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# USE OF LiDAR TECHNOLOGY AND CITYGML IN THE PROCESS OF DIGITALIZATION OF CULTURAL HERITAGE

**Abstract**. Cultural heritage is the foundation of a country's culture. The importance of cultural heritage documentation is recognized, and there is a growing need to document and preserve them also digitally. In order to maintain preservation and restoration of certain sights, it is necessary to know all information of such objects. With the progress of modern technologies, there are increasing opportunities for the collection, processing and visualization of objects with national significance. LiDAR technology has emerged as one of the most efficient methods of collecting data nowadays. It offers a fast, high quality and accurate 3D model. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges to the Earth. Main aim of this paper is to show how, using this technology, data of objects with significance can be collected and stored in database. Study area is Petrovardin Fortress, which is located in Novi Sad, Autonomous Province of Vojvodina, Serbia. The present fortress was built by Austria from 1692 to 1780. It represents the biggest symbol of Novi Sad. The collected data were obtained in the form of a point cloud. Further processing of data brings a classified point cloud and 3D representation. The 3D vector data that was extracted are stored in 3DCityDB. CityGML is a common information model and XML-based encoding for the representation, storage, and exchange of virtual 3D city and landscape models. CityGML provides a standard model and mechanism for describing 3D objects with respect to their geometry, topology, semantics and appearance, and defines five different levels of detail. The results of this paper are in the LOD 2 level.
**Keywords:** LiDAR, cultural heritage, CityGML, 3DCityDB, preservation

## 1. Introduction

Reconstructing objects of interest and the scenes is an important topic not only for surveying but also for data visualization and archiving. Recently, the main focus of research is on 3D reconstruction based on 2D image data, the laser scanning technology gets nowadays more and more popular. 3D digitization has found it's place in a lot of areas including reverse engineering, quality control, virtual reality and digital heritage. Cultural heritage is an essential part of one nation. It includes artifacts such as paintings, drawings, mosaics, sculptures, and historical monuments, buildings, as well as archaeological sites. The goal is to preserve these elements of the past in any way possible. There is a big progress in 3D digitizing technology facilitates archaeology and digital preservation of cultural heritage. The best way to save various elements of cultural heritage data is to digitize these same objects. Complete recording of Cultural Heritage is a complex process.

The problem is what technology to use for the collecting 3D data, then how to process, store and then represent the same data. Main focus is on aspects of new digital content management, representation and reproduction. Within this paper, the methodology of data collecting with the latest LiDAR technology will be exposed and how these data can be stored in spatial database. Also, the processed data will be transformed and stored in the rich spatial format CityGML.

There is a lot of work on the topic of preserving cultural heritage. The most commonly used technology is laser scanning or LiDAR technology. The scanner allows the collection of large datasets which later contribute to better representation and visualization of objects. Barrile used a laser scanner to record the church S. Salvatore and then obtained data visualized through open source application WEB GIS [1]. Reynicek and Pavelika have shown the use of new cheaper technologies for recording historical monuments such as optical 3D scanner [2]. The terrestrial scanners function the same as a LiDAR, the main difference is that the terrestrial scanner is in a fixed position only in the moment of shooting. LiDAR is a mobile technology. In the case of Abmayr, the data were collected using a terrestrial scanner. Data were processed in two softwares, ZFLaserScaning and Light Form Modeler [3].

Also, a combination of 2 sets of data can be performed, such as data obtained by terrestrial recording and data from aerial vehicle photogrammetry. One of the better examples is the work of Y. H. Jo and J.Y. Kim [4]. Another example of a combination of laser scanning and photogrammetry for the purpose of documenting and recording is Al-Khasneh Monument in Petra city [5]. Amovic used only LIDAR technology and created 3D model of the faculty building [6]. In the work of Pajic, the process of terrestrial scanning, collecting and modeling of the facade of the City Town is shown [7]. The same principle was in the case study of Kersten [8]. One of the works dealing with the topic of LiDAR and CityGML is Malamboa and Popovic, who used similar approach like in this paper. [9] [10] Preka also used the similar approach, and the results were approximately the same [11].

