3D CITY MODELLING IN RUSSIA

St. Petersburg city model

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Abstract

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Abstract

The appearance of 3D city models has opened up many new ways for the development of the urban environment. They allow to competently plan new structures by fitting them first into the existing environment. The public use of these models allows citizens to participate in the development of city regions through the communication with the city's authorities.

In this paper, considered 3D city models in Russia and examined in detail the model of the city of St. Petersburg. Methods of their creation are reviewed from the practical and theoretical side. Also carried a survey of construction participants of their interest in the emergence of 3D models of cities in public use.

The results of the study allow to get an idea of the development of three-dimensional urban modeling in Russia, as well as its current state in St. Petersburg in particular. This research also aimed to find out what problems related to urban modeling are currently facing the cities of Russia.

Summing up, Russia is definitely need to create open 3D models for the cities. They will allow to easily solve a bunch of current urban problems and to competent develop the municipalities in future. Current St. Petersburg city model that was reviewed in this study is now obsolete and is limited in use. And the survey results show that the production of a new open model of the city will be useful not only for the construction industry, but also for other areas of production.

Keywords

3D city model, Russia, Urban model

Contents

1 Introduction

With the economic development of the Russian Federation, there is a growing need for efficient management in urban environment, energy efficiency, and competent traffic management in large cities. In this regard, it becomes necessary to introduce a system of 3D city models that takes into account the models of real estate objects, landscaping, architectural monuments, and also allows citizens to take part in the development of the urban environment. This topic is aimed to contribute in the future production and development of the 3D city models in Russia.

The client of this study is a Finnish software company, Sova 3D. The company presents an open web service for publishing 3D city models - Kunta3D. The three-dimensional city model subsequently serves as a platform for interaction between all participants in construction and urban planning projects.

In this paper, considered 3D city models in Russia and examined in detail the model of the city of St. Petersburg. Methods of their creation are reviewed from the practical and theoretical side. Also carried a survey of construction participants of their interest in the emergence of 3D models of cities in public use.

This paper supposed to determine the current state of the urban modelling in Russian municipalities. At the time of the survey process, only several Russian cities have the 3D models, because there is still too many challenges in their production. First of all, it is the absence of the national 3D city model standards. That led to the fact that the existing models are produced in a different programs. To address this challenge, during the research each city model have been considered separately and have been taken into account all of the aspects in the complex. Also most of the city models in Russia were created by the commercial companies and the reports about creation process haven’t been published. To address this challenge, personal communication with companies representatives to obtain the necessary information was established.

The main methodology in this paper is a literature review, but also survey and personal communication with designers. Were considered literature, project reports as well as online resources on 3D geoinformation science with a focus on the creation principles of 3D city models in Russia.

2 What is the City Model?

The digital model of municipal area that represent its relief, infrastructure, vegetation, elements of landscaping and building in three-dimensional scale is a 3D city model. That model consist of the geospatial data and gives the representation of the view in which the city exists in the real world. As the 3D city model gives the visualization of the real view, it can be used for urban planning, risk management, traffic jam control, energy efficiency and noise level estimation and etc.

A key characteristic of the city model is its Level of Detail or Level of Development (LoD). It is a term that describes how precise the model is. Level of Detail is about the visual representation of the model while Level of Development is about how deeply the model is produced (Reis 2017).

By nowadays standards commonly used Level of Development. In application to Building Information Modelling used LOD Standards, published by American Institute of Architect in 2009 and further developed by American General Contractors. There are five basic levels of development that don’t describe any modelling guidelines but contain a definition of model content and permitted use cases of the model for the given LoDs (Biljecki 2013, p.13):

- LoD 100 - the model consist of overall building massing and can be used for different types of analysis (volume, building orientation, etc.) (Fig.1a);
- LoD 200 - the model consist of generalized systems or assemblies with approximate quantities, size, shape, location and orientation. Can be used for analysis of selected systems by application of generalized performance criteria (Fig.1b);
- LoD 300 – elements of the model are suitable for the creation of the construction documents and shop drawings. Can be used for analysis of the detailed elements and systems (Fig.1c);
- LoD 400 - the level of development is suitable for fabrication and assembly. The Model Element Author (MEA) for this LOD is most likely to be the trade contractor or fabricator (Fig.1d);
- LoD 500 - the final level of development represents the project’s as-built-data. The model can be used for maintenance and operation of the facility (Fig.1e).

The examples of LODs in Building information model are shown in the Figure 1.

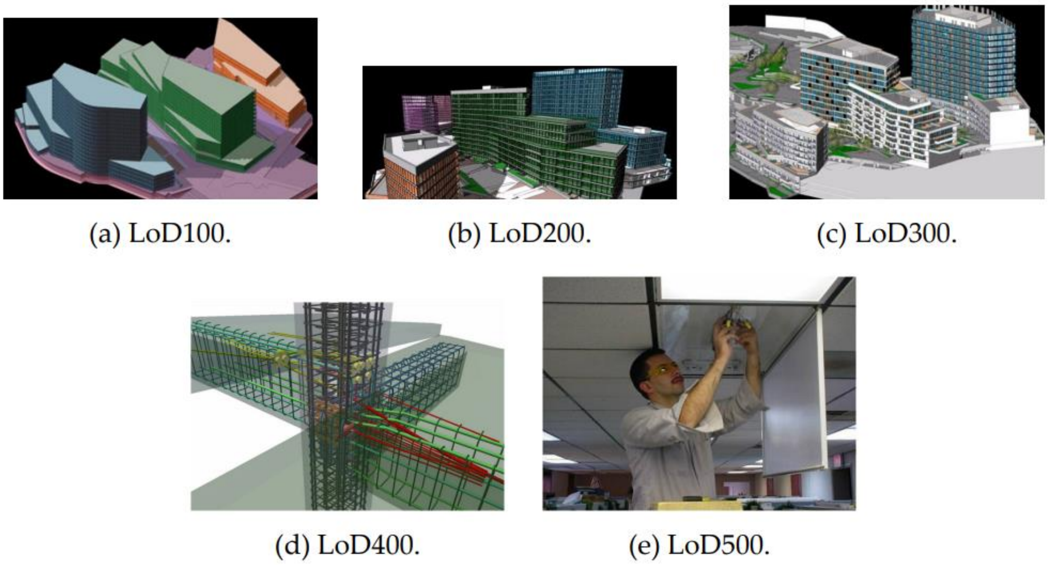

Figure 1. LoD in BIM (Biljecki 2013, p.14).

