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Effects of urban expansion on environment by morphological study

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Abstract. Urban expansion in recent decades brought about profound nature environmental effects such as heated island, flooding, soil erosion, air pollution and biodiversity loss. Ignorance of these effects will lead to further irreversible destructions. It is necessary to study about “how and to what aspects can land use morphology affect environmental performance?”. In this paper, the effects of urban expansion on environment are studied by morphology in order to link the knowledge of environment with urban planning/design. Firstly, the relationship between urban expansion and natural environment is generally described by introducing some concepts of land use morphology and environmental performance, the significance of applying morphological study to environment is highlighted. Secondly, a lot of research results of environment problems such as carbon emission, the pollution of air, water, soil erosion, and biodiversity loss are reviewed from the viewpoint of morphology. Finally, some conclusions and discussion are remarked for future urban planning/design for making contributions to environment.

1. Introduction

The land on earth and its anthropogenic exploitation are crucial links between human activities and natural environment. Human-involved land cover, land use and land cover change such as forest over-exploitation, agricultural intensification and urbanization not only accelerate global warming via increasing greenhouse gas emissions [1-2], but also pervasively cause irreversible biotical diversity losses across the globe [3-4]. In the environmental field, a lot of papers have explained various consequences of natural environmental issues from traffic energy consumption, biodiversity loss, heated island, flooding, water pollution, soil erosion, etc. [5]. However, most of them did not link the change of natural environment with urban expansion comprehensively. Since urban expansion-happened extremely nowadays can cause great destructions of natural environment by blocking series ecological processes such as energy flow process, material circulation process and biogeochemical process [6-7], this paper purposes to link the knowledge of environment and urban planning/design by the application of morphological study, which focus on the question “How and to what aspects can land use morphology affect its environmental performance?”

For this goal, this paper is organized by following three sections. Firstly, the relationship between urban expansion and natural environment is generally described by introducing the relevant concepts



of land use morphology and environmental performance, as well as the significance of applying morphological study. Secondly, some cases of morphological studies are reviewed from five aspects. Finally, some conclusions are remarked based on perspectives of both urban planning/design and environmental field.

2. Background

2.1. Concepts

Urban expansion refers to the development of new urban areas as well as their related infrastructures. Generally, urban expansion is based on road networks, which continuously sacrifice surrounding original farmland, pastures, and forests etc. In urban planning/design field, morphology refers to the consequence of urban expansion. It contains several indicators to measure ever-changing urban physical structure from dynamic interactions between human and nature [8-9]. Generally, morphology can be described qualitatively and quantitatively. Qualitative indicators describe the question of “How can urban expand?”, in which include such as single-center expansion, multi-center expansion, linear expansion, network expansion and circular expansion. Quantitative indicator tries to answer the question of “to what extent can urban expand?”, in which include such as form, intensity, heterogeneity, and connectivity.

Natural environment is the sum of all kinds of factors that surround organisms such as atmosphere, energy, water, soil, rock, minerals, and solar radiation. It is material basis of subsistence for human being. In environmental field, these factors are usually divided into five categories of natural cycles: atmosphere circle, energy circle, hydrosphere, biosphere, soil circle and lithosphere [10-11]. Environmental performance can be measured based on the knowledge of five natural cycles such as carbon environment generally represents energy circle, water environment represents hydrosphere, air environment generally represents atmosphere circle, soil environment generally represents soil circle and lithosphere, and biodiversity generally represents biosphere. Indicators of each kind of environmental performance are applied for further measurement.

2.2. Methodological study

The morphological study has been established as a backbone methodology for decomposing complex relationship between urban expansion and natural environment. It is based on assumption that urban expansion will cause interactive changes in urban physical structure. This process will gradually affect biogeochemical process provided by natural environment [12]. Indicators in both morphology and environmental performance can be changed synchronously. The morphological study can elaborate the evolution process of both urban expansion and natural environment at various scales. The followings are some important research tools:

2.2.1. Mapping. Mapping is an important tool for morphological study. Visualized maps can facilitate us to understand complexity, dynamic processes of both urban expansion and natural environment in various scales by multi-sources data. A series of spatially explicit maps not only reveal the quantitative characteristics of current regional morphological structure, but also exposit potential changes caused by different morphological scenarios.

