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Automated generation of versatile data model for analyzing urban architectural void

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ABSTRACT

Urban environments are defined and modeled in a variety of ways depending on the scientific approach to analyze them. Even though a number of analysis could benefit from using a single model and re-using results of one for the sake of the other, so far no single data model is available. Moreover, the existing standardized models focus on describing objects in and around urban architectural void rather than the spaces themselves. Nevertheless, a number of phenomena such as heat, energy, pollution, also including social and mobility aspects would undoubtedly benefit from using a model that is explicitly focused on defining the urban architectural void and its characteristics as continuous field, interconnected network or series of spatial units. Therefore, this paper aims to suggest a versatile data model that would allow to separate, interpret, analyze and visualize the urban architectural void using a standardized automated procedure. The model relies on Gestalt theories for space compartmentalization. It allows performing various kinds of analysis and storing their results in a unified format using core concepts of GIS. The model can be rendered both as a 2D and 3D representation. Finally, user intervention and parameter calibration is allowed at every principal step of an automated procedure.

1. Introduction

Urbanized areas can be conceived as a complex compound of systems, which need to be simplified based on deliberate considerations and scientific assumptions in order to be assessed. The data and tools that are used for the assessment induce the reduction even further, making it only possible to explore a certain system by its subsystem represented as a model (Klaasen, 2003). Fortunately, due to the constant emergence of various sensing, mobile and network technologies, data collection and dissemination has become rather a matter of creativity than a technological issue. However, data alone is not knowledge and does not provide answers by itself, thus respective models need to be made in order to transform data into information.

Urban open spaces can be perceived, defined and modeled in a variety of ways depending on the scientific approach to analyze them. They can be understood as street or pedestrian networks, proprietary lots, functional units, three-dimensional objects, etc. A substantial amount of research has already been done in order to investigate and prove the importance of the urban spatial structure for various phenomena. Beirão, Chaszar, and Čavić (2014, 2015) have used the discretization of urban void into smaller particles in order to investigate how the observed characteristics of individual spatial volumes – 'Convex Voids' – and their aggregation can engage with intended, possible, and probable uses of spaces, based on different geometric characteristics. Davies and Johnson (2015) have investigated the impact of space network structure for the burglary risk confirming a higher risk of burglary for streets with more potential usage. The density, the networks, and the sharing between built and empty spaces in the city have been identified as having impact on the energy consumption in the city (Salat, Labbé, & Nowacki, 2011). Shach-Pinsly, Fisher-Gewirtzman, and Burt (2011) have investigated urban voids concerning privacy and visual openness from and towards the surrounding facades. Kato and Huang (2009) have identified the importance of urban void shape to the ventilation efficiency in cities, that has impact on heat island effect, windiness and air pollution. Wu and Plantinga (2003) have explored how urban spatial structure influences land development, real estate price and income diversity. The variety of commonly used models reflects the multipurpose those models are intended for.

So far no single data model is able to account for all the different types of analysis. However, a number of analysis could benefit from using a single model and re-using results of one analysis for the sake of the other. The reuse of the same model facilitates the raw data processing, especially in case of the update, induces flexibility

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of analysis, reduces storage and helps interpreting analysis results, especially while looking for the relations between distinct phenomena. In that respect, a data model that overlaps various data structuring allows for models' particular shortcomings to be overcome by advantages of the system as a whole. Furthermore, considering the ambiguity that a single representation model can have of reality, having a model, consensually accepted and reused by a large community of researchers, not only allows for more direct comparability and integrated information obtained from different types of research, but also progressively builds the acceptance and consistency of that model.

The challenge of creating such data model arises first of all from the lack of formal definition of what is an urban architectural void. The open areas are not explicitly defined like the obstructed ones are defined by the built geometry. This determines that any of the analysis require a substantial amount of manual work in order to employ human expertise in building a representation model. Next challenge is the automation procedure itself. The lack of formal standardized definition leads to the uncertainty of the initial input data for building a representation model. Finally, there is no consensus on the necessity to have higher than 2-dimensional representation and how much detail does the third dimension require (e.g. as in Ratti (2005), where a DEM raster already effectively complements computation of urban lines of sight, viewsheds, travelling time maps, and simulations based on cellular automata).

Therefore, this research aims to provide a versatile data model that allows to separate, interpret, analyze and visualize the urban architectural void using a standardized automated procedure. The paper is organized as follows: first, an overview of the related work and background research is given, then the proposed data model is explained in detail, which is followed by the overview of algorithms used for the automation procedure. The next section introduces research results, upon which conclusions are drawn and discussed in the final section.

