Application of Sponge City Concept in Water Supply and Drainage Design of Civil Buildings: Dilemmas and Solutions

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Keywords: Civil Buildings; Water Supply and Drainage Design; Sponge City Concept; Maintenance Management; Spatial Constraints

Abstract: The accelerating pace of urbanization has led to challenges such as water scarcity and urban waterlogging. Traditional water supply and drainage design models for civil buildings struggle to effectively address these complex water-related issues. Applying the Sponge City concept to the water supply and drainage design of civil buildings has become an inevitable trend. However, its practical application faces numerous difficulties. This paper analyzes the importance of integrating the Sponge City concept into the water supply and drainage design of civil buildings, identifies the dilemmas encountered during its application, and proposes reasonable and effective implementation pathways. It aims to provide a valuable reference for the rational utilization of urban water resources and the sustainable development of the ecological environment.

1 Introduction

Under the dual influences of climate change and urban development, problems such as urban waterlogging and water environmental pollution have become increasingly severe. The Sponge City concept advocates for urban planning, construction, and management that fully utilizes ecosystems like roads, green spaces, and water bodies to absorb rainwater, achieving natural infiltration and purification. Civil buildings are major components of cities, and their water supply and drainage design is a crucial link in implementing the Sponge City philosophy. However, applying the Sponge City concept to the water supply and drainage design of civil buildings faces many challenges. Therefore, deeply exploring the application pathways of the Sponge City concept in this context holds significant practical importance for urban sustainable development.

2 Importance of Applying the Sponge City Concept to Water Supply and Drainage Design in Civil Buildings

2.1 Enhancing Urban Flood Prevention and Drainage Capacity

The application of the Sponge City concept in the water supply and drainage design of civil buildings can enhance urban flood prevention and drainage capacity from multiple dimensions. It implements decentralized rainwater management at the source, leveraging facilities such as roads, green roofs, and sunken green spaces to reduce peak surface runoff. Building clusters can form micro-sponge entities that, during heavy rainfall, slow down runoff through infiltration and storage, providing adequate buffer time for the urban drainage system[1]. Simultaneously, the Sponge City concept in civil building design also advocates for using facilities like rain gardens and ecological tree pits to purify rainwater, which can then be recycled and reused in conjunction with landscape water bodies or underground storage tanks. The deep integration of sponge facilities with civil building drainage systems forms a multi-level defense system. Through three-dimensional design, individual buildings become important nodes in the urban flood control network, creating a synergistic effect with the drainage system of the entire area.

2.2 Optimizing Water Resource Recycling

The application of the Sponge City concept in civil building water supply and drainage design

  DOI: 10.25236/icacel.2025.212

creates favorable pathways for efficient water resource recycling[2]. This concept advocates for building a three-dimensional system to maximize rainwater utilization. Permeable paving facilities are chosen for building roofs and roads, significantly improving rainwater infiltration efficiency. Water purified through units like rain gardens and grassed swales can be used for green irrigation and landscape water supplementation, effectively reducing the dependence of civil buildings on municipal water supply. The application of the Sponge City concept also strengthens the closed-loop management capability of civil building water systems. Through the interaction of rainwater storage tanks and reclaimed water recycling systems, rainwater and sewage separation as well as greywater recycling are achieved, significantly enhancing water resource utilization efficiency.

2.3 Improving the Building Microclimate Environment

The application of the Sponge City concept in civil building water supply and drainage design effectively improves the building microclimate environment. Applying Sponge City design schemes for temperature regulation involves adding facilities like sunken green spaces and rain gardens around buildings, significantly enhancing surface permeability. The vegetation communities within the Sponge City system also adsorb dust and release large amounts of oxygen through photosynthesis, improving air quality around civil buildings and creating a healthier breathing environment for residents. Furthermore, the layout of Sponge City facilities can guide natural ventilation. The topography formed by sunken green spaces and vegetation buffer strips can effectively increase air flow speed, improve ventilation conditions in the leeward areas of buildings, and enhance the natural ventilation effect between building clusters.

3 Dilemmas in Applying the Sponge City Concept to Water Supply and Drainage Design in Civil Buildings

3.1 Insufficient Adaptability of Technology and Facilities

The lack of adaptability between technology and facilities is a common problem in applying the Sponge City concept to civil building water supply and drainage design. Some new sponge facility technologies are not yet mature. For instance, the materials of rainwater storage tanks may not match the soil environment and water quality characteristics, leading to seepage and corrosion problems that affect the normal function of storage. Simultaneously, there are obstacles to the integration of existing water supply and drainage technologies with sponge facilities. Traditional building drainage systems focus more on rapid drainage in a short time, while the Sponge City concept emphasizes comprehensive multi-faceted management. Additionally, the standardized design of Sponge Cities is prevalent, causing sponge facilities to fail to deliver their intended value in regions with special climatic environments.

