Research on Green Infrastructure of Sustainable Built Environment

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Abstract. Over the past few decades, the phenomenon of climate change has raised a global concern. The majority tend to see urbanization as a primary cause for it. Due to the vegetated surfaces decrease continually with the hard surface expanding such as pavement and concrete rooftops, the problems of heat island effect and increased surface runoff have become increasing serious. In order to mitigate these climatic issues, the green infrastructure should play a constructive role becomes as it provides essential services for communities. This network connecting with nature is able to deal with the climatic and urban challenges we facing today. This paper will explore the important role that the green infrastructure can play in sustainable built environment. The green infrastructure management as a strategy to alleviate the issues caused by urbanization will be discussed. The case in Seattle will be analyzed and evaluated because this city is one of the pioneers in the GI field. Some recommendation and conclusion will be given at the end.

Keywords: Green Infrastructure; Sustainable Built Environment; Seattle.

1. Introduction

The percentage of global urban population has reached 47% in the early 21st century, it is predicted to reach 60% in 2025 (Zhang, 2008). Facing with the increasing and continuing expansion of the urban population and density, expanding the scale of infrastructure and using the traditional method of technology is difficult to meet the demand. Moreover, these conventional approaches will result in a larger scale of destruction on the ecosystem, leading people to seek the best planning method and construction technology. Green infrastructure (GI) came into being in this context.

GI refers to a new open space planning and land conservation strategy in recent years, the green space network and its continuous vegetation are emphasized (Benedict and McMahon, 2006). This concept is based on ecological theory, comparing with the 'gray infrastructure' (such as roads, municipal sewer network and other municipal support system) and social infrastructure (such as hospitals, schools, etc.), GI creates a green network that includes urban open space, forests, wildlife, parks and other natural areas, which can be seen as another necessary infrastructure that supports urban and community development. Reasonable planning and construction of green infrastructure can effectively reduce the dependency for gray infrastructure, saving input from public resources, decreasing the possibility of natural disasters. Furthermore, maintaining the operation of ecosystem with GI is very important for the reason that there is a very close relationship with the urban ecosystem and human health.

The theory of GI comes from two aspects: one is the maintenance of a variety of connected green space systems; the other is the habitat conservation network for the protection of biodiversity and species. The GI construction is supposed to make full use of natural condition without changing the existing environment. The green area of the city is a real biological system, which means that the elements of green infrastructure only include green area, not including other open spaces, such as hard pavement and square. In addition to the traditional green system, using artificial wetland to collect and purify mountain water in order to supply the city water usage is another important part of GI network. Because this system guarantees the operation of ecological processes, providing high-quality living environment for the residents of city and community.

2. Background

The climatic issues and urban challenges in modern cites are most related to the urban thermal environment and urban water environment, such as urban heat island effect and increased surface runoff. In order to migrate these problems, the GI has great potential to play a key role in these fields.

Urban thermal environment is an important part of the urban ecological environment. In recent years, the issues of heat island effects have become increasingly prominent. The main reason relates to the sustained, rapid urbanization and urban sprawl, leading to an increase in the building density and a larger proportion of urban impervious surface (Rizwan et al., 2008). The urban heat island effects will bring a series of climatic issues such extreme summer heat and retention of poisonous exhaust, which leads to multiple urban diseases that increasingly threaten public health. At the same time, bad urban thermal environment results in an increase in summer cooling demand and energy consumption. Therefore, the loss of a huge amount of natural resources raise a concern for city water and electricity supply. Recognizing urban thermal environment as a significant part in urban environment and take mitigation measures are necessary to create a low-carbon city with harmonious development. The quality of urban thermal environment is effected by many factors such as urban surface structure, geographical location and other climatic conditions. However, the changes in the structure of urban underlying surface and anthropogenic heat emissions are the primary causes of the urban heat island effects. Therefore, parks, water area, ecological corridor and other green infrastructure is an important guarantee for urban livable environment system. The reasonable arrangements for green infrastructure and other land sources have a great significance for mediation of urban thermal environment and reduction of energy consumption.

