Study on the Ecological Mechanism of Urban Morphology based on Urban Metabolism

Xiaoming Gao [1, a]

[1] College of Architecture & Urban Planning, Shandong Jianzhu University, Jinan City, Shandong Prov., China, 251010

[a]aaron_lennon@163.com

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Abstract. Urban metabolism and urban morphology have become a bilateral entry point to solve the disorders of urban ecosystem. By analyzing the concepts of urban metabolism and urban morphology, a symbiotic relationship is defined within the urban ecosystem: urban metabolism is the inner core of the urban ecosystem, and urban morphology is the external manifestations of the urban ecosystem. Therefore, basing on the attribute linkage between urban metabolism and urban morphology, the research intends to propose a research framework of the urban morphology from the construction of conceptual model, the deduction of analytical methods and the generation of spatial forms for the ecological mechanism in order to provide guidance for the future eco-city design.

Introduction

With the rapid development of urbanization in China, the overcrowding, waste of land and traffic congestion have be making the environment quality decline and leading to the urban ecological ills such as the climatic deterioration, resource depletion and environmental pollution, which thereby impeding the sustainable development of cities. As an urban ecosystem analogous to natural ecosystems, it is an incomplete ecosystem which maintains its function running required by human activities through the sustained exchanges of material and energy with the outside world: as the function support of urban operation, urban metabolism is the inner core of the urban ecosystems; as the spatial vector of urban activities, urban morphology is the external representation of the urban ecosystem. Therefore, the ecological nature of urban morphology is urban metabolism, and the ecological-coping mechanisms based on the urban metabolism become an important issue of today's urban morphology research.

Based on the above, the study intends to construct a research framework of the ecological mechanism of urban morphology which is based on the core of urban metabolism through the interpretation of the connotation of the urban metabolism theory in order to provide theoretical guidance for the eco-city design.

Concept of Urban Metabolism

The original concept of “Metabolism” means the exchange processes of material and energy with the natural environment in order to maintain the stable function operations of the ecosystem. Thereafter, the metabolism research based on ecology theories gradually penetrates to the urban sociology, urban economics and other related disciplines, and finally forms an inter-disciplinary concept basing on different objective vectors.

For the urban vector, the US ecologist Abel Wolman firstly proposed the concept of urban metabolism in 1965. He compared the urban ecological system to an organism in order to simulate the demand, consumption and emissions of material and energy for a city by metabolism analysis. Accordingly, Abel Wolman took the assumed city of one million in the US for example and accounted the metabolic processes of water, food, energy and other wastes, and assessed the effects on natural ecosystems from regional scope [1]. Later, Duvigneaud and Denayer-De Smet established the early urban metabolism model by studying the urban metabolism of Brussels, Belgium in the early 1970s, which is shown in Fig. 1.

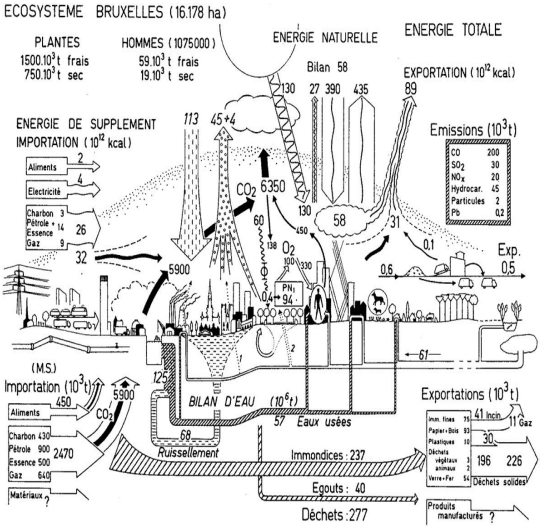

Fig. 1: Urban metabolism of Brussels.

