Summary of the Concept of Resilient Infrastructure and Its Research Progress

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Abstract. In recent years, the theory of resilient cities has provided a new research idea for solving urban crises. This paper takes urban infrastructure as the research object. Firstly, it sorts out the source and main characteristics of the resilient city. By summarizing the development history, research status and existing issues of urban infrastructure, the concept of resilient infrastructure is further clarified, and the resilient infrastructure is characterized by adaptability, network, natural connectivity, functional complexity and redundancy.

Introduction

Since the reform and opening up, Chinese economy has developed rapidly. However, the development of the city has led to a serious imbalance between people and nature, between people, and between spirit and material. Environmental degradation, traffic congestion, resource shortages and other issues are common occurrences, seriously weakening the normal function of urban systems. At the same time, the vulnerability of the supporting infrastructure as the basic "meridian skeleton" of the city is increasingly prominent. In recent years, the theory of "resilient city" has gradually come into people's vision and become one of the research hotspots in the field of planning and design, which undoubtedly provides new research ideas for the renewal and development of urban infrastructure. At present, scholars' researches on infrastructure only focus on the concepts of ecological infrastructure and landscape infrastructure, while the research on resilient infrastructure is still in its infancy and a mature theoretical system has not yet been formed. Therefore, based on the theory of "resilient city", this study attempts to find the relationship between "resilience theory" and urban infrastructure through the summarization and analysis of previous studies, so as to clearly define the concept of "resilient infrastructure" and provide references for further researches on resilient infrastructure in the future.

The Theory of Resilience and Resilience City

The Origin and Evolution of Resilience Concept

The term “resilient” is derived from the Latin “resilio” and was first used to represent the properties of springs and to describe the stability of materials and their ability to withstand external shocks. In the 1960s, Holling, a Canadian ecologist, first applied the idea of resilience to the field of systems ecology to define the characteristics of ecosystem stability[1]. In the process of continuous development and evolution, the concept of resilience went through three stages of engineering resilience, ecological resilience and evolution resilience, which greatly enriched the profound connotation of the concept of resilience and enhanced the cognitive depth of the concept of resilience.

The Theory of Resilience City

Since the 1990s, the study of resilience has gradually extended from natural ecology to human ecology. As an indispensable research subject of human ecology, the resilience theory is also naturally applied to urban research, laying an ideological foundation for the formation of resilience city theory[2].
The Key Features of Resilient Cities. In the urban area, resilience means that the urban system maintains its structure or function stability through a series of reaction processes such as absorption, change, adaptation, and learning when encountering external disturbances. Of course, stability here refers to a dynamic balance. Urban resilience refers to the ability of urban systems and regions to achieve normal operations such as public security, social order, and economic construction through reasonable preparation, buffering, and coping with uncertain disturbances. However, resilient cities have not yet formed a definition that is generally accepted by the academic community so far.

Most researchers have turned to expound the essential characteristics of resilient cities, which are summarized as follows (table 1) [3]:

<table>
<thead>
<tr>
<th>Time</th>
<th>Proposer</th>
<th>Main feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>Wildavsky</td>
<td>Homeostasis, Omnivory, High flux, Flatness, Buffering, Redundancy</td>
</tr>
<tr>
<td>2011</td>
<td>Allan et al</td>
<td>Diversity, Adaptability, Modularization, Innovation, Swift feedback, Reserves of social capita, Ecosystem service capacity</td>
</tr>
<tr>
<td>2013</td>
<td>Carlos</td>
<td>Multi-functionality, Redundancy and modularization, Bio and social diversity, Multi-scale networks and connectivity, Adaptive planning and design</td>
</tr>
</tbody>
</table>

It can be seen that the characteristics of diversity, flexibility, integration, redundancy and learning are the most important features of resilient cities.

The Concept and Evolution of Urban Infrastructure

From the structure of words, infrastructure is the basic structure of the whole city and plays an important role in the development of human society. With the expansion of city scale, the renewal of function and the transformation of structure, the content of infrastructure is developing and changing constantly. Due to the different issues faced by different countries and what the research focuses are not the same, new types of ecological infrastructure, green infrastructure and landscape infrastructure have emerged successively.

