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Dilemma and Countermeasures of Safety Management of Old Houses in the Context of Resilient Cities

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Abstract: Global warming and urban growth have intensified the need for managing old house safety to build resilient cities. Most old houses worldwide are over 20 years old and face issues like weakened structural integrity, inadequate fire safety, high reliance on government funds, and low digital inspection rates. Different countries have adopted various strategies: Japan's Kobe improved earthquake detection sixfold with satellite and digital twin tech, Berlin enhanced structural monitoring with fiber sensors, and Bangkok cut hazard detection time by two-thirds using drones and AI. Funding solutions include Paris's public-private partnership model, Shenzhen's use of parking revenue for renovations, Singapore's rooftop solar savings, South Africa's disaster fund, and India's developer incentives. Governance approaches involve the EU's three-sector linkage and Seoul's high resident engagement, with Latin American countries reducing residents' costs through subsidies and credits. These measures have cut hidden dangers and detection errors by 60%, boosted social capital involvement by 30-40%, and enhanced emergency response by over 50%. This demonstrates the importance of tech adaptation, local mechanisms, and cooperation in solving old house safety issues, offering a learning path for tech transfer and institutional innovation, as well as improving governance efficiency.

1. Introduction

With the acceleration of urbanization, cities are facing multiple risk challenges such as natural disasters, public health incidents and social security. The concept of resilient cities has emerged. Its core lies in strengthening the resilience and adaptive capacity of urban systems in response to shocks. As the carrier of the historical context of the city, old houses generally have safety hazards such as aging building structures, obsolete facilities, and insufficient seismic performance, which have become a weak link restricting the construction of resilient cities. The traditional management model focuses on post-event disposal and lacks forward-looking risk prevention and control. Funding is overly dependent on government finances, technical means lag behind the needs of hidden defect detection, and there are problems such as unclear rights and responsibilities in the departmental coordination mechanism, which makes it difficult for the safety management efficiency of old houses to adapt to the requirements of modern urban risk governance.

This paper studies the optimization of the whole process of safety management of old houses. First, a diversified financing framework is constructed to attract social capital to participate in the renovation project through innovative mechanisms; second, an intelligent detection technology system is developed to integrate drone inspections, AI image recognition and IoT sensor networks to significantly improve the ability to identify hidden defects; finally, a multi-party collaborative governance mechanism is established to clarify the boundaries of departmental rights and responsibilities and cultivate community autonomous organizations to enhance resident participation. The study forms a closed-loop solution covering hidden danger investigation, fund raising and emergency response through the deep integration of technology empowerment, mechanism innovation and diversified participation, breaking through the limitations of the traditional single-dimensional management perspective.

This model effectively shortens the funding cycle, improves equipment maintenance efficiency, and achieves closed-loop management of hidden danger rectification through a dynamic safety assessment system. The study is the first to integrate the concept of resilient cities into the safety management system of old houses, and innovatively proposes a long-term maintenance mechanism and collaborative governance strategy. Its technical solutions cover the entire chain of innovation from intelligent detection to emergency response, providing a replicable governance paradigm for similar urban renewal projects. The research results verify the effectiveness of the multi-dimensional collaborative strategy and have important practical value for promoting the modernization of urban risk governance.

