Journal of World Architecture

Review Article

An Exploration of the Application of Smart Sponge City Engineering System Based on TRIZ Theory

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Abstract: This paper first analyzes the current status of sponge city construction at home and abroad, and combines the actual construction of sponge cities at home and abroad to study and explore its problems in engineering construction. Based on the principle of sustainable development, using TRIZ theory and related engineering theories to further explore the high-efficiency collection of rainwater and high-efficiency comprehensive utilization, and combine the concept of smart city with the practice of sponge city construction to create a new type of sponge city rainwater recycling process system. This method and means of exploring and solving problems is the only way to further develop the construction of sponge cities, and it is also the general law of social development to provide exploratory reference for the construction and development of the sponge city.

Keywords: *TRIZ theory, Intelligent rainwater collection and utilization in sponge city*

Publication date: July, 2019

Publication online: 31 July, 2019

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1 Introduction

Today China is facing a variety of water crises: water shortages, water pollution, floods, urban shackles, falling water tables, loss of aquatic habitats, etc., the problem is very serious[1]. The water crisis brought about by the syndrome of these water problems is not a problem under the management of the water sector or a certain department, but a systematic and comprehensive problem. We need a more comprehensive solution. The "sponge city" theory is based on China's water characteristics and water issues. At present, many cities in China are carrying out pilot construction of the sponge city, but there are still a series of problems in the project. In some cities, there will still be urban stagnation after the heavy rain. This paper analyzes the practice cases of traditional sponge cities and explores the existence of its engineering system, problems, and through a tool such as TRIZ innovation method to explore a new type of sponge city system engineering construction.

2 Current status of sponge city construction at home and abroad

2.1 Low-impact development (LID) and construction mode in the United States

It was implemented in Maryland in the United States in the 1990s. The low-impact development mainly maintains the original hydrological conditions before development, controls the runoff pollution, reduces the pollution discharge, and realizes the sustainable water cycle in the development area through measures such as bioretention facilities, roof greening, shallow vegetation, and rainwater utilization. Compared with foreign countries, low-impact development technology is currently used less in China, but it has been included in the national "12th Five-Year" water special project for research. The specific practices are as follows.

(1) In the process of expanding and building new urban water systems, some technical measures are taken, such as deepening the depth of the reservoir, lowering the water temperature to increase the water storage capacity and rationally controlling the evaporation amount, and giving full play to the regulation of natural water bodies.

(2) It is to renovate the city's plazas and roads, and

to preserve the rainwater to the greatest extent by constructing a modular rainwater storage system, a groundwater storage tank, or a sinking rainwater storage plaza. In some practices, the ratio of the permeable floor of the road plaza is ≥70%, the proportion of the recessed green space is ≥2.5%, and the integrated runoff coefficient is ≤0.5.

(3) In the residential, industrial and commercial area LID design, change the traditional centralized green space construction mode, infiltrate the small-scale recessed green space into each block, and increase the proportion of green space without reducing the building area. The permeable floor is ≥75%, the green rate is ≥30% (in which the recessed green space is ≥70%), and the runoff coefficient is ≤0.45.

(4) The LID design is adopted in the garden green space, and the ecological benefits of the green space are more obvious. In the practice of sponge city construction, by constructing low-impact development facilities such as detention ponds and recessed green spaces, and integrating rainwater storage facilities with landscape design, it is possible to achieve per capita green space ≥20m2, green land rate ≥40%, greening Coverage ≥50%. The target of the permeable floor ≥75% (including the recessed green space ≥70%), the runoff coefficient can be controlled at about 0.15. At the same time, the collected rainwater can be recycled, and the park can be used as an emergency water source[2].

2.2 The construction mode of sponge city in Germany

The application concept of the construction of the sponge city in Germany is to comprehensively manage and apply rainwater. According to the degree of pollution of the rainwater, the ability to accept the water body is treated differently. Thanks to the developed underground pipe network system, advanced rainwater comprehensive utilization technology and well-planned urban green space construction, the construction of the German "Sponge City" has been quite effective[3].

