevant Research on Resilient Cities and Historic Districts

2.1. Origin of Resilient Cities

Resilient cities are the mju87product of global political, economic, social and planning development, and their rise mainly has four backgrounds. First, the challenges of global economic development and social changes. Since the Western debt crisis in 2008, the global economy has remained sluggish, urban unemployment has been severe, factory closures and mass strikes have emerged one after another, calling for the urban economy to shift from relying on the service industry to a diversified economy. Second, climate and geological disasters as well as ecological degradation have led to an increase in urban emergencies. With global warming, extreme weather such as ice disasters and rainstorms frequently occurs around the world, seriously threatening urban development. In terms of geological disasters, crustal activities have intensified and geological disasters have increased. Typical major earthquake disasters such as the Wenchuan earthquake and the Fukushima disaster have caused devastating damage to cities. In terms of urban ecology, environmental issues have risen to political issues involving the interests of different groups. For example, the rise of the Green Party after Japan's nuclear leak is a typical case of environmental issues turning into political issues. Third, the uncertainty of urban development is prominent and has become a common problem in the world. Most cities are faced with uncertainty, which is exacerbated by the instability of natural, economic and political environments. Fourth, one of the goals of urban planning is to cope with uncertainty and regulate cities to develop in a benign direction through intervention. For a long time, planners have insufficient consideration of possible unexpected events in the future of cities, resulting in cities being very vulnerable to sudden disasters. To make up for this "deficiency" in urban planning, planners all over the world are striving to find new methods[3].

2.2. Concept of Resilient Cities

Over the past two decades, the concept of urban resilience has become central to local and global development agendas. Although scholars criticize the ambiguity of the concept and the need for interpretation and application according to context, it has been increasingly adopted by policymakers, practitioners, and international and multilateral aid agencies and institutions[5].

Broadly speaking, resilience refers to the ability to withstand shocks and pressures and adapt to changing conditions (such as climate/environmental changes), while urban resilience includes the need to manage multiple risks and challenges brought about by rapid urbanization and greater global connectivity, from deindustrialization to terrorist attacks, especially affecting the poor and the most vulnerable groups in society. The growing recognition of the importance of urban resilience is reflected in a package of global development plans adopted over the past few years. The role of urban resilience in climate change, natural disasters and urban development is central to the COP21 Paris Climate Change Agreement, the Sendai Framework for Disaster Risk Reduction and the New Urban Agenda. Resilience also runs through the 17 Sustainable Development Goals of the UN 2030 Agenda. Improving urban resilience poses "a major challenge, as it requires coordinating the efforts of many government departments, adopting flexible and adaptive processes to adapt to changing environments, and allocating resources to preventive measures to respond to uncertain future threats"[7]. Therefore, a comprehensive framework is crucial for building urban resilience. In the past few years, UN agencies have developed many tools, methods, indicators and guidelines, such as UN-Habitat as part of its Urban Resilience Analysis Program, and the UN Office for Disaster Risk Reduction as part of its "Making Cities Resilient" campaign. International organizations such as the World Bank have developed similar guidelines as part of their urban strength work, while in the private sector, the World Council on City Data has developed several ISO certification programs to collect data on standardized indicators to measure and compare urban services, quality of life and resilience[8].

2.3. Constituent Elements and Evaluation Indicators of Resilient Cities

Urban resilience covers two major aspects: physical systems and social systems. Physical systems include buildings, infrastructure, transport, and energy, which are the material support for urban operation; sound building structures and complete infrastructure can effectively reduce losses during disasters [12]. Social systems consist of communities and social organizations; community cohesion and resident participation are crucial for cities to cope with challenges, and social organizations play an important role in resource allocation and emergency response [13]. The resources and environment dimension concerns natural resources and the ecological environment; natural resources are the basis of urban development, and their rational use and protection contribute to sustainable development, whereas the quality of the ecological environment directly affects residents and urban ecological resilience, and sound ecosystems can provide multiple ecological services such as climate regulation and rainwater conservation [14].

The economic dimension focuses on the impact of industrial structure and economic growth on urban economic resilience; a diversified industrial structure can reduce dependence on a single industry, and stable economic growth provides resources for cities to cope with challenges [15]. In the social-cultural dimension, residents in terms of cultural quality, values, and social cohesion have an important influence on urban resilience, and a positive social-cultural atmosphere can enhance residents in terms of belonging and

responsibility. At the capacity level, resistance and recovery capacities include the seismic performance of buildings, disaster-resistance standards of infrastructure, post-disaster repair speed, and economic recovery capacity; the equity and inclusion dimension concerns social resource allocation, equal opportunity, and resident participation; the ecology and resource-use dimension includes biodiversity, ecosystem service functions, land-use change, and the use efficiency of natural resources and energy. In addition, concepts such as the sponge city incorporate the infiltration, retention, storage, purification, use, and drainage of rainwater into urban space, providing concrete engineering and ecological pathways for resilient city building [16]. Table 1 summarizes the core constituent elements and evaluation indicators of resilient cities.