2.2.2. Matric calculation. Matric calculation helps us to find the quantitative relationship between urban expansion and natural environment by establishing infer mathematical formula and graphs derived from data. This method is helpful in finding threshold points during evolution process from past experience. Several normal ways of matric calculation are usually applied including correlation analysis, regression analysis, cluster analysis and redundancy analysis.

2.2.3. Urban-rural gradient analysis. Gradient analysis is a geographic way based cross-sectional method. By dividing morphological sections into different samples, morphology indicators and

environmental performance indicators in different sections would be analysed. Its biggest advantage can be illustrated by comparing a sequence of different sections especially in the cross-sectional urban-rural interactive areas. Generally, the widespread usage of geographic information system (GIS) and remote sensing system (RS) have prominently promoted capability [13]. With the help of GIS and RS, traditional data collection can be made great breakthrough on three aspects. First, data can be combined from different time by directly viewing overlaying results. Second, data can be linked from different scales to measure the potential sequence of scale-effectiveness. Third, data can be compared from different environmental performance groups for discovering the results of trade-offs and synergies.

3. Study review

3.1. Carbon environment

Carbon source and carbon sink are mainly concerned elements for morphological study between urban expansion and carbon environment. Carbon source is mainly from traffic consumption, industrial consumption and architectural consumption. Carbon sink mainly refers to the capacity of absorption or storage of carbon dioxide from its environment. When urban expansion, both carbon source and carbon sink are automatically shifted from its original distribution.

Different morphologies of form, connectivity and intensity can differently influence the spatial distribution of carbon source. For form perspective, it had been shown that different form of urban expansion will cause greatly different effects on carbon emission. Single-centre expansion of urban area could generate less carbon emission [14]. Some studies found that higher fragmentation of green land with lower connection can cause more energy consumption. In another word means that single-centre green land expansion is benefit for energy reduction [15-16]. From intensity aspect, it had been proved that low density urban area inducing more carbon consumption [17]. The appropriate density degree for the best carbon environment performance is supposed by comparing some cases [18].

Land use heterogeneity and form can influence the spatial distribution of carbon source. Compared with single-centre expansion and multi-centre expansion, multi-centre expansion will lead to less carbon emission situation by short travelling distance between different parallel centres [19]. In addition, mixed land use planning can reduce carbon emission because of its great contributions to positive carbon cycling process [20-21]. Land use morphology can influence the spatial distribution of carbon sink. For example, it is proved that carbon sink is keeping increasing from urban area to rural area according to its increasing green land percentage some case by gradient analysis [22]. In other situation, carbon sink in successive urban park is lower than that in same size of forest [23-24].

3.2. Air environment

The relationship between urban expansion and air environment mainly can be presented from the aspects of air quality and heat island. Land use form can influence air environment. Compared with multi-centre expansion, single-centre expansion is more effective on dealing with heat island. Connective green land is better than fragmented green land in the effects of mitigating urban heat island [25-26]. Also, it is found that compact cities seem to be friendlier to their air environment because of less ozone concentration [27-28]. Simulation of air quality in many case studies shown that single-centre expansion can emit less air pollution in total amount [29-30]. Meanwhile, bigger size green land is better performance in controlling temperature no matter what kind of expansion form [31]. Land use intensity can also affect air environment. When urban expansion by 30% with density increased by 20%, temperature will increased by 0.17°C [32]. Green volume ratio, building density and building height also make effects on micro temperature. For instance, when green volume ratio is increased by 2 times, the surrounding nearby temperature will be decreased by 12%. Tall buildings could generate shadow which can cool down site temperature [33]. Higher road network density can make poor outdoor air temperature and air quality [34].

3.3. *Water environment*

Water environment is based on the connection of surface or subsurface water flow between different cross-sectional hydrological units like water catchment areas [35-36]. Based on that, the mechanism of urban expansion on water environment can be better understood. With the development of city surface or subsurface, water flow will be blocked because it changes nature pathways. Surface or subsurface water flow is constrained in drainage pipes which are always under grid-shaped road networks. This will result in congestions at road junctions and lead to flooding issues in cities during peak rainfall times. Urban expansion can influence overall water environment by changing surface / subsurface water flow, changing spatial disturbances of hydrological units, changing potential green-blue networks.

