ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20240909232934

Original scientific paper
Received: 2024-09-09, Accepted: 2024-10-25

Assessment and the Future Development of the Zagreb 3D City Model

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Abstract: The first 3D model of the city of Zagreb was developed in 2008. Since then, the model has been improved and updated. Today, it is used for various purposes in the city planning and management. It is also publicly available to citizens through the ZG3D Web application. In this paper, an assessment of the existing 3D model is provided by considering different factors (i.e. consistency between models, standardization, data quality, data interoperability, data maintenance/governance, and use cases) that need to be tackled in order for the 3D city model to be further improved and used towards the creation of the digital twin and ultimately to support the smart city concept. The assessment considered some general criteria and also the 3D City Index assessment tool developed by the Urban Analytics Lab, National University of Singapore (NUS). The assessment results show that the existing model is used for various purposes, but to evolve towards a true digital twin, it must be improved.

Keywords: 3D city model; assessment; city of Zagreb

1 INTRODUCTION

In today's digital age, analogue maps are increasingly being replaced by 3D digital models that have become the basis for planning and managing space, especially in urban areas. Digital city twins and smart cities need 3D city models as a basis for further development. Thanks to surveying and ICT developments, 3D models are already mainstream in many cities around the world. Their usage is evident in many different areas. New challenges arise with the smart city concept. There, the 3D city model is not enough, but rather a digital twin that integrates static 3D city models with different sensors.

3D city models are available in two different representations. Semantic 3D models (information models) and 3D mesh models. The two have established themselves as valuable tools for the digital description of the physical environment. Their characteristics, usage scenarios, and production methods are, however, different. There are also use cases when both model types can be complementary [12].

3D city model provides numerous potential advantages and benefits in the maintenance of city infrastructure, including simpler and more efficient management, reduction of redundancy, easier access to relevant information, easier communication, etc. [21].

The City of Zagreb also followed this trend through the development of the initial 3D model in 2008 [1, 2]. Since then, the initial 3D model has been updated several times, which was mostly done at certain city locations of interest [3, 4].

The city of Zagreb, like other major cities, is complex and requires a lot of effort to measure and model it. Therefore, usually, only a part of a city (e.g. a building or a group of buildings) is measured and modelled at one time. Moreover, any single act of measuring and modelling a city is not enough, because cities are never completed, but continue to expand and develop. Given the needs of modern cities, existing 3D models are not sufficient because they most often represent static models. The development of the Internet of Things (IoT) imposes the need to integrate a static 3D model with various sensors and create a dynamic environment that can meet the increasing needs and challenges of cities for sustainable real-time management. The biggest challenge urban management teams face today in data-driven processes is to extract value from the ever-increasing volume, frequency of change, and diversity of data, also known as Big data).

Stoter et al. [5] state several basic challenges regarding 3D data models:

- consistency between models
- standardization
- data quality
- data interoperability
- data maintenance/governance
- from utopian pilots to real-world use cases.

All listed challenges need to be tackled in order for 3D city models to be used for sustainable urban environments.

Existing studies usually validate some aspects of 3D models such as geometry [15], compliance with standards [16], [17], and application requirements [18]. Also, metadata for describing 3D models [19] and data openness [20], [22] are in focus.

In this paper, an assessment of the existing Zagreb 3D city model is provided by considering above mentioned challenges [5]. The assessment was done as a combination of different factors including previous studies [7], other data sources (e.g. cadastral data), 3D city index [6] which is a very comprehensive and relevant tool, and also insights from the city employees who are in charge of the data, but also data users.

2 ZAGREB 3D CITY MODEL

The Zagreb 3D city model is under the responsibility of the City Office for Economy, Environmental Sustainability and Strategic Planning [13]. The office is in charge of data maintenance, as well as data sharing and publishing.

2.1 The Existing Model

The initiative for the creation of a 3D model came in 2008 from the private company Geofoto LLC from Zagreb. The idea was to create a digital terrain model (DTM), a 3D building model and a true orthophoto map. Geofoto conducted aerial photography in September 2008, taking 4,000 shots (Ground Sample Distance = 8 cm) with 80% overlap within the array and 60% between the arrays. The model was created by using photogrammetric mapping of roof lines, along with DTM, aero-photo and real ortho-photo shots. A physical model of the city with 3D printing technology was also made [8]. The most of the 3D model was made at the level of detail LOD 2 [9].