The three types of urban rainwater utilization methods are as follows:

(1) Roof rainwater harvesting system: The collected rainwater can be used for non-potable water in homes, public places and businesses after simple treatment.

(2) Rainwater interception and infiltration system: Road rainwater is discharged through sewers into large reservoirs along the way or through infiltration to replenish groundwater. There are sewage intercepting baskets at the rainwater pipelines of German city streets to intercept pollutants carried by stormwater runoff. Urban floors use permeable floor tiles to reduce runoff[4].

(3) Rainwater utilization system in ecological community: The community is built with permeable shallow trenches along the drainage channel, and the surface is planted with turf for infiltration during rainwater runoff. Rainwater exceeding the infiltration capacity enters the rainwater pond or constructed wetland as a water feature or continues to infiltrate[5].

2.3 Overview of the development of China's "sponge city"

The pilot of China's sponge city is relatively late compared to other countries. The earlier practice cases include the Zhongguancun Life Science Park in Beijing in 2000. The design uses a green space system that collects rainwater and purifies the water in a constructed wetland. It is called the cell of the earth[6]; In 2007, the Tianjin Qiaoyuan Wetland System formed a bubble-like ecological sponge by simple filling and excavation, collecting rainwater, and carrying out ecological restoration of urban brownfields while solving urban shackles, and exerting comprehensive ecosystem services[7]; Similar green sponge project is also in Qinhuangdao coastal ecological restoration.

3 The technical analysis of the specific construction of the traditional sponge city

3.1 Water storage facilities

3.1.1 Water storage module

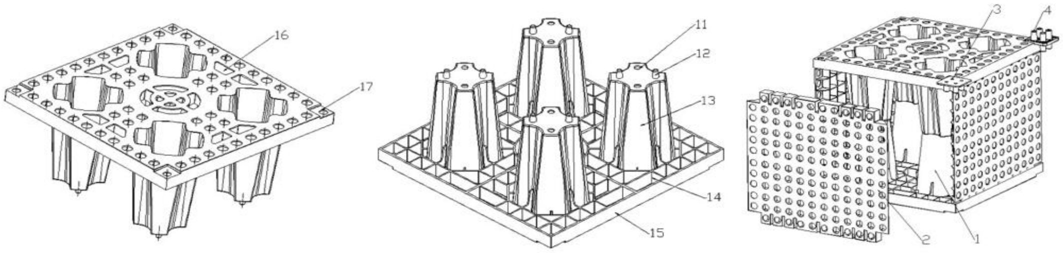

Figure1. Construction of water storage module

As shown in Figure 1, the water storage module is a new type of rainwater storage module structure. The rainwater storage module is composed of N modular units, and each modular unit includes a composite support block 1, a side plate 2, a connecting member 3, and a connecting member 4.

The composite support block is designed and manufactured by the bottom plate 15 and the four bearing support columns 13 to ensure the stability and firmness of the water storage module. The four bearing columns have a cavity design with a horizontal section of X shape, which is superior to a circular or rectangular section and has higher structural stability. The vertical section extends from the top to the bottom in a tapered shape to the bottom plate, which has a strong bearing capacity. The bottom plate is square, and the four edges are provided with side plate slots 14. The four bearing support columns are integrated with the bottom plate, and vertical and horizontal reinforcing ribs are formed at the connecting space to ensure the strength of the bottom plate. The four corners of the bottom plate are provided with square slots and the insertion holes 17 are connected with the connecting member 3 or the connecting member 4, and the water-permeable hole 16 is arranged on the bottom plate to ensure the space transfer of the water body in the water storage module[8]. According to the above functional principle, the water storage module has a low engineering cost and is relatively simple to install, but the whole does not have water permeability. If installed in a large area, it is easy to block the rainwater by groundwater. The water storage facility is only suitable for small area paving and setting in local areas.

3.1.2 Open circular reservoir

The open reservoir body consists of two parts, the bottom of the pool and the wall of the pool. The circular pool structure is under good stress conditions, and the construction materials used in the case of the same water storage capacity are less economical and less investment.