3.2 Lack of a Sound Maintenance Management Mechanism

A common issue in applying the Sponge City concept to civil building water supply and drainage design is the lack of a long-term maintenance management mechanism. This limits the performance of low-impact development facilities and may even lead to the failure of the entire system. Property management departments or owners often lack professional maintenance knowledge for sponge facilities, such as how to correctly clean infiltration trenches, when to replace filter layers, or how to unclog potentially blocked perforated pipes. The responsibility entity for maintenance is often unclear, and the absence of a funding guarantee mechanism hinders routine tasks like inspection, dredging, maintenance, and equipment replacement. Problems like facility damage and functional degradation are not repaired promptly. The lack of a monitoring and evaluation system means maintenance lacks data support, making it difficult to accurately identify problem nodes and formulate targeted strategies. This ultimately weakens the ecological benefits of Sponge City facilities and may even increase the risk of waterlogging due to poor drainage.

3.3 Spatial Constraints

Spatial constraints pose a major challenge when applying the Sponge City concept to the water supply and drainage design of civil buildings. In high-density urban areas, land around civil buildings is limited, making it difficult to reserve sufficient space for large sponge facilities like sunken green spaces or rain gardens. The internal space of buildings also restricts the installation of sponge facilities. Forced installation may lead to problems like poor plant growth and drainage issues, affecting the effectiveness and durability of the sponge facilities. Spatial constraints not only impact hydrological performance but also increase construction and maintenance costs, practically limiting the large-scale promotion of the Sponge City concept in civil buildings.

3.4 Standardization Needs Updating

In the process of deeply integrating the Sponge City concept into civil building water supply and drainage design, the lag in updating standardized norms has become increasingly prominent. With the innovative development of Sponge City technologies and materials, the application of new permeable materials, intelligent monitoring and control systems, etc., lacks standards for technical indicators, acceptance procedures, and later operation and maintenance management. This lack of standards hinders the promotion of new technologies and makes it difficult to quantify engineering effectiveness. Some units still use static calculation methods, which cannot accurately quantify the actual effectiveness of Sponge City facilities in complex building environments nor provide effective feedback for design optimization[3].

3.5 Poor Interdepartmental Collaboration

Applying the Sponge City concept to civil building water supply and drainage design involves multiple departments such as urban planning, architectural design, water supply and drainage engineering, landscape architecture, and municipal management. However, departments often operate from their own professional perspectives, lacking overall coordination and synergy awareness. This can lead to situations where completed sponge facilities need rework or modification because they do not meet municipal requirements. This disconnection in interdepartmental collaboration not only causes project delays and cost increases but also seriously affects the effective implementation of the Sponge City concept. Crucially, misunderstandings often arise between developers, contractors, and later operators: construction units might not understand the hydrological principles, leading to flawed construction, or property management departments might lack professional knowledge and maintenance budgets, ultimately resulting in the abandonment of facilities. This makes it difficult to translate Sponge City designs from blueprints into efficient and sustainable systems.

4 Pathways for Applying the Sponge City Concept in Civil Building Water Supply and Drainage Design

4.1 Enhancing the Adaptability of Technology and Facilities

In the application process of the Sponge City concept in civil building water supply and drainage design, the adaptability between technology and facilities should be strengthened. Modular technical packages should be developed according to building types. Integrated rainwater collection systems should be prioritized in new building complexes, allowing facilities like sunken green spaces and permeable pavements to combine with vertical greening on building facades, forming a multi-level rainwater retention and storage network. High-rise buildings can design garage roof decks as composite structures of permeable pavement and bioretention ponds, ensuring full-process management of rainwater runoff. For old buildings, lightweight adaptive technologies can be chosen to reduce the burden on the building structure. Simultaneously, the application of the Sponge City concept must break away from traditional design thinking, achieving deep integration of facilities and building space. Three-dimensional infiltration systems should be set up, placing rain gardens on the ground floor or rooftop of buildings to maximize the use of vertical space and create larger green areas. Furthermore, relevant units can use IoT sensors to monitor rainwater collection volume and water quality indicators, coupled with big data analysis technology to analyze facility operation status. Based on the analysis results, preventive maintenance measures can be formulated to minimize facility failure rates.

4.2 Establishing a Sound Maintenance Management Mechanism

In the process of introducing the Sponge City concept into civil building water supply and drainage design, a sound maintenance management mechanism should be constructed, establishing a full-lifecycle management system. Standardized operation and maintenance processes should define the maintenance cycles and acceptance standards for facilities like permeable pavement and green roofs, making maintenance work traceable. Cross-professional maintenance teams should be established, integrating professionals from property management, landscaping, and water supply and drainage engineering to regularly address common failures of sponge facilities. Simultaneously, relevant units should build BIM models for sponge facilities, integrating and analyzing construction records and maintenance log information. GIS technology can be used to accurately locate facilities, providing reliable data support for later fault troubleshooting and upgrades. Architectural design units should establish a collaborative communication platform with urban management departments and water authorities to share extreme weather information in real-time and coordinate the scheduling of sponge facilities within the building area. On this basis, regular open days for owners should be organized, featuring permeable pavement experiments to enhance residents' understanding of the Sponge City concept, encouraging them to actively participate in the maintenance of green roof vegetation. Additionally, maintenance management should develop economic safeguards, raising funds through multiple channels and selecting native plants with strong weather resistance and low maintenance costs. This transforms sponge facilities from a construction concept into a management philosophy, providing fundamental support for urban resilient development.