The city office responsible for spatial planning took over the 3D model only a few years later, due to slow and complicated public procurement procedures. At the time of the takeover, the city had two main objectives: to assess the data quality and its fit for purpose in the city planning. In addition, the plan included the development of an online application for reviewing and using the 3D city model. In 2014, the Faculty of Geodesy at the University of Zagreb made a quality test of the 3D model. The project included the following [2]:

- Data analysis of the existing 3D model
- Quality assessment of existing 3D model data in accordance with HRN EN ISO 19157:2014 Geoinformation - Data quality (integrity, logical consistency, positional and altitude accuracy, thematic accuracy, temporal quality, usability).
- Transformation of data into the official coordinate system and cartographic projection of the Republic of Croatia
- Harmonization of data according to INSPIRE (Infrastructure for Spatial Information in Europe) data specifications (Buildings and Heights)
- Data testing in AutoDesk and ESRI software packages
- Creating 3D displays - visualization for the areas of 15 strategic city projects (shadow displays, minimum 4 for each area)
- Analysis of the volume of buildings for the areas of strategic city projects
- Guidelines for updating and creating a web application for using 3D model data
- Guidelines for the integration of 3D model data into the Zagreb Spatial Data Infrastructure.

Figure 1 Zagreb 3D city model in the ZG3D Web application (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

Overall the results showed that data was incomplete and inconsistent. For the purpose of wider application, the company GDi, created the Web application ZG3D in 2016 (Fig. 1).

The application contains 3D building data in combination with other 3D and 2D data layers in the areas of urban planning, architecture, topography, geotechnics, public green spaces, heritage protection, urban renewal and statistics [10].

2.2 Applications of the existing model

There are many areas in which the existing model is already in use or is planned to be used [3].

In July 2022, the Energy Info Centre of the City of Zagreb platform was presented. The platform enables the calculation of basic parameters of solar power plants integrated into single-family houses, i.e. multi-dwelling buildings, and the basic data used are the 3D model data (Fig. 2).

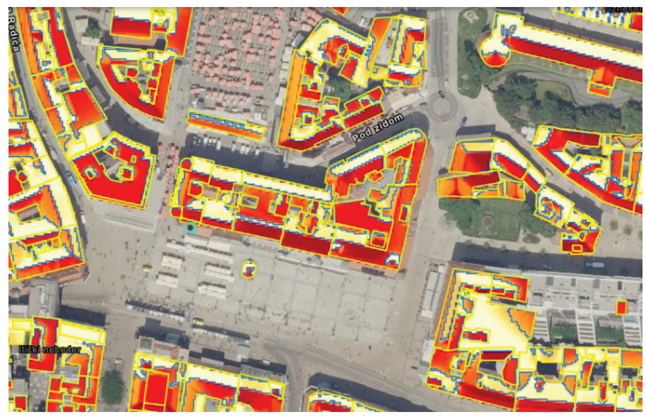

Figure 2 Map of the sunny potential of the City of Zagreb (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

The 3D model is also recognized as one of the fundamental sources for the post-earthquake reconstruction after the earthquake in 2020. A lot of projects for the reconstruction of public buildings are carried out by using Web GIS solutions with online ZG3D application integration.

2.3 Data Assessment

Data assessment in this research was made in 2024 as a continuation of previous studies (Fig. 3).

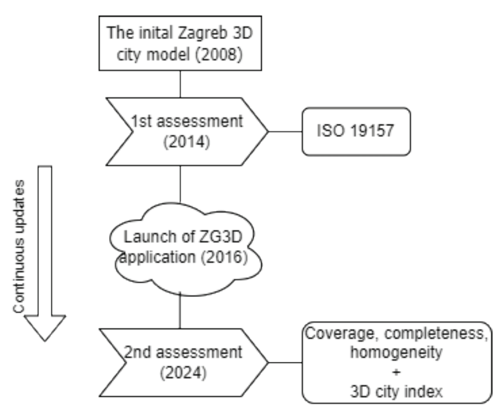

Figure 3 Methodology (source authors)

The initial 3D model was created in 2008 only for the urban area, but the data update over the years was slow and based on a fragmented project approach. There were several reasons, the lack of resources and the usage of 3D collected data from different projects in the city area. The updates were made mostly using LiDAR and aero-photogrammetry data from 2012, and unmanned aerial vehicle images in 2016, 2019 and 2020. The existing model is semantic in mostly LOD 2 and for some areas LOD 1. Fig. 4 shows the current coverage of the 3D model.

