Habitat International 51 (2016) 48–58

Contents lists available at ScienceDirect

Habitat International

journal homepage: www.elsevier.com/locate/habitatint

On the potential of urban three-dimensional space development: The case of Liuzhou, China

Fangzhou Xia [a, b], Yue Shen [a], Jinming Yan [a], Helen X.H. Bao [b, *]

[a] Department of Land Management, School of Public Administration & Policy, Renmin University of China, Beijing, China
[b] Department of Land Economy, University of Cambridge, Cambridge, UK

ARTICLE INFO

Article history:
Received 29 June 2015
Received in revised form
25 September 2015
Accepted 15 October 2015
Available online 26 October 2015

Keywords:
Three-dimensional space
Landscape view
Mixed model
New-type urbanization

ABSTRACT

The New-type Urbanization Plan in China is facing planning, economic, and environmental constraints. A fast-growing urban population imposes distinct pressure on social and natural resources in most cities. As a result, the urban land use pattern in China has rapidly expanded from planar to stereoscopic. Although the pattern has effectively maximized the utilization of land resources, the "one-size-fits-all" solution is not applicable to all cities in China. The assessment of the suitability of a city is important before the application of the "three-dimensional" (3D) development approach, especially for cities with important natural endowment at stake. This study proposes a framework to assess the potential of a city for 3D space development in China. Our model considers land use suitability, economic feasibility, and landscape visibility in urban 3D space development decisions. We use Liuzhou City as a case study to demonstrate the empirical implementation of this framework. Our analysis shows that the model can assist urban planners to visualize urban morphology and to identify optimal development directions. By balancing planning, economic, and environmental needs, our model enables local governments to meet their development targets without sacrificing the environment. The proposed framework is a useful tool for local government to realize the New-type Urbanization Plan while ensuring that urban residents "see the mountains, view the rivers, and remember their past."

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1. Introduction

Higher levels of urbanization are associated with advanced economic development (Bertinelli & Strobl, 2007; M. X. Chen, Zhang, Liu, & Zhang, 2014). Moreover, rapid urbanization leads to various urban problems, such as congestion, crime, environmental externality, and housing affordability issues (See, for example, Burak, Dogan, & Gazioglu, 2004; Deng, Huang, Rozelle, Zhang, & Li, 2015; Glaeser, 2011; Voith & Wachter, 2009). An estimated 66% of the world's population will become urban by 2050, and China plays a significant role in this process with its unprecedented urbanization speed (United Nations, 2014). Consequently, the demand for construction land for social and economic development has been increasing rapidly in China (Ding & Lichtenberg, 2011; Gong, Chen, Liu, & Wang, 2014). This demand has led to conflicts among sustainable development, environment protection, and economic growth, and to problems such as the disappearance of ecological land and the reduction of urban green space (Chen & Hu, 2015; Long, Liu, Hou, Li, & Li, 2014).

In March 2014, China announced the "New-type Urbanization Plan" that calls for coordination among land urbanization, population growth, and environment protection (Xinhuanet, 2014). This plan indicates that the current land use pattern must be reviewed to reduce the waste of resources and to improve land use efficiency (Yan, Xia, & Bao, 2015). Moreover, Chairman Jinping Xi stressed the importance of visible landscape in urban areas and demanded urban planners to ensure that residents can "see the mountains, view the rivers, and remember their past" (Taylor, 2015; Xinhuanet, 2013). In an effort to achieve these goals, many cities have opted to develop vertically into higher space and/or underground instead of sprawling out (Chen, Yan, Gao, & Liu, 2015; Qin, Fang, Wang, Li, & Wang, 2015; Shi & Yang, 2015). This three-dimensional (3D) space development model has the benefits of promoting intensive and effective utilization of both overground and underground space (Wei, Huang, Lam, & Yuan, 2015). The model is regarded as an important way to promote urban carrying capacity (Bendewald &

* Corresponding author.
E-mail addresses: ark_xiafangzhou@hotmail.com (F. Xia), shenyue_7@126.com (Y. Shen), yanjinming@mparuc.edu.cn (J. Yan), hxb20@cam.ac.uk (H.X.H. Bao).

http://dx.doi.org/10.1016/j.habitatint.2015.10.012
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Zhai, 2013; Liu, 2012; S. Liu, Fan, Wen, Liang, & Wu, 2014; Tian, Wu, & Yang, 2010).

However, the 3D space development model is not a "one-size-fits-all" solution for all cities in China. The assessment of the suitability of a city for such an approach is important. In particular, cities with important natural endowment at stake should be carefully studied. This step can be done by evaluating the potential for 3D development at the city level. "Potential" refers to a currently unrealized ability or capacity by which an index may increase or reduce in a certain period or under a certain technical level (Krellenberg, Welz, & Reyes-Packe, 2014). Therefore, we define urban 3D space potential as the capacity to increase available vertical space achieved through administrative, economic, legal, and technical measurements within planning and regulatory constraints in a certain period and at given technical levels (Joardar, 1998; Liu, 2012). Three aspects must be considered in estimating potential. First, the land must be suitable for 3D development construction (Zhang, Fang, Wang, & Ma, 2013). Second, economic demand for 3D development should be present (Bendewald & Zhai, 2013; Wei et al., 2015; Wong, Tang, & van Horen, 2006). Third, the utilization of the 3D space should not block the line-of-sight and result in landscape invisibility (Miller, 2001; Sander & Manson, 2007). At the time of the writing of this study, the literature has focused on each of these three aspects. Other isolated efforts include studies on land use suitability evaluation (Gong, Liu, & Chen, 2012; Wei et al., 2015; Xu, Kong, Li, Zhang, & Wu, 2011), economic demand analysis (Wragg & Lim, 2015; Zacharias, 1999), and viewshed analysis (Llobera, 2003; Miller, 2001; Sander & Manson, 2007; Wang et al., 2015). Few researchers have conducted quantitative research on 3D urban morphology (see, e.g., Qin, et al., 2015), and most existing studies have focused on subregions of a city rather than the whole city area (see, e.g., Yoshida & Omae, 2005; Yu, Liu, Wu, Hu, & Zhang, 2010). Most importantly, no studies have investigated the potential for 3D space development by considering land use suitability, economic feasibility, and landscape visibility at the same time.