## 2. Materials and Methods

**2.1. Study Area**. The study area consists of the location that represents a part of Novi Sad Petrovaradin Fortress, Serbia. Construction of the fortress lasted for 88 years, until 1780. It was built during the reign of the Austrian Emperors Leopold I, Joseph I, Charles IV, Mary Theresa and Joseph II, according to the system of building the Marquis of Petrovaradin Fortress Sebastian Voban (16533-1707), a French military commander, architect and writer. Under this system, many fortresses were built in Europe, and Petrovaradin is the largest one, spreading to more than 110 hectares, and it is observed.

The specialty of this system are high and steep slopes, coarse and deep mined shanks, all of which are flooded with water shunts and channels with mobile bridges, control gates. The picture of Petrovardin Fortress is given in Figure 1.

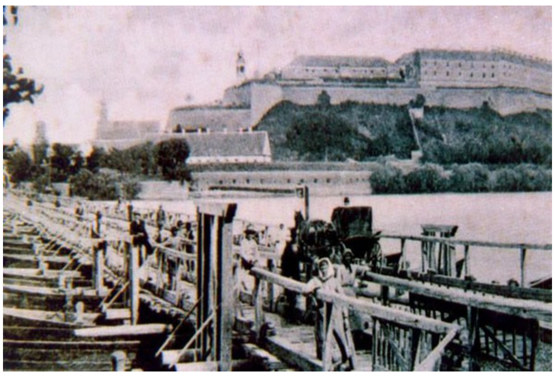

Figure 1. Petrovaradin Fortress (left: begin of XIX Century, right: present)

The Petrovaradin Fortress was completely demilitarized in the middle of the 20th century. It was proclaimed a historical monument, it was placed under state protection and reserved for civilian use. There are Museum and Archives of Novi Sad, hotels and restaurants, ateliers and galleries of fine artists, academies of art, astronomical observatory, planetarium and many other contents on the fortress. The Clock Tower is a recognizable sign of the Petrovaradin Fortress and Novi Sad.

**2.2. Technology.** The 3D Laser Scanning is a non-destructive, non-contact technology that digitally captures the shape of real objects using a line of laser light. The 3D laser scanners create point clouds of data from the surface of an object. 3D laser scanning is technology that captures a physical object's exact size and shape into digital format in 3-dimensional representation.
The Scanner methodology can be divided into 5 steps:

- Data Acquisition via 3D Laser Scanning
- Resulting Data
- Modeling Choice Depends on Application
- Point Cloud Data for Inspection
- CAD Model for Reverse Engineering

LiDAR is an "active" remote sensing technique, because the sensor both emits and records the radiation signal in the form of frequent, short-duration laser pulses. LiDAR system is a complex, multi-sensor system consisting of at least three sensors, the GPS and INS navigation sensors, and the laser scanner system[11]. LiDAR is a mobile technology that can be found on the vehicle as well as aircrafts. LiDAR instruments measure the location of objects in $x$, $y$, $z$ space when an emitted laser pulse strikes a target surface and returns a portion of that laser energy to the sensor. The elapsed time between pulse emission and detection produces the round-trip distance between the sensor and target, and the vertical distribution of surfaces can be recorded on either discrete point-by-point or continuous bases [12].

**2.3. Methodology.** Within this part of the paper, data processing and storing data in 3DCityDB. The CityGML format will be explained.

**2.3.1. Collected data.** The data is collected with LiDAR system. The point cloud and the obliques are shown in Figure 2. The obliques are collected during the scanning and they are required for the classification of points. LiDAR dataset was given in Universal Transverse Mercator (UTM) WGS 84 / UTM zone 34N -horizontal coordinate system and in Ellipsoid WGS 84, vertical coordinate system.

