

# 3D MODEL AND A SCALE MODEL OF THE CITY OF ZAGREB

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## ABSTRACT:

This paper presents the process of making the virtual 3D model as well as the scale model of Croatian capital Zagreb. The whole model is based upon the photogrammetric mapping of roof structure lines. The virtual model was generated based on the photogrammetric mapping of rooflines and Digital Terrain Model (DTM) using CityGRID – a powerful technology for the 3D city data management. The whole system is based upon the relational database and is line-oriented. This line-oriented approach is the most suitable for systems which use the photogrammetry as the data extraction method. After the city of Zagreb was modeled it was printed out using 3D printing technology. The scale model, as the materialization of the 3D model of the City, is only a physical proof of the information base possessed by Geofoto and may be used as a basis for physically fitting-in any future buildings. It is worth mentioning that this is the first and the largest scale model of this type, providing citizens and experts with the best insight into the progress of the City, physical planning and other analyses. The scale model that represents the centre of the City of Zagreb, now exhibited in the City Government building, has dimensions 3x3 meters and consists of 120 panels.

## 1. INTRODUCTION

The production of the 3D digital model and the scale model of the City of Zagreb, which was contracted with the company Geofoto, was initiated by the City of Zagreb in late 2008 with the aim of producing a high-quality and updated geodetic survey map which would contain all the topographic data, including a digital terrain model, a 3D model of buildings and the true orthophoto map. Its presentation was created in the last two years by a series of aerial photos taken by Geofoto's aerophotogrammetric camera Vexcel UltraCam-X. Thanks to the supreme quality of images, Geofoto's map has an exceptionally good resolution, and it was the quality of resolution that was the main prerequisite for using the data for public purposes.

The technological process of producing the scale model is completely digitalized and is performed by a 3D printer Zcorp Spectrum Z510, which features the maximum print size of 254x356x203 mm and the average printing speed of approximately 14 hours, which makes it the most state-of-the-art equipment on the global level at this moment. The 3D printer functions in such manner that it forms three-dimensional figures from slowly applied layers of plaster powder, the figures being pre-set in the form of a computer model.

## 2. DATA COLLECTION

### 2.1 Data set

Typical input data was used for the creation of Zagreb's 3D model:

- Digital Terrain Model (DTM)
- Photogrammetric mapping of the roof structure

- True orthophoto
- Terrestrial and aerial images

### 2.2 Aerophotogrammetric flight and aerial triangulation

Over 4000 aerial images (GSD=8cm) with the 80/60% overlap, in 57 strips were captured for the purpose of Zagreb's 3D model and true orthophoto creation. Using the high resolution digital sensor Vexcel UltraCam X, time cost of image capturing and processing was reduced with the very good geometric and radiometric results.

Because of huge number of aerial images we split the project area into 8 aerial blocks which also resulted in easier and faster calculations in aerial triangulation process. Such procedure however did not have any impact on accuracy of calculation because the camera was equipped with the GPS/IMU system.