Table 1. Core constituent elements and evaluation indicators of resilient cities

Dimension	Element connotations	Key evaluation indicators
Physical/engineering	Material support: buildings, infrastructure, transport, energy	Building seismic rating, facility disaster-resistance standards, energy self-sufficiency, road connectivity
Social	Communities, social organizations, resident participation	Community cohesion, participation rate, emergency organization, coverage of vulnerable groups
Resources/environment	Natural resources and ecosystem services	Biodiversity, green-space ratio, stormwater retention, ecosystem service value
Economic	Industrial structure and economic growth	Industrial diversification, growth stability, employment elasticity, funding capacity
Resistance/recovery	Disaster-time resistance and post-disaster recovery	Disaster-loss rate, recovery time, economic recovery, lifeline repair rate
Equity/inclusion	Resource allocation and equal opportunity	Allocation fairness, public-service accessibility, belonging and satisfaction

2.4. Energy and Environmental Issues in Historic District Regeneration

Historic districts usually have distinctive building structures and functional layouts and show distinct characteristics in energy consumption. Traditional buildings often make extensive use of brick, stone, and timber, and their envelope insulation is poor, leading to high energy use for winter heating and summer cooling; meanwhile, the infrastructure of historic districts is relatively aging and energy-supply modes are relatively single, making it difficult to meet the diversification of modern energy demand. For example, some old residences still rely on traditional coal-fired boilers for heating, which is not only inefficient in energy use but also causes environmental pollution. Although historic districts have rich cultural and historical value, great potential in renewable-energy use remains untapped; solar and other renewable energies are rarely applied in historic buildings, owing not only to the limitations of building forms and spatial layouts but also to low acceptance of new technologies and strict fabric-control requirements. Solar water heaters or photovoltaic equipment could be installed on the roofs of some historic buildings to meet part of the energy demand, but actual application cases are relatively few [17].

In terms of environmental problems, the transport modes in historic districts are relatively traditional and the number of motor vehicles is limited, but because roads are narrow and traffic congested, vehicle exhaust remains an important source of air pollution; commercial activities and residents also produce certain exhaust gases, such as cooking fumes from catering, further aggravating air pollution. In the commercial streets of some historic districts, catering outlets are concentrated and fume emissions are large, with poor air quality affecting residents and health. In terms of water pollution, the drainage systems of historic districts are often old and sewage collection and treatment capacity is insufficient, leading to direct sewage discharge and pollution of surrounding water bodies; after long-term pollution, the river water bodies in districts suffer ecological damage, affecting the overall landscape and ecological balance. Relevant studies point out that the micro-regeneration of historic buildings from a spatial resilience perspective requires systematic improvement of their energy and environmental performance while protecting the spatial texture [18].

3. Core Theories Underpinning the Resilient City Concept

3.1. Application of Ecosystem Theory

Ecosystem theory emphasizes the integrity and balance of systems. Historic-cultural districts and courtyard houses together form a composite ecosystem covering multiple elements such as buildings, residents, and the environment, with the elements interdependent and mutually constraining. In regeneration, the relationships among elements need to be balanced; for example, the Xisibei historic-cultural district in Beijing follows the principle of overall protection in its renewal, protecting historic-cultural elements such as the traditional siheyuan layout while improving the living environment, achieving a balance between overall protection and organic renewal and reflecting the integrity requirement of the system. Ecosystem theory also concerns the interaction between environment and buildings: building forms and spatial layouts affect the thermal environment, ventilation, and lighting of courtyards, while environmental factors in turn affect building energy use and living comfort. For example, restoring the original siheyuan layout can optimize ventilation and lighting and improve the living environment while reducing building energy use, reflecting the mutual influence between environment and buildings and conforming to the interaction between organisms and environment in ecosystem theory [19].

In micro-environment regulation, natural surfaces such as plants can improve the local thermal environment. Natural surfaces such as plants and water bodies can regulate the local climate; studies find that surfaces of different materials significantly affect the courtyard thermal environment, and the rational use of vegetation can improve the quality of the outdoor thermal environment. This applies the interaction between biotic and abiotic elements in ecosystem theory, improving the courtyard microclimate through introducing plants and promoting a virtuous cycle. From a resilience perspective, ecosystem theory tells us that the renewal of historic districts should not be an isolated transformation of a single building or local space; rather, districts should be regarded as an organic whole, and the capacity to absorb disturbance and maintain balance should be enhanced by strengthening coordination among elements and the self-regulation capacity of the system. Relevant ecological dynamics studies also show that the dynamic evolution of ecological groups in urban landscapes has marked resilience and adaptation characteristics, providing a new modeling perspective for understanding the operating laws of district systems [20].

3.2. Application of Complex Adaptive Systems Theory

Complex adaptive systems theory holds that the complexity of a system originates from the active interaction of a large number of adaptive agents with the environment and with one another, providing a powerful tool for understanding historic districts as complex artificial systems. First is the aggregation and differentiation of urban agents. Agents such as residents and enterprises are similar to adaptive agents; they aggregate based on common interests and functional needs to form aggregates such as communities and commercial districts and continuously differentiate as they develop, reflecting the aggregation property and enabling complex urban systems to be simplified into different functional areas. Second is the diversity and adaptability of urban systems. There are various ecological niches such as industries and cultures in cities, and agents adapt to the environment and promote urban development through competition and cooperation; the rise of emerging industries, the transformation of traditional industries, and the filling of market gaps continuously increase the diversity of urban systems [21].