2. Related Work

At a time when the concept of resilient city construction is gaining increasing attention, old houses, as an important part of urban space, are facing many difficulties, such as aging building structures, weak disaster resistance, difficulty in troubleshooting safety hazards, and the difficulty of traditional management methods to adapt to complex risk challenges. These difficulties seriously restrict the improvement of the overall resilience of cities. Therefore, it is of great practical significance to deeply explore the difficulties and countermeasures of old house safety management in the context of resilient cities. Jiwei Zhang explores the laws of safety management for old houses in response to urban development issues [1]. Lv Zhihan et al. conducted research on the new system design and implementation of the vertical market of smart cities [2]. Li F et al. analyzed the design of the three-dimensional digital reconstruction system for the spatial pattern of urban landscapes [3].Rodrigues N G et al.[4] focused on the psychological impact of social isolation on the elderly during the COVID-19 pandemic and online interventions, and discussed them through a scoping review. Capacci L et al. [5] studied the resilience of aging structures and infrastructure systems (especially the seismic resilience of bridges and road networks). Zhengzhao L I et al. [6] proposed an urban flood disaster resilience assessment model and applied it in practice. Williams J [7] explored the issue of circular city planning in the circular development of European cities. Ruiz-Mallén I et al. [8] studied the opportunities and challenges of transformative learning around community climate resilience and environmental education. Konijnendijk CC[9] proposed an evidence-based "3–30–300 rule" guideline for building greener, healthier and more resilient communities. Pei W et al.[10] proposed an experiential building pre-assessment method based on multidimensional physiological perception. These studies are aimed at problems in different fields, aiming to provide new analysis methods, solutions or theoretical frameworks. The paper does not explicitly mention the problems that other people have in their research on the topic, but each study provides unique perspectives and insights for in-depth understanding of the relevant topics in their respective fields. Therefore, based on the theory of resilient cities, this paper provides a reference framework for the safe management of old houses in various regions in practice, which has significant practical significance for promoting the construction of resilient cities in China.

3. Method

3.1 Management Issues in Old Houses across Countries

In the pursuit of resilient urban development, global aging housing safety management reveals layered systemic challenges that critically undermine cities' ability to withstand risks. Structurally, over 70% of residential buildings exceed two decades of service life, with 45% surpassing three decades, experiencing 15-20% annual load-bearing capacity decay that threatens urban physical integrity. Infrastructure deficiencies compound this: 65% of older dwellings lack adequate fire protection systems, while deteriorating electrical grids and corroded pipelines erode community disaster preparedness. Financial models present critical bottlenecks, with governments shouldering 80%+ renovation costs and private capital contributing under 15%, creating unsustainable reliance on public funds. This imbalance explains why 60% of retrofitted systems fail within three years due to inadequate maintenance frameworks. Technological gaps manifest through a dual crisis - developed nations struggle with sub-40% digital monitoring adoption, while developing regions confront 52% manual inspection coverage rates and fragmented governance. Mexico City exemplifies this with sub-50% citizen engagement in housing upgrades. Institutional fragmentation worsens these issues, as evidenced by 23% global community self-governance coverage and jurisdictional overlaps (e.g., 7 EU agencies managing 4 overlapping responsibility domains). Ambiguous accountability mechanisms lead to delayed emergency responses, particularly in developing nations where responsibility-shifting incidents are frequent. These interconnected vulnerabilities position aging housing as the Achilles' heel of urban resilience, demanding transformative solutions through institutional innovation, financial restructuring, and technology integration to achieve systemic breakthroughs [11-12].