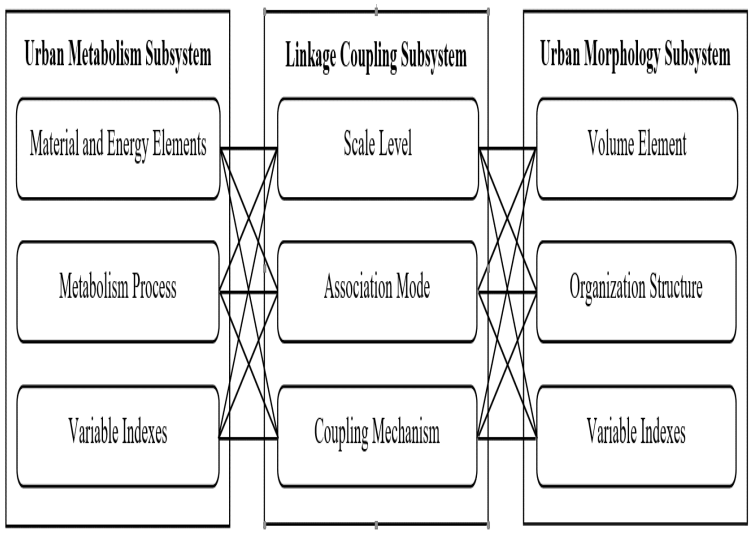

Fig. 2: Conceptual model of ecological mechanism.

The concept of urban metabolism has three primary attributes: the first one is elemental attribute which refers to the object elements of urban metabolism, including water, air, foods, energy, raw materials and wastes; the second is spacial attribute which refers to the objective vectors of urban metabolism, including system boundary, flow paths, cumulative orientation and other space organization hosting the metabolic processes; the third is media attribute which refers to the driving factors of urban metabolism, including the production, residence, consumption, services and other medium functions meeting the demands of cities. Thus, the concept of urban metabolism distinguishes different functions in urban ecosystem, and then possesses the meaning of urban morphology through taking the functions as the body, the material and energy elements as blood and the material and energy flows as the contexts of the morphology. Overall, urban metabolism and urban morphology constitute a whole internal and external associated unity.

Therefore, the ecological mechanism of urban morphology based on urban metabolism become an inevitable theory which researchers must study from the perspective of urban morphology.

Study on the Ecological Mechanism

The concepts of urban metabolism and urban morphology have the consistencies on the elemental, spacial and functional attributes, so that the construction of the operating mechanism of urban ecosystem could be realized through the association of the above properties. Therefore, based on the attribute linkage between urban metabolism and urban morphology, the research intends to establish the framework for ecological mechanism from the construction of conceptual model, the deduction of analytical methods and the generation of spatial forms.

The Construction of Conceptual Model

Based on the linkage between urban metabolism and urban morphology, the conceptual model consists of Urban Metabolism Subsystem, Urban Morphology Subsystem and Linkage Coupling Subsystem. As it is shown in Fig. 2, the Urban Metabolism Subsystem is composed of material and energy elements, metabolism processes and variable indexes indicators: the material and energy elements select water, energy, nutrients, and wastes which maintain the urban ecosystem function running as the research object; metabolic processes construct the dynamic changes of enter, conversion and export of material and energy elements in the urban ecosystem; the variable indexes establish the metabolic flux, intensity and efficiency of the material and energy elements. The Urban Morphology Subsystem is composed of volume elements, organization structures and variable indexes; the volume elements include land use, road network, buildings and public spaces; the organization structures mean the division, arrangement and combination of layout organization of volume elements; the variable indexes include the density, volume rate and compactness of volume elements. The Linkage Coupling Subsystem is composed of

scale level, association mode and coupling mechanism: the scale level determines the city, neighborhoods and block as three levels in urban ecosystem; the association mode means the interaction between the urban infrastructures and urban physical spaces; the coupling mechanism determines the symbiotic drive relationship between the urban metabolism and urban morphology.