In 3D city modelling LoD is determined by the standards used in the creating process. For 3D city models used open standard City Geography Markup Language (CityGML). It provides a standard model and mechanism for describing 3D objects with respect to their geometry, topology and meaning. CityGML is based on a public XML-based data transfer format (OGC 2012).

The CityGML standard describes five LoDs (OGC 2012):

- LOD0 – two and a half dimensional Digital Terrain Model (DTM) over which an aerial image or a map may be draped. Buildings represented in that level by footprint or roof polygons. LOD0 is used for regional and landscape applications;
- LOD1 – a blocks model comprising prismatic buildings with flat roof structures. This level is used for the municipality coverage;
- LOD2 – building model has differentiated roof structures and thematically differentiated boundary surfaces. It is mostly used for city districts and projects;
- LOD3 - architectural model with detailed wall and roof structures potentially including doors and windows. It is mostly used for landmarks;
- LOD4 - completes a LOD3 model by adding interior structures for buildings. In LOD4 buildings are composed of rooms, interior doors, stairs, and furniture.

The examples of LODs in 3D city model are shown in the Figure 2.

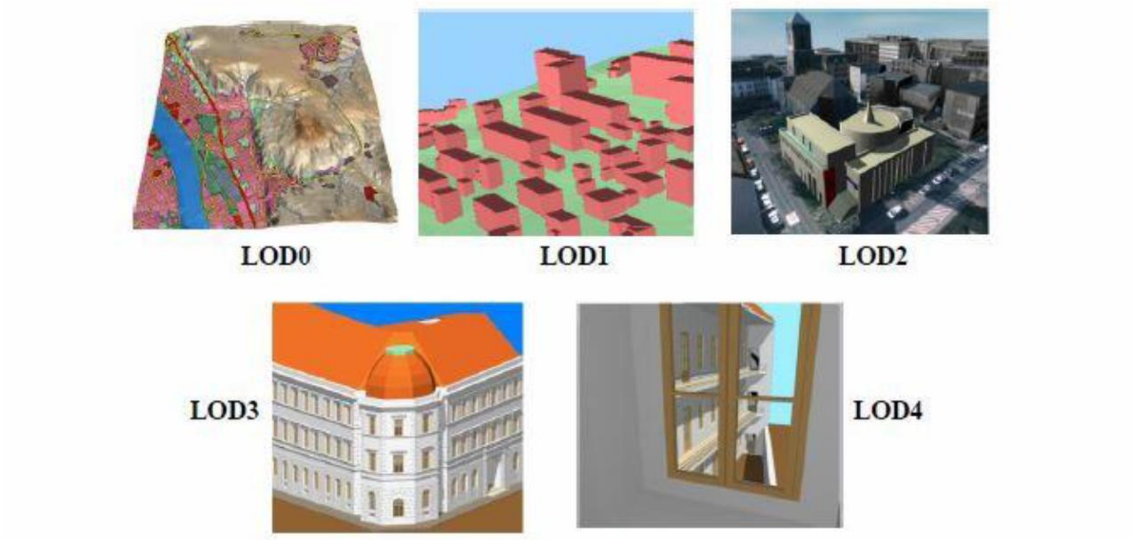

Figure 2. LOD levels in CityGML standard (OGC 2012).

In all LoDs textures can be mapped onto the structures. More information about LOD in CityGML standard will be introduced in the next chapters.

2.1 Ways of production of the 3D city model

Depending on the use case of the model, its expecting quality and the initial data, there are several ways to create 3D city model. To produce 3D city model it is possible to use Conventional Techniques (vector map data, aerial images), High Resolution Satellite Images with laser scanning, Terrestrial Images by using photogrammetry. Photogrammetry, lasergrammetry, Global Positioning System (GPS) and their combination usually used for creating city models. But there are also possibility to create the model manually in a designing software. Further will be considered manual, automatically and semi-automatically methods of the city model creation.

2.1.1 Manual production

This is the most time consuming way. Building models are created in programs such as ArchiCAD, ArcGIS + 3DAnalyst, 3ds Max, Google SketchUp and etc. Geometry modeling and texturing are done manually.

To simplify the process in urban development, can be used sets of the standard buildings. Models are created for each type of building and then multiplied the required number of times when placed on the map.

To speed up the process, three-dimensional objects are often obtained by extruding buildings from their prints on a city plan. The height to which each building is extruded is obtained from an attribute containing the number of floors. Texturing is usually done with terrestrial photographs and images from texture libraries. This method of creating 3D models of cities is the oldest one.

This method has it's advantages. For example (Bondarec 2010):

- Ability to create models with very high geometric detail;
- Only one model is created for each type of building. This model is loaded once during rendering and is used for all buildings of a given type. This significantly saves RAM and reduces the size of the 3D city model;
- Three-dimensional buildings are separate objects in which any attribute information can be associated.