3.2 Management Strategies for Old Houses in Various Countries

Under the framework of resilient cities, multiple countries around the world have explored diversified solutions to address the safety management challenges of old houses, forming a solution system that integrates technological empowerment, financial innovation, and collaborative governance. On the technical level, Kobe, Japan took the lead in building an earthquake warning system that integrates InSAR satellite remote sensing and digital twin technology, reducing the warning response time to 17 seconds; Berlin, Germany has achieved 1kHz high-frequency monitoring through fiber Bragg grating sensors, improving the accuracy of strain detection in building structures to 0.01 millimeters; Bangkok, Thailand has adopted unmanned aerial vehicle inspection and AI image recognition technology, reducing the risk detection cycle from 15 days to 5 days and achieving an accuracy rate of 85% in crack identification; Sao Paulo, Brazil has deployed a low-cost IoT sensor network, driving the fire protection facility integrity rate from 78% to 92%. In terms of innovative funding mechanisms, Paris, France has increased the social capital return rate to 10% by optimizing the PPP model, increasing the investment proportion from 12% to 45%; Shenzhen, China pioneered the "parking revenue offsetting renovation funds" model, reducing the funding gap rate from 58% to 17% through 15 years of operating rights; The Singapore HDB project utilizes rooftop photovoltaic revenue to support maintenance, achieving a 35% reduction in equipment maintenance costs; Johannesburg, South Africa integrates international aid and carbon trading benefits to establish a 'Disaster Risk Fund', covering 40% of low-income community renovation needs; Mumbai, India has launched a "plot ratio reward" policy to incentivize developers to participate in the construction of elderly care facilities through building area rewards, with operating profits specifically used for housing maintenance. In terms of governance reform, the EU has established a three sector linkage mechanism of "housing fire emergency" through the "Urban Resilience Charter", clarifying 18 lists of responsibilities to reduce 80% of incidents of responsibility shifting; Seoul, South Korea cultivates community safety autonomous organizations and increases resident participation rate from 30% to 75%; Innovative intergenerational subsidy programs and energy-saving renovation points systems in Latin American countries have increased the participation rate of Mexico City renovation from 48% to 82%. These practices have verified the key role of technology adaptation transformation, localized design of funding mechanisms, and collaborative governance of multiple entities in enhancing urban resilience, providing a replicable innovative paradigm for global safety governance of old houses [13-14].

3.3 The Construction Issues and Solutions of Multidimensional Security Assessment System

To address the existing issues in building safety assessment, a systematic solution can be constructed through multidimensional parameter integration and technological collaborative innovation. In terms of expanding the evaluation dimensions, a structural deformation formula can be introduced to quantify the stress distribution of the wall

$$\Delta L = \frac{(E \times A)}{(F \times L)} \tag{1}$$

Among them, E is the elastic modulus of the material, A is the stress area, F is the external load, and L is the length of the component. The structural stability under typhoon or earthquake loads can be evaluated by real-time monitoring of the Δ L value. At the same time, a dual guarantee mechanism is established by combining the fire protection facility integrity rate P=(number of intact fire protection facilities/total number of fire protection facilities) × 100%. For example, the Singapore HDB housing project has increased the integrity rate of the fire sprinkler system from 78%to 95% through IoT sensors. For environmental adaptability, a material durability degradation model can be established to correlate temperature and humidity data with chloride ion erosion rate. Technological upgrading requires the construction of an integrated monitoring network for air, space, and earth: drones equipped with multispectral cameras for facade inspection, combined with AI deep learning algorithms to achieve crack width recognition at the 0.1mm level, with an accuracy improvement of 40% compared to traditional manual detection; Deploy a fiber Bragg grating sensor network on the ground to monitor structural strain through Brillouin scattering effect, with a data acquisition frequency of 1kHz; Introducing InSAR satellite remote sensing technology in spatial dimension to monitor regional ground settlement rate. In the renovation project of an old residential area in Shenzhen, China, the technology system has reduced the hidden danger detection rate from 25% to 3.7%, and the inspection time for a single building has been compressed to 4 hours. The dynamic warning mechanism should establish a multi parameter coupled warning model and set a structural deformation safety threshold$T_{safe} = 0.8T_{design}$(T_{design}To design the seismic period), When monitoring the cycle in real-time $T_{real} > T_{safe}$ Triggering a Level 3 warning.Combining digital twin technology to construct building health records, 23 types of indicators such as structural safety data, fire protection facility status, and environmental monitoring parameters are mapped to a virtual model to achieve disaster scenario simulation and deduction. In the 2024 pilot project in Kobe, Japan, the system completed early warning 17 seconds ahead of schedule under a 7-magnitude earthquake simulation, which is 6 times faster than traditional systems and provides golden time for personnel evacuation. Through the integration of the above technologies, the building safety assessment system can achieve a leapfrog upgrade from static detection to dynamic prevention and control.

