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Ying, Shen; Van Oosterom, Peter; Fan, Hongchao

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New Techniques and Methods for Modelling, Visualization, and Analysis of a 3D City

Shen Ying[1] · **Peter Van Oosterom**[2] · **Hongchao Fan**[3]

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Abstract
The recent years observe the vast development in new techniques and methods for modelling, visualization, and analysis of 3D digital cities, as the need of digital twins of urban environment in different applications and simulations has been increased dramatically. This special issue attempts to give an overview of the recent progress and future tendency of research activities in the aforementioned domain. The special issue includes seven articles with topics ranging from data acquisition and data processing, to data modelling and applications. The experience in this special issue says that 3D building models should contain semantic information for various applications and therefore set the corresponding requirement in techniques and methods for 3D objects detection and modelling.

Keywords 3D model · CityGML · 3D city model · Street image · Urban analysis

Semantics, geometries, and spatial relationships of 3D city objects are fundamental elements for smart cities. Modelling 3D cities includes extracting the semantics and spatial geometry of 3D city objects and reconstruct city scenes with them to support precise 3D city analysis, like solar radiation and heating analysis, airflow facility management, energy simulation, disaster management, and digital government in 3D environments.

In this special issue, we called for research and application-oriented papers closely related to the topics of modelling, visualizing, and analyzing 3D city models that contain rich information of semantics, geometries, and topologies. In total, we gathered seven articles in this special issue. These seven articles contributed techniques and knowledges which almost cover the whole life of 3D digital cities, namely, from data acquisition and data processing, to data modelling and applications.

In the domain of GIS, CityGML is the best and worldwide well-recognized exchange format and language for 3D city modelling. CityGML became OGC (Open Geospatial Consortium) standard in the year of 2008 (Kolbe 2009). From then on, an increasing number of municipalities started using CityGML to model 3D digital cities, especially in Western European countries, because CityGML has the promising mechanism to integrate semantic and attribute information within 3D geometric information. The latest version of CityGML 3.0 reveals that its Conceptual Model provides models for the most important types of objects within virtual 3D city and landscape models. Its feature types include building, bridge, tunnel, city furniture, CityObjectGroup, land use, relief, transportation, vegetation, and water body (Kolbe et al. 2022).

Nevertheless, there are many other types of geospatial data which cannot easily be modeled in CityGML because their data feature types have not yet been modelled in CityGML. Fortunately, CityGML offers the mechanism of ADE (Application Domain Extension) to solve this kind of problem. In the article (Liamis and Mimis 2022), an example of such an ADE was developed to store and exchange real estate data. The new extension module proposed in this work

✉ Shen Ying
shy@whu.edu.cn

Peter Van Oosterom
P.J.M.vanOosterom@tudelft.nl

Hongchao Fan
hongchao.fan@ntnu.no

[1] School of Resource and Environmental Sciences, Wuhan University, Wuhan, China

[2] Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands

[3] Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway

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is called GRextADE. Unlike previous work, GRextADE also proposes a specific XSD/UML. This makes the module more general and it can easily be applied for applications. Moreover, GRextADE does not simply expand the capabilities of the base standard but also describes national peculiarities that characterize the Greek laws and regulations.

Since CityGML is now regarded as standard modelling language in many countries, it is a default requirement to generate 3D building models in CityGML in many projects. In the work presented by Zhang et al. (2021), the authors developed an interactive and low-cost solution for 3D building modeling from street-level VGI (Volunteered Geographic Information) images. The platform is called VGI3D. It allows internet users to upload images of building façades through a WebGL-based interface. This platform requests least interventions from internet contributors because it integrates a deep learning-based approach (Fan et al. 2021; Kong and Fan 2021) to detect façade objects such as windows and doors automatically. The detected façade objects are then projected from the 2D image coordinate system to the 3D façade system and are georeferenced by taking the corresponding edges of building footprints on OpenStreetMap (OSM). The roof structure of a building is reconstructed with a model-driven approach. And the final 3D building models are stored by CityGML format since semantic information is also collected at the same time when processing geometrical information.

Mao and Li (2020) proposed a method which could generate 3D polygonal building models from CAD blueprint. In this method, a CAD plan needs to be generalized based on K-means clustering in the first step. Then, a line segment graph is generated to represent the generalized CAD blueprint. In the third step, 3D cadastral information can be automatically created using the relations among floor information and semantic tags in the CAD blueprint. The 3D cadastral model generated in this way is represented as polygons and can therefore be further modelled by using CityGML as indoor environment. Besides the applications mentioned in this article, the method proposed in this paper could also be deployed to generate BIM models, as shown in the work conducted by VARLIK and DURSUN (2022). Different city, indoor, and component LOD models can be derived and they can be assembled to create the LODs of building models suited for particular applications (Tang et al. 2020). As a special field, 3D cadasters can be enriched with rights, responsibilities, and restrictions in a 3D legal space, as a part of a 3D city model that may not be consistent with what the physical objects look like, to analyze, visualize, and manage the 3D properties and 3D land spaces through all the processes of land administration (Ying et al. 2015; Dimopoulou et al. 2018; Pouliot et al. 2018; Ying et al. 2019; Kalogianni et al. 2020).

For applications using 3D building models, Mao and Li (2020) proposed a graph-based method to extract semantic information together with generalized information such as number of windows, height between floors, and structure of roof. In their work, the simulation was designed for energy calculation of sustainability analysis on a city level. In the project where the proposed method was tested, a module of EnergyADE was used to model energy-related information with 3D building models. This is important evidence that CityGML and its ADE have been used in big projects. On the other hand, it is worth pointing out that the proposed method can also serve as a typification tool for model generalization, by which a similar type of building components such as windows or balconies will be represented as the prototype with different transformation parameters. It can hence reduce data amount aiming to speed up data transmission during 3D visualization.

Another application of 3D city models in this special issue is the work presented by Li et al. (2021). In their work, the method of visibility analysis based on 3D objects was deployed to evaluate the friendliness of pedestrian footbridges. Adopting the perspective of visibility, viewshed, degree of dispersion, function compactness, and landscape esthetics are selected using the Pearson correlation coefficient. Combined with spatial analysis theory and mathematical modeling, the entropy weight method is used to calculate the comprehensive index. After that, an evaluation could be carried out by scoring the pedestrian friendliness of footbridges. The proposed approach has the potential for more precise evaluation by taking into consideration 3D terrains and other 3D city object models.

Besides 3D building models, 3D city models also need other types of 2D or 3D objects since they are indivisible components in urban area. For instance, land use and land cover are important information in the virtual 3D environment in an urban area and therefore need to be modeled and visualized together with 3D city models. In the work of Du et al. (2020), the state of the art for classification of land cover and land use from satellite and aerial images is presented. In this work, four different types of classification methods (i.e., support vector machine (SVM)-based kernel learning, semi-supervised and active learning, ensemble learning, and deep learning) were reviewed and compared from the existing research work. The authors concluded that machine learning methods are very effective in handling geospatial data. Following this conclusion, another article (Wang et al. 2019) in this special issue proposed a method for the classification of high-resolution remote sensing images by using ResNet. This method can well identify different scenes including buildings and built-up area in urban regions. The results could be further used for object detection and 3D reconstruction in other related tasks.

As elaborated above, the seven articles in this special issue cover the topics 3D modelling, 3D generation, 3D simulation, and 3D calculation, as well as extraction of information in 3D city environments. The concepts, frameworks, and methods presented in this special issue reflect current research trends in the domain of 3D city modelling. They have great potential to be further improved and adapted for different applications in future projects.

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Declarations

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