But there also a lot of disadvantages (Bondarec 2010):

- Very high labor intensity. Despite the fact that modern 3D software allow to speed up some stages of modeling, all of them are still performed manually in that case;
- Potentially low metric accuracy. The source of dimensions for a building model is usually photographs of facades, a floor plans, or an prints of the buildings on a city plan. A flat plan does not provide all the necessary information about the shape of the building. Missing dimensions are calculated approximately. This, of course, does not apply to the case when the initial data for the design is the architectural model of the building used in its construction, or the data of ground laser scanning. However, such a cases are very rare;
- The standard templated buildings. The inability to create a set of types that describes all the variants of buildings in a city leads to a generalization and simplification of the city model. Unique buildings are replaced by a generic model;
- Lack of photorealism. Ground photos are usually used as textures in this method. These are high quality, high resolution photos. However, it is not possible to photograph every building in the city from all sides. Missing photos are replaced with standard textures from libraries.

The example of manual produced model is St. Petersburg city model that is shown in the Figure 3.

Figure 3. Manually produced St. Petersburg city model (Avrutin et. al., 2009).

The described method is used when creating city models using ArcGIS software and its extension - 3D Analyst module. Basically, these models include only a few city blocks, due to the enormous complexity of the process. The production of 3D model of St. Petersburg will be described in the next chapters.

2.1.2 Automatically production

In this method used algorithms for restoring the geometric shape of the objects from their stereo images. Stereo images are obtained from an aircraft using tilt digital cameras. The same images are used as a source of textures for building facades. An airborne laser scanner can be used to refine the geometry of buildings and obtain a terrain model.

The example of automatically produced model is Tomsk city model that is shown in the Figure 4.

Figure 4. Tomsk 3D city model made with aerial photography (Tomsk 3D 2016).

The whole process is fully automated. Searching for the same points on overlapping images forms a point cloud describing the earth's surface and objects towering over it. The point cloud is then triangulated to obtain a surface. The resulting surface is searched for planes to better reproduce the walls and roofs of buildings. The end product is a 3D terrain model, presented in varying degrees of detail. As an example of the method – Tomsk city model.

There is also a technology for automatic construction of three-dimensional models of building facades, developed at the University of Berkeley, USA (Zakhor 2001). Here aerial photography and aerial laser scanning data are complemented by photographs and point clouds from a ground laser scanner. The laser scanner and camera are mounted on a vehicle that moves through the streets and takes pictures of buildings. A laser scanner helps to restore the shape of building facades and cut off obstacles in front of buildings: trees, cars, pedestrians. Also, the point cloud of the laser scanner helps to reconstruct the trajectory of the vehicle, which is necessary to accurately determine the position of buildings and georeference photos for subsequent automatic texturing.

Advantages of a method (Bondarec 2010):

- High speed of creating city models;
- High photorealism. Texturing is performed automatically based on aerial or georeferenced images of a ground camera. Complete absence of typical

textures from libraries. All building facades look exactly as they were at the time of shooting;

- Low cost of creating a model by eliminating manual labor of operators.

But, of course, there are disadvantages as well (Bondarec 2010):

- Insufficient geometric accuracy of the model. Algorithms for automatic reconstruction of the shape of objects from their photographs or laser scanning data, despite significant advances in this area, are still imperfect. As a result, the figures of the buildings are restored with errors. Vertical walls can be highly inclined, and the size of buildings is significantly distorted. This fact excludes the possibility of making accurate measurements (the accuracy of which is comparable with the accuracy of the original data);
- Inability to separate building objects from the surface of the relief or from each other. Automatic recognition is currently unable to reliably classify objects and reliably determine their boundaries. As a consequence, the automatically generated city models are composed of a single solid surface that includes buildings, trees and terrain or from the surface of the terrain and city blocks (technology of the University of Berkeley). Since buildings in such models are not represented as separate objects, they cannot be assigned attributes. This complicates the creation of the address database and limits the application of the model. For example, to calculate the noise level, it is required to classify objects according to the type of material they are made of, which cannot be done in the absence of separate objects;
- Low quality textures. With automatic texturing, extraneous objects projected onto building facades remain on the textures. In addition, the positioning accuracy of the textures is low. On the sides of a building shot at an acute angle, textures are blurred.

2.1.3 Semi-automatically production

This technique eliminates the weaknesses of the fully automatic process of generating city models. Geometric models of buildings here are created by operators from aerial photographs and also allows the use of laser scanning data for building models.

The creation of a three-dimensional model of a building consists of the operator measuring the characteristic points of the roof contour. The measurements are carried out using a stereoscopic method. To speed up the process, templates developed for the main types of roofs are used. Intricate shapes are formed by combining simple geometric shapes. The height of the walls of buildings is not measured. The walls are formed by projecting the points of the roof base onto the relief surface.

The described technique allows to create models of buildings quickly and efficiently. The measurement accuracy is comparable to the geometric accuracy of the original aerial photographs.

Building models is the only manual process when generating a 3D city model. Further processing of the created models is carried out completely automatically. Facade and roof textures are extracted from the same images used to create the geometry. At this stage, it is very important that all sides of the building are visible in the images. To achieve this, used lateral inclined cameras.

Advantages of the method (Bondarec 2010):

- Relatively high creation speed;
- High geometric accuracy. The position of the points of the building contour is measured from stereo images. The error in determining the coordinates of points is proportionate with the geometric accuracy of images. The LoD of building models is set by the terms of reference;
- Buildings are separate objects that can be assigned any attributes: address, year of construction, building type, wall material. The city model with buildings as separate objects has wider applications. It can be used for urban planning, calculating noise levels, building a map of radio propagation, predicting flooding.
- High photorealism. Texturing as in fully automatic modeling technology is performed automatically. Textures are extracted from aerial photographs and look very natural. Shadows are not removed from textures, which creates the illusion of high-quality lighting of a three-dimensional scene.

The example of semi-automatically produced model is Vinnytsia city model that is shown in the Figure 5.

Figure 5. Vinnytsia (Ukraine) 3D city model made created using semi-automatic technologies (Vinnytsia 3D).

Disadvantages (Bondarec 2010):

- Compared to fully automatic generation of models, this method involves manual labor of operators. This increases the cost of the entire model and increases the time to work on it;
- Low quality textures. Textures are extracted from aerial photographs and have a low resolution compared to ground photography.