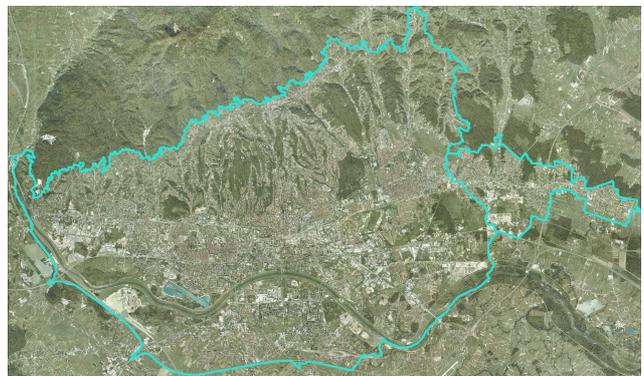


Figure 1. Project area

### 2.3 Photogrammetric mapping

DTM and roof structure data was collected using digital photogrammetric stations. DTM data was collected according to the current mapping specifications prescribed by the State Geodetic Administration. For the roof mapping we established the new model which meets the requirements of the algorithm that was used for the generation of 3D building models. The most important roof feature that the algorithm recognizes as a basic unit in the city model is the eave line (blue line in the figure 1 and figure 2). Eave line defines the building not only by geometrical means but also logically as a unit. The speed of roof structure mapping besides the level of detail depends on how the operator is using an eave line. So the question “what do we need the city model for” had to be answered prior to mapping process. If the semantic and logic structure of the data is necessary for the usage of 3D model then the operator has to consider not only the geometry of the roof but also the logic of the building as a unit. In this case the eave line often breaks in vertical direction, so the special lines like upper and lower break edges have to be introduced into the mapping model. Those structure lines are necessary for the algorithm to generate the vertical roof faces in a proper way. Every upper edge line must have corresponding lower edge line, lying strictly below the upper line with the same number of corresponding nodes with identical x and y coordinates (Figure 1a and 1b)

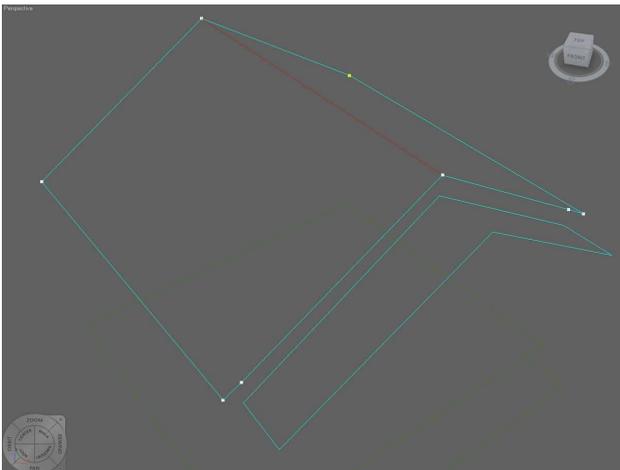


Figure 1a. Correct geometric interpretation of the building

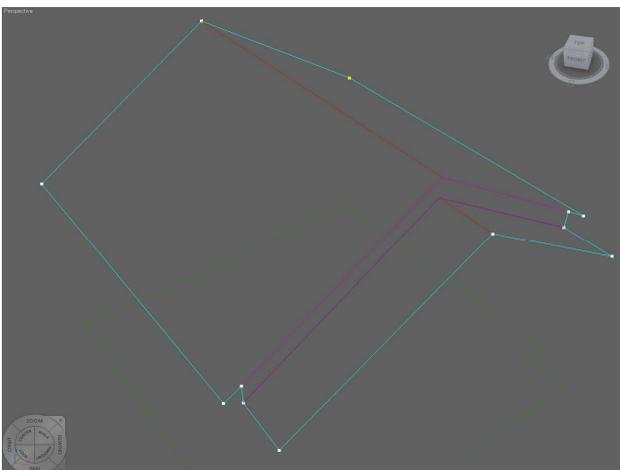


Figure 1b. Correct geometric and logic interpretation of the building

Roof structure mapping is highly demanding and time-consuming task. In order to get the uniform, accurate, logic and rational roof linework, mapping rules have to be clearly defined. According to the experience from this project, great results were achieved after photogrammetry operators had an opportunity to gain some experience with the 3D city modeling. They got acquainted with the way that algorithm interprets the mapping linework which afterwards improved quality of their image interpretation.

The mapping model is made of several feature classes: eave lines, ridge lines, dormer windows, façade lines, chimneys etc. This data structure should be respected in its entirety so the algorithm could generate the roof and the façade faces correctly with the minimal effort of manual editing.

Regarding the level of detail of the 3D model, the general decision was that it should be LoD3. The 3D model was printed out in the scale of 1,000 which also had to be considered in general decision which roof details should be mapped. In other words, we had to determine the minimum size of the building element that could be printed out without being destroyed during the removal from the 3D printer device and depowdering processes. So consequently it was determined that the details whose horizontal area doesn't exceeds 5 sq m should be excluded from mapping process.