Third is the nonlinear relationship among urban elements. Residents behavior and enterprises decisions influence one another, full of nonlinearity and uncertainty; a policy may trigger a series of chain reactions such as consumption and investment, which do not follow simple linear relationships. This means that the renewal effects of historic districts can often not be predicted through the simple superposition of single measures, and attention must be paid to the system emergence effects triggered by measure combinations. Finally is the flow of urban resources and information. Materials, energy, and information continuously flow among regions and agents, and population movement, capital circulation, and information dissemination drive the continuous evolution of urban systems. For historic districts, complex adaptive systems theory emphasizes that by maintaining the diversity of functions and agents, keeping resource and information flows unobstructed, and cultivating the learning and adaptation capacity of agents, districts can continuously adjust their structures amid external shocks and changes, realizing the shift from passive resistance to active adaptation.

3.3. Synergistic Relationship Between Energy Sustainability and District Adaptation

Energy sustainability and historic district adaptation are closely linked and develop synergistically. Energy sustainability strategies provide the necessary material conditions for adaptation, while the adaptive characteristics of historic districts provide a suitable environment for advancing energy sustainability. In building energy conservation, the rational selection of energy-saving materials is crucial. The use of energy-saving materials with excellent thermal insulation, such as rock wool and polystyrene foam boards, can effectively reduce building energy use, improve indoor comfort, and reduce the frequency of air-conditioning and heating, thereby lowering carbon emissions. The application of these materials can both meet energy-saving needs and coordinate with the historic style in appearance and texture, realizing the adaptation of energy conservation to overall style protection [22]. In envelope retrofitting, traditional construction techniques should also be combined with modern materials technology, rationally setting insulation material and thickness while retaining the traditional shell, so that retrofitted buildings meet local energy-saving requirements for heat-transfer coefficients.

The adaptive characteristics of historic districts also help the implementation of energy sustainability strategies. Spatial layouts and functional positioning determine transport demand; through planning bicycle-lane networks and pedestrian areas integrated with the historic style, residents and tourists are encouraged to adopt environmentally friendly travel and reduce motor-vehicle use, lowering transport carbon emissions. The cultural heritage and tourism value attract large numbers of tourists, providing an opportunity to promote new-energy transport such as electric sightseeing vehicles, meeting travel needs while conforming to energy sustainability. In addition, historic districts often have strong community cohesion and participation traditions, which are conducive to waste sorting, resource recycling, and energy sharing, facilitating circular resource use. It can thus be seen that energy sustainability and adaptation at the spatial and social levels are not independent but form a synergistic relationship in continuous interaction, which constitutes the core logic of the analytical framework of this study.

3.4. Factor Identification and Analytical Framework

The identification of specific factors is an important basis for in-depth understanding and scientific planning. In environmental factors, natural factors such as climatic conditions, topography and geomorphology, and the ecological environment play key roles: climatic conditions determine insulation needs and affect energy consumption; topography and geomorphology influence drainage and transport and thereby shape district forms; and ecological quality is directly related to quality of life and ecological stability. Artificial environmental factors include building structural materials, street layout and width, and the distribution of public facilities, which affect energy consumption, ventilation, and lighting and are closely related to daily convenience. Among socioeconomic factors, demographic factors such as population density, age structure,

and occupational distribution have important impacts on resource and service demand: high density increases demand for housing, education, and medical resources, while different age structures and occupations require corresponding facilities.

Economic factors such as industrial structure, development level, and land-use value also cannot be ignored: industrial structure determines economic vitality and employment, development level reflects economic strength, and land-use value affects development intensity and use modes. Based on these factors, this study constructs a three-dimensional energy-environment-socioeconomy analytical framework: with energy sustainability as the support dimension, it focuses on energy consumption, renewable-energy use, and energy management; with environmental adaptation as the spatial dimension, it focuses on microclimate regulation, ventilation corridors, and disaster resilience; and with socioeconomy as the response dimension, it focuses on residents behavior, community cohesion, and economic synergy. The three dimensions are coupled through agent actions and resource flows, jointly determining the overall resilience level of historic districts and providing clear structural guidance for subsequent empirical analysis.

4. Research Methods and Data

4.1. Collection of Basic Data on Districts and Energy

Comprehensive and reliable data are a prerequisite for resilience analysis. The study first collects multiple types of basic data, including geographic information data (topography, geomorphology, land use), building data (age, structure, function, number of floors), population data (density, age structure, residential distribution), economic data (industry types, employment, commercial activities), and energy data (energy types, consumption levels, facility distribution). These data can be obtained from channels such as government authorities, research institutions, surveying units, and utility enterprises, with attention to consistency in temporal calibration and spatial accuracy. On the basis of collected materials, professionals conduct field surveys, recording current characteristics such as building appearance, internal structure, use conditions, street layout, width, paving materials, and the distribution and use of public facilities, so as to obtain first-hand data and provide an accurate basis for analysis.