3.1.3 Open rectangular reservoir

The pool composition, ancillary facilities, and wall structure of the rectangular reservoir are basically the same as those of the circular reservoir, except that the circle is changed to a rectangle according to the terrain. However, the structure of the rectangular reservoir is not subject to a circular reservoir, and the corner is a weak link, and it is necessary to take measures to prevent reinforcement. Open rectangular reservoirs and circular reservoirs are common reservoirs in urban water storage systems. Due to the structural characteristics of the reservoir, it is limited to installation on the ground, and due to the huge impact on the surrounding environment, the reservoir is limited to installation in special areas of the city.

3.1.4 Closed reservoir

The closed reservoir body is mostly located below the ground, which increases the anti-freeze and heat insulation effect. The thickness of the anti-freezing heat insulating layer should be determined according to the local climate and the maximum frozen soil depth to ensure that the pool water does not freeze and cause frost damage. The structure of the closed reservoir is more complicated and the investment is increased. The roof of the tank is mostly made of thin-shell concrete arch or rib arch to reduce the load and save investment[9]. Due to its structural characteristics, the reservoir can be installed under the ground to reduce the impact on the landscape system on the ground. However, due to its high engineering cost and its lack of water permeability, the reservoir is not suitable for large-scale laying.

3.2 Water retention design

The water retention design mainly includes the following contents:

3.2.1 Design the rain garden

If trees and shrubs are planted in urban parks, the roots of plants can play a certain role in water storage. In the process of designing the rain garden, the surface runoff can be appropriately reduced to conserve the groundwater resources. And give full play to the degradation ability and adsorption capacity of different plant roots, so as to ensure that the rainwater penetrates better into the soil layer to prevent the city from accumulating water in heavy rain.

3.2.2 Green roof design

In the city, the green roof can also fully apply the water storage capacity of the green space, thereby alleviating the problem of urban flooding caused by surface runoff and increasing the evaporation of rainwater, which can effectively improve the air quality of the city. For areas that are not suitable for building green roofs, roof rainwater can be directed to the reservoir on the ground.

3.2.3 Design of ecological detention areas

The ecological detention area is designed to store rainwater resources by means of diving and shovel. The rainwater infiltration rate is improved by means of ponds, rainwater wetlands and grassland ditch, and the effects of vegetation and soil are fully applied to reduce surface runoff and effectively prevent urban flooding problems[10].

In summary, this article will guide the construction concept of LID sponge city, use the technical method of smart city, introduce a new type of sponge city rainwater recycling system through TRIZ innovation methodology, and introduce a system suitable for this new rainwater reservoir design. Through intelligent management and control, the efficiency of rainwater recycling is effectively improved, and the situation in the city during heavy rains is reduced.

4 The application of TRIZ theory

The TRIZ theory was founded in 1946 by the former Soviet scientist Genrich S. Altshuller. After nearly 50 years of systematic research, the public relations team consisting of dozens of research institutions, universities and enterprises headed by Genrich S. Altshuller found a systematic and practical invention and innovation method extracted from 2.5 million high-level invention patents from all over the world[11]. TRIZ originated in Russian, referring to a systematic approach to solve knowledge-based, human-oriented invention problems. The method has eight rules and related tools, including 1) the S-curve evolution rule of the technical system; 2) the principle of improving the ideality; 3) the unbalanced evolution rule of the subsystem; 4) the evolution rule of dynamics and controllability; 5) The law of increasing integration and then simplifying; 6) the principle of coordinated evolution of subsystems; 7) the rule of application to the microscopic level and the addition of fields; 8) the evolutionary rule of reducing artificial intervention.

4.1 The ultimate ideal solution

The ultimate ideal solution is to set the ultimate ideal goal for the solution, and then explore the obstacles that may be encountered to reach the final goal. Then, by exploring the conditions and the rules needed to solve these obstacles, the best solution is finally obtained.