Introducing of the buildings foot prints as the reference for the mapping procedure can be a great help for the operators, giving them additional ground aspect of the buildings that really can not be entirely extracted from the aerial images.

3D printer – device that we used for making the scale model - has the output capacity of 25×35×20 cm. Based upon this the grid network with the element size of 25×30 cm was established in the very beginning of the mapping processes to be the main reference base for the data processing and the data exchange. It was also used for cutting the 3D model into printable areas.

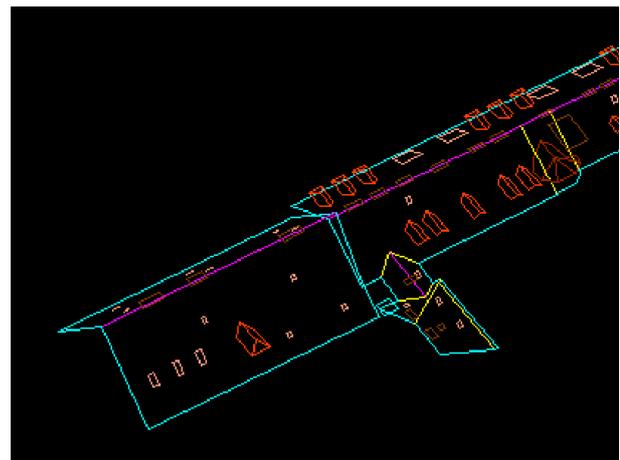


Figure 2. Mapping of the roof structure

### 2.4 True orthophoto

True orthophoto was used for visualization of the terrain of the 3D city model. True orthophotos are orthophotos on which all the defects are corrected including the leaning due to the building heights and on which every object is in its correct geometric position (Ettarid eo, 2005). Advantages of the true

orthophoto compared to the regular orthophoto are visible in the urban areas at first look (Figure 3). The buildings on the regular orthophoto are not taken into orthorectification calculation so they remain projected on the ground outside their footprints. This anomaly results in the fact that area surrounding the building is being invisible to the user.



Figure 3. “Regular” and true orthophoto covering the same area

The same DTM and the roof mapping data were used both for the true orthophoto and for the 3D city model production. The 3D city model was generated prior to the true orthophoto. The nature of the true orthophoto production is very demanding regarding the topological and geometrical data quality. So, examining the data for the true orthophoto production provided a very effective quality control for the 3D model respectively, detecting the data which is either missing or is incorrect.

Pixel size of the true orthophoto was 10 cm and tiles were made in the scale of 1,000.

### 3. 3D CITY MODEL

#### 3.1 3D model

3D city model is digital representation of the Earth’s surface and associated built objects in the urban area. Digital city models are usually classified by level of detail (LoD). There are 5 different categories urban areas presentation, starting from LoD0 to LoD 4.

Choosing an appropriate LoD for representation is determined by its purpose and intended implementation. For instance, when the main goal for 3D model is noise analysis in the city areas, it is preferred to use LoD1 model. However, if one is building a significant object like hotel, museum, stadium or some kind of settlements, with intention to represent it to the investors and for public insight, it should be modeled in LoD4.

Reference source for digital city models usually vary from cartographic (2D) representation of objects to precisely, in smallest detail measured roofs in combination with dense point clouds acquired by either airborne or terrestrial laser scanning.

Digital model of Zagreb city varies between LoD2 and LoD3. Roof segments that are larger than 5 m<sup>2</sup> are modeled, whereas smaller elements and facades could not be acquired and therefore have not been represented in great detail.

Correctly defined data acquisition in combination with optimized triangulation algorithm makes it possible to get modeled object, or even whole object sets, in relatively short time, which is definitely an advantage that has to be considered.