The Deduction of Analytical Methods

The research methods of ecological mechanism of urban morphology adopt the research methods of urban metabolism which include Material Flow Analysis, Energy flow Analysis and Ecological Footprint. Material Flow Analysis (MFA) intends to calculate the quality changes of the material input, consumption and output in the system boundary according to the mass conservation law in order to explore the throughput difference, flow path and conversion efficiency of material metabolism [2]; Energy Flow Analysis (MFA) is formally proposed by Haberl of Austrian in 1997. Energy Flow Analysis (EFA) intends to calculate the amount changes of the energy input, consumption and output in the system boundary according to the energy conservation law in order to explore the throughput difference, flow path and conversion efficiency of energy metabolism [3]. In addition, American ecologist Odum proposed the unified *exergy* which is transformed from energy to study the urban energy metabolism. The exergy method transforms the total energy direct or indirect invested in the production processes to the unified total amount of solar energy by multiplying its solar energy conversion rate [4]. Ecological Footprint (EF) is presented by Canadian economist William Rees in 1992, and then Mathis Wackernagel built the calculation model of Ecological Footprint in 1996 [5]. Ecological Footprint refers to the virtual land area which has some biological productive forces to meet their material consumption and waste elimination functions in the social economic system. Ecological Footprint divides the lands that have the biological productive forces into fossil energy land, arable land, grassland, woodland, buildings land and waters land such 6 kinds of ecologically productive lands, and then converts the material and energy consumption in the social economic system into land area that can be compared with the ecological capacity with the corresponding conversion ratio in order to determine the state of metabolism. Fig. 3 shows the merits and shortages of the different analytical methods.

Method	Merit	Shortage
Material Flow Analysis	Sustainable calculation of integrated quantitative indicators	Fuzzy data sources and unintegrated material transformation
Energy Flow Analysis	Unified quantization energy and mass	Double counting and different accounting coefficient
Ecological Footprint	Visual description of the environmental impact of substances	Short of geolocation information

Fig. 3: The merits and shortages of three methods.

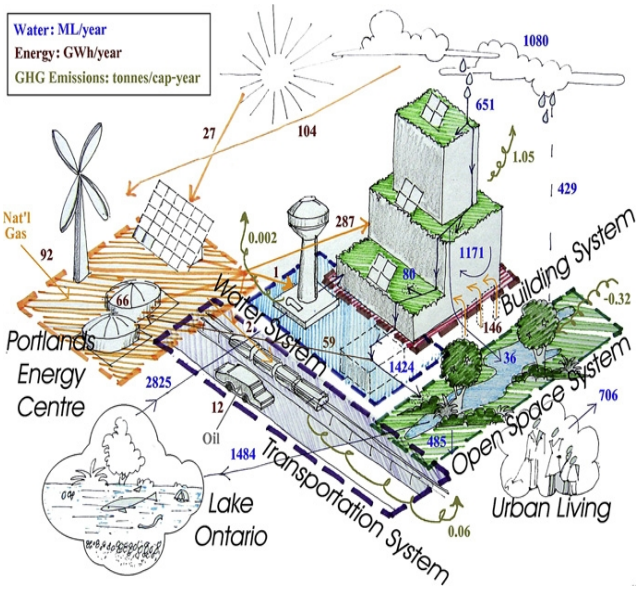

Fig. 4: The generation of spatial forms.

The Generation of Spatial Forms

As the ecological mechanism of urban morphology, urban metabolism determines the generation of the spatial forms in cities. And the determination processes consist of system dynamic analysis,

infrastructure reconstruction and spatial forms generation. The system dynamic analysis uses Vensim to simulate and build the system dynamics model of the linkage-coupling between urban infrastructures and spatial forms in order to propose the ecological model of urban form. Infrastructure reconstruction means to use the energy recycling, sewage purification, heat utilization, garbage regeneration and other technical measures to construct the green technical measures system, and then build the urban infrastructure network which is composed of energy, landscape and municipal services infrastructure from the macro, meso and micro level in order to achieve the efficient use of energy. Spacial forms use simulation to analyze the service effectiveness of the urban infrastructure network in terms of resource transmission, distribution and recycling, and the interaction with the quantitative indicators of urban spatial morphology in terms of density, compactness and mixed degrees etc, and then construct the function layout, land use, transportation organization, building combination and landscape construction from the macro, meso and micro level in order to generate the ecological spatial pattern that is complementary and symbiosis with the urban infrastructure network. Fig. 4 shows the generation of spatial forms in the sustainable urban design processes according to the urban infrastructure network which uses the urban metabolism as a guidance.

Conclusions

Thus, the urban metabolism concerns the flows, accumulation and efficiency of the material and energy in the urban scale and forms the concept frame which takes the urban space as the carrier, the material and energy metabolism as the power core and the ecological functions as the drive. The research aims to propose the ecological mechanism of linkage-coupling between the urban infrastructures and spatial forms to construct the ecological analysis, evaluation and design theory in order to provide guidance for the future eco-city design.

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