The ultimate ideal solution for this project is to design a low-cost rainwater recycling system suitable for urban construction at the present stage, which makes rainwater recycling more flexible and no longer limited by terrain. At the same time, the program also needs to systematically manage the rainwater recycling and utilization in various areas of the city, effectively solve the problem of urban flooding during heavy rains, and maximize the utilization rate of rainwater in all areas of the city.

In response to this ideal goal, the device solves the problems encountered in achieving the goal through the following aspects.

A. By improving the gutter, the impact of the basket material and the width of the sink is minimized to reduce the impact on the surrounding landscape, and the basket material is used to decorate the park grass while reducing its environmental and ecological impact. The effect of rain and sewage diversion is achieved by placing a rainwater collection channel above the sewer wellhead.

B. Through the structural design of the rainwater reservoir, the space utilization rate of the space under the grassland is increased, and the rainwater is not blocked by the groundwater supply. See the impact on the underground ecological space and reduce the construction cost of the storage tank in order to achieve a wide range of installations of water storage tanks and improve the overall water storage capacity of urban water storage facilities.

C. By connecting the system with the urban water body, the rainwater that exceeds the urban water storage capacity during the rainy season is discharged into the urban water body, and the influence of the device on the use of the rainy season and the dry season due to the rainfall is minimized.

D. Through the intelligent hardware system and the large database system, the rainwater wells in each area of the city are connected, and the rainwater in the areas with more rainwater is transported to the areas with less rainwater through the rainwater pipelines, thereby realizing the macro-control of rainwater.

4.2 Nine screen analysis

The nine-screen analysis model is to systematically analyze the past, present and future of the device itself and its subsystems and super-systems to grasp the objective law of system evolution and improvement and thus design a system of ideal solution. Through the nine-screen analysis of the traditional sponge city construction system, subsystems and super system, it is found that the construction of China’s sponge city is systematically carried out from the traditional centralized rainwater recycling mode for a single region to each region of the city under the LID model. The evolution of the rainwater recycling model is to achieve the future ideal sponge city construction model to expand the scale of rainwater recycling and the ability to cope with urban floods during heavy rains by establishing a system of rainwater recycling networks in each region of the city.

4.3 Object-field model analysis

The object-field model is to study the unfavorable external conditions that affect the system itself to achieve the ultimate ideal goal by studying the relationship between the device system itself and the surrounding environment. Then, by studying and solving these unfavorable conditions, the final ideal solution is generated.

Because the underground rainwater wells in various areas of the city in the initial system are independent of each other, there is no connection, resulting in the accumulation of rainwater in the lower-lying areas of the city after the heavy rains, forming urban shackles and seriously hampering urban traffic. Through the object field analysis, the main way to solve the current problem is found by introducing the intelligent hardware system; the rainwater wells in each area of the city are connected in parallel. Under the control of the central processor, rainwater from areas with more rain in the city will be pumped to areas with less rainwater to achieve uniform distribution of rainwater and reduce waste of rainwater resources. In Summary, through the nine-screen analysis model and the object-field analysis model for the device system, the final ideal solution is to establish a urban rainwater recycling network through the intelligent hardware system under the LID low-impact development mode, and the urban rainwater recycling is intelligently controlled and utilized.

5 Design of ideal sponge city rainwater recycling system

5.1 Rainwater sump setting

Rainwater and sewage diversion is achieved by placing a rainwater sump between the road and the sewer wellhead. Most of the rainwater on the urban roads is collected into the rainwater sump to improve the recycling and utilization of rainwater.

5.2 Setting of underground rainwater wells

As shown in Figure 2, the system reduces the energy consumption during rainwater recycling and utilization, and adopts the form of mining and use, that is, the rainwater collected in each area and the greening irrigation used in the area. Therefore, it is necessary to set up a rainwater storage area below each area of the city. The water storage area is formed by several water storage tanks connected in parallel through the rainwater pipeline. The number of rainwater wells in each area is set by investigating the rainfall of the city. The quantity is proportional to the area of the roads collected. The rainwater wells adopt the tip-cone structure to timely discharge the rainwater that seeps up and down from the ground. At the same time, the rainwater wells are connected in parallel through pipelines, which can flexibly control the amount of rainwater recycled in each area of the city while minimizing the cost of construction.