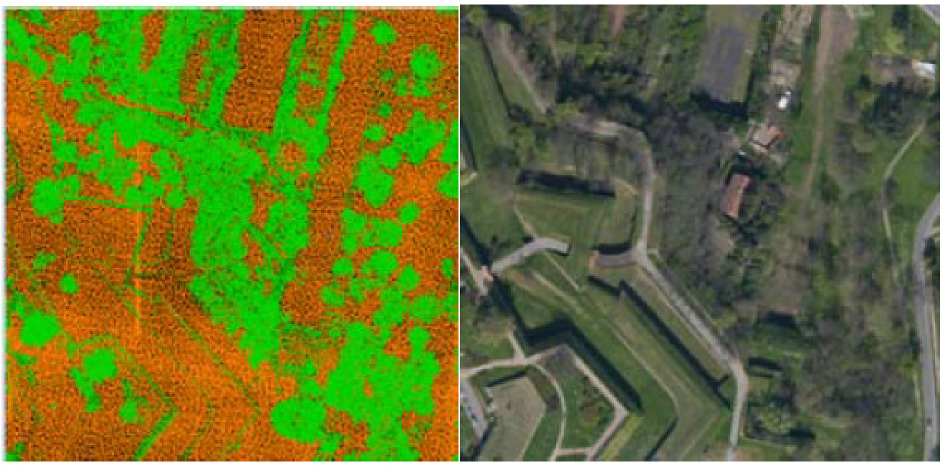

Figure 2. LiDAR point cloud and obliques

**2.3.2. Point classification and 2D/3D vectorization.** The used processing software is Microstation with extensions such as the TerraScan, TerraPhoto, Terrra Modeler. TerraScan supports several import and export formats, including the LAS format. The point cloud management, processing and visualization is only one part of TerraScan. In addition, the software provides tools for creating 3D vector data based on the laser points. There is also the opportunity to produce 3D vector models of buildings (up to LOD2) automatically over large areas. Toolsets for checking and modifying the building models manually enable the creation of more accurate and higher-quality building models. For the application field of power line processing [13].

At the very beginning the point cloud is located in the default point class. This project defined 32 different point class. After the release of an automatic macro, the three most important classes were extracted ground, vegetation, buildings. Within this work, 6 most needed ones are allocated. The class of points is defined based on the position on which it is located. If it is not possible to classify the point class of a point, it is necessary to manually find the appropriate class. Classification methods can be automatic, semi-automatic and manual. It is possible to apply each method separately over some data, but for best results all of these methods are commonly used in combination with one another [14]. The Figure 3 contains results of the point classification.


Figure 3. Point Classification

2D/3D vectorization is process where vector-formatted data is extracted from the point cloud.There is the same number of layers as the point classes.

### 2.4. Data storage in 3DCityDB and the CityGML format

**2.4.1. CityGML.** The CityGML is an open standardized data model and exchange format to store digital 3D models of cities and landscapes. It defines ways to describe most of the common 3D features and objects found in cities (such as buildings, roads, rivers, bridges, vegetation and city furniture) and the relationships between them. It also defines different standard levels of detail (LODs) for the 3D objects, which allows us to represent objects for different applications and purposes.

CityGML mainly describes the geometry, attributes and semantics of different kinds of 3D city objects. These can be supplemented with textures and/or colors in order to give a better impression of their appearance. Specific relationships between different objects can also be stored using CityGML, e.g. that a building is decomposed into three parts, or that a building has a both a carport and a balcony [15].

The CityGML supports different levels of display. Figure 4 The results of this paper are presented in LOD2.