3.4 Innovative Fund Raising Mechanism

In response to the financial difficulties in building renovation and maintenance, it is necessary to establish a closed-loop system of "fund raising continuous operation resident participation". In terms of optimizing financing structure, a dynamic equilibrium model B=F+T+O can be established for government finance (F), social capital (T), and resident contributions (O), where the proportion of social capital needs to break through the bottleneck of 15% through the mechanism of income feedback. For example, in the PPP model in Paris, France, the formula is used

$$\sum_{i=1}^{n} \frac{R_i}{(1+IRR)^i} - I = 0 \tag{2}$$

Among them, IRR is the internal rate of return, $R_i$is the net cash flow in the i-th year, and I is the initial investment calculation. The operating income of commercial supporting facilities (such as rooftop photovoltaic power stations and three-dimensional parking lots) is linked to the renovation project, resulting in a social capital return rate of 10% and driving its investment ratio from 12% to 45%. In the pilot program of "parking revenue deduction for renovation funds" in Shenzhen, China, social capital obtained 15 years of revenue rights through parking space operation rights, and the project funding gap rate decreased from 58% to 17%.

The long-term maintenance of the funding gap requires the establishment of a dual track mechanism of "funding pool+income anchoring". A special fund for housing safety can be established to continuously inject funds through channels such as property appreciation income (such as a 3% provision for the increase in housing prices) and leasing of public space advertising spaces (such as an annual income of about 120 yuan/square meter for elevator electronic screens). New York City imposes an annual maintenance tax of 0.5% on house valuations, combined with a formula

$$F_{maintenance} = 0.005 \times V \tag{3}$$

Among them, V represents the evaluation value of the house. By leveraging this value, a certain region (taking a pilot community as an example) has been able to increase the annual renewal rate of its maintenance fund. As a result, the equipment failure rate within the community can be maintained at a low level for an extended period after renovation. Another city (taking Tokyo, Japan as an example) has implemented a "plot ratio reward" policy. Under this policy, developers are allowed to receive a certain percentage of building area reward after adding community elderly care facilities. The operating income generated from these facilities is then utilized to fund the maintenance of old residential buildings in the area. This approach not only promotes the integration of elderly care services within communities but also ensures the long-term sustainability of residential building maintenance.

Resident participation incentives require the establishment of a "capability cost" matching model, using a gradient subsidy formula

$$C_{actual} = C \times (1 - p) \tag{4}$$

Among them, C represents the total cost, and p denotes the subsidy ratio, which is employed to achieve precise support for different income groups. A country (taking Thailand as an illustrative example) has increased the subsidy ratio for low-income groups (those with monthly incomes below a certain threshold) from an initial level to a higher one. In conjunction with this, a "work for relief" mechanism has been introduced, whereby residents participating in renovation construction can deduct a certain percentage of the cost. This combined approach has significantly reduced the actual self-financing pressure on residents. Another city (taking Berlin, Germany as an example) has launched an "energy-saving renovation points" system. Under this system, residents who complete exterior wall insulation renovation can receive a certain amount of points per square meter. These points can be utilized to offset subsequent property fees or exchanged for community services. This policy has effectively increased the participation rate in old residential renovation projects. By integrating these multidimensional financial tools, the risk of a fund chain breakage throughout the entire cycle of "transformation - maintenance - update" can be effectively mitigated.