	LOD0	LOD1	LOD2	LOD3	LOD4
Data volume	Larger areas	County and cities	City areas and specific project areas	Individual models	Individual models
Precision (XY/Z)	<LOD1	5m/5m	2m/2m	0.5m/0.5m	0.2m/0.2m
Generalization rate	Maximum generalization rate	Blocks of generalized objects 6x6m/3m	Individual generalized objects >4x4m/2m	Individual generalized objects >2x2m/1m	Modeled structure lines of objects
Roof structure	-	Flat roof	Standard roof types with their orientation	Real roof structure	Real roof structure
Standard objects in urban environment	-	Only significant objects	Standard objects	Real objects	Modeled real objects
Vegetation	-	Important significant objects	Standard objects higher than 6m	Standard objects higher than 2m	Modeled real objects
Land usage	-	>50x50m	>5x5m	<LOD1	<LOD2

Table 2. 3D model categories of LoD

#### 3.2 Making the digital model

Geofoto is using Met Geo Info’s CityGRID Modeler for the city modeling. CityGRID Modeler is a powerful tool for creation of 3D building models which uses specially developed algorithms that generate 3D faces based on the roof structure lines gained from the photogrammetry mapping method. Moreover, every roof or facade surface is defined and composed of triangle surfaces as the least surface element. Depending on the purpose of 3D model, it is necessary to define the correct way of mapping the object line elements that can considerably lighten the modeling time and the effort, based on better or worse object mapping.

Apart from making digital 3D model, this system enables effective geospatial data managing of urban area stored in the relational databases. Among numerous technological solutions that have been taken into consideration when developing the plan for project actualization, the software CityGRID has been

chosen for its line oriented concept that takes into account semantics and topology aspect of data. Storing of 3D data in the database is not based on surfaces, but on line elements that surfaces are created from. Every time the building geometry is changed, it is necessary to triangulate that object to get the changed surface. Therefore, we are talking about line oriented system.

**3.2.1 Data structure:** Basic data format used in CityGRID is XML (Extensible Mark-up Language), and all the data (besides raster orthophoto files and aerial photos) is imported using standard XML inscription that has an useful advantage of being easily readable to people as it is for different software. Structure of XML record is composed of contents that is framed with appropriate symbols that define it and has known or easily comprehensible meaning.

Data that has been used for creating the 3d model is following;

- Oriented aerial photos
- Digital terrain model (DTM)
- Digital buildings model (DBM)
- True orthophoto

During conversion of vector data sets (DWG file format) into XML file format hierarchy data set is created. Set of all objects that are contained in vector data set is defined as a model. Closed lines and polygons that are contained in layer "outer eave" are automatically recognized and create building objects (units). Every unit within the system gets an identification mark that usually contains the name of according model and a number for each unit. One object can contain more physically connected or unconnected complexes. Furthermore, every complex is composed of one or several element groups that form some geometrical element (roof or facade) (Figure 4).

During object input for every vector file that we want to convert into XML file format, it is necessary to define digital terrain model also in XML file format. Digital terrain model (DTM) is important for visualizing the Earth's surface and also because this software creates object facades by vertically projecting (extruding) outer eave lines to corresponding lowest terrain point. To create triangulated surfaces software CityGRID uses algorithm that is optimized for creation of 3D building models whereat it uses different rules to create surfaces for different building elements.

It is important that outer eave (line that defines outer boundary of object) is closed line or polygon, and also that all mapped line elements are put in according layer, which is defined prior to mapping.

Data sets can also be arranged in a way that cadastral model is assigned to vector roof data. Such combination of different data sets of this kind is very advisable. When creating XML file, like above mentioned, it is necessary to define the way of creating building objects as basic 3D model elements.