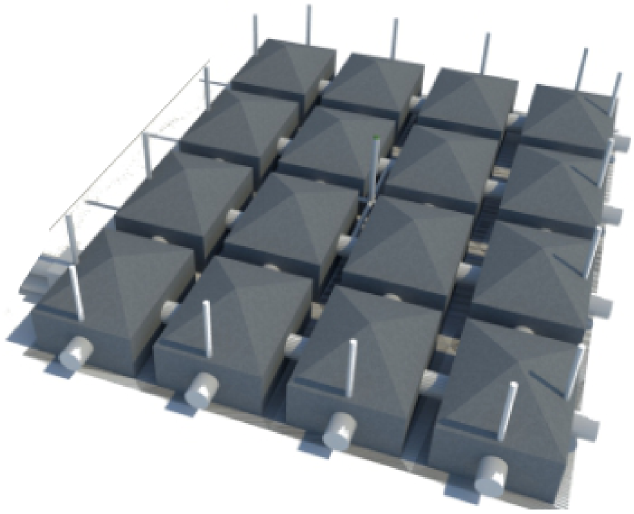

Figure 2. Cone top parallel water storage tanks

5.3 Intelligent hardware system settings

As shown in Figure 3, smart cities lead the transformation of urban development with information innovation, comprehensively promote the integration and innovation of the new generation of information and communication technologies and urban development, improve the modernization level of urban governance capabilities, and realize new models, new ways and new forms of urban sustainable development[12]. By introducing relevant technical means of smart cities, the program realizes intelligent control and regulation of urban rainwater division, thereby improving the overall rainwater recycling efficiency of the city.

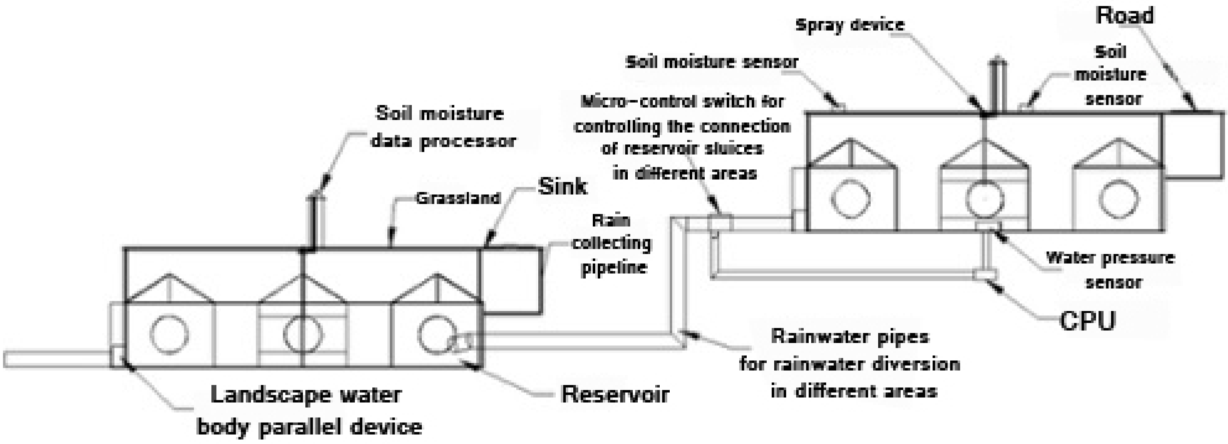

Figure 3. Section of the device system

5.3.1 Hardware settings for regional irrigation systems

The underground reservoir in each area of the city is connected to the green irrigation device in the area. The soil moisture sensor is placed in the regional green grass to detect the humidity data in the soil on sunny days, and the spray device is activated when the plants need green irrigation in the area to prevent waste of water due to over-irrigation.