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2.2 Examples of use cases of the 3D city model

Some of the existing use cases of the 3D city models (Biljecki 2015) are showed in the Table 1.

Use Case	Application example
Estimation of the solar irradiation	Determining the suitability of a roof surface for installing photovoltaic panels
Energy demand estimation	Assessing the return of a building energy retrofit
Aiding positioning	Map matching
Determination of the floorspace	Valuation of buildings
Classifying building types	Semantic enrichment of data sets
Geo-visualisation and visualisation enhancement	Flight simulation
Visibility analysis	Finding the optimal location to place a surveillance camera
Estimation of shadows cast by urban features	Determination of solar envelopes
Estimation of the propagation of noise in an urban environment	Traffic planning
3D cadastre	Property registration
Urban planning	Designing green areas
Visualisation for communication of urban information to citizenry	Virtual tours
Reconstruction of sunlight direction	Object recognition
Emergency response	Planning evacuation
Lighting simulations	Planning lighting of landmarks
Radio-wave propagation	Optimising radio infrastructure
Estimating the population in an area	Crisis managemen
Routing	Understanding accessibility
Forecasting seismic damage	Insurance

Table 1. Overview of the some documented use cases of 3D city models.

Few of the cases will be further described.

2.2.1 Estimation of the solar irradiation

In that case 3D city model is used to estimate how much solar energy is consumed by each building during the daytime with respect of the surrounding buildings affect. This information is further used to rationally install the solar panels on the roof surface.

With the help of 3D modelling of the environment it is possible to respect all of the factors that can have an influence on the solar energy distribution. For example, tilt level of the roofs, geometrical parameters of each building, orientation relative to the cardinal points.

The process of solar rays projection modelling is shown in the Figure 6.

Figure 6. Estimation of the solar irradiation of the building (Biljecki 2015).

2.2.2 Estimation of the Propagation of Noise in an Urban Environment

3D city models are also very helpful in the question of noise estimation. In a compare with application of 2D GIS for this purpose, 3D models have an advantage. Due to the sound refracting, the noise level can considerably change at different elevation levels - that the planar model is not able to foresee.

The simulation of the noise level in a city district is shown in the Figure 7.

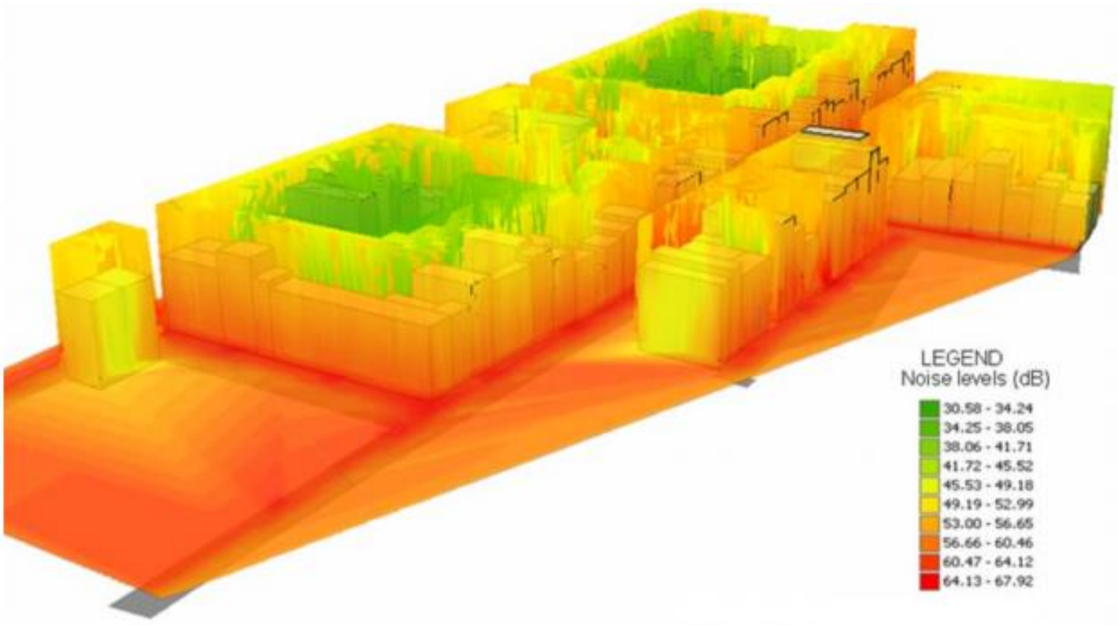

Figure 7. Noise level simulation in a 3D city model (Biljecki 2015).

Generally, 3d city model allows to calculate the noise level and then properly design the noise barriers. Semantic part of the 3D city model is not necessary in that case, but may have an influence on a noise level estimation. For example, the information about the walls material can be helpful for the more accurate calculation.

2.2.3 Estimating the Population in an Area

With the help of the availability of the information about the number of inhabitants in each building, 3D city models can be used in a crisis management. For example, possible application can be prediction of the disaster effect on the urban infrastructure. In that case, people estimation is used to design safety and effective ways of evacuation.

The simulation of the blast pressure in the urban environment is shown in the Figure 8.