The water resources also have a significant ecological impact. At present, at least 40% of the urban area is made up by non-permeate surface, including roads, parking lots and buildings, etc. These non-permeate surface greatly influences the water cycle in nature environment. The traditional gray infrastructure makes it hard for rainwater permeate into the surface, forming a much higher storm water runoff, leading to more serious urban waterlogging issue (Gill et al., 2007). The rainwater cannot permeate into the ground, increasing the likelihood of flooding, reducing the self-purification ability of natural groundwater system. Meanwhile, the increased surface runoff brings a lot of pollutants into the city, this input of some chemicals, sediment and concentrated urban sewage not only reduce the water quality, but also deteriorates the ecological balance in a small area, such as water eutrophication. Discharging the urban stormwater by conventional drainage system would seriously affect the hydrological cycle of urban water environment and groundwater, as well as endangering the ecosystem. Therefore, GI will be an effective method to manage urban stormwater through a series of green stormwater facilities to cut down the emission of pollutants. Moreover, GI is able promote the natural water cycle and provide a landscape function in the meantime.

3. Theoretical Basis of GI

3.1 Definition and Development

The first definition of the GI appeared in August 1999. Under the organization of the Conservation Fund and the USDA Forest Service, the government and experts established the Green Infrastructure Work Group to help communities promote GI development in local, regional and state government programs and policies. The group defined the GI as a "nation's natural life support system", an interconnected network of natural areas and other open spaces to preserve the values and functions of ecosystems, maintaining clean air and water, providing a wide range of benefits for human and wildlife (Benedict & McMahon, 2012).

From the mid-1990s, the United States began to implement GI research and practice. Compared to other concepts of sustainable development, such as ecological city and green city, the research of GI focused directly on the specific problems of the sites, as well as the actual demands of different construction projects. Therefore, in western countries, more and more departments devote themselves

to GI research and practice, contributing to achieve a higher level sustainability in cites. In the United States, Maryland is the first state to start the GI research, followed by Florida. The Maryland model is a typical case all around the world, its "Hubs-Links" natural system has been promoted by the Conservation Fund as a large-scale planning strategy that imitated by other states (Weber et al., 2006).

3.2 Elements of a Green Infrastructure System

The GI consists mainly of hubs, links and sites (Williamson, 2003), there may also be different levels of external buffer. GI is not all about green space, other natural environment such as rivers, snow-capped mountains and desert also contribute to the construction of GI system.

3.2.1 Hubs

Hub refers to a large natural area, which is less affected by the external interference, providing natural habitat for wildlife and plants. Its shape and scale will be different, including: (1) Large-scale ecological conservation area, such as national parks and habitat; (2) Large-scale public land, such as national forest with both the natural and recreational value; (3) Farmland, including farms, woodlands and pastures; (4) Parks and open spaces, including parks, natural areas, playgrounds and golf courses, etc .; (5) Recycling land, the public or private lands that have been excessive used and damaged which can be re-repair or reclamation, such as mine and landfill.

3.2.2 Links

Links can be described as linear ecological corridors that connect the hubs and the sites to form a complete GI system, which play a key role in promoting the operation of ecological processes and maintaining biodiversity and ecosystems. The links include: (1) Landscape corridor, an open space that connects wildlife habits, parks and agricultural land, providing growing and developing areas for local flora and fauna. In addition to the protection of local ecological environment, these links may also offer leisure opportunities for communities to improve their comfortability; (2) Protection corridor, providing channel and some necessary services for the wildlife, such as rivers and riverbank. (3) Greenbelt, protecting natural landscapes while preserving local farms or pastures by separating neighboring lands, such as farmland protection areas.

3.2.3 Sites

Sites are smaller than the hubs, they are ecological nodes for animal migration or human recreation where the hubs or links cannot reach. They are a supplement to the hubs and links that made up of independent regional environment. Sites have both ecological and social value since that they also provide habitats for wildlife and recreational areas for human.

4. Practical Evaluation

In order to promote the extensive application of GI, the first is the construction of various site-scale practice. Based on ‘life support’ value of the ecosystem services, GI practices can be categorized into the following seven concepts and approaches:

(1) Bioretention Systems: bioretention systems can be used in small greening nodes, such as parking lots, residential areas, freeways and so on. It includes filter media and plants that help to improve the water quality, these media and plants can be used to protect the hydrological environment at the same time (Trowsdale & Simcock, 2011). They are basically in low-lying areas in landscape design for retention of contaminants. The basic function of the system is to control the runoff, focusing on the concentration and reduction of pollutants. In practice, bioretention systems are proved to have a significant effect on pollutant treatment.

(2) Constructed Wetlands: artificial constructed wetlands refer to artificial systems that composed of saturated substrates, plants, animals, and water, which imitate natural wetlands to meet human demands (Brix, 1997). Similar to natural wetland, constructed wetland is also a complex integrated system that can also provide multiple benefits. It can be seen as a cost-effective flood

protection measure, as well as providing a wildlife habitat. Moreover, it enhances the aesthetic value of the landscape and provides entertainment facilities.