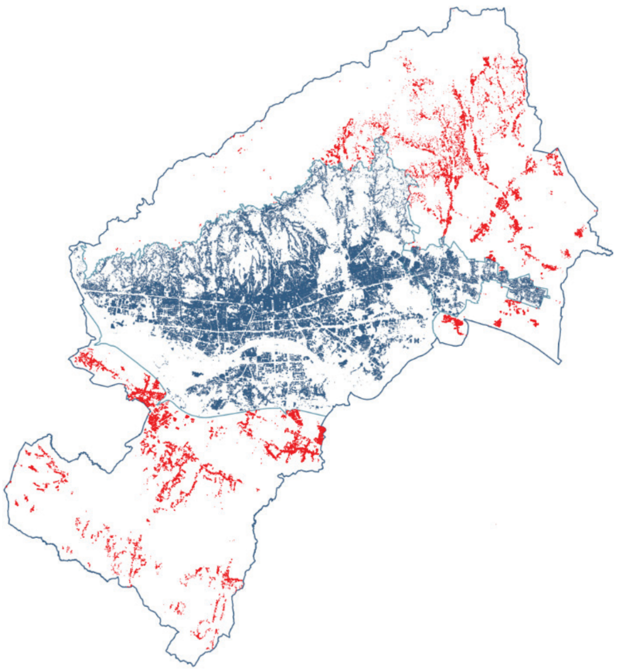

Figure 4 Zagreb 3D city model coverage (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

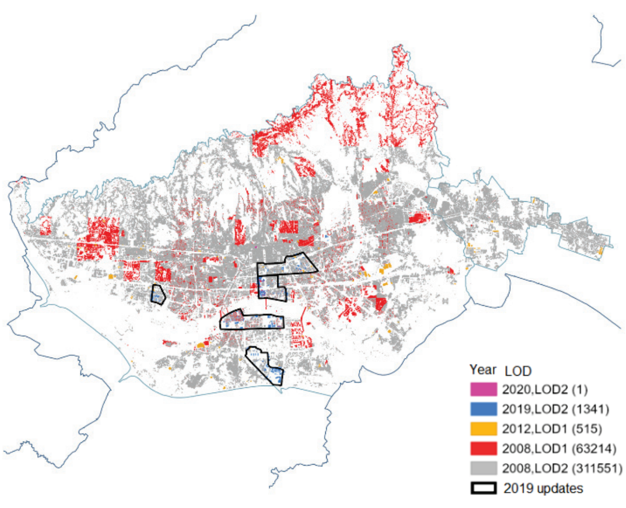

Figure 5 Zagreb 3D city model 3D model coverage by the year of recording and level of detail (LoD) (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

The coverage with a 3D model is approximately 37 % of the whole administrative area of the City of Zagreb. The 3D model contains an estimated 80% of buildings (the blue part) compared with cadastral map data.

The existing 3D model data are still largely outdated and inhomogeneous despite updates in recent years (Fig. 5).

Fig. 6 and Fig. 7 show the out-of-dateness and inhomogeneity of the data of the 3D model in more detail.

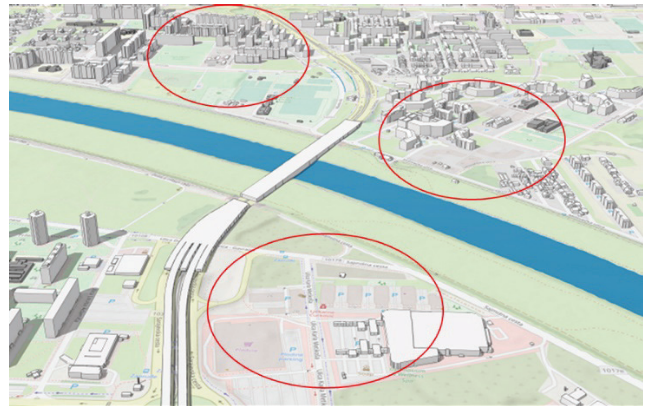

Figure 6 Out-of-date of the existing 3D model (absence of buildings) (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

Figure 7 Inhomogeneity of the existing 3D model (different LoDs) (source Zagreb City Office for Economy, Environmental Sustainability and Strategic Planning)

After the initial assessment, the 3D City Index Assessment [6] developed by the Urban Analytics Lab [14] was used for the more comprehensive assessment of the existing 3D model.

The 3D city index is a holistic and comprehensive framework containing 4 categories. It includes 47 criteria for identification of the main features of 3D city models, enabling their assessment and comparison, as well as for suggesting usability. The implementation of the framework enables a comprehensive and structured understanding of the landscape of semantic 3D geospatial data, as well as a double assessment of the collection of open 3D models of cities.