The land uses of different heterogeneity, form and intensity can differently affect water environment by changing surface or subsurface flow and the spatial distribution of hydrological units. For instance, it has become vulnerable for the amount of uncontrollable surface or subsurface flow caused by increasing impermeable coverage as well as underground drainage pipes [37]. It is also more vulnerable for mal-function such as water storage, water purification of hydrological units [38]. Quantitative measurement is helpful to discover relationship between impermeable surface connection and flow performance by comparing difference. For instance, when impermeable surface's connection is increased from 10% to 100%, peak runoff flow will synchronously increase from 200% to 500% [39]. However, when the surface's connection is increased by 13%, the peak runoff flow will be increased by 35% [40]. The smaller of each impermeable surface, the better flow performance will be [41-42]. Meanwhile, some researches also make valuable contributions to explore relationship between density and flow performance. For example, when urban density increased from 51.6% to 100%, peak runoff flow will increase from 45.4% to 83.3% [43].

3.4. *Soil environment*

Urban expansion can gradually generate heavy metal gathering areas on soil surface by changing its beneath organic elements. Quantitatively, the soil composition remains 71.71% difference when comparing the situation of forest and urban [44]. The capacity of providing soil nutrient is 50% more efficiently in forest soil than in urban soil [45]. Since urban areas can block material cycling provided by soil environment, this negative process can result in soil pollution, soil erosion, etc.

However, it is not to say that the transfer of all urban area to forest area will totally improve soil environment. As several case studies have been illustrated that appropriate mixed land use of farmland, grassland, forest and urban will bring about better soil environment because its fast soil metabolism performance [46-47]. Mixed urban transportation types can improve soil environment [48-49].

3.5. *Bio-environment*

A healthy bio-environment requires interactive energy, material, information transformation. Interactive transformation requires complete nature surface and biological corridors. Like water environment is based on the connection of flow among different cross-sectional hydrological units, bio-environment is based on the connection of nature corridors between different cross-sectional nature habitats provided by high quality nature surface. Generally, urban expansion has negative impact on biodiversity via reducing coverage nature surface like forests, wetlands, water [50-51]. Fragmented nature surface and discontinuous biological corridors are negative impacts on bio-environment. Biodiversity is the most general indicator to measure healthy bio-environment. It is backbone to support our whole life system.

Land use connectivity of nature corridors will facilitate or block transformation. Length and width of different nature corridors will cause different bio-environmental performance. For example, discontinuous nature surface and corridors which is overpassed by impermeable road networks can cause the decrease of biodiversity [52-53]. The wider the roads are, the less amount of types of bird will be [54]. Appropriate nature corridors surrounded by high quality habitats is benefit for biodiversity [55]. Meanwhile, nature surface- fragmented changes the quality of nature habitats which cause issues

of species. Quantitatively, when the fragmented degree of nature surfaces are over 13.8%, the total amount of species would decrease by 3% [56]. When the fragmented degree of nature surfaces increases from 50% to 100%, the total amount of species will correspondently decrease from 5 to 10 times [57].

4. Conclusions

Economic value once dominated in urban expansion process which left natural environment vulnerability when urban faces future uncertainties. In current context, urban expansion and environmental protection are both important. The common ground of above researches is to take advantage of knowledge from multidiscipline. Morphology study may become a bridge between urban planning/design and environmental field. Different types of morphology such as form, intensity, heterogeneity, and connectivity can differently affect environment qualities like carbon emission, air, water, soil and biodiversity etc. Among them, trade-offs arise when the change of morphology may enhance one service quality at the cost of another service. Synergies are needed when morphology may cause multiple service quality. Faced to so many indicators of environmental performances, morphology becomes an appropriate analysis method by cooperation of multidisciplinary efforts. In addition, research by design and scenario analysis is helpful to create situations for multi-stakeholders decision-making process that the cooperation of different departments within multiple planning scales should be constructed by a comprehensive framework in the future.

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