To bridge the gap in the literature, we develop a framework to assess the potential for 3D space development in urban China. Our model considers land use suitability, economic feasibility, and landscape visibility in urban 3D space development decisions. The framework consists of four steps. First, we divide a study area into evaluation units. Second, the land use suitability of these evaluation units is assessed to identify areas that are appropriate for construction. Third, the development potential (i.e., maximum development height for overground buildings and maximum development depth for underground constructions) of the identified evaluation units is determined through economic feasibility analysis. Finally, the overground development potential is adjusted to ensure landscape visibility. We use Liuzhou City as a case study to demonstrate the empirical implementation of this framework. Our analysis shows that the model can assist urban planners to visualize urban morphology and identify optimal development directions. By balancing planning, economic, and environmental needs, our model enables local governments to meet their development targets without sacrificing the environment. The proposed framework is a useful tool for local governments to realize the New-type Urbanization Plan while still ensuring urban residents that they will "see the mountains and water."

The rest of the study is structured as follows. Section 2 discusses the methodology and establishment of a digital three-dimensional space potential model (DTSPM). Taking Liuzhou City as a case study, Section 3 presents the details of the evaluation of land use suitability, economic feasibility, and landscape visibility. Section 4 presents and discusses the empirical findings. Section 5 provides the conclusion and policy implications.

2. Methodology

The composition of stakeholders and their alliances in the urbanization process could shift because the consensus on methods to utilize urban space varies over time (Jenkins-Smith & Sabatier, 1994). Nevertheless, several stakeholder groups can still influence the direction of urban development by upholding values, such as livability, economic development, and environment protection (Berke & Kaiser, 2006). Livability means that urban space development should support community activities, safety considerations, and preferred lifestyles. By meeting such a standard, developable land should be at least suitable for construction purposes. To deliver economic values, urban development and land use should generate profit from the sale of land and buildings. As a result, potential of urban space development is reflected by market demand (Logan & Molotch, 1987). Urban development should seek to protect urban environment for direct and indirect utility, as well as intrinsic values (Berke & Kaiser, 2006). In the process of the New-type Urbanization in China, landscape visibility should be prioritized because the quality of view contributes significantly to the experiences of residents in the urban area (Bishop, Lange, & Mahbubul, 2004; Guzey, 2014; Oh & Lee, 2002; Rinner, 2007). The abovementioned values are integral to the quality living experience in urban China. Therefore, our research model is designed to recognize and reconcile land use suitability, economic feasibility, and landscape visibility in a unified framework. This goal is achieved by utilizing the digital elevation model (DEM) technique to develop the DTSPM outlined below.

DEM is a digital model that provides a 3D representation of a terrain that enables users to locate, visualize, and interpret vast amounts of geo-referenced information (F. Wang et al., 2015). By using the data set of the plane coordinate (X, Y) and height (Z) of a regularly spaced grid, the spatial distribution of a topography can be described from a mathematical perspective (Sander & Manson, 2007). DEM data can be converted into all types of thematic map productions, such as contour, slope, sectional drawing, hill shading, and landscape maps. DEM can also calculate volume, spatial distance, and coverage size of objects. This technique has been widely used in environmental studies (see, e.g., Daniels & Lapping, 2005; Lindberg & Grimmond, 2011; Stefanov, Ramsey, & Christensen, 2001). By utilizing some carefully selected sample points, the model can appropriately interpolate and distribute discrete sample points to build a continuous 3D surface. Therefore, the technique enables us to utilize and consolidate a large amount of information effectively and efficiently. The technique is particularly useful in our research design, as our model inevitably needs to handle a wide range of indicators in considering livability, economic development, and landscape visibility at the same time. The technique also enables the 3D visualization of urbanization models of different specifications. The friendly interface is particularly useful for policy makers and the public that do not necessarily have special knowledge in areas, such as geology and construction.

We build the DTSPM by applying the DEM principle. As shown in Fig. 1, the model considers the preconditions of sustainable urban development, such as livability, economic feasibility, and ecology from a top–down perspective (van Lier, 1998). Through the evaluation of land use, economic feasibility, and landscape visibility, the model is capable of incorporating local particulars. Therefore, the model is regarded as an intermediate toward the bottom–up approaches. DTSPM can visualize any specific New-type Urbanization form, as the model can illustrate 3D space potential at any spatial position of a city or a region. The model provides insights into whether a city or a region is suitable for 3D development in terms of livability, economic development, and landscape visibility. In the

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