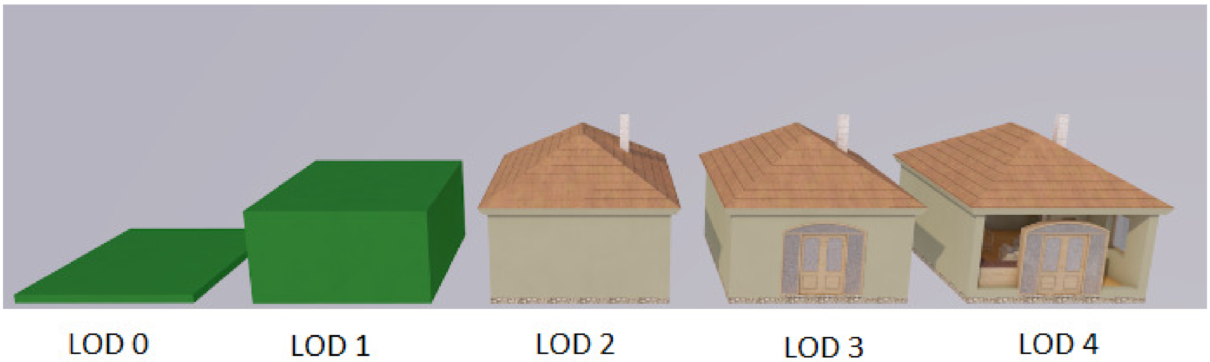


Figure 4. Level of Display

**2.4.2. Feature Manipulation Engine.** The Feature Manipulation Engine (FME) is a platform that streamlines the translation of spatial data between geometric and digital formats. It is intended especially for use with geographic information system, computer-aided design and raster graphic software [16]. Within the process of conversion from CAD to CityGML format several transformations were applied. As the result of this process the CityGML format of the Petrovardine Fortress was derived. The transformation diagram is shown in the Figure 5.

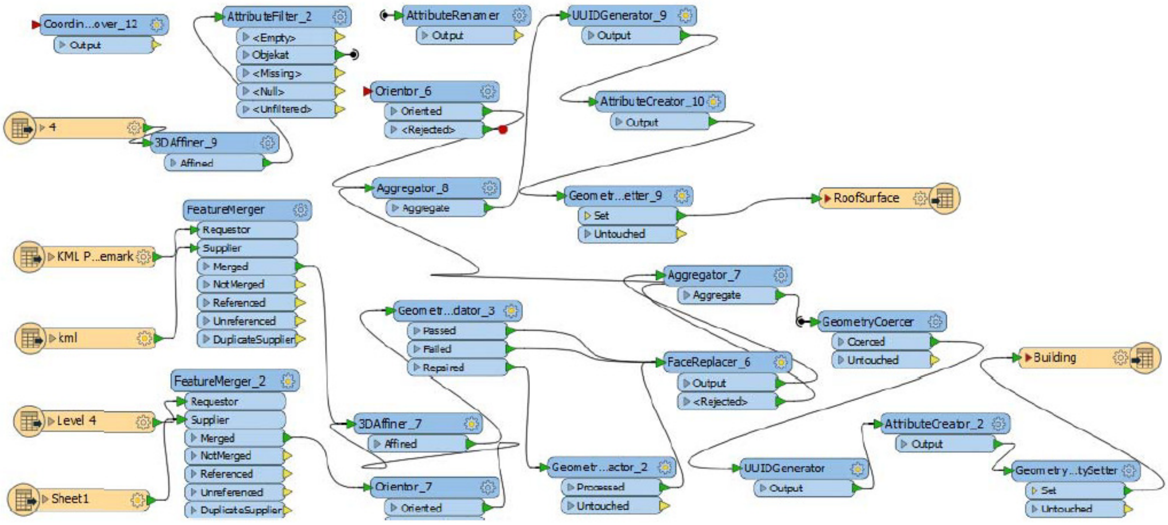


Figure 5. FME Transformation

Used transformations age given in Table 1.

| *Feature* | *Used transformations* |
|---|---|
| Building, Roof Surface | FeatureMerger, 3DAffiner, Orientor, FaceReplacer, Aggregator, GeometryCoercer, UUIDGenerator, AttributeCreater, GeometryPropertySetter |
| Plant cover | 3DAffiner, Orientator ,FaceReplacer, UUIDGenerator, AttributeCreater, GeometryPropertySetter |
| Water Body | 3DAffiner, GeometryValidator, UUIDGenerator, AttributeCreater, GeometryPropertySetter |
| Traffic Area | 3DAffiner, Orientor, FaceReplacer, Aggregator, UUIDGenerator, AttributeCreater, GeometryPropertySetter |
| Road | 3DAffiner, Orientor, FaceReplacer, Aggregator, UUIDGenerator, AttributeCreater, GeometryPropertySetter |
| City Furniture | 3DAffiner, AzimuthCalculator, VertexExtractor, AttributeFilter, FeatureMerger, SharedItemAdder, SharedItemIDSetter, Rotator, |

Table 1. Used Transformations

**2.4.3. 3D City Database.** The CityGML data was finally stored is 3D City Database model. 3D City DB is a free geo database to store, represent, and manage virtual 3D city models on top of a standard spatial relational database. The database schema implements the CityGML standard with semantically rich and multi-scale urban objects facilitating complex analysis tasks, far beyond visualization. The 3DCityDB is in productive and commercial use for more than 10 years in many places around the world. It is also employed in numerous research projects related to 3D city models [17]. The Core Model of 3DCityGML Database is given in Figure 6.