The Concept of Urban Infrastructure

Urban infrastructure is a general term for all kinds of equipment built in cities to carry out various economic activities and other social activities smoothly. It includes two categories which are engineering infrastructure and social infrastructure.

Chinese urban infrastructure refers to engineering infrastructure, which mainly includes six major systems: energy supply system, water supply and drainage system, transportation system, post and telecommunications system, environmental sanitation system and disaster prevention and security system. This paper mainly focuses on engineering infrastructure.

Major Issues with Infrastructure

Urban infrastructure, as a general material condition for the survival and development of society, is becoming more and more important in modern society. However, in recent years, various types of disasters have frequently erupted, seriously affecting the normal operation of urban systems, and the infrastructure system is even scarred. The destruction of urban traffic and track facilities, satellite communication failures, natural disasters such as wind and snow, and various human factors have brought different degrees of impact and damage to the infrastructure system, seriously affecting social production and people's livelihood, and also caused significant economic losses. Infrastructure is extremely vulnerable to urban disasters.

The main issues faced by the infrastructure are summarized as follows:

1. The lack of planning and design of the whole infrastructure system;
The single-function infrastructure model is developed in complex urban systems in a way of simple superposition;
(3) Losing the connection with the natural environment gradually and ignoring the natural ecological function of the city completely;
(4) Independent infrastructure system, isolated urban space, lack of overall connectivity;
(5) Overloading of infrastructure, facing the problem of renewal and transformation.

Connection between Resilient City Theory and Infrastructure

Based on the analysis of the main characteristics and evaluation system of resilient city, the common points are summarized from the hard environment composed of natural ecology and the soft environment corresponding to social humanity. The current issues in urban infrastructure are related to the main characteristics of resilient city, for example, (1) The adaptability of resilient city corresponds to the lack of overall planning and design of urban infrastructure; (2) The multi-scale network connectivity of resilient city corresponds to the independent system and spatial isolation of urban infrastructure; (3) The ecological nature of resilient city corresponds to the relationship between the loss of urban infrastructure and the natural environment; (4) The diversity of resilient city corresponds to the issue of single and simple superposition of urban infrastructure functions; (5) The redundancy of resilient city corresponds to the overloading of urban infrastructure and the lack of capacity and so on.

In addition, the index system to resilient city constructed by scholars, several representative views, such as the Rockefeller Foundation of the United States, Cutter, Carlos, etc. all use urban infrastructure as an indispensable component to evaluate the resilient urban system, which lays a deeply theoretical foundation for the study of resilient infrastructure.

Research Status and Concept Definition of Resilience Infrastructure

Research Status of Resilience Infrastructure

Bruneau et al. (2010) concluded that the resilience of infrastructure refers to its ability to adapt to and recover from external disturbances and disasters. Based on the theory of optimal control design mathematics, Camphouse et al. (2011) described a new method to quantitatively assess the resilience of critical infrastructure systems. Turquist M et al. (2013) introduced a stochastic optimization model for elastic design of network infrastructure, expecting to give specific planning strategies in terms of investment-recovery portfolio. Soldi et al. (2015) used complex network theory to evaluate the structural connectivity for elasticity and vulnerability, and used hydraulic simulation technology (EPANET) to estimate the potential stress of the pipeline according to the service level of the pipeline to provide decision support function.

In the past two years, China has begun to pay attention to resilience infrastructure and the research results are so few that there is not yet mature theory. Ning, X et al. (2013) proposed a model of infrastructure resilience for long-term potential risks by studying urban sewage discharge systems. Shao Yiwen et al. (2015) pointed out from the perspective of urban resilience that infrastructure resilience refers to the reduction of the vulnerability of built structures and facilities, as well as the emergency response capacity. Li Ya et al. (2016) summarized and compared the research framework and quantitative assessment method of urban infrastructure resilience by explaining the concept and connotation of infrastructure resilience. Hu Yue (2016) combined resilience city theory with urban infrastructure construction to discuss the construction, advantages and core strategies of urban water system. Liang Fuziyi (2017) considered the necessity of combining infrastructure renewal and landscape in resource-exhausted cities in China from the perspective of resilience and proposed specific planning objectives and strategies. Teng Wuxiao et al. (2018) proposed a planning strategy for the resilient urban infrastructure system in the study of the combination of the resilient city theory and the urban safety and disaster prevention system. Wang Jing et al. (2018) analyzed the concept and measurement method of urban road network resilience under ice and snow weather based on the perspective of resilience cities.
**Concept Resilience Infrastructure**