Additional benefits of this framework are reflected in the standardisation of 3D data characterisation: monitor developments and trends in 3D modelling of cities and enable findability of the fit-for-purpose datasets to all interested users to satisfy their needs. The framework is designed for continuous measurement of datasets and can also be applied to other instances in the spatial data infrastructure.

The 3D City Index contains the following categories:

1) Data Portal
2) Basic Information
3) Thematic Content
4) Attribute Content.

In each category, there is a set of criteria to comprehensively highlight different viewpoints [11].

The maximum total score can be 47 points based on the 4 categories (Tab. 1):

1) The Data Portal category is scored with max. 6 points.
2) Basic Information category is scored with max. 15 points.
3) Thematic Content category is scored with max. 11 points.
4) The Attribute Content category is scored with max. 15 points.

Better scores of course reflect better performance. The framework is generic and flexible by allowing users to adapt it to specific use cases or geospatial context. To obtain a standardised comparison, the scoring system tries to give a result from two aspects. One is an overview of the measures of the included 3D models by comparing their performance, and the second is a study of the properties of datasets within each category. Users can select the relevant parts in the dataset.

The Zagreb 3D city model was scored with a total of 26 points [7] (Tab. 1), which places it relatively high on the current list of scoring cities between, for example, Helsinki with 32 points and Vienna with 24 points.

Table 1 Zagreb 3D city index assessment

Category	Criteria	3D model of the City of Zagreb
Data portal	1C1 - Does the dataset have a dedicated website?	YES
	1C2 - Is there a web browser in 3D?	YES
	1C3 - Is there near real-time information in the viewer?	YES
	1C4 - Is it available in local language?	YES
	1C5 - Is it available in English?	NO
	1C6 - Is there a way to leave feedback?	YES
Background information	2C1 - Is this a semantic 3D (information) model?	YES
	2C2 - Is it a 3D mesh model?	YES
	2C3 - Can it be downloaded?	YES
	2C4 - Is it free?	YES
	2C5 - Can it be downloaded without registration?	NO
	2C6 - Is it available for download in more than one format?	YES
	2C7 - Is it generated using open data standards?	NO
	2C8 - Is it openly licensed?	NO
	2C9 - Does it provide metadata?	YES
	2C10 – Has it been published recently (in the last 5 years)?	NO
	2C11 - Is it up to date?	YES
	2C12 - Is there a plan to update?	YES
	2C13 - Does it preserve historical datasets?	NO
	2C14 - Does it include more than one level of detail (LoD)?	YES
	2C15 - Does it cover the entire administrative unit?	NO
Thematic content	3C1 - Are buildings modelled with semantic differentiated surfaces?	YES
	3C2 - Does it contain bridges?	YES
	3C3 - Does it contain land use?	YES
	3C4 - Does the terrain contain?	YES
	3C5 - Does it contain roads?	NO
	3C6 - Does it contain tunnels?	NO
	3C7 - Does it contain lines?	NO
	3C8 - Does it contain urban equipment?	NO
	3C9 - Does it contain vegetation?	YES
	3C10 - Does it contain individual trees?	YES
	3C11 - Does it contain water bodies?	YES
Attribute content	4C1 - Does it contain a postal code?	YES
	4C2 - Do buildings have a texture?	NO
	4C3 - Does the building ID contain?	NO
	4C4 - Does it have a year of construction?	NO
	4C5 - Does it contain the address of the buildings?	NO
	4C6 - Does it contain a building function?	YES
	4C7 - Does it contain the height of the buildings?	YES
	4C8 - Does the volume of buildings contain?	YES
	4C9 - Does it contain a catholicity?	NO
	4C10 - Does it contain a wall surface?	YES
	4C11 - Does it contain a roof surface?	NO
	4C12 - Does it contain a type of roof?	NO
	4C13 - Does it contain the surface of the terrain under the building?	NO
	4C14 - Does it contain gross floor area?	NO
	4C15 - Does it contain building materials?	NO

Such a status confirms the assumption of a quality concept and the correct development of the 3D model project of the City of Zagreb so far. However, it is necessary to bear in mind the shortcomings of the existing 3D model in terms of non-coverage, inhomogeneity and out-of-date existing data, which ultimately results in the necessary and unquestionable need for its further development and updating.

3 DISCUSSION

To improve the existing 3D model and create a digital twin for further development a set of guidelines is proposed.

When defining the guidelines, all the facts listed in the previous chapters were used, including the state of the art, regulations, theory, foreign experiences, characteristics of the existing model and the need for its application.