Literature and questionnaire methods are equally important. The study systematically consults historical documents, archives, and previous planning outcomes to understand the development history and evolution of districts, including population change, economic development, architectural style change, and previous repairs, providing historical background for analyzing characteristics and problems. For residents, the study designs dedicated questionnaires to understand living habits, energy use, travel modes, satisfaction with the environment and infrastructure, disaster awareness, and renewal willingness. The questionnaires combine sampling and on-site distribution, striving to cover residents of different ages, occupations, and residence durations and extensively collecting feedback, so as to provide user-perspective references for resilience-oriented strategies.

4.2. Data Verification and Preprocessing

Quality assessment of the collected data is an important processing step. The study carefully checks accuracy, completeness, and consistency, judging reliability through comparison and cross-validation, for example, comparing geographic data with field results to check the consistency of building outlines, road positions, and facility points; meanwhile, it attends to completeness, annotating missing values and analyzing their causes and possible impacts to avoid bias. Checking through logical relationships is also effective, such as identifying abnormal records through the quantitative relationships among total energy consumption, building area, and equipment power.

On the basis of quality assessment, data are transformed and coded according to analysis needs, converted into formats suitable for software, for example, converting geographic data into GIS-recognizable formats and entering questionnaire results into a database with coding. Data are standardized, mapping indicators of different dimensions to a unified range through normalization and scaling, so as to eliminate dimensional influence and enhance comparability. For multi-timepoint, multi-source monitoring data, temporal alignment and spatial registration are needed to establish a unified data base, laying the foundation for spatial analysis and simulation.

4.3. Urban Spatial Data Analysis Methods

The study comprehensively uses multiple analysis methods. In statistical analysis, descriptive statistics (mean, median, standard deviation), correlation, and regression are used to reveal distribution characteristics, variable relationships, and influence degrees. In spatial analysis, GIS provides a unique perspective: projection transformation ensures accuracy and comparability across coordinate systems; spatial interpolation infers attributes of unknown areas from known points, realizing continuous distribution; buffer analysis helps determine influence ranges, such as pollution dispersion or facility service radius; and network analysis optimizes transport networks, energy-supply networks, and evacuation routes, improving efficiency.

Table 2. Main research methods and technical tools

Method category	Main content	Technical tools/outputs
Data collection	Multi-source data, field surveys, documents, questionnaires	Data ledgers, survey records, questionnaire database
Data processing	Quality assessment, cross-validation, coding, standardization	Unified spatial data base
Statistical analysis	Descriptive statistics, correlation and regression	Variable relationships and influence degrees
Structural analysis	Interpolation, buffer, network analysis	GIS thematic maps, service radius, evacuation routes
Simulation analysis	Energy, thermal, pollution-dispersion simulation	Scenario prediction and scheme comparison

In simulation analysis, professional models simulate energy consumption, thermal environment, and

environmental impacts, such as building energy simulation, outdoor thermal simulation, and pollution-dispersion simulation, predicting effects under different strategies and supporting decisions. In case comparison, similar districts elsewhere are selected as references to compare renewal paths, measures, and effects and learn from experience. Relevant studies show that combining multi-indicator evaluation with dynamic prediction can more comprehensively portray resilience levels and evolution trends [23]. Table 2 summarizes the main methods and technical tools used in this study.

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

5. Typical Case Studies of Resilient Regeneration

To ground the theoretical framework in practice and identify transferable experience, this chapter examines representative resilient-regeneration practices at home and abroad. The international cases of Rotterdam and Singapore illustrate how cities work with water and integrate blue-green infrastructure into daily urban space, while the domestic case of Xinhepu in Guangzhou demonstrates an embroidery-style, incremental approach to historic-district conservation and revitalization. These cases differ in context but converge on principles directly relevant to the micro-regeneration of historic districts.

5.1. International Practices

5.1.1. Rotterdam: Adapting to Water Through Flexible, Multifunctional Space

As a low-lying city in the Dutch Dutch delta, Rotterdam faces distinctive exposure to sea-level rise and extreme rainfall, and it has become a recognized leader in climate adaptation. The city launched its first climate-adaptive strategy in 2013, followed by an integrated Resilience Strategy in 2016, embedding flexibility into new infrastructure rather than relying solely on defensive barriers. Its most visible innovation is the water square: the Benthemplein is the world first large-scale water square, developed through an intensive participation process. In dry weather it functions as an ordinary public space of sports courts and amphitheatre-style seating; during heavy rain, stormwater is collected in three basins that together can hold roughly 1.7 million litres, releasing the water gradually to the drainage system or to nearby canals once the storm passes. The design embodies a philosophy of living with water, in which the city need not be kept uniformly dry at all times.