In September 2015, at the UN summit on sustainable development, the need to build resilient infrastructure was first raised from an official perspective. Official from the UNDP in China, Dawn, interpreted SDG 9 to build resilient infrastructure, promote inclusive and sustainable industrialization, and promote innovation. The main objectives include developing a quality, reliable and sustainable infrastructure and ensuring that all people have equitable access to affordable infrastructure.

However, there is no clear definition of what a resilient infrastructure is and what it includes. Based on the resilient city theory and previous studies, this paper will define the resilient infrastructure. Resilience infrastructure is a large and complex network system, which includes energy supply system, water supply and drainage system, transportation system, post and telecommunications system, environmental protection and sanitation system, defense and disaster prevention and safety system, and urban ecological resilience infrastructure. Under the guidance of the theory of resilient city, comprehensive planning and management are carried out through intelligent means, so as to improve the ability to cope with external disturbances and provide a security framework for the healthy development of urban society, economy and environment.

**Main Features of Resilient Infrastructure**

As an important sub-topic in the study of resilient city, the characteristics of resilient infrastructure must come from the basic theory of resilient city. By summarizing the main characteristics of resilient city and corresponding existing issues of infrastructure with each other, the main features of resilient infrastructure can be summarized as follows (table 2):

<table>
<thead>
<tr>
<th>Main features of resilient infrastructure</th>
<th>Existing issues with infrastructure</th>
<th>Key features of resilient infrastructure</th>
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<tbody>
<tr>
<td>Adaptability</td>
<td>Lack of overall planning and design</td>
<td>Adaptive planning and design. Infrastructure construction should be advanced in terms of time or space. It is necessary to plan ahead and leave some room for future risks.</td>
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<tr>
<td>Network connection of multi-scale</td>
<td>Independent system and isolation space</td>
<td>Networking of the system. The infrastructure should be able to connect with ecological spaces such as water networks and green nets, as well as social spaces such as activity venues, and work at multiple levels to promote ecological, social and economic development. Water network, green network and other ecological networks and gray infrastructure network connectivity et al.</td>
</tr>
<tr>
<td>Bionomics</td>
<td>Loss of connection with the natural environment</td>
<td>Natural connectivity. Infrastructure systems should be closely integrated with natural factors to transform itself into an ecologically complex organic system. Such as sponge city, roof garden, etc.</td>
</tr>
<tr>
<td>Diversity</td>
<td>Single function and simple superposition</td>
<td>Functional complexity. The infrastructure should be a diversified complex, and each subsystem should have a composite function to form a complex, functionally interconnected resilient system. For example, the combination of disaster prevention facilities with daily activities facilities.</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Insufficient capacity</td>
<td>Redundancy. Infrastructure systems should be designed to be redundant to ensure sufficient space to buffer and increase flexibility when disturbed. For example, the appropriate widening of road width and the appropriate combination of evacuation site and activity site.</td>
</tr>
</tbody>
</table>

**Conclusion**

At present, the research of resilient infrastructure is still in a new field in China, and its theoretical system is not mature yet. This is mainly due to the late start of Chinese research on resilient cities, so there is a certain gap between China and western countries in both theory and practice.
Fortunately, researches on "resilient infrastructure" have been paid more and more attention by relevant scholars. Therefore, the issues to be studied in the future include the establishment of evaluation system for resilient infrastructure and resilient strategies to solve the infrastructure issues. With the deepening of research, resilient infrastructure will provide an important guarantee for the construction of eco-smart city.

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References