(3) Stormwater Management: stormwater management is the approach to collect, concentrate and store rainwater from a natural or rainwater harvesting for human use. It can provide a regulatory function to balance the water storage by reserving or releasing according to the climatic condition.

(4) Permeable Paving: through the application of a series of technologies to reduce the impermeable paving, many urban problems caused by impermeable pavement can be prevented, such as water pollution and soil erosion caused by stormwater runoff, as well as urban heat island effect.

(5) Green Street: according to the practice in Portland, green street is the combination of permeable surface, trees and landscaping. Green streets are designed to reduce stormwater runoff and water pollution, as well as mitigating air pollution from vehicle exhaust by incorporating natural environment into the streets.

(6) Green Roofs and Green Walls: green roofs use the roof-covered vegetation to replace the traditional concrete roof. The primary purpose is to reduce stormwater runoff. Another important function of green roof is the mitigation of the urban heat island effect, its cooling effect can lower the risk of urban pollution generated by extreme temperature (Zinzi & Agnoli, 2012). Green wall is a kind of building structure consists of vertical vegetation. The plants will grow on the support structure attached to external building walls. It provides cooling for the buildings by the effects of shading and evapotranspiration, as well as reflecting solar radiation.

(7) Urban Parks: the benefits of urban parks have been quantified, according to Bowler et al. (2010), temperatures in urban parks can be around 10 °C lower than in areas that are not greening. In addition, other advantages include reducing energy consumption and carbon emissions, improving air quality, deterring heavy rain and preventing health damage from extreme heat.

5. Case Study

In 1903, Seattle started to develop an open space system that contains a series of interconnected park and boulevard, which was the initial framework for Seattle's GI system. This framework has a population capacity of 500,000. However, at the beginning of the 21st century, the population in Seattle has been growing beyond 500,000. Moreover, with the issues of global climate change, energy scarcity and environmental pollution, it is necessary to explore the existing GI system to achieve multiple functions and enhance the livability of the city (Rottle, 2006). In February 2006, led by the Department of Landscape Architecture and the Green Futures Lab in the University of Washington, more than 400 professors and students, government officials, environmentalists, artists, landscape architects and related professionals put forward the idea of a new urban green framework in Seattle (Department of Landscape Architecture, 2007). This collaborative planning and design seminar for Seattle's green future, raising the awareness of the public government to contribute to GI construction and stimulating them to participate in the full implementation of GI in Seattle.

The Seattle model is the development and innovation of the Maryland model. In fact, they are both a natural life support system and an important strategy for sustainable development. The difference is that the Maryland model is based on suburbs, but Seattle expend the regional scale to the urban scale. Focusing on urban structure and scope, Seattle explores the concepts of GI and seeks to optimise urban natural ecosystems as a method to create a livable sustainable city. Facing with more complex urban environment and living demands, the traditional Maryland 'Hubs – Links' model could not meet the current requirements (Wickham et al., 2010). In order to deal with this, the new GI system in Seattle continues the initial objective to satisfy human needs by interconnected green spaces, while also protecting and connecting natural areas for the needs of other creatures. Furthermore, it takes the city as the key point, and takes advantages of a series of urban ecological research achievements, such as urban stormwater management, urban low-impact traffic, urban forest and urban stream restoration. This more complex GI network provide a variety of services which located within the city scale, improving the quality of the natural life support system.

GI is attractive because it can benefit the human and natural systems, while providing a wide range of functions such as entertainment and recreation. But it is a challenge to integrate these services into clear structures and present them to the public. The GI research of the Seattle aims at high-density urban areas, the proposed adjustment of existing urban structures will be the most difficult part. How to create an urban GI system that encourages sustainable lifestyles, considering the existing structures of the city, and providing a life support system for human and other natural lives in the urban context? Liu et al. (2012) indicate that the Seattle model integrates new concepts and practices such as urban stormwater management, green streets, green roofs, green walls and urban agriculture with the existing open space system to create a 'five networks'. These five networks are the results of various research fields with multi-functional feature, which is separated from each other but essentially connected. These five systems --- open spaces/ low-impact transport/ water management/ biological habitats/ metabolism, are interconnected and highly integrated that also linked with greenways and parks in suburb areas. By implementing these, Seattle achieves the purpose of enhancing the sustainability and livability of the city.