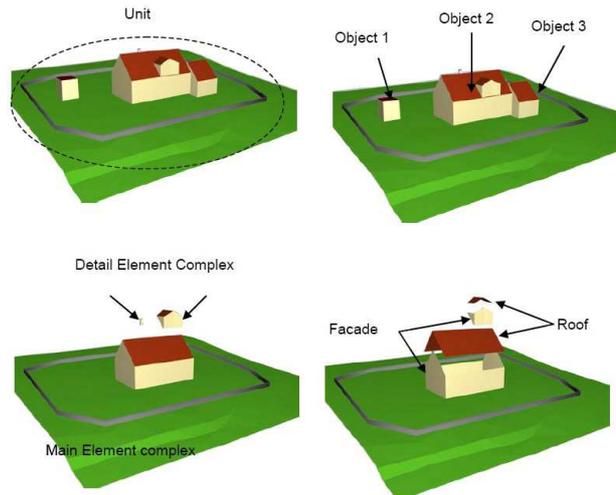


Figure 4. Example of data structure hierarchy (© Met Geo Info 2009, CityGRID Manual)

**3.2.2 Data processing:** Line oriented system that is based on relation database enables simple and efficient data maintenance and processing. XML files that are acquired from vector data sets are imported into the database. During the import, faces of 3D building models are automatically derived from the roof and terrain structure lines (Figure 5). Creating surfaces by triangulation line structures of objects is never lost and if necessary it is possible to continue with line editing so surfaces can be smoothed, aligned with nearby surface, trimmed or extended so that real state of object could be represented. Every time the building geometry or texture is changed, the system creates a new version of the building in the database providing the editing history of the same object which can be searched at any time. This way the original input data is always available and is never lost. Another convenience of creating different versions of the same object, while the old versions are not overwritten by new ones or deleted, is the possibility to assign the fourth dimension (time) to that specific object that has been changed, and in the same sense to the whole 3D model. This way it is possible to get the representation of 3D model in some specific time, but also to show changes during some specific time period.

Default data model in the database is automatically created with the data import. From the default data model it is possible to shape and group the data into the new data set models, depending on the various purposes and users. This way, 3D model can be used for multiple planning and analysis tasks by different city organizations as well as any other user that has need for spatial urban data such as city development and planning, environmental analysis, display of current built-up situation, different urbanism projects, etc.

However, it has to be noted that for most of above mentioned purposes, 3D model has to be constantly maintained and updated with new data so it can be up-to-date at all time. As we wanted to print out our city model using 3D printing technology we had to divide it into printable areas so we organized the city model in 250x300 m "panels", which dimensions were determined dependent on the scale of 3D printout, respectively to the useful printing dimensions output of 3D printer. All objects that are contained inside these panels even with their smallest part are associated with appropriate panel. Panel

division is made based on Official Croatian Map Division of 1:5000 scale, whilst every map is divided into 50 equal parts.

Names of newly created panels are composed of the map name combined with relevant sequence number. This division is implemented in the earliest phase of project as reference frame that greatly helped in coordination and archiving of input, operating and output data.

It is important to note that data inside the system is arranged on above described way exclusively for 3D city scale model printing purposes. If some other purpose for 3D model appliance appears, existing models can be rearranged or archived while buildings inside of them are unchanged and still present in the default model. This way new object sets can be organized.

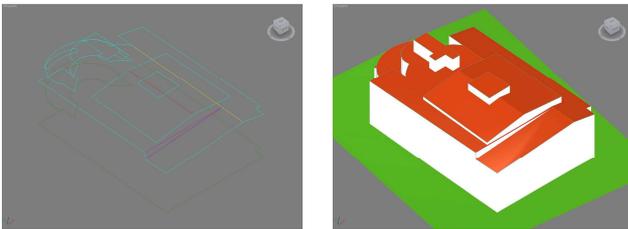


Figure 5. Model creation based on roof and terrain structure lines

**3.2.3 Visualization:** Most common usage of digital city model is visualization of urban area. Visually most persuasive model is one with roofs and facades that are represented in great detail. Roof textures are usually textured using aerial photos, while most accurate and visually most effective results on facades can be obtained using the data acquired by terrestrial laser scanner combined with digital images. Because of their complexity, those methods are used mainly for landmark buildings like historical and cultural heritage, churches and other objects of greater importance (Figure 6). Facade texturing on other objects is usually performed using facade photos taken from the ground. This method enables very good visualization; although there is a slight drawback because usually it is not possible to automatically apply textures to facades as it is possible with roof texturing, and has to be done manually. Therefore texturing facades manually becomes rather demanding and long lasting process.