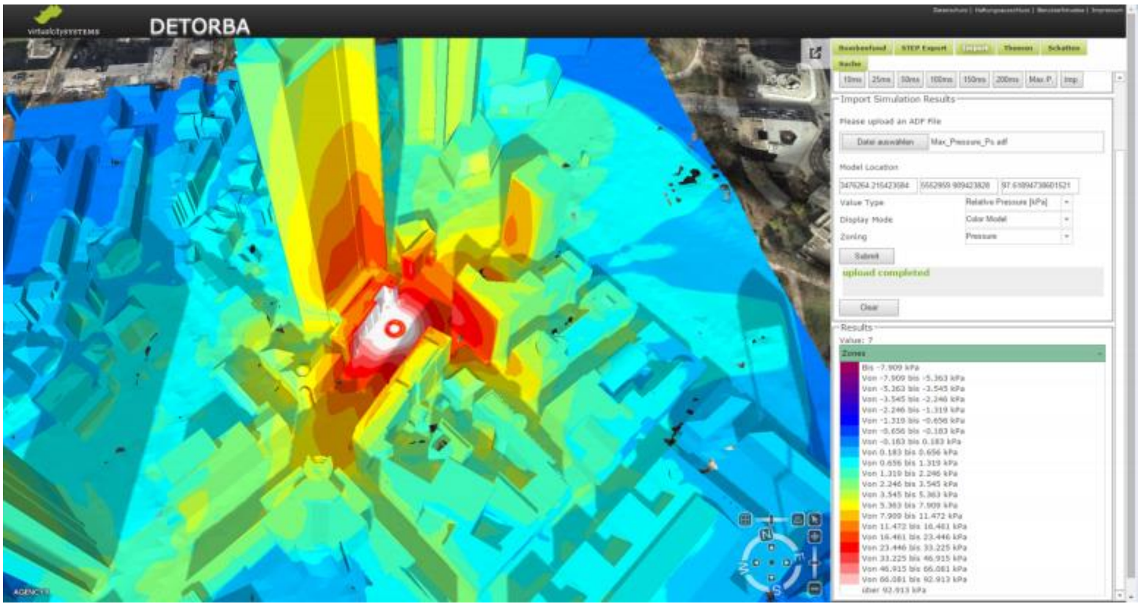

Figure 8. Blast pressure wave propagation in urban environments (Biljecki 2015).

3 Standard for the 3D city information models – CityGML

The wide range of applications of 3D city models in various areas of urban planning and management creates the need for a universal format for such models. Since different purposes require different semantic data contained in the model, as well as their relationship. In order to ensure the compatibility of the model with various software systems, the Open Geospatial Consortium has released an international standard – CityGML - City Geography Markup Language (OGC 2012).

This language, based on the XML-like format for the exchange of spatial data GML3 (Geographical Markup Language 3), is a tool for describing urban objects, and not only buildings and structures, but also terrain, vegetation, hydrology, roads, sidewalks, paths, bridges and tunnels. (Yao et al. 2018). In the following, it will be described what the CityGML model is.

3.1 Background

Since 2002 the Special Interest Group 3D (SIG 3D) develops CityGML by the initiative of Geodata Infrastructure North-Rhine Westphalia, Germany. The SIG 3D has over 70 participants from different areas, such as public administration, industry and academia. They have been relate with urban planning, cadastre, civil engineering and architecture, geoinformation, telecommunications and etc. (Lee & Zlatanova 2009).

The first version of the standard was published in 2008. In the CityGML version 1.0.0 was introduced the modularization of the data model. And in 2012 was introduced version 2.0 that can be described as a revision of the previous version with additions of the new features to the thematic model of CityGML (OGC 2012).

The aim of the standard is to be a common definition of the entities and their relations in 3D city models. CityGML provides for the city model semantic data, geometry, topology and appearance that further allow to make necessary calculations and analysis (Kolbe 2009).

3.2 Modularisation

The CityGML model is thematically divided into a core module and thematic extension modules. Based on the core, each sub-module defines the special thematic feature. CityGML introduces thirteen thematic extension modules: Appearance, Bridge, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody, and TexturedSurface (OGC 2012). That scheme shown in the Figure 9:

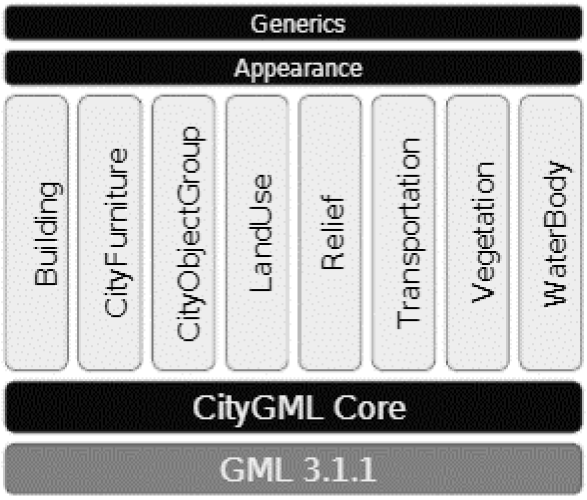

Figure 9. Modularization of CityGML (Kolbe 2009).

Vertical modules here define thematic properties (water body, vegetation, building and etc.), while the horizontal modules define structures that related to all thematic modules. Such combinations of modules are called CityGML profiles (OGC 2012).

Each CityGML module has its own XML Schema definition file and is defined within an individual and globally unique XML target namespace. The modules can be related to each other and, in that case, they may import namespaces associated with the related modules. But one namespace shouldn't be directly connected with two different modules. That means that one module elements are associated only with that module's namespace (OGC 2012). The relations between modules are shown in the Figure 10.

