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Discussion of application of low impact development technology in the construction of sponge city in China

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ABSTRACT

Low impact development (LID) technology has become a crucial urban design tool in Europe and North America. In China, although LID is still a new technology to them, the Chinese government is charmed by this technology, and they have come up with the policy that builds sponge city through the LID technology. The goal of "Sponge City" is to achieve efficient stormwater management and wastewater treatments. This paper discusses this stormwater management and wastewater treatments, as well as their evaluation, through various case studies. Recommendations will be provided for the researchers and professionals based on the discussion of these cases.

Keywords: Low Impact Development, Sponge cities, Stormwater Management

1. Introduction

Preservation of the natural water balance, after years of national and international programs, is commonly agreed by all countries. However, this principle in cities has not sufficiently been followed, even though techniques for balancing the water cycle in urban areas have been available for a long time. The main reasons for this are the following: economic goals are always given priority in city planning and not controlling regulations for stormwater management and wastewater treatment sufficiently. It is necessary to establish a new storm management system that can address both urban flooding and water shortages. The concept of a Sponge City was developed within this context.

The Sponge City context emphasizes combining natural and constructed methods of stormwater management that will collect, store, and filter rainwater in urban areas, in order to promote rainwater conservation. The Sponge City construction process protects existing urban ecosystems and water sensitive areas while restoring polluted water bodies and integrating low impact development (LID) tools into urban design. LID aims to maintain and restore hydrological conditions to predevelopment levels by using distributed, small-scale source-control facilities. This is done by reducing runoff, by increasing storage and infiltration, LID facilities can reduce runoff by 30%–90% during a peak flow of 5–40 min and eliminate runoff pollutants by 80%–90% [1]. The most common LID design methods include pervious pavements, rain gardens, natural drainage systems, ecological planters, sunken green spaces, and green roofs.

LID technology has currently adapted to the construction of sponge city. With the acceleration of the urbanization process, then it begins to highlight the problem of backward management, including poor urban stormwater management waterlogging caused by non-point source water pollution. A series of structural problems have seriously affected the operational and environmental quality of urban safety [2].

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Given the above, in October 2013 the State Council issued the "urban drainage and wastewater treatment," which state that "the preparation of urban waterlogging prevention special plan to make full use of natural ecosystems, improve stormwater infiltration, and emissions regulation and storage capacity," Furthermore, "new renovation and expansion of municipal infrastructure projects should be supporting the construction of rainwater harvesting facilities, reduce stormwater runoff, improve urban waterlogging control capacity," "clearly the concept of low-impact development is facilitated to people who manage urban stormwater" [3,4].

In December 2013, the president of China, Xi Jinping put forward the "Sponge City" concept in the central working conference on urbanization. In October 2014, the State Department of Housing released the "SpongeBob urban construction technical guide—LID stormwater system construction (Trial)" which was officially classified as low-impact development and implementation of guidelines path sponge urban construction. In December 2014, the Ministry of Finance, the Ministry of Housing, Ministry of Water Resources, and other ministries jointly issued a document to declare sponge pilot urban construction in the country, and more than 130 cities participated in the competition. In April 2015, 16 cities were selected on the final list of the first batch of-pilot cities to construct sponge. Afterward, the construction of sponge cities has rapidly developed under the guidance of LID Technology in China [5–7].

More importantly, regulations in most Chinese cities request to retain storm runoff as much as possible, that is, for direct use or for recharging groundwater for subsequent water supply, acknowledging that underground soils have enormous storage capacity. If not all stormwater can be retained, a runoff shall be detained by further ponding, maximizing evaporation and facilitating infiltration into the ground, thus lowering peak runoff rates and volume (Fig. 1) [8]. However, rainwater harvesting plays diverse roles under different climates, various types of urban development, topography, and soil, as well as existing drainage systems.

This paper will investigate the effects of Sponge City and LID technology in terms of engineering for sustainability. Case studies illustrate the procedures of LID Technology, and also tests the impacts and the results of the constructions of Sponge City.

2. Different types of lid technology in the application of Sponge City

2.1. The usage of non-conventional water

Groundwater and water resources allocation aims to strengthen rainwater reuse [9]. As the core infrastructure, rainwater storage providing a good environment for the city district, with combined central pergola rainwater storage hub construction to increase the water and wetlands rainwater reservoir space, the role of regulation and storage of rainwater runoff pergola produced annually by the city can be cut in half.

2.2. Green roof technology

Green roof is a kind of runoff control, which by be defined as "an engineered roofing system that allows for the propagation of rooftop vegetation and the retention of stormwater while maintaining the integrity of the underlying roof structure and membrane" [10].

With this technology, the roof itself is designed to mimic the previously permeable environment, using alternative roofing design and materials.