While creating 3D model of the city of Zagreb, roof faces are automatically textured using aerial photos with resolution of GSD=8cm. Aerial photos are imported in the database where every aerial photo has been assigned with its inner and outer orientations parameters. Based on this, software is able to automatically connect roof faces with correspondent parts of aerial photo. Therefore, every roof is assigned with its raster file that is automatically created and stored on computer hard drive which requires that there is enough disc space ensured.

Digital terrain model is textured using true orthophoto with resolution of 10cm that in combination with accurately mapped terrain model results in a very effective manner. Also it is desirable that resolution of true orthophoto and aerial photos that are used for texturing terrain and roofs are in the same or similar resolution, so that the whole 3D model altogether could be as much as possibly uniformed.



Figure 6. Detailed representation of Saint Mark's church

## 4. MAKING THE SCALE MODEL WITH 3D PRINT TECHNOLOGY

### 4.1 Preparation of the model for 3D print

As it is mentioned previously, one of the project goals was to make the scale model of the city by printing the 3D city model using the 3D printing technology.

The 3D model was divided into printable areas by creating 250×300 m city models and defining them in the data base with a unique nomenclature. Every model is then exported from the data base into VRML (Virtual Reality Modeling Language) file format. This file format is chosen because it keeps the data information which is important for 3D printing: model's geometry and textures. It does not keep the semantic structure of the data, but for the purpose of 3D printing purpose it is of no importance.

3D models represent reality using a collection of various geometric entities, in this case the collection of triangles. Those triangles are organized into shells and solids. The first postulate of transferring the virtual reality into material world is that the model has to be represented with one solid geometric body.

Magics RP was used as a software tool for the purpose of examining and fixing the 3D city models' triangulation structure. It is a powerful tool which handles various data formats like VRML, STL, PLY, ZPR, DXF etc. It provides analyses of the triangulation surfaces of 3D entities, classifies different error types and features tools for automatic and semi-automatic error fixing (Figure 7a and 7b).