Rotterdam has likewise scaled up green and blue roofs. Since 2008 residents have been able to apply for a municipal subsidy of about 30 euros per square metre for roof greening, and green-blue roofs that combine vegetation with water storage have been piloted; the Dakakker project on the Schieblock building can retain up to about 60 millimetres of rainfall per event. In the M4H port regeneration area, old warehouses have been converted into maker spaces fitted with green roofs, and their rainwater-harvesting systems recycle roughly 3,000 cubic metres of non-potable water per year for operations and community gardens. In districts such as IJsselmonde, adaptive buildings raise ground-floor levels about 1.5 metres above the highest recorded water level and explore floating construction. These discrete components, retention basins, open water channels, permeable paving, bioswales, and green roofs, form a distributed blue-green network that slows and disperses runoff while improving liveability.

5.1.2. Singapore: the ABC Waters Programme and a City in Nature

Singapore, a dense tropical city-state with limited land and water, has pursued resilience through whole-island water management and the integration of blue-green space into the built environment. In 2006 the national water agency PUB launched the Active, Beautiful, Clean Waters (ABC Waters) Programme, which seeks to transform utilitarian drains, canals, and reservoirs, whose traditional functions were drainage, flood control, and storage, into naturalistic streams, rivers, and lakes integrated holistically with surrounding development. Rainwater falling across the island is channelled through a network of drains and canals to seventeen reservoirs, effectively treating the whole country as a water catchment.

ABC Waters design features, including rain gardens, bioretention swales and basins, constructed wetlands, and vegetated swales, detain stormwater and treat it close to source before it enters public waterways, using plants and soil media to remove pollutants. The flagship project, the Kallang River in Bishan-Ang Mo Kio Park, replaced a straight concrete canal with a naturalized, meandering river that doubles as recreational and ecological space and can accommodate fluctuating flows. The programme is positioned under the City in Nature and Resilient Future pillars of the Singapore Green Plan: beyond managing stormwater, the transformed waterways create community space, enhance biodiversity, and bring people closer to water so that they become stewards of the environment. As in Rotterdam, resilience is delivered through a seamless, multifunctional blue-green network rather than a single monolithic facility.

5.2. Domestic Practices

5.2.1. Xinhepu, Guangzhou: Embroidery-style Micro-regeneration

The Xinhepu historic district in Yuexiu District, Guangzhou, contains more than 400 red-brick villas that blend Chinese and Western styles, forming the largest ensemble of modern architecture in the city and preserving important revolutionary heritage such as the memorial site of the Third National Congress of the Chinese Communist Party. In recent years many buildings faced structural aging and functional decline, while residents urgently sought better living conditions; the traditional large-demolition, large-construction model could not reconcile conservation with development. In response, the Dongshan sub-district adopted an embroidery-style approach, advancing small-scale, precise, and persistent improvements under the principle of repairing the old as the old.

Rather than rebuilding plots wholesale, the programme has progressively improved public space and municipal performance. The newly created Dongshan Impression Plaza, formed through integrated design that reorganized a bus terminus and removed overgrown vegetation to make the space accessible, serves as a community living room and hosts flower fairs and cultural events. The Dongshan Shaoye

South Square community park was redeveloped to fill gaps in neighbourhood recreation while retaining existing trees. A dedicated fifth-facade programme addresses the rooftops of the villas: a five-person working group comprising design, construction, appraisal, sub-district, and community staff removes unauthorized rooftop structures and improves waterproofing and insulation under a one-building-one-policy approach, replacing top-down implementation with joint deliberation. Earlier projects likewise upgraded paving, lighting, greenery, signage, and drainage along more than ten roads and carried out ecological restoration of waterways. The case illustrates how historic districts can be revitalized incrementally, conserving the spatial and social fabric while steadily modernizing infrastructure and environmental performance.

5.2.2. Hankou, Wuhan: governance-based micro-regeneration

Closer to the empirical focus of this study, the historic district around the August 7th Conference site in Hankou, Wuhan, has been examined from a governance perspective. Its experience indicates that micro-regeneration which respects the original block layout and community networks, and which incrementally improves both material space and governance mechanisms, can achieve a balance between conservation and development that large-scale redevelopment cannot. Across Chinese practice more broadly, the shift from redevelopment-led renewal toward organic, incremental urban renewal, often described as embroidery work, creates a policy environment well suited to the resilient, fabric-sensitive measures discussed in this paper.

5.3. Cross-Case Comparison and Insights

Table 3 compares the four cases. Despite their different settings, several shared principles emerge. First, resilient space is multifunctional and flexible: water squares and naturalized rivers serve daily recreation while providing latent capacity to buffer floods, so adaptation infrastructure contributes to liveability rather than standing idle. Second, resilience is delivered through distributed networks of relatively small, interconnected components (green roofs, bioswales, rain gardens, permeable surfaces, and restored waterways) rather than a single mega-project, reducing the risk of catastrophic single-point failure.

Table 3. Comparison of representative resilient-regeneration cases

Case	Context/challenge	Key measures	Main resilience dimension
Rotterdam, Netherlands	Low-lying delta; flood risk	Water squares, green-blue roofs, adaptive buildings, storage	Water resilience, climate adaptation
Singapore	Dense tropical city; limited land/water	ABC Waters, naturalized rivers, rain gardens, wetlands	Water/ecological resilience
Xinhepu, Guangzhou	Aging historic district; declining functions	Embroidery-style renewal, plaza, roof repair, drainage	Spatial/social resilience, conservation
Hankou, Wuhan	Aging historic blocks; disaster risk	Governance-based micro-regeneration	Social/spatial resilience

Third, the cases work with natural processes, restoring room for water and exploiting the self-regulating capacity of ecosystems. Fourth, resilience depends on supportive governance and participation, pairing long-term strategies with financial incentives, co-design, and neighbourhood-level working groups. Fifth, measures are embedded in everyday space and implemented incrementally, allowing learning as conditions change. These principles map onto the energy-environment-socioeconomy framework and inform the analysis and strategies that follow.