2.3. Stormwater runoff process of management

Rainwater runoff should be under a variety of measures, the accumulator that is full use of green space, parks, water, construction of rainwater storage tanks, peak flow regulation, and storage to collect rainwater storage lag; bleeding that is given to priority sunken green, permeable formula new ground to increase the proportion of land surface area permeable-hat is, net of construction of artificial wetland drainage port area, the use of small decentralized control measures purify rainwater, reduce non-point source pollution; defecation combine urban renewal, improve network standards [11]. Rainwater drainage system planning and

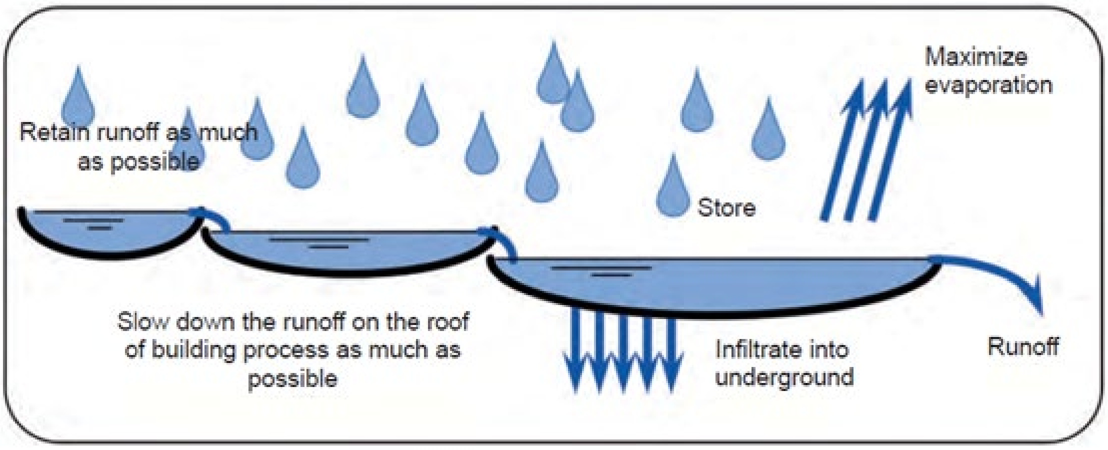

Fig. 1. Urban stormwater management principles.

urban waterlogging prevention planning belong to the construction of the LID plan.

2.4. Water reclamation

Reclaimed water is the water that has been treated in sewage or greywater treatment systems; effective treatment methods are now available such that the treated water can be "reclaimed" or reused safety to meet a variety of community water resources demands [12–14]. The reuse of reclaimed water can be an effective component of a community strategy to become more sustainable. In some applications, using reclaimed water can reduce water consumption and outflow by more than 90% (35% overall) compared to conventional water sewage system-reducing freshwater use and reducing impacts on the environment from waste outflows [15–17].

3. Evaluation of low impact development technology in the construction of Sponge City

3.1. Considerations

Significant considerations for the evaluation of various types of LID technology include, but are not limited to:

- *Rainwater utilization*: This paper will imply how efficient rainwater utilization is done through some types of LID technology.
- *Cost*: Include the direct cost for materials and equipment for applying LID technology and also indirect costs for human capital and maintenance.
- *Limitation*: Obviously, the difficulties in the execution of LID in Sponge City are not the same, and the limitations can vary from case to case.
- *Improvement*: Seeking the improvement of LID Technology in projects through the analysis of problems.

Methods of evaluating these qualitative and quantitative considerations will now be discussed.

3.2. Methods of evaluation

The projects of LID Technology can be evaluated by economic growth, social benefit, and environmental protection. Besides, stakeholder engagement is also a good measurement, because the good involvement of shareholders can lead to better engineering design and better engineering project implementation.

A case study that reveals different facilities of LID will be investigated in the first case study.

Stakeholder engagement is significant in the development of community projects. An example of this will be shown in the second case study.

4. Case studies

4.1. Case study 1–LID facilities at the civil and structural engineering buildings at Shenzhen University

The LID facilities at the civil and structural engineering buildings of Shenzhen University include 2,000 m^2 of green roof and surface LID facilities covering an area of 907 m^2. A 25 y storm with a daily rainfall of 387 mm was the design standard. The LID facilities and landscape were designed by the Architectural Design and Research Institute of Shenzhen University and was constructed by Shenzhen LWL landscape engineering. ETICE supervised design and construction and was responsible for monitoring and measuring LID performance. Construction began in July 2012 and was completed in April 2013 [18].