5.3.2 Hardware settings of urban overall district control system

Water pressure sensors are installed in the underground rainwater reservoirs in each area. During heavy rain, rainwater recycling system in each area transmits its sensor data to the urban rainwater recycling central processor, and the central processor performs analysis of rainfall data on different areas. After the analysis, the pumping device is activated by controlling the micro-control switch on the rainwater pipeline connecting the various areas, and the rainwater in the area with a large amount of water is pumped to the area with less water, thereby achieving the macro-control of urban rainwater.

5.4 The central processor settings

5.4.1 Setting the right to allocate rainwater in rainwater wells in different areas

A. The topography of the city is uneven: the urban rainwater control central processor processes the data from the rainwater recycling system in different areas of the city, and then the rainwater in areas with heavy rainfall is transferred to the area where the rainfall is less. When the rainfall reaches the upper limit of the reservoir, the rainwater in the area where the reservoir is full is pumped to the reservoir in the area closest to it.

B. The city is affected by the terrain and the high-lying and low-lying areas are concentrated: in this case, the urban rainwater is more likely to be concentrated in a large area, causing the reservoirs of multiple adjacent areas to be in full water at the same time. By controlling the rainwater in the outermost area of the area to be transferred to the area with less rainfall, the rainwater in the inner area is transported from the inside to the outside to form a “rainwater corridor”.

5.4.2 Data setting for rainwater utilization in single area irrigation system settings

As shown in Figure 4, the grassland irrigation system in each area needs to store the soil moisture range of the urban green plant growth in the area. The soil moisture data is collected by the soil moisture sensor and uploaded to the soil moisture data processor in the area, and the processor controls the spraying device to irrigate the greener grassland by processing the data.

6 Conclusion

The program aims to create an intelligent urban rainwater utilization system, and use intelligent hardware systems to monitor important system information such as water quality, flow rate, liquid level, etc., to remove blind spots in the traditional rainwater recycling process, and to achieve high efficiency of rainwater recycling, while passing through the central processor’s big data analysis and other processing methods will control the rainwater in different areas of the city to solve the problem of urban flooding after the rainstorm, and minimize the power consumption of rainwater utilization. Explore the road for future sponge city construction and smart city management by comparing the cost with the traditional rainwater recycling process, the system can reduce the