The Seattle case not only connect and protect existing natural ecosystems by interconnected networks, but also take sustainable urban context into consideration. Seattle's open space network aims to interconnect existing parks; low-impact transport is achieved by integrating walkways and bikeways into open space systems, creating a low-impact traveling model; by simulating natural hydrological systems in urban water management, the reduction of pollution will be achieved; the recovery of habitats enhances urban biodiversity; and metabolism stands for urban agriculture and food production, which also can be seen as a system that taken into account (Rottle & Maryman, 2006). The most special distinction of the Seattle GI system is that it is based on the city, integrating research in various fields, providing a green framework for sustainable urban life.

The case in Seattle provides a set of effective methods for the highly artificial urban built-up area. This illustrates another perspective on what can be improved in such a basically completed city, leading to a move advanced livable and sustainable direction. The cooperative planning and design in Seattle GI construction encourages public, experts and government officials to participate in the planning and design of urban green open space, so that public opinion can be fully expressed which also makes it easy to reach a consensus by public education. This planning and design process are worth to be learned by other regions in order to promote the sustainable livable city.

6. Recommendation

Although GI research and practice has been promoted globally, there are some problems and challenges associated with the management performance of GI system in developing countries. According to Liu (2013), the problems are as following:

(1) In developing countries, the GI research and practice pay more attention to theoretical research but lack of practical research results.
(2) As a public service, the development and construction of GI should be led by the government. However, the participation of government management is not satisfactory, the lack of policy establishment, management methodology and evaluation system slow down the development of GI.
(3) From the perspective of planning, it fails to achieve multi-function. The planning department often make a decision without the public participation, thereby some of the specific aspects are often not considered, which leads to a situation that only find the problem after practice.
(4) In some developing countries, the more common situation is when the government facing with the choice that how to deal with the undeveloped green area, the government often choose to sacrifice green land to develop it into business land use or industry in order to obtain more economic benefits.

Some recommendations can be put forward by considering these situation, this will be focused on public cooperation and management system. In order to establish basic understanding and consensus

of GI, firstly, it is necessary to establish a more accurate understanding and consensus on the connotation, meaning and implementation of urban GI construction in the fields of theory and practice research, government management and the public participation. Secondly, establish a common platform for sharing ideas and information for different countries and regions, as well as for different sectors and disciplines. Thirdly, GI theory and technology content should be widely involved in different levels and different disciplines of the education system, and effective public education in this field should be promoted.

For GI management mechanism, an active green infrastructure development policy should be developed to attract non-governmental organizations and individuals to join in GI planning. Encouraging resource conservation and ecological restoration related enterprises that in favor of forests, water and vegetation by providing tax subsidies or technical support is an effective strategy. With the official recognition or other awards, the public will raise their environmental awareness and devote themselves to GI construction.

An authoritative and effective management mechanism should be carried out with the administration of GI, including a mandated regulatory body and a regulatory policy. The implementation of the GI system requires a long-term stable organization and long-term cooperation with government. Therefore, it is necessary to set up a special institution or authorize a government department to coordinate the relationship between state land and collectively-owned land, as well as coordinating the contradictions and interests of different departments. It is necessary to recognize that the GI construction is not highly relative to individual efforts, but must rely on government and regional cooperation. It is a long-term strategy that requires the whole society to reach a consensus and joint effort.

7. Conclusion

In conclusion, the GI provides a number of benefits for the city, the associated functions can be classified as ecological services and social public services.

The ecological services are the benefits people derive from ecosystems. Changes in these services affect human well-being, such as security, living, health, social and cultural relations, which in turn affect their freedom and choice. The function of ecological service of GI can be divided into provisioning services, supporting services, regulating services and cultural services.

The function of social public service contains multiple values that integrate a series of activities on the land and meet the various demands for the land use, which is a sustainable utilization approach for urban construction, including:

(1) eco-function: creation of biodiversity, energy conservation, carbon fixation and storage.
(2) healthy environment: comfortable microclimatic, water purification, air filtration, healthy food supply, removal of toxins and other functions.
(3) daily activities: recreational activities, public safety (eg, flood risk), community activities, and prevention of crime.
(4) economic value: increased values of commercial, housing and other properties, the promotion of economic development and so on.
(5) spiritual needs: aesthetic values of culture and cultural landscapes, as well as public education.

The urban GI system is an ecological network based on the needs of sustainable development from environmental, social and economic perspectives. As a nation's natural life support system, its significance comes from the protection and utilization of urban open spaces and natural resources. The establishment of a GI system creates a framework and a management theory to maintain the value and function of natural ecosystems, meeting the demand for human, wildlife and plants. It is a macroscopic method to help human achieve sustainable development, which can be seen as a long-term strategy for modern cites.

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