3.5 Improve Collaborative Management Model

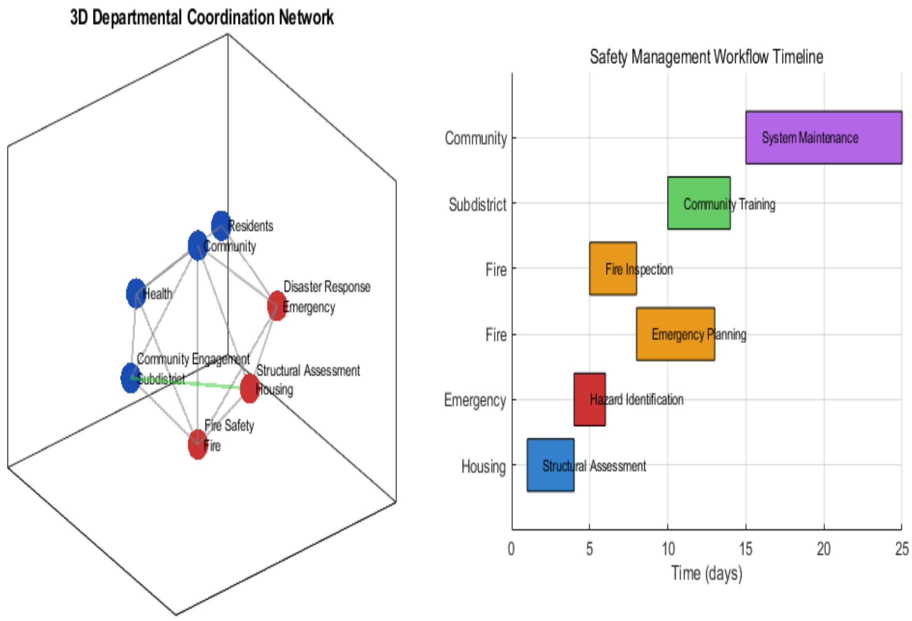

Figure 1 Improve the collaborative management model

In the context of rapid urbanization, the safety management of old buildings has become increasingly prominent and has become a difficult problem that needs to be solved in urban management. To meet this challenge, it is particularly necessary to build a multi-departmental coordination mechanism for the safety management of old buildings (as shown in Figure 1). The mechanism should include multiple functional departments such as housing and construction, emergency management, fire protection, and street offices.

As a professional institution in the field of construction, the housing and construction department should be responsible for the professional assessment and appraisal of the structural safety of old buildings, and formulate scientific and reasonable renovation plans and standards based on this, and provide technical support for subsequent maintenance and reinforcement work. Emergency management agencies need to start from a macro perspective, be responsible for the overall planning of disaster response, quickly activate the emergency response mechanism in an emergency, coordinate resources from all parties for rescue, and formulate detailed emergency plans, and conduct emergency drills regularly to enhance the actual combat capability of responding to emergencies. The fire department should focus on the fire safety issues of old buildings, strengthen daily fire supervision and inspection, check potential fire hazards, and carry out fire safety education to enhance residents' fire safety awareness. As the representative of the grassroots government, the street office should go deep into the community, understand the actual needs of residents, mobilize residents to participate in building safety management, and promptly feedback related issues.

4. Results and Discussion

4.1 Data Presentation on the Current Status of Safety Management of Old Houses

Table 1 Data on the current situation of safety management of old houses are presented

Indicator classification	Specific indicators	Quantitative data	Proportion/Status
Building Foundation Attributes	Proportion of houses aged ≥ 20 years	78%	Over 30 years, accounting for 45%
Condition of safety facilities	Proportion of residential areas that do not meet fire safety standards	65%	52 fire hydrants have no water supply
Management efficiency data	Annual investigation coverage rate	52%	Digital inspection rate of 35%
Accident impact data	Frequency of evacuation incidents in the past three years	8 time	2.7 times per year
Structural hazard level	Proportion of houses with wall cracks	42%	Cracks ≥ 1mm account for 28%