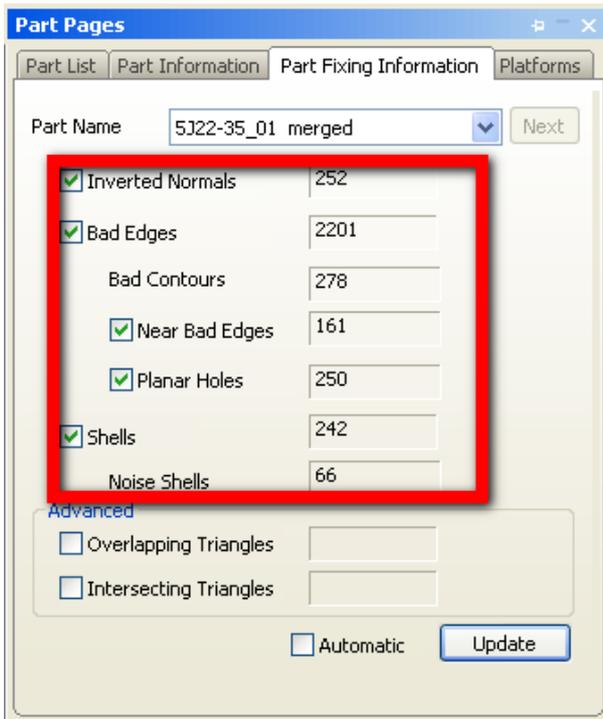


Figure 7a. 3D model's statistics after it is imported in Magics RP

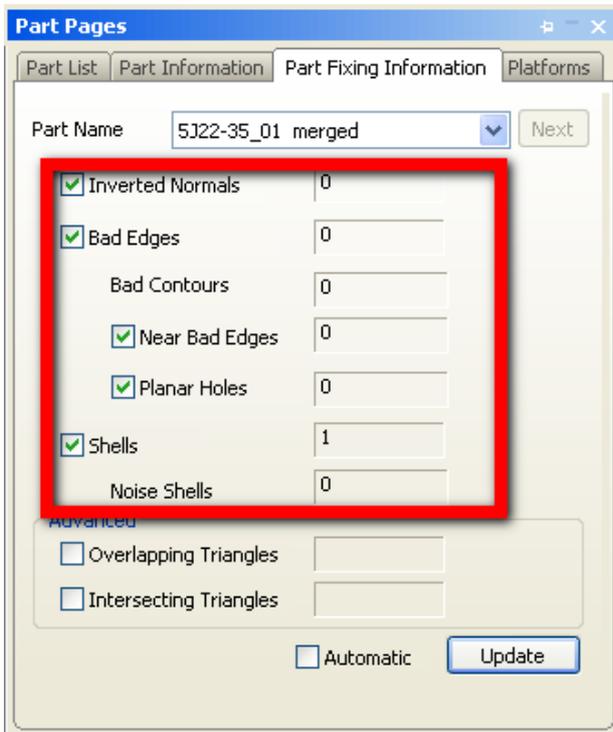


Figure 7b. 3D model's statistics after "fixing" in Magics RP

City model parts typically consist of the terrain and building's faces. On every data set, triangulation network was examined and fixed, afterwards all the buildings were united with the terrain into one part (Figure 7a and 7b).

## 4.2 3D printing

3D printing is a form of additive manufacturing technology, where a three dimensional object is created by successive layers of material. They are generally faster, more affordable and easier to use than other additive manufacturing technologies. 3D printers offer product developers the ability to print parts and assemblies made of several materials with different mechanical and physical properties in a single build process. Advanced 3D printing technologies yield models that closely emulate the look, feel and functionality of product prototypes. In recent years 3D printers have become financially accessible to small and medium sized business, thereby taking prototyping out of the heavy industry and into the office environment. It is now also possible to simultaneously deposit different types of materials.

Geofoto is in possession of 2 Z510 Spectrum 3D printers. Those printers use standard inkjet printing technology to create parts layer-by-layer by depositing a liquid binder onto thin layers of powder. Process time depends on the height of the part or parts being built.

So far Geofoto made over 500 panels of a city scale model and 120 of them are put together so far forming a scale model of Zagreb's city centre. The model is currently exhibited in City Hall and is open for general public to see it.



Figure 8. Scale model of Zagreb's city centre

## 5. CONCLUSION

This paper presents the process of creation of Zagreb's 3D city model and the scale model which is made by printing the 3D model using the 3D printing technology.

3D city model is up to this date 90 % finished and is already proven to be very accurate and trustworthy 3D data base, especially for the city planners - in couple of occasions some data sets have been provided to the Zagreb City Bureau for Strategic Planning and the feedback was more than good. Also, some strategic infrastructure projects were presented to the City Government based on this 3D model. The potential of this model is indeed great, but it depends on the City Government services how its potential will be utilized and how much impact it will have on the development of the urban infrastructure.

The scale model drew a lot of public attention when it was exhibited in the City Hall in last May. People saw it as a city's new attraction and experts were impressed with an overlook it

provides with its authentic roof and terrain structures and textures (Figure 8).

The city of Zagreb suffered the lack of strategic urban development for over sixty year, especially in the last twenty years. Recently, some constructing interventions in the Zagreb's down town historic house blocks have alarmed both general and expert public because of the lack of transparency in process of planning and decision making. There is no doubt that similar situations will repeat itself in the future, so the decision of the City Government to invest in the long term project based on the solutions presented in this paper is definitely a step in the right direction.

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