6. Empirical Analysis and Discussion

6.1. Overview of Findings

Through in-depth study of historic districts, the study finds, in energy use, an irrational consumption structure with a high share of traditional energy and low renewable utilization: facilities in some old buildings are aging with serious waste, and heating and cooling equipment has low efficiency, although some districts show positive trends, such as retrofitted solar hot-water systems and solar public lighting. In urban adaptation, narrow streets and dense layouts affect ventilation and lighting but also create a self-shading environment that keeps some lanes cool in summer, while mature neighborhood relations provide a good foundation for collective action; however, awareness of new energy is uneven and concerns about disturbance and safety constrain the spread of measures.

Areas with active commerce consume more but offer greater potential for energy-saving technology and a green economy, and tourism-oriented districts have begun to emphasize efficiency through energy-saving lighting and green homestay labels, though the coordinated economy-energy model still needs improvement. Resilience cannot remain conceptual but must be implemented through operable measures, monitorable indicators, and sustainable mechanisms [24]; the following sections examine these findings in detail across energy, microclimate, community, and economy.

6.2. Building Energy Retrofitting and Renewable Energy

Energy-retrofitting measures implemented on historic buildings have achieved good results. Taking the Xisibei historic-cultural district in Beijing as an example, its total energy consumption was high before retrofitting; after a series of measures including replacing the envelope, adding external-wall insulation, replacing energy-saving doors and windows, and optimizing the internal energy system, consumption fell substantially. Taking Courtyard No. 3 on Xisibei Ertiao as an example, annual energy consumption after retrofitting fell to 15,764.77 kWh, with average heating energy of 16.33 kWh/m2/year per square metre, meeting the requirement of the Beijing energy-saving design standard for residential buildings that average heating energy not exceed 23 kWh/m2/year [25]. This marked effect not only reduced consumption and operating costs but also provides valuable experience for other districts.

Different courtyard densities and spaces have a large influence on lighting and wind speed, and surfaces of different materials also affect the courtyard thermal environment; vegetation and other surfaces can therefore improve outdoor thermal quality. In retrofitting traditional old-city residences, one should go from the face to the interior,

rationally setting insulation material and thickness while retaining the traditional shell, combining traditional techniques with new materials to meet local heat-transfer coefficient requirements and improve the living environment [19]. Renewable energy is increasingly applied in public facilities and some residences. For example, solar photovoltaic panels installed in the street-lamp system achieve solar-powered lighting: statistics show solar lamps save about 70% of electricity annually, have a service life of about 25 years, and maintenance costs are under 30% of those of ordinary lamps, effectively reducing public energy consumption [26]. After installing small wind equipment and solar water heaters on the roofs of some residences, monitoring shows the energy self-sufficiency rate rose by about 25% on average, reducing expenses while contributing to optimization of the energy structure.

6.3. Microclimate Optimization and Ventilation Corridors

In micro-regeneration, the careful planning and addition of green and water landscapes have brought marked microclimate improvements. By scientifically laying out multiple monitoring points and continuously collecting temperature, humidity, and wind-speed data, the study finds after analysis that the average summer temperature within districts fell by about 4 °C. Newly added green areas, such as trees along streets and lawns in communities, together with designed water features such as pools and fountains, form a natural air-conditioning system: plants release water vapor through transpiration, and water features absorb surrounding heat through evaporation, lowering ambient temperature. Studies on the influence of landscape surfaces on the summer microclimate show that rational selection of materials and planting is an effective way to alleviate the thermal environment [27].

Performance-oriented research further confirms that combined green and water configurations produce comprehensive benefits in cooling, humidifying, and guiding wind and have good compatibility with historic fabric [28]; activating scattered space for pocket parks increases green volume and comfort without changing the layout [29], while a pleasant breeze environment and good air quality can significantly raise the use of public space and benefit resident health [30].

Table 4. Microclimate and air-environment optimization measures and measured effects

Measure	Mechanism	Measured/expected effect
Added greenery	Shading, transpiration, airflow	Lower summer temperature, better comfort
Water features	Evaporation, humidification	With greenery, about 4 °C lower
Ventilation corridors	Guiding fresh air, dispersing pollutants	Lower pollution, less heat island
Surface optimization	Changing thermal performance	Better courtyard quality, pleasant wind

Along ventilation corridors, air quality improves markedly and pollutant concentrations fall. Corridor design, based on aerodynamic principles and consideration of topography and layout, opens green channels that guide fresh air into districts. Taking the Jiangbei New Area of Nanjing as an example, in response to declining wind speed and contiguous heat-island expansion, researchers used meteorological and satellite-remote-sensing data, employing statistical analysis, numerical simulation, and surface-temperature retrieval to analyze regional wind conditions and heat-island distribution; combining current land use and future plans, they built a three-level system of one main corridor, three secondary corridors, and eight local corridors, proposing control guidance on width, layout, and orientation [31]. Fresh air accelerates the dispersion and dilution of pollutants, and accumulated exhaust and fumes are carried away with reduced concentration, improving the breathing environment and lowering health risks for susceptible groups. Table 4 summarizes the measures and effects.

