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Review

# Integrating the third dimension into the concept of urban ecosystem services: A review

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ABSTRACT

The spatial configuration of urban environments and its impact on local and global ecological functions were the subject of recent urban ecosystem service (UES) research projects. The outcomes of these projects with respect to the data they used, however, mainly consisted of two dimensions (2D). Studies that assess aspects of the third dimension (3D) of UES – such as height, volume and shadowing effects – were absent. The objective of this paper is to contribute to a better understanding of the local ecological functions based on knowledge of three-dimensional UES. 298 articles were selected for in-depth critical analyses. The technical and computational approaches for extracting urban 3D structures and 3D structures of vegetation were the focus of the reviewed literature. Authors' affiliations would be a better indicator for assessing the spatial distribution of articles. Uneven distribution of knowledge among countries is related to the technical and scientific advancement of countries. There was a shift in the subtheme of reviewed publications discussing the concept of ecosystem services in the first few years, while later researchers' interests moved towards UES and adaptation of cities to the changing climate. Further studies should progress in the development of both 3D data and results. Implementing 3D data and results helps to better understand the coupling of humans and their environs. It will be then a critically important step toward developing ecologically friendly cities.



**Contents**



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## 1. Introduction

The spatial configuration of urban elements such as buildings and grey, blue and green spaces is one of the main characteristics of the urban form (Schwarz, 2010). On the one hand, its complexity influences both ecological functioning and human well-being in urban areas (Ahern, 2012; Ervin et al., 2012; Alberti and Marzluff, 2004). On the other hand, any change in the green and blue densities or area sizes significantly affects the performance of urban ecosystem service (UES) (Gomez-Baggethun and Barton, 2013).

Urban areas are centers of demand for ecosystem services (Elmqvist et al., 2015), which are dependent on nearby and distant resources (Kremer et al., 2015). Based on an expected increase of up to 75% by 2015 of the population living in urban areas (United Nations, 2014), concerns about the quality of life in cities have also increased. In addition, climate change, particularly extreme events, has become another challenge for human well-being in the urban environment. Therefore, the concept of ecosystem services in urban areas has increasingly drawn attention (Haase et al., 2014a,b,c).

In this regard, a large number of studies have examined the state of the art in research on ecosystem services (Haase et al., 2014a,b,c; Seppelt et al., 2015). For example, Breuste et al. (2013a,b) studied different services that provided green spaces in cities. Doick and Hutchings (2013) reported a key role of green spaces in contributing to the regulation of urban microclimate. Other recent studies concluded that natural landscapes at the local level have substantial direct and indirect impacts on the quality of life in urban areas (Derkzen et al., 2015; Ervin et al., 2012).

Nevertheless, the number of studies investigating ecosystem services in urban areas is less than 10% of all ecosystem services publications (Gómez-Baggethun et al., 2010; Hubacek and Kronenberg, 2013; Haase et al., 2014a,b,c). Among these, only a few covered more multiple ecosystem services (e.g., multiple services). These articles mainly focused on the benefits that ecosystem services provide to improve the socio-environmental quality of life in urban areas, such as the provision of food, regulation of the microclimate and storm water retention (Haase et al., 2014a,b,c).

Yet, among the studies on ecosystem services undertaken in urban areas, the dimension 'volume and height', i.e., the third dimension of urban systems was ignored. A publication by Larondelle et al. (2014), included as one of the first studies on regulating services, covered more than two dimensions by using land cover data and building height. However, research that studies UES three dimensionally and takes the volume of urban ecosystem services and the urban built environment into consideration are sorely lacking.

Incorporating the third dimension of the urban environment (volume) into ecological studies will increase the level of details associated with studies on urban structure-function relationships. In addition, it can also increase knowledge about the complex functioning of the urban area. With this background in mind, the main objectives of this paper are as follows:

i. to review the status of the current research and the geographic distribution of research projects since the first publication that addressed the third dimension of ecosystem services in urban areas,
ii. to evaluate the articles most relevant to our first research objective by applying a set of criteria, and
iii. to highlight the role of urban three dimensional studies in closing existing knowledge gaps about sustainability in cities.

## 2. Methods

To address our research objectives, we conducted a comprehensive literature search to estimate how well the third dimension of UES was reflected in scientific publications. From this first main pool of literature, we applied three systematic steps to address our research objectives (Fig. 1).

First, we refined the pool of literature to meet the concept of our research (first research objective). Second, we cross-examined the pool of literature with several criteria (twelve) to select the most relevant articles (second research objective). Finally, we analyzed the frequency with which the selected literature's objective was to highlight the role of 3D data in closing the existing knowledge gap (third research objective).

### 2.1. Selection of articles

To refine the pool of searched literature that met our criteria, two pertinent search engines for scientific and academic research were used, i.e., Scopus and ISI Web of knowledge, which hold the world's largest citation databases of peer-reviewed research literature. The search was set from the date of the first relevant article until the end of the year 2014. The year 2015 was not considered because some of the literature found in 2015 was not yet published.

To find publications that investigated urban 3D ecosystem services, the following keywords were used at each query: (1) "three-dimensional urban ecosystem services", (2) "urban three-dimensional", (3) "three-dimensional shape", (4) "urban three-dimensional modeling", (5) "urban three-dimensional function", and (6) "three-dimensional city model". Moreover, '3D' was replaced with 'three-dimensional' to comprehensively review the current state of 3D in the literature on UES. Additionally, the following keywords were used: (7) "3D urban ecosystem services", (8) "urban 3D", (9) '3D shape', (10) "urban 3D modeling", (11) "urban 3D function" and (12) "3D city model". During our literature search, we did not include books, grey literature, extended abstracts, reports and presentations.

The initial search returned 3480 published articles between the years 1991–2014. These publications possessed at least one of the defined keywords. Afterward, to exclude non-relevant articles, several systematic criteria were implemented. For instance, duplicated literature found in both citation databases was excluded (n = 1473). English is the first and main language of academic publications. Therefore, we did not consider literature that was not fully published in English (n = 355). For example, the language of published articles by Zhang et al. (2014) was Chinese; however, the abstract was published in English. Hence, such publications were not included in our analysis. We also excluded literature published in non-academic journals or those with no common scientific themes related to our research. For example, the Journal of Mining and Mineral Engineering, the Journal of Mining and Metallurgy, the Oil & Gas Journal, among others, were not included. Consequently, 1652 articles were not included, and 298 scientific publications received further in-depth analysis. Fig. 1 illustrates the systematic process of selecting articles, as well as the amount of literature excluded.

We are aware of the fact that the selected publications do not comprise the complete number of papers that mentioned the keywords related to 3D UES. There are also certain studies that might not use the term 'ecosystem services' but actually perform an 'ecosystem services analysis' simply because they are from a different academic background. However, the selected publications provided us with a broad overview of the most significant literature that drew relevant conclusions on the evolution of three dimensional ecosystem service research. To meet the research objectives, each of the selected publications (n = 298) was validated with the following twelve criteria, which were in the form of questions:

- Date of the publication (year),