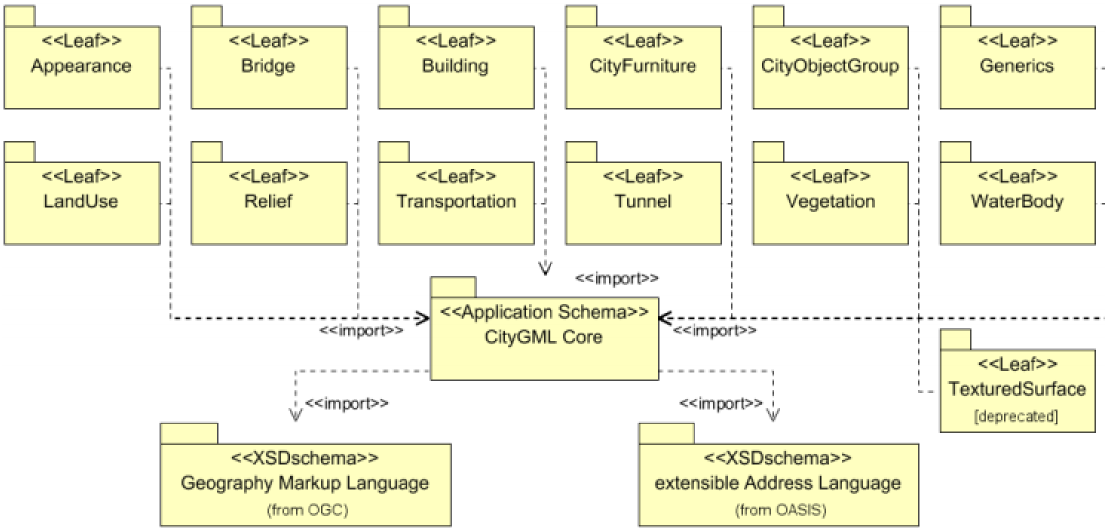

Figure 10. UML package diagram (OGC 2012).

Each module is represented by a package, where the leaf packages – extension modules import the schema of the CityGML Core module. A short description example of the modules is given in the Figure 11.

Module name	CityGML Core
XML namespace identifier	http://www.opengis.net/citygml/2.0
XML Schema file	cityGMLBase.xsd
Recommended namespace prefix	core
Module description	The *CityGML Core* module defines the basic components of the CityGML data model. Primarily, this comprises abstract base classes from which all thematic classes are (transitively) derived. But also non-abstract content common to more than one extension module, for example basic data types, is defined within the core module. The core module itself imports the XML schema definition files of GML version 3.1.1 and the OASIS extensible Address Language xAL.

Module name	Appearance
XML namespace identifier	http://www.opengis.net/citygml/appearance/2.0
XML Schema file	appearance.xsd
Recommended namespace prefix	app
Module description	The *Appearance* module provides the means to model appearances of CityGML features, i.e. observable properties of the feature's surface. Appearance data may be stored for each city object. Therefore, the abstract base class *_CityObject* defined within the core module is augmented by an additional property using CityGML's *Application Domain Extension* mechanism. Thus, the *Appearance* module has a deliberate impact on all thematic extension modules.

Module name	Building
XML namespace identifier	http://www.opengis.net/citygml/building/2.0
XML Schema file	building.xsd
Recommended namespace prefix	bldg
Module description	The *Building* module allows the representation of thematic and spatial aspects of buildings, building parts, building installations, and interior building structures in five levels of detail (LOD 0 – 4).

Figure 11. Modules overview (OGC 2012).

3.3 LOD

As have been told in the previous chapter, CityGML supports several Levels of Detail. The higher LOD of the object – the more detailed it represented in the model. In a CityGML model, the same object is possible to represent in different LODs at the same time. That opens an opportunity to produce analysis and visualization of one object in different resolution levels (OGC 2012). The CityGML standard describes five LoDs, which shown in a previous chapter.

In addition, LODs are defined by accuracy level and minimal objects dimension. Accuracy by that means is described as a deflection of the absolute 3D point coordinates. The table of accuracy is shown in the Figure 12.

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city, city districts, projects	city districts, architectural models (exterior), landmark	architectural models (interior), landmark
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	no	no	yes	representative exterior features	real object form
Roof structure/representation	yes	flat	differentiated roof structures	real object form	real object form
Roof overhanging parts	yes	no	yes, if known	yes	yes
CityFurniture	no	important objects	prototypes, generalized objects	real object form	real object form
SolitaryVegetationObject	no	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	no	>50*50m	>5*5m	< LOD2	<LOD2
…to be continued for the other feature themes					

Figure 12. LODs of CityGML accuracy requirements (OGC 2012).

For example, in LOD3 accuracy of the position and height should be 0.5 m as minimum, all of the objects with the footprint dimensions at least 2*2 m^2 should be considered. While in the LOD1, height accuracy has to be be 5 m or better and 6*6 m^2 objects should be considered.

To be represented in different LODs, the same object will be generalized in order to representation in a lower LOD.

3.4 Semantic

CityGML refer to family of standards ISO 191xx. And while modelling geographical objects it uses ISO 19109 that defines those objects as the real world abstraction. Geographical objects in CityGML may have several spatial and non-spatial attributes. It also provides definition for classes, normative regulations and explanations of the semantics for the important geographic features in city models (buildings, water bodies, vegetation, city furniture).

The UML diagram of the hierarchy in CityGML is shown in the Figure 13.