I) Selection of 3D model types:

- It is recommended to create a semantic 3D model of the level of detail LOD 2.2 for the entire city administrative area.
- It is recommended to create a network photo realistic 3D model for the area of protected building units and individual protected buildings outside protected units, as well as other significant buildings (investments, tourist significant buildings, etc.).

II) Priorities:

- It is recommended to create a semantic 3D model of the level of detail LOD 2.2 for the area not previously covered by the 3D model of the City of Zagreb (63% of the administrative area, approx. 20% and 40,000 buildings, respectively).
- It is recommended to create a semantic 3D model of the level of detail LOD 2.2 for all complete areas where in the existing model the data are at the level of detail LOD 1 (approx. 40,000 buildings).
- When updating, it is necessary to assess the state of the existing 3D model in a particular area, and accordingly maintain or delete the existing models. In doing so, it is necessary to consider the geometric accuracy and fidelity of the model, as well as recommendations on linking with official registers.
- It is recommended to carry out the update according to predefined milestones, and include the updated data as soon as possible in existing applications and applications, providing information on the up-to-date of the data.

III) To update the existing 3D model, it is proposed to use the data of multisensor imaging of the Republic of Croatia:

- It is recommended to use LiDAR data for the City of Zagreb as well as other products (DOF5, DMR and DMP) from multisensor imaging of the Republic of Croatia (SGA) to create a semantic 3D model of the level of detail LOD 2.2. This data can be used directly to update and complement the existing model with missing objects.
- It is recommended to use existing data sources (terrestrial and aero-photogrammetric UAV imaging) if they exist, or to conduct a new data collection (recommendation aero-photogrammetric UAV and/or LiDAR imaging) to create an online photo-realistic 3D model.

IV) Link the 3D model to the official registers:

- It is recommended to align the semantic model with the cadastral parcels of the real estate cadastre (land), according to the principle that one model of the building is located on a floor plan on one or possibly more cadastral parcels.
- It is recommended to align the semantic model with the official address model of the Regional Register of Spatial Units of the City of Zagreb
- It is recommended to align the semantic model in the future with the building register when it officially begins to be produced for the City of Zagreb.

V) Formats:

- It is recommended to convert all existing data once that will not be updated to CityGML 2.0 format and put such data to open use.
- It is recommended to convert new or updated data to CityGML 2.0 format and put such data to open use.

VI) Technology:

- It is recommended to use the ESRI technology platform because it enables the correct technical development of the model, and at the same time it is used as a basic GIS platform for the city administration.

VII) Recommendations for further maintenance and updating of data:

- It is recommended to maintain the new (or improved) model regularly, ideally when completing the construction of individual buildings, after the issue of a use permit or registration in the cadastre. Implementation requires the establishment of a clear procedure, work process, stakeholders and financial resources.
- It is recommended to update the complete model periodically, in accordance with the development of new official LiDAR and aero-photogrammetry imaging, or based on imaging specifically ordered for the purpose of updating the model.
- It is recommended to provide funding for model updates from sources outside the city budget (EU and national funds and projects). Funding is possible through projects using 3D models as a data source, analytics or visualisation technology and platform.

VIII) Recommendations for the development of a digital twin:

- When updating the existing 3D model, it is recommended to expand the model in thematic terms by including transport and energy infrastructure, and other content that is missing in the existing model and exists in the real world.
- It is recommended to connect the new (or improved) 3D model with various sensors in real-time (traffic, lines, environmental monitoring, etc.) which will support the monitoring and functioning of the city in real-time. Additionally, carry out accuracy and reliability analyses of the data collected so far.

4 CONCLUSION

This paper aimed to investigate if the existing Zagreb 3D city model fits the new challenges towards the digital twin and ultimately the smart city concept. The model was assessed by using different criteria. The general ones like completeness, coverage, homogeneity and up-to-dateness showed that there are serious gaps in the existing model. The further assessment used the 3D city index. The overall score shows that the existing model is not bad but however, needs improvement and future developments.

Based on the assessment results a set of recommendations (guidelines) is proposed. The guidelines for further development and improvement cover the topics of choice of model type, priorities for updating, input data sources, technology, data format, further update, digital twin development, and application in smart city development.

By following the proposed guidelines, the existing Zagreb 3D city model could be significantly upgraded and improved to evolve towards the real digital twin.

Acknowledgment

The research was partially supported by University North, Croatia, Scientific project UNIN-TEH-24-1-16 "The role of geodesy and geomatics in the development of smart spaces (2024)".

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