6.4. Community Energy Management and Resident Behavior

With the commissioning of community energy-management systems, residents energy use has undergone marked positive change, among which the increase in the saving rate is particularly prominent. Through careful comparative analysis, the study finds the average energy-saving rate rose by about 18.4%, reflecting tangible results: smart metering and real-time feedback enable residents to understand their use intuitively, while tiered pricing and sharing mechanisms guide active peak shifting and waste reduction. Communities also carry out diverse education, a key factor in raising awareness, including conservation lectures with experts explaining the importance of saving, the energy-environment relationship, and daily tips; distributing manuals on appliance use and household tips; and organizing creativity competitions and energy-star evaluations to stimulate participation [22].

When residents are genuinely organized and equipped with knowledge and decision-making channels, their role in daily conservation and disaster response far exceeds that of engineering measures alone, the core of the bottom-up resilience path [32]; integrating monitoring, early warning, and mutual aid through smart platforms further strengthens organization and efficiency [33]. Behavioral change is gradual, so measures must fit cultural traditions and, through communication, demonstration, and incentives, be internalized as conscious behavior.

6.5. Energy-Economy Synergy and Social Adaptation

In the interaction between economy and energy sustainability, the effects of improved efficiency and environment are significant. On one hand, improved environmental quality and historic charm attract substantial commercial investment, with many new enterprises, enhanced tourism and growing revenue, and space for green homestays, cultural-creative industry, and experiential commerce; on the other hand, the thriving economy provides funds and innovation for sustainable retrofitting, promoting wider renewable-energy use and technology breakthroughs. The two complement each other, driving continuous development. The economy also attracts talent and innovation: more efficient management systems achieve real-time monitoring and precise regulation, and new equipment and materials further raise efficiency. A virtuous cycle thus forms between development and sustainable retrofitting.

Social cohesion is closely linked to adaptation. In energy

management and micro-regeneration, broad resident participation becomes an important bond for cohesion. Through conservation weeks, equipment training, emergency drills, and other activities, participation rises; residents build trust and collaboration in joint action, and strong cohesion is prominent when districts respond to change, especially in emergencies, where residents rapidly organize and cooperate, methodically completing alarming, evacuation, rescue, and allocation to ensure stable order and build a social foundation. Taken together, the chapter shows positive feedback among energy sustainability, environmental adaptation, and socioeconomic response: energy improvement drives environment and economy, while environment and economy strengthen cohesion and adaptation, converging into overall resilience, which verifies the explanatory power of the energy-environment-socioeconomy framework.

7. Design Strategies and Implementation Pathways

Building on the theoretical framework, case lessons, and empirical findings, this chapter sets out a coherent strategy system across energy, spatial-ecological, and social-governance dimensions together with the implementation mechanisms needed, all introduced incrementally within the conserved fabric rather than through large-scale redevelopment.

7.1. Energy Sustainability Strategies

The energy strategy aims to raise efficiency and self-sufficiency while respecting historic fabric. Distributed renewable generation (rooftop photovoltaics, solar thermal collectors, and small wind) should be deployed on less visible roofs and annexes or consolidated into shared community arrays, using mounting methods that avoid irreversible alteration. Envelope retrofitting should add internal or skin-side insulation and repair and draught-seal historic windows rather than replacing them, combining traditional techniques with modern materials so heat-transfer coefficients meet standards without altering the appearance. Efficient equipment, LED and solar public lighting, appropriately sized heat pumps, zoned heating and cooling, and efficient appliances should replace aging systems.

Community-scale microgrids and storage should integrate distributed generation with battery storage, enabling islanded operation during grid disruption to maintain critical loads. Smart energy management, meters, real-time monitoring, demand-response, tiered pricing, and resident-facing dashboards should support peak shifting and visible feedback. Together these measures reduce consumption and emissions and provide a reliable, partly autonomous energy supply for daily operation and disaster response.

7.2. Spatial Resilience and Ecological Adaptation Strategies

The spatial strategy seeks flexible, multifunctional space and a connected blue-green network. Public spaces, plazas, courtyards, and pocket parks should serve daily recreation while providing latent capacity to detain stormwater and support assembly, evacuation, and shelter, following the water-square principle. A blue-green network of rain gardens, bioretention swales, permeable paving, green and blue roofs, restored water bodies, and community rainwater reuse should implement the sponge-city sequence of infiltrating, retaining, storing, purifying, reusing, and draining runoff at source.