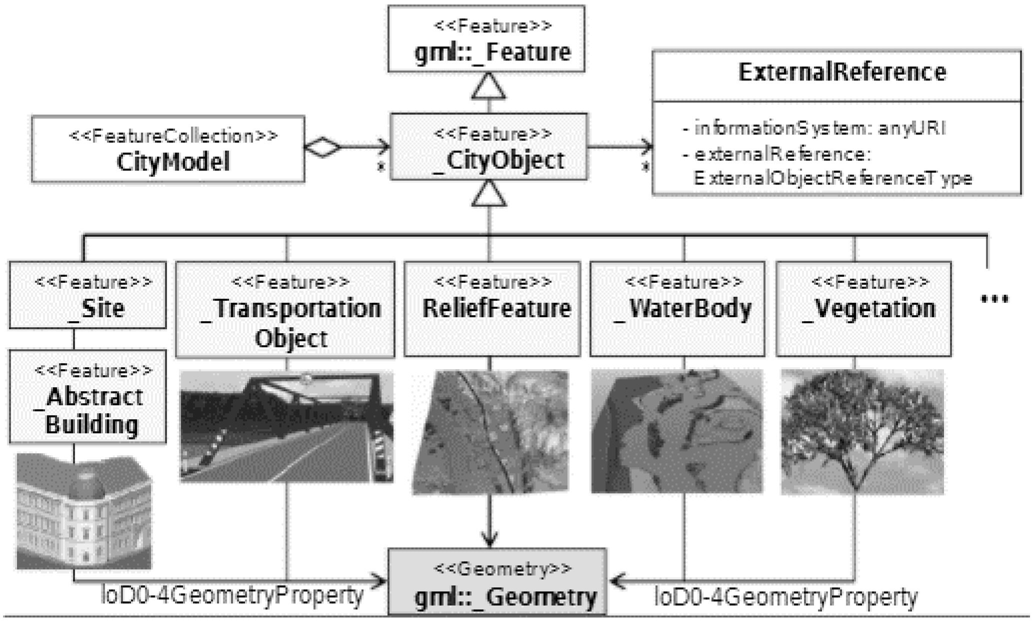

Figure 13. UML diagram of the hierarchy in CityGML (Kolbe 2009).

The main class for building in the model is the AbstractBuilding, that further provides two non-abstract classes - Building and BuildingPart (AbstractBuilding may consist from BuildingParts).

Simplified CityGML building model is represented in the Figure 14.

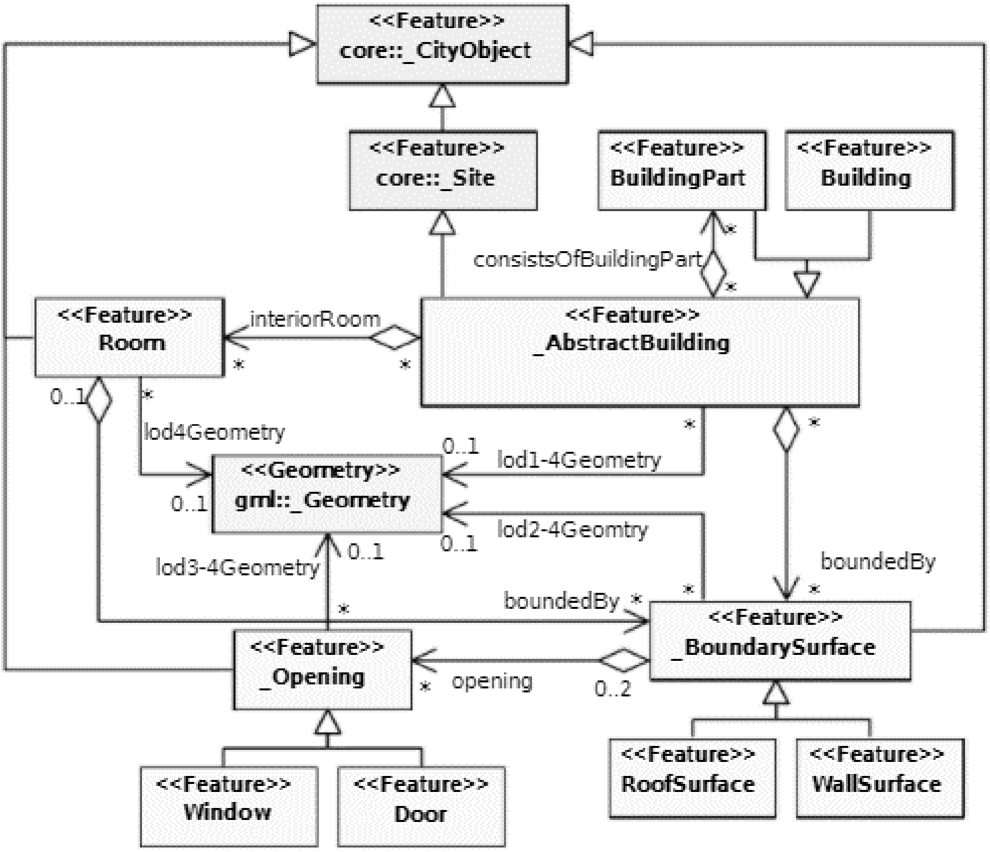

Figure 14. UML diagram of the CityGML building model (Kolbe 2009).

After LOD2 the boundary surfaces of Buildings and Building-Parts can be defined as semantic objects. BoundarySurface consist of the thematic objects having RoofSurface, WallSurface, GroundSurface, ClosureSurface as subclasses. In LOD3 and LOD4 openings in building surfaces can be defined by the thematic features of the classes Window or Door. And in a LOD4, buildings are allowed to have Rooms (Kolbe 2009).

3.5 Geometry

According to ISO 19107 that CityGML refers to, objects geometry is represented as object that has an identify and geometric substructures (OGC 2012).

Each solid object should be bounded by a closed surface. All of the coordinates should belong to a world coordinate reference system. Coordinate reference system (CRS) defines a base for the real world coordinates and can be different for the different countries and regions. Usage of the CRS and association of the objects with it makes easier the data integration process into the model. Each object in the model has its own fixed position.

According to ISO 19109, one geographical object may have several spatial features. That can be seen, for example, in the building models where, depending of the LOD, for the AbstractBuilding and the Room are assigned unique geometrical parameters.

3.6 Topology

The main condition for the 3D City Models is the topological correctness. That, the surfaces, forming buildings, should be closed. That is necessary for the possibility of the volume calculation. Also, objects of the model shouldn't intersect with each other, because space can be only occupied by one object (Kolbe 2009).

For 3D topology there are geometry-topology structure. The coordinates are stored in the points or nodes. Then higher primitives are constructed from the lower primitives. Nodes, faces and edges can be common for the different primitives in the complex objects (Kolbe 2009).

In the Figure 15 is shown the case, illustrating that to topologically connect building and the garage is not necessary to decompose the model to the nodes level, it is enough only to reuse the common wall surface of the house and garage.