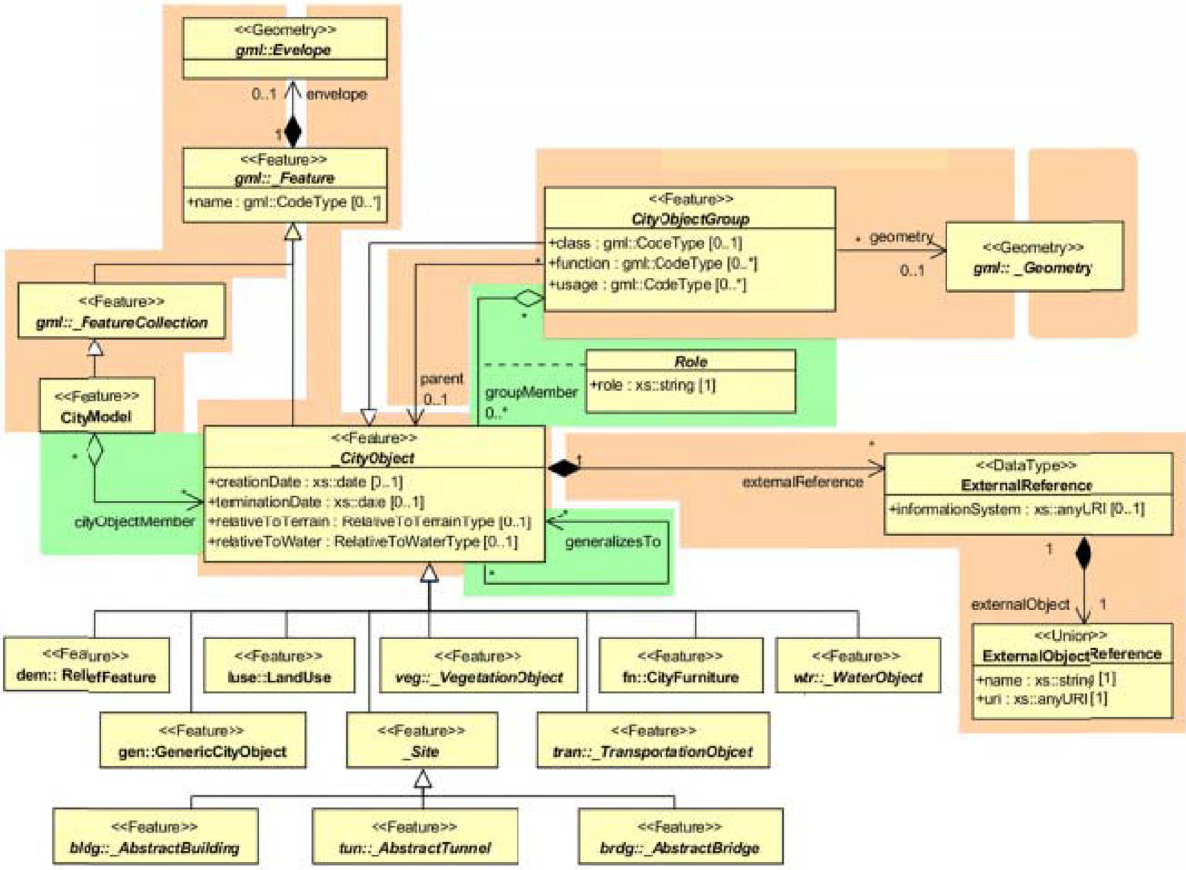


Figure 6. Core Model of 3DCityGML Database

The database was implemented in PostGIS. The PostGIS is an extension to the PostgreSQL object-relational database system which allows Geographic Information Systems objects to be stored in the database. The 3DCityDatabase Schema implemented in PostGIS is given in Figure 7.