2. Related work

A number of data models have already been suggested for modeling urban environments. They typically range from those suitable for small scale models, such as architectural modeling, to large scale ones suitable for urban planning or monitoring, typically relying on the principles of Geographic Information Science (GIS). A number of initiatives also aim to merge various models using unique standard that would allow multiple representations in various levels of detail, scales and dimensions, the most famous of them probably being CityGML (Kolbe, 2009). Those models, however, focus on describing objects in and around urban architectural void rather than the spaces themselves. E.g. CityGML only supports representation of hollow spaces with non-ambiguous boundaries such as spaces inside tunnels (Borrmann, Kolbe, Donaubauer, Steuer, & Jubierre, 2013).

Information becomes spatial through spatial referencing, typically using coordinates, spatial relations, or place names and other identifiers. Kuhn (2012) have summarized the core concepts of spatial information that connect spatial thinking to computing and provide a high-level vocabulary about phenomena in space and time. Based on their definitions, this research aims to propose a spatial data model that would be able to store data and provide information using all of the core concepts, depending on the demand.

Another important feature of the model is its multidimensionality, when the data is stored and manipulated in 3 physical dimensions with the possibility for future extension by time and scale. The demand for multidimensionality comes from the frequent criticism of such urban analysis methods as Space Syntax, which fail to account for the effects of building heights, topography, non-planar networks and other factors (Ratti, 2004).

While field-based representation of the urban architectural void only requires 3-dimensional limits of the open space to be known, the network and object-based representations demands decomposition of the urban void into separate compartments. Compartments serve for storing data and information, faster space-search and establishment of topology. Space compartmentalization has been explored by various researches and not only for the purpose of urban analysis. Hale, Youngblood, and Dixit (2008) have given an overview of space compartmentalization algorithms for the agent navigation in the virtual worlds. The reviewed approaches (Space Filling Volumes, Navigation Mesh construction, DEACCON) do suggest robust algorithms for space decomposition, however, focus on providing navigational meshes of the virtual world instead of decomposing the space based on agent's perception.

In a popular approach of Space Syntax (Hillier & Hanson, 1984), spaces are represented by axial lines — the longest directional lines of uninterrupted movement and visibility in two-dimensional urban spaces. Even though Jiang and Liu (2010) developed a set of algorithms, which calculate axial lines automatically, the polygons of spaces need to be given as an input and such data is rarely available on a large scale. Beirão et al. (2015) have further discretized the urban void into convex and solid voids producing 3D representations by considering the height of space surrounding buildings. However, all these representations of urban architectural void also favor the dominant, well-defined open spaces, whose geometrical form tend to determine the surrounding building layout (Teller, 2003) disregarding the residual ones that are formed by the capricious layout of built structures.

The only aspect all the previously mentioned researches agree on is the convexity of a single compartment. This assumption comes from the mental tendency to organize open space as defined by discrete entities similar to the objects we interact with in our daily lives (Teller, 2003). In addition, if all discrete regions are convex, every point inside a single region is visible (and accessible) from every other point located in that region (Hale et al., 2008).

The most popular procedure of generating convex maps for the purpose of urban analysis has been described by Hillier and Hanson (1984), however the lack of automatic methods confirms that the translation of the initial description into an algorithm is not straightforward. Even though convex partitioning of polygons is a basic problem of computational geometry (Preparata & Shamos, 1985), the subdivision of a polygon with holes has been proven to belong to the NP Hard complexity class (Lingas, 1982). Moreover, standard methods only incidentally produce partitions that are relevant from a spatial analysis perspective (Carranza & Koch, 2013). One of the few methods suitable for subdividing architectural plans into non-overlapping, convex partitions has been developed by Carranza and Koch (2013) based on the medial axis transform, taking into account the 2D geometry of buildings.

Regarding all the mentioned research, this paper presents a method for the compartmentalization of the urban void as a 3-dimensional continuous space in between visual, physical or perceptual limits that emerge in the urban environments.

3. Data model

Model Driven Engineering (MDE) represents a software engineering approach which allows creating links between systems. The systems are represented by models which conform to meta-models and which can be transformed into other models based on the given definitions (Bézivin, 2005). The advantages for MDE include simplifying the design process and re-using standardized models and their components. Thus, rather than building the variants of each new system from scratch, domain-specific reusable components are implemented (Czarnecki & Eisenecker, 2000).