The new buildings consisted of a structure and experiment hall in the west, north, central, and south buildings, and a landscaped courtyard in the center (as shown in Fig. 2). A 25 cm green roof was constructed on the south and central buildings. The eco-roofs were planted with drought-tolerant vegetation, a medium growth soil layer, a root resistant gravel layer, and a waterproof layer. Outlet controls were set in all the eco-roofs to enhance stormwater management, increase evapotranspiration, and facilitate nitrogen retention. The growth medium is a mix of sand, rare earth lanthanum slag, recycled water factory sediment, and shredded coconut fibers for water retention. The installed eco-roofs need little irrigation, fertilization, or maintenance, and it is estimated that they can reduce storm runoff by 30%–50% during a peak flow of 20 min while meeting a Surface Water Environment Quality Standard of grade II. A simple eco-roof of the structure experimental hall was constructed by using pervious bricks made of recycled construction waste because of the poor waterproofing conditions on the existing roof [18].

The LID facilities in the central courtyard make up a natural drainage system consisting of pervious pavements, bio-retention cells, cisterns, natural drainage system rain gardens, and detention ponds. The courtyard sidewalks are paved with pervious bricks made of construction waste layered with a gravel drainage layer with perforated pipes. Three bio-retention cells can treat runoff from the north building and toilets from the south building. Additionally, 2 m^3 cisterns were installed at the south side of the bio-retention cells. Water flowing out of the bio-retention cells could be carried to the rain garden by the natural drainage system. The rain garden is planted with *Thalia dealbata*, *Phragmites australis*, and *Cyperus alternifolius* to help further purify the water. Purified water can then be transferred to a detention pond via the perforated pipes at the gravel layer and stored for landscape irrigation [18].

Since the completion of the new LID facilities, the building has experienced several large storm events including a torrential, 50 y storm on May 11, 2014, when 430 mm of rain fell over a 12 h period. The Shenzhen University campus suffered extreme flooding in some places. There was no waterlogging around the Civil and structural engineering buildings due to the LID improvements. Monitored data shows that the surface LID facilities have larger detention capabilities than that of the eco-roofs [1].

The lessons learned from the project can be summarized into three main points. First, the construction lacked technical expertise because the builders were not completely proficient with LID techniques and materials performance. The result was a decrease in product quality. It is necessary to have builders with LID knowledge. Second, because LID construction is relatively unpracticed in China, it is difficult

Fig. 2. The LID facilities in the central yard of Civil Engineering Structural Buildings at Shenzhen University.

to find appropriate construction materials. This proved to be an opportunity for innovation and we used recycled sediment as a growth medium and made previous bricks from construction waste. Third, the project provided an opportunity for teaching experiments, educational demonstrations, and environmental improvement, which brought gratifying and far-reaching social benefits.

4.2. Case study 2–Community projects in Fengxi New Town–rain gardens and ecological filter ditch

4.2.1. Rain gardens

Rain gardens and natural landscape construction combined with the use of a large number of decentralized stormwater treatment unit, through physical filler filtration, chemical adsorption, biological effects, and plant uptake and utilization at the source control storm runoff and pollution, in order to purify the city water, reduce flood peak, recharge groundwater, and alleviate urban waterlogging target [19,20]. Feng Xi's Government and Universities jointly launched a Feng xi rainwater purification and utilization of technology research and demonstration projects. By Tongde Jiayuan Community rain gardens, ecological filter ditch water quality, and quantity and other indicators to monitor—obtained from soil and rainfall data, provide a scientific basis for the practice of rainwater utilization [21].

Test rain gardens run to the end of 2014, 23 rainfalls during the period were completely monitored, only three games short of rainfall occurs overflow monitoring period. More than 95% after 4 m of stormwater runoff from the start in early 2012 loess recharge underground infiltration of rainwater runoff occurs in a thick layer of less precipitation, soil adsorption, absorption by plant roots, nitrification, and denitrification microorganisms of various pollutants in stormwater runoff purification, and decontamination good effect. Due to the relatively low levels of pollutants, each roof rainwater through rainwater treated reaches back to the irrigation water quality standards, will not cause groundwater pollution, and it is possible that the infiltration recharge to the underground stormwater runoff treatment rate of 100% [19].

Roof drainage passage residential area residential building directly to the ground through rain gardens, set in a landscape with a lot of aquatic vegetation, mainly to collect, clean, replenish groundwater infiltration mainly as roof, floors, and rain all together absorbed by plants and soil purification and rainwater into the ground. Surplus rainwater that overflows in a sunken plaza landscape can form bodies of water or a collection tank to purify a stagnant reservoir. Combined with the overall design of outdoor cells, by collecting, purifying, stagnant green water reservoir to supplement, thereby forming landscape water to improve the local climate and other ways to achieve effective stormwater management.