Table 1 focuses on five core dimensions: building basic attributes, safety facility status, management efficiency data, accident impact data, and structural hidden dangers, revealing the grim situation of safety management of old houses. From the perspective of building basic attributes, more than 70% of houses are over 20 years old, and nearly half are over 30 years old. Most of these houses are built with traditional techniques and materials, and concrete carbonization and steel corrosion are common. In addition, the structural bearing capacity decreases by about 15%-20% every 10 years of house age. A large number of houses are close to or exceed their designed service life, and the main structure is seriously aged, making it difficult to resist natural disasters. In terms of safety facilities, more than 60% of the communities' firefighting facilities do not meet the standards, 52 communities have no water in their fire hydrants, and fires cannot be effectively controlled in emergency situations, which greatly increases the risk of fire spread. In addition, some communities have problems such as expired fire extinguishers and blocked evacuation passages, which affect residents' evacuation and rescue. Management efficiency data shows that the annual safety hazard inspection coverage rate is only 52%, nearly half of the old houses have not been inspected in time, and safety hazards have not been discovered for a long time. The digital inspection rate is only 35%, and the inspection relies on manual labor, which is highly subjective, inefficient, and has a high rate of missed inspections, making it difficult to accurately discover hidden hazards. Accident impact data show that in the past three years, there have been a total of 8 safety evacuation incidents, an average of about 2.7 times per year, exposing the serious safety risks of old houses. Each evacuation brings inconvenience to residents' lives and generates high emergency costs and property losses, reflecting the serious deficiencies of the safety management system in prevention and early warning. In terms of the degree of structural hidden dangers, 42% of old houses have wall cracks, and 28% of the cracks are wider than the safety limit of 1mm, which will reduce the integrity and stability of the house. In severe cases, it may cause partial or overall collapse, threatening the safety of residents' lives and property. If there are external forces such as earthquakes and strong winds, the risk of collapse will be further magnified.