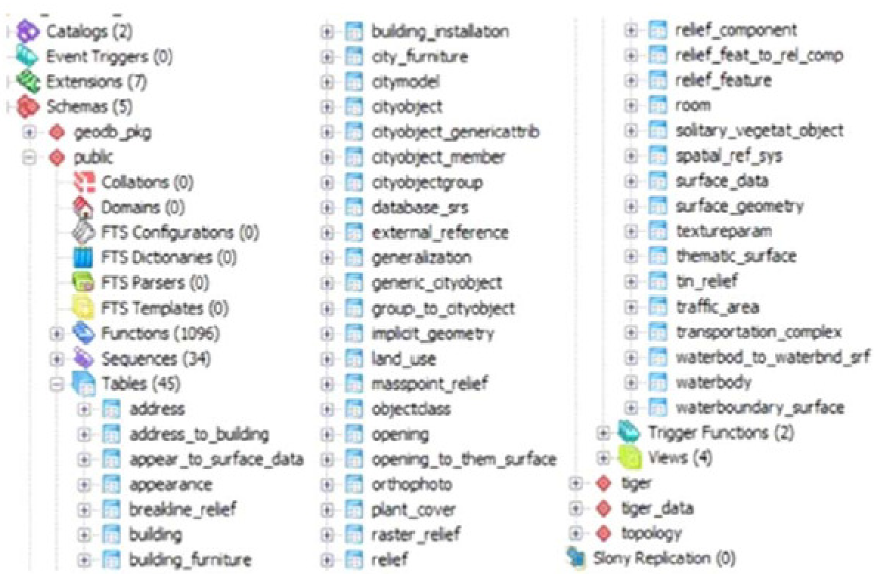


Figure 7. 3DCityDatabase Schema

## 3. Results

There are several results that can produced with this approach. The first of them is a digital plan that contains layers defined for different spatial elements. The buildings are presented with res color, roads with grey, complex polygons with green in this case. Figure 8.

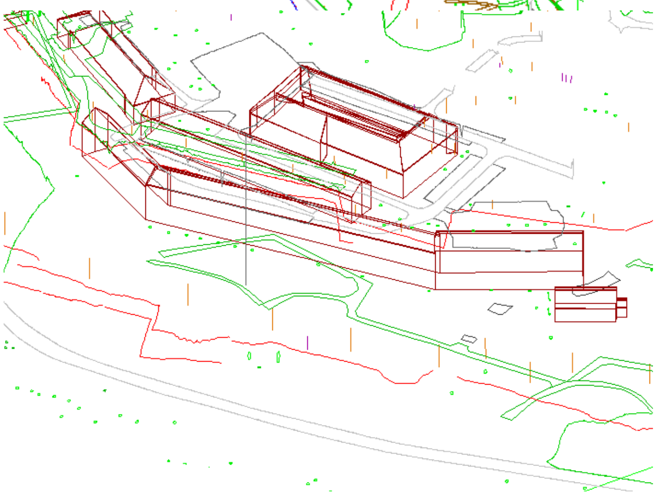

Figure 8. Vectorized: Petrovardin Fortress and Suburban: 2D (left ); 3D (right)

The next of the results of this processing is the digital elevation model. A Digital Elevation Model (DEM) is a database that represents the relief of a surface between points of known elevation. By interpolating known elevation data from sources such as LiDAR, ground surveys and photogrammetric data capture, a rectangular digital elevation model grid can be created. The Digital Surface Model (DSM) measure the height values of the first surface on the ground. This includes terrain features, vegetation buildings, etc. DSM provides a topographic model of the earth's surface (Figure 9).