4.2.2. Ecological filter ditch

Biological ditch as a biological retention system which is simple and efficient, low cost, is widely used in urban areas, stormwater runoff source control management. Based on previous work and technical LID basis, Xi designed an urban stormwater runoff pollution control and used a combination of the biological ditch—ditch ecological filter (also known as bio-retention zone), located mainly in the district both sides of the main road, the depth were: aquifer, planting soil, filler layer, and gravel layer [22–24].

Ecological filter test using artificial ditch water distribution, water distribution main road in Xi'an rainwater quality can be configured according to the Chicago rain design rainfall that simulated rainfall and investigated influent water (simulated runoff), water quality, eco-interval filter, and output ditch effect. Tests showed that six ecological filter ditches in 0.5 y return period without flooding phenomenon, in the next 2 y return period, is only a short-term filter ditch overflow, overflow filter appears under the 5 y return period ditch increased significantly, but the overflow volume is small, while the maximum overflow flow rate of about 4% [25]. Ecological ditch on each filter TP, ammonia, DP, Zn, and other indicators purifying effect is more stable [26–28].

This fusion of the whole situation layout low-impact development techniques can only be possible in the construction of the new city fully implemented, so in the future construction of urbanization, we should vigorously promote the development and application of LID construction mode and, eco-cities, Wise urban planning, the construction of green buildings and the inclusion of drainage waterlogging sponge urban construction requirements and local conditions to carry out new city rainwater utilization system so close before hydrological characteristics of urban construction and development.

5. Implementation issues and recommendations

Important issues are discussed in the case studies of additional literature. In addition, technical issues, political issues, and institutional issues play an important role in the development of LID technology [29,30]. Therefore, the principle for low-impact development stormwater management are explicitly written into the "People's Republic of China Water Law." Furthermore, it should strengthen the field of technical specifications and relevant industry standards coordination and matching. For example, urban planning relevant norms and standards should be developed to increase the impact of low runoff control requirements.

LID and Sponge City designs have tremendous potentials. However, in cases of extreme events, which largely exceed normal storm conditions, the connection between the urban stormwater system and major natural rivers and lakes must be secured. Usually, storm drainage systems exist, and LID designs only can be done in case of new or re-developments. So their effect only shows after years of further urban development. The idea of LID sometimes is extremely difficult to be realized under local constraints [31–35].

Urban planners need knowledge equally in landscape planning and hydrology, especially to account for the local specific soil and climate conditions and to include climate change effects into their design. They should be qualified to calibrate and run simulation tools that allow them to test the effectiveness of their design. For any concept it seems advisable to choose resilient design options. Furthermore, in early planning stages, attention must be paid to material choices, the potential integration into the urban environment, available construction qualifications and maintenance needs and costs.

To guarantee the smooth implementation of low-impact development in China, these must be changed as soon as possible of the current low-impact development: the development of incentives to break trade barriers, the establishment of coordination of interests: relief ways to encourage enterprises and social institutions: public participation in the development of low-impact and other aspects of efforts to establish and improve various aspects of supporting policy development to create a good institutional environment for low-impact.

For urban planning, relevant norms and standards should be developed to increase the impact of low runoff control requirements. Water planning standards and specifications should be added to the receiving water body and the development of low-impact facilities cohesion. Low-impact development involves many aspects of regional development, as well as a comprehensive engineering system: therefore, the responsibility of the unit in terms of the overall work of the local government level should undertake the development of the region in order to avoid various functional departments buck-passing phenomenon.

Low-impact development goals and targets need to break down to various special plans to achieve the planning harmonization. In the design and construction phase, construction management units should be (typically Construction Bureau) as the lead unit, roads, green spaces, water, drainage systems, and other projects as a unit with the unit, this is done to ensure that all construction projects designed to follow the overall development of low-impact and special planning, as well as to ensure that all construction projects meet the relevant technical specifications and quality control requirements. In the design and construction area, this will be accomplished to speed up the implementation of planned supervision, to ensure that project design meets the planning requirements for the development of low-impact. The establishment of direct low-impact development projects through the national science and technology sector, this will be done to encourage universities, research institutions, and science and technology enterprises to participate in project development. In addition to direct excitation of the last stage, but more important is to do an indirect incentive to create good long-term, low-impact development for the technological innovation environment. By strongly promoting the development of low-impact expanding market demand, this will stimulate technological innovation.

6. Conclusion

The applied LID Technology in the constructions of Sponge City can bring economic growth, social benefit, and environmental protection in China. Further LID research is required to establish guidelines for engineers who are designing and implementing the Sponge City projects. Effective and functioning LID and Sponge City designs need knowledgeable and experienced planning; much more than conventional drainage designs do. However, the major obstacle for planning can be seen in inadequate regulations and control. Therefore, it is important to communicate with local government departments and local people to have facilities in local stakeholder engagement in the construction of Sponge City in the different regions of China.

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