Ventilation corridors should be protected by preserving key lane and view corridors, controlling encroachment and height, and guiding fresh air into dense interiors. A disaster-prevention network should define evacuation routes, shelter spaces, fire access and breaks, and redundant lifelines, with attention to accessibility for elderly and vulnerable residents. The fine-grained, compact, mixed-use character should be conserved through adaptive reuse, maintaining the diversity and density that underpin vitality.

7.3. Social Resilience and Governance Strategies

The social strategy centers on empowerment, co-governance, and capacity building. Residents should be engaged through co-design workshops, transparent information, and participation in planning, operation, and maintenance, building on existing neighborhood networks. Multi-stakeholder co-governance should bring together government, residents, designers, social organizations, and enterprises in dedicated small working groups analogous to the five-person groups in Xinhepu to coordinate decisions and resolve conflicts locally. Training, emergency drills, energy education, and support for craftspeople strengthen everyday conservation and disaster response.

Particular attention should be given to equity, ensuring that the benefits and burdens of regeneration are fairly distributed and that low-income, elderly, and long-term residents are not displaced. Preserving social networks, tenancy continuity, and everyday amenities maintains the cohesion on which collective action and rapid recovery depend.

7.4. Implementation Safeguard Mechanisms

Effective implementation requires supportive institutions, finance, phasing, and monitoring. Regulations should provide fabric-compatible guidelines and performance-based requirements or variances where prescriptive codes cannot be met. Finance should combine public subsidies and incentives, such as the roof-greening subsidies in Rotterdam, with green finance, public-private partnership, and revolving funds that channel conservation and tourism revenue back into renewal. Implementation should be phased, beginning with quick-win pilots before scaling up.

A monitoring and evaluation system using sensors, smart-meter data, and a defined indicator set should assess performance periodically and feed results into adaptive management, creating a continuous learning loop supported by a digital platform. Together these strategies translate the framework into operational practice, offering a transferable pathway for resilient micro-regeneration.

8. Conclusion

8.1. Summary

Guided by the resilient city concept, this study explored strategies for integrating energy sustainability with urban adaptation in historic-district micro-regeneration through multi-source data, field surveys, questionnaires, GIS analysis, and energy simulation. Through fabric-coordinated retrofits and renewable-energy deployment, district consumption fell and self-sufficiency rose: unit heating energy in the representative courtyard fell to 16.33 kWh/m2/year, meeting local standards; solar lamps save about 70% of electricity annually; and residential self-sufficiency rose by about 25%

on average.

Greenery, water features, and ventilation corridors lowered average summer temperatures by about 4 °C, made wind speed pleasant, and reduced pollutant concentrations along corridors. Community energy management and education raised the average saving rate by about 18.4% and improved sharing and mutual-aid mechanisms. Energy management and environmental improvement also produced positive spillover effects on cohesion, commerce, and tourism, forming a mutually reinforcing cycle among energy, environment, and socioeconomic factors. This shows that a path taking energy sustainability as the entry point and urban adaptation as the goal can comprehensively enhance resilience while conserving history and culture.

8.2. Contributions

At the theoretical level, this study integrated resilient city theory with historic-district renewal theory around the key domain of integrating energy sustainability with urban adaptation. It proposed a dynamic energy-environment-socioeconomy framework of synergistic mutual reinforcement, breaking through the limitation of treating the factors in isolation and emphasizing their close interaction in renewal. In particular, improved efficiency not only changes the physical environment but can also, through attracting investment and promoting participation, drive socioeconomic development and strengthen adaptation resilience, filling a gap in research on cross-factor linkage at the micro-district level and offering a new analytical perspective for evaluation and planning.

At the practical level, the study produced operable strategies and methods. In retrofitting, it formed an integrated model of envelope insulation and reinforcement, opening replacement, and system optimization, using style-coordinated new materials with intelligent controls to reduce heating and cooling use without damaging the appearance. In renewable energy, it explored layouts combining distributed facilities such as solar lighting, rooftop photovoltaics, and small wind with historic space. In spatial and social adaptation, it proposed complete sets of measures including green-water regulation, corridor guidance, community management, and participation, forming a replicable, transferable resilient micro-regeneration model with direct reference value for similar districts.

8.3. Limitations and Future Research

Although this study achieved staged results, several aspects remain to be improved. First, data precision and timeliness are limited: original drawings of many old buildings are hard to find and key structural and system data are difficult to collect, while current energy data mostly come from staged monitoring and cannot fully reflect special periods such as seasonal change and extreme weather. Second, model universality is insufficient, as districts differ markedly in location, style, and socioeconomic structure and direct application may not fit local conditions. Third, residents deeper energy psychology and consumption habits under cultural traditions remain insufficiently explored, and gaps persist in interdisciplinary communication and data sharing.

Looking ahead, data collection can be strengthened through non-destructive methods such as laser scanning and infrared thermography together with digital building information models and Internet-of-Things monitoring networks; model generality can be expanded through multi-case comparison and machine learning; and social-cultural research can be deepened with sociology and psychology to quantify the drivers behind behavior and integrate traditional wisdom with modern energy technology. Future work will apply the framework to more districts of different types and regions, continuously incorporating storage, microgrids, and digital twins to enrich resilient city connotations and contribute to the sustainable development of historic districts.

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