4.3 Breaking Spatial Limitations

To apply the Sponge City concept in civil building water supply and drainage design, multi-dimensional, cross-regional collaborative strategies should be adopted to break spatial limitations. Vertical space can be expanded to achieve a three-dimensional layout for rainwater storage and utilization. Simultaneously, relevant units should strengthen the horizontal spatial linkage between buildings and the surrounding environment, breaking site boundary restrictions. By installing permeable pavements, constructing sunken green spaces, and other low-impact development facilities, rainwater runoff within the building property line can be directed to surrounding public green spaces or municipal storage facilities, forming a regionally linked sponge network. Utilizing terrain elevation differences, ecological drainage ditches or grassed swales can be designed to connect dispersed rainwater collection facilities into a line, creating continuous rainwater transmission channels and integrating the building site organically with urban green spaces, roads, and other public areas. Furthermore, relevant units should use IoT sensors to monitor rainfall and runoff conditions on building roofs and sites in real-time, dynamically adjusting the operation status of rainwater facilities to maximize the efficiency of rainwater resource utilization and flood prevention capacity within limited space. This creates a multi-dimensional spatial adaptation system, enabling the successful implementation of the Sponge City concept in high-density building environments.

4.4 Establishing Standardized Norms that Meet the Needs of Contemporary Development

The application of the Sponge City concept in civil building water supply and drainage design should establish standardized norms that meet the needs of contemporary development[4]. The primary task is to establish a full-lifecycle standard system covering design, construction, operation, and maintenance, clarifying technical parameters and acceptance criteria for each stage. For instance, in rainwater collection systems, pipeline materials should meet corrosion resistance and permeability requirements; storage facilities should possess waterproofing, anti-seepage, and water quality monitoring functions; water storage capacity thresholds should be set differentially based on building scale and climatic conditions. Relevant units should improve dynamic update mechanisms, regularly revising maintenance standards for sponge facilities based on regional rainfall characteristics and the effectiveness of new technology applications. Key indicators such as the dredging cycle for permeable pavement and the replacement frequency of interception baskets at rainwater inlets should be clarified, ultimately forming a full-chain standardized system that provides a quantifiable practical paradigm for Sponge City construction. Additionally, the application design of the Sponge City concept should encourage digital empowerment, promoting BIM-based performance simulation and smart management platforms to achieve real-time monitoring and efficiency evaluation of stormwater regulation processes. Long-term operation and maintenance mechanisms and post-evaluation systems should be established for the management responsibilities of construction units, designers, contractors, and property managers in civil engineering projects to ensure the continuous and effective operation of facilities.

4.5 Implementing Interdepartmental Collaboration

Integrating the Sponge City concept into civil building water supply and drainage design requires implementing interdepartmental collaboration strategies. A collaborative team comprising multiple professions such as architecture, landscape, and municipal engineering should be established, clarifying the responsibility boundaries and technical connection points for each profession in links like rainwater collection, infiltration, storage, and purification. Multi-party collaboration should run through the entire project cycle. During the construction phase, the design department should jointly conduct on-site briefings with construction and supervision units on key processes like permeable material paving and grassed swale slope treatment to ensure the construction quality of sponge facilities. During the operation and maintenance phase, they should work with property management departments to develop long-term management plans for tasks like dredging rainwater tanks and vegetation maintenance, avoiding facility failure due to lack of later maintenance. Furthermore, the design department should communicate with the electrical specialty to integrate the control, monitoring, and alarm systems of rainwater reuse into the building intelligent management system. This ensures that Sponge City facilities continuously perform their functions in runoff control, rainwater utilization, and ecological benefits throughout their lifecycle, transforming the Sponge City concept from technical drawings into buildable, manageable, and sustainable engineering practice, truly achieving harmonious coexistence between buildings and the environment.

5 Conclusion

In summary, integrating the Sponge City concept into the water supply and drainage design of civil buildings is an important measure to promote urban sustainable development and improve the quality of the living environment. However, its practical application faces many problems. Therefore, in the practical application of the Sponge City concept, it is necessary to strengthen the adaptability of technology and facilities, construct a sound maintenance management mechanism, break spatial limitations, establish new standards and norms, and implement interdepartmental collaboration, thereby building an ecological and livable urban environment.

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