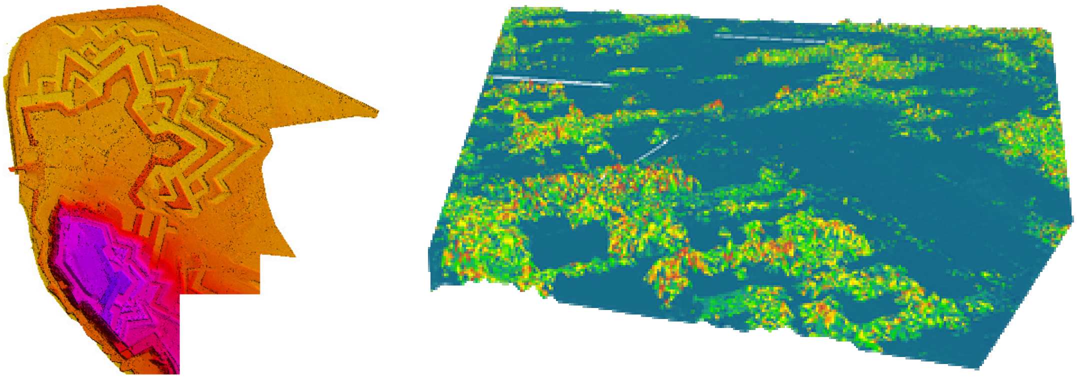

Figure 9. Petrovardin Fortress: DEM (right); DSM (left)

The final result is a format that is located in the 3D space and can be used further for processing, analyzing and manipulating data. The objects are displayed in LOD2 (Figure 10).

The next step in processing and storing data would be to add texture to objects. Texture substrates could be collected by a camera.

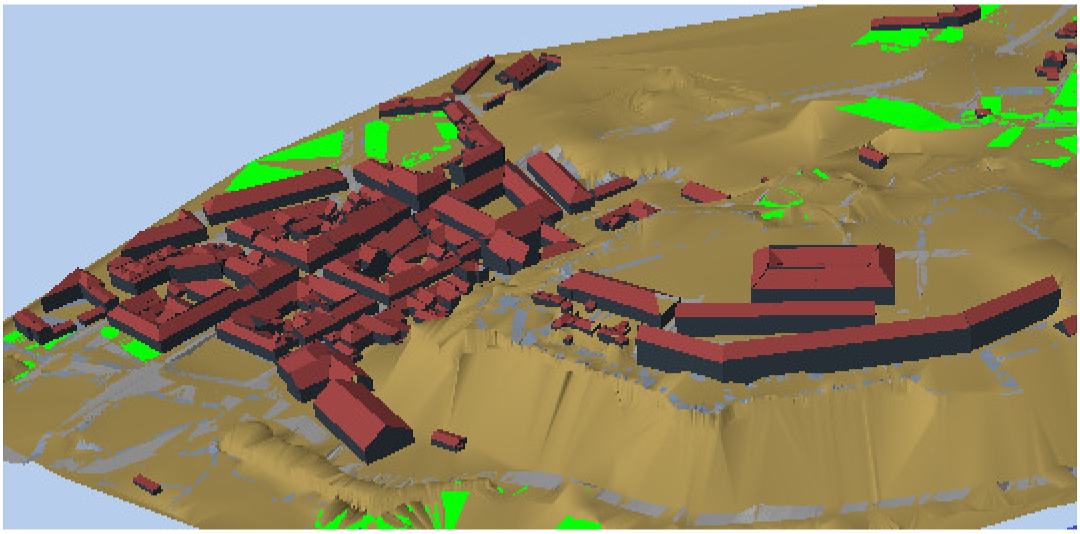

Figure 10 Petrovardin Fortress and Petovaradin Suburban in CityGML format LOD2

## 4. Conclusion

3D scanning techniques have to be preferred when very complex and irregular objects like monuments, old buildings, or archaeological findings are to be documented. Those objects can be captured by 3D scanners very accurately, precisely and in high level of detail. In addition the results of scanning projects can be presented and visualized much better than the results of any other survey method. Main aims of 3D recording are in the preservation and promotion of the cultural heritage. In this work one approach of 3D digitalization was presented. This paper demonstrate one of the most popular methods for 3D digitization that can be applied for cultural architecture recording. The models thus obtained can be actively applied in rebuilding or reconstructing the cultural heritage.

## 5. Literature

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