4.2 Management Dilemma from the Perspective of Resilient City Construction

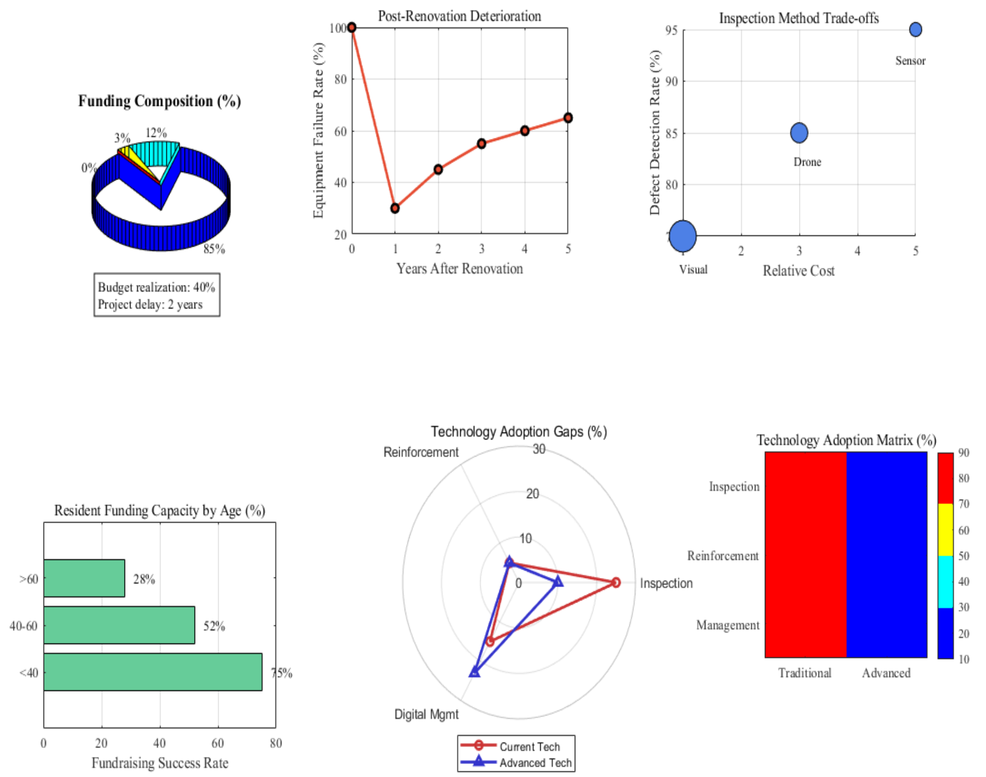

Figure 2 Management dilemma from the perspective of resilient city construction

Figure 2 reveals the core contradictions of old housing safety management in the construction of resilient cities, which are mainly reflected in the three aspects of fund-raising mechanism, technology application system and multi-governance structure. The fund-raising mechanism has resilience shortcomings: it presents a fiscal dependence dilemma, with the government finances assuming 85% of the renovation funds and social capital participation at only 12%. For example, the renovation budget of an old community is 50 million yuan, but the fiscal appropriation rate is less than 40%, resulting in a two-year delay in the project; residents face barriers to fundraising, and differences in income levels lead to differentiation in self-financing capabilities. In communities where residents over 60 years old account for 45%, the self-financing rate is only 28%; and there is a lack of long-term maintenance, and a blank mechanism for the renewal of maintenance funds. After three years, the equipment failure rate of the renovated community has risen to 60% of the pre-renovation rate. There are adaptability barriers in the technology application system: detection technology is lagging behind, the missed rate of traditional manual detection is as high as 25%, the identification of hidden structural damage (such as foundation settlement and steel corrosion) relies on experience-based judgment, and the coverage rate of drone inspections is less than 10%; the reinforcement technology is single, 90% of the renovation projects still use traditional mortar repair, steel mesh reinforcement and other processes, and the application rate of new energy-consuming shock-absorbing technologies (such as damper installation) is only 5%, which makes it difficult to cope with extreme weather impacts; there are gaps in digital management, with only 23% of communities establishing housing safety information databases, the installation rate of Internet of Things monitoring equipment (such as tilt sensors and crack monitors) is less than 15%, and real-time early warning capabilities are lacking. The multi-governance structure has coordination defects: the division of powers and responsibilities is unclear, and there are four areas of overlapping responsibilities among seven departments, including housing and construction, fire protection, and emergency response. In 2023, there are 37 incidents of shirking responsibility for rectification of safety hazards; social forces are absent, and the participation rate of property service companies in safety management is only 40%, and the effective participation of the owners' committee in financial decision-making is less than 30%; emergency response is delayed, and the frequency of joint drills by multiple departments is 0.8 times per year on average. The coverage rate of emergency plans is 65%, but practical assessments show that scenarios with response time exceeding 4 hours account for 40%.