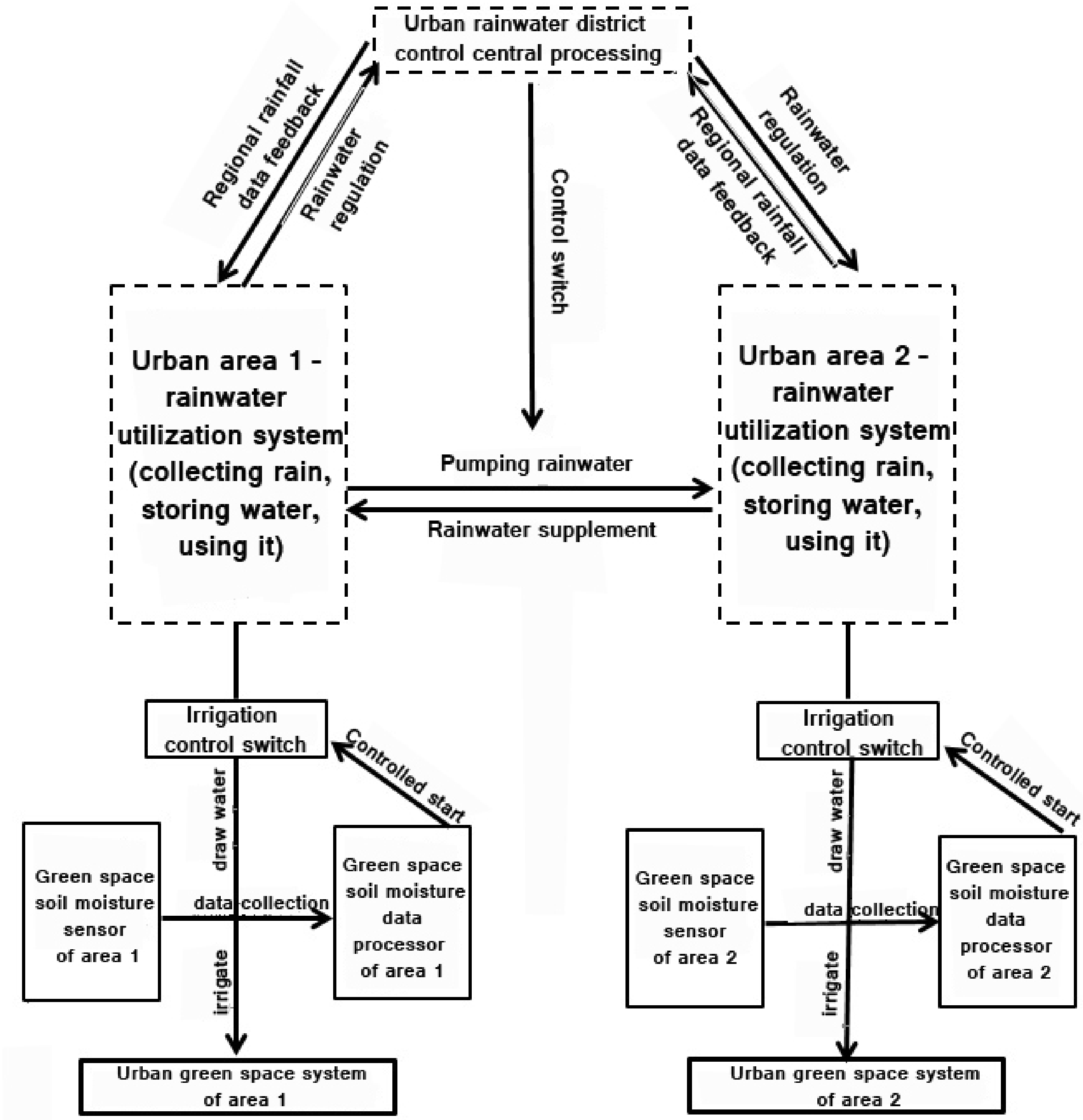

Figure 4. Functional block diagram of urban rainwater district control system

engineering cost by about 30%.

References

[1] Wang H. China's water resources issue and its scientific response, report of the 13th Congress of China Association for Science and Technology [EB/OL]. 2011-09-21.

[2] Qiu BX. The Connotation, Ways and Prospects of Sponge City (LID)[J]. Modern City, 2015, 10(04):1–6.

[3] Meng HR, Chen LH. Experimental Research on Improving the Performance of Pervious Concrete[J]. Journal of Shaanxi University of Technology(Natural Science Edition), 2010, 26(1):32–5, 53.

[4] Xu L. Application research of German sponge city technology in Hangzhou district[J]. New building materials, 2018, 45(11):116–8, 122.

[5] JIANG Zhengwu, SUN Zhenping, WANG Peiming. Effects of Several Factors on the Performance of Porous Pervious Concrete[J]. Journal of Building Materials, 2005(5):513–9.

[6] Yu KJ, Zhang D, Li XH, et al. Life Cell, Landscape Pattern and Innovation Network - Zhongguancun Life Science Park Planning[J]. Urban Planning, 2001, 25(5):76–80.

[7] Yu KJ, Shi C, Wen HJ. Sampling Tianjin: Bridge Park Design Plan[J]. Journal of Architecture, 2006(5):80–1.

[8] Li QL, Li Y. Design of modular water storage device based on rainwater harvesting and utilization[J]. Southern Agricultural Machinery, 2019, 50(09):129.

[9] Yang Y. Application of Sponge City Concept in Municipal Drainage Design[J]. Modern Trade and Industry, 2017(15):25–6.

[10] Wang C. Overview of urban water storage system[J]. Jiangxi Building Materials, 2016(11):24, 29.

[11] Wu CX, Xu J, Hu X, Pan JY. Analysis of the application of TRIZ theory in patents[J].Zhejiang Metallurgy, 2017(03):4–8.

[12] Hao LJ, Liu DZ. Research on the technical outline of the construction of smart city time and space big data cloud platform [J/OL]. Geospatial information, 2019(06):33–5, 5.