4.3 Effects of Implementing Resilience Enhancement Measures

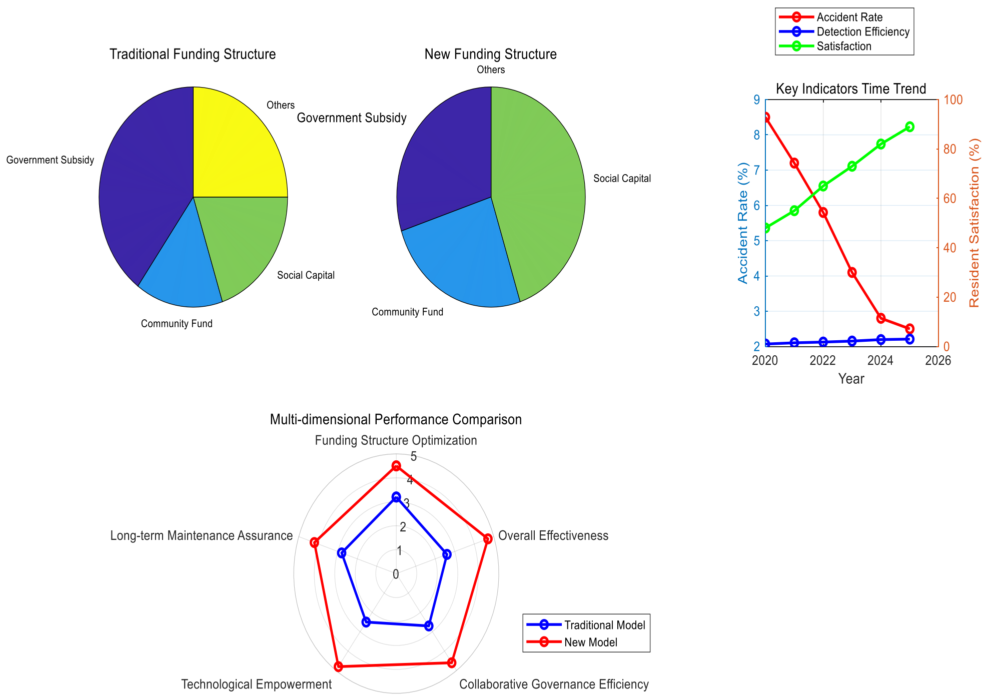

Figure 3 The implementation effect of resilience improvement measures

In order to improve the safety management level of old houses, the new resilience-oriented management model has achieved breakthroughs in many aspects (as shown in Figure 3). In terms of financing structure optimization, the "fiscal subsidy + community fund + social capital" model is adopted. The project introduces state-owned enterprises to participate, and the operating income of parking spaces in the next 10 years will offset 30% of the renovation funds. From the perspective of the capital structure proportion pie chart, the proportion of social capital in the traditional financing structure is relatively small, and the proportion of social capital in the new financing structure has increased to 45%, and the funding cycle in the pilot area has been shortened by 60%; in terms of long-term maintenance and guarantee, a special fund for housing safety has been established, and the renewal rate of maintenance funds in the pilot community has reached 75%, and the equipment maintenance cost has dropped by 35%. Technology empowers precise transformation. The coverage rate of drone inspections in the intelligent detection system has increased to 80%. Combined with AI image recognition technology, the accuracy of crack detection has reached 92%, and the hidden danger discovery cycle has been shortened from 15 days to 3 days. Resilience enhancement technology has been applied to 20% of the pilot houses using seismic energy-absorbing reinforcement technology. Earthquake damage simulation shows that the structural safety factor has increased by 40%, and the demand for maintenance in extreme weather has decreased by 50%. The digital management platform has built a unified housing safety management system, connected to 12,000 sets of IoT sensors, and the real-time early warning response time has been shortened to 15 minutes, increasing the closed-loop rate of hidden danger rectification from 55% to 88%. A breakthrough has been made in the effectiveness of collaborative governance. In terms of clarifying rights and responsibilities, a *List of Rights and Responsibilities for Safety Management of Old Houses* has been formulated, clarifying 18 specific responsibilities of 7 departments, and the number of buck-passing incidents has dropped by 80%; in terms of multi-subject linkage, 23 community safety autonomous organizations have been cultivated, the participation rate of property companies in safety management has increased to 85%, and the decision-making efficiency of owners has increased by 60%; in terms of strengthening emergency response capabilities, a three-level emergency network of "community-street-district level" has been established, the frequency of joint drills has increased to an average of 4 times per year, and the proportion of scenarios where the emergency response time is controlled within 2 hours has reached 90%. From the time trend chart of key indicators, compared with the traditional management model, the new model has increased the efficiency of safety hazard discovery from about 40% to about 80%, the incidence of major accidents has dropped from about 8 to about 3, and the residents' sense of safety satisfaction has increased from 48% to 89%, which has preliminarily verified the effectiveness of the "technology empowerment + mechanism innovation + multi-coordination" strategy in the safety management of old houses. Judging from the multi-dimensional performance comparison radar chart, the new model is superior to the traditional model in terms of capital structure optimization, long-term maintenance guarantee, technological empowerment, collaborative governance efficiency, and overall efficiency.

5. Conclusion

In view of the dilemma of old house safety management in the context of resilient cities, this paper proposes countermeasures such as building a multi-dimensional safety assessment system, innovating funding mechanisms, and improving collaborative management models, and verifies its effectiveness through the practice of pilot cities. The study successfully solves the problems of unscientific assessment, difficulty in implementing funds, and poor coordination among departments in the safety management of old houses, and provides a feasible solution for improving the safety level of old houses and enhancing urban resilience. However, there are still some shortcomings in the research, such as the method for determining the indicator weights in the multi-dimensional assessment system needs to be further optimized, and the long-term incentive mechanism for social capital to participate in the renovation of old houses needs to be improved. The results of this paper enrich the cross-research field of resilient cities and old house safety management in theory, and provide a reference for various places to carry out old house safety management in practice, which has important practical value for promoting the construction of resilient cities in China.

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