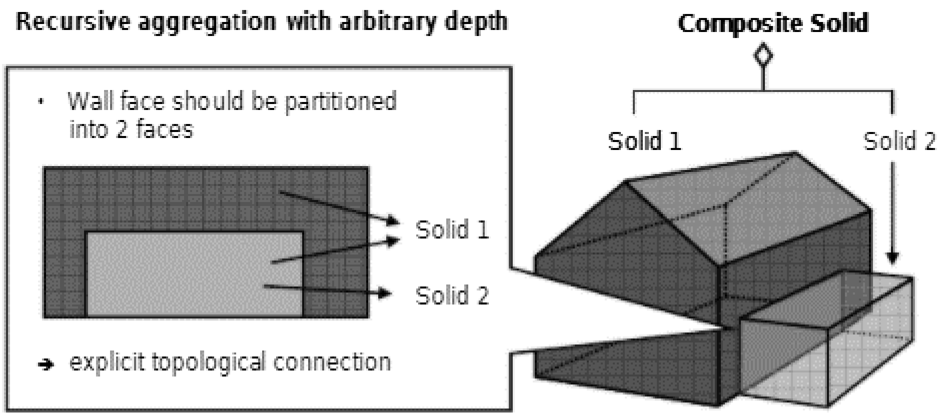

Figure 15. Building and a garage shared a common wall. A garage wall surface shared surfaces of Solid 1 and Solid 2 (Kolbe 2009).

3.7 Appearance

Virtual 3D models necessarily imply information about the appearance of the surface. Appearance is not only visual data, it is also infrared radiation, noise level, transparency to sunlight. Therefore, the appearance and its features can be used to perform the analysis.

Each surface can also have more than one appearance property. For example, rendering of one building in summer and winter. Different looks will be assigned their special theme - for example, "winter" and "summer". Switching between themes in a program means replacing textures and surfaces. Multitexturing is also possible in CityGML. So, it is possible to compute shadow maps for each surface and then associate it with a theme that can be called "shadows". The shadow textures can then be mapped to the texture images on the corresponding surface. Appearance data by texture images or material definitions.

CityGML supports several ways to display surface textures:

- GeoreferencedTextures – are used to describe the appearance of irregular surfaces;
- Parameterized textures – use explicit texture coordinates for each surface to be mapped, or a projection matrix.

4 3D city modelling in Russia

In this chapter will be introduced the examples of the 3D city models in Russia.

4.1 Tomsk 3D city model

St. Petersburg company "Geoscan" in 2,5 months has created a detailed three-dimensional model of Tomsk using drones for aerial photography. The market value of the project in Tomsk is 10 million rubles, but this is not very large compared to the city budgets. This project was extremely helpful for the municipality, because only during the month were found ten thousand cadastral violations. Also, Tomsk's authorities now using the 3D model for the planning of the future building projects. This helped to abandon unrealizable projects and strongly affected the urban economy (Geoscan Group 2017).

The fragment of the existing model is shown in the Figure 16.

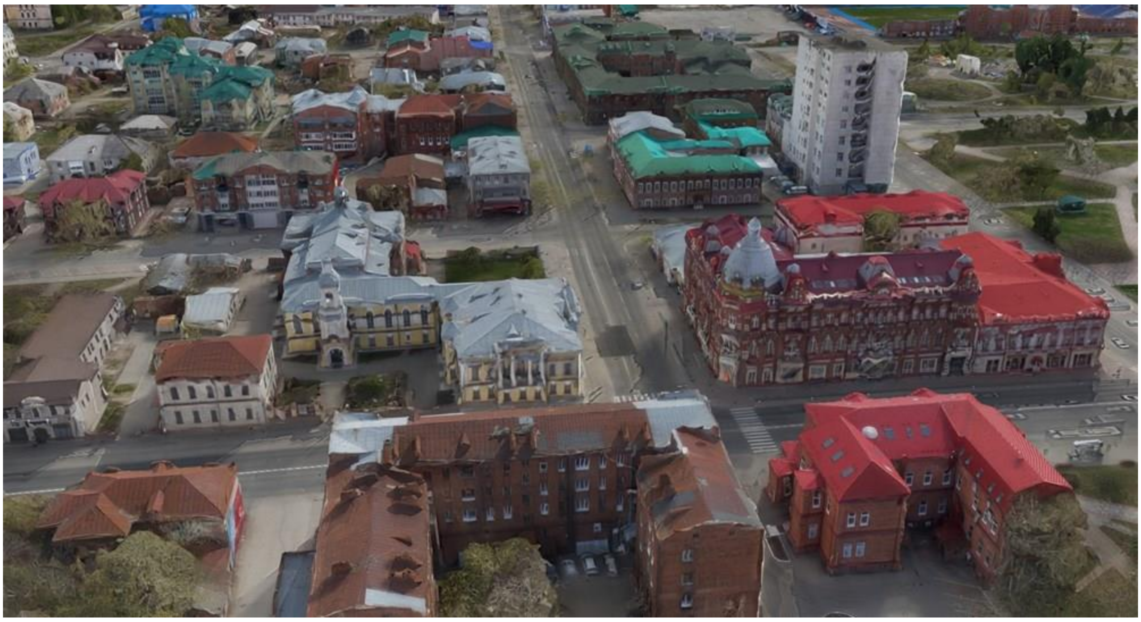

Figure 16. Tomsk 3D city model – fragment (Tomsk 3D 2016).

The 3D city model is LOD1-accurate and can be exported in 3DS models, COLLADA, Google Earth KMZ and etc (Pavlov 2020).

For the effective usage of the model was created open web portal of the city of Tomsk "Building the city together". In this portal posted the designing solutions for changing the urban environment and then the decisions are being discussed. The 3D portal provides the most visual representation of the proposed solutions and thereby allows professionals (architects and designers) to engage in dialogue with non-professionals in this area (citizens, deputies, members of public committees, etc.). One of the features of the web portal – municipalities parks and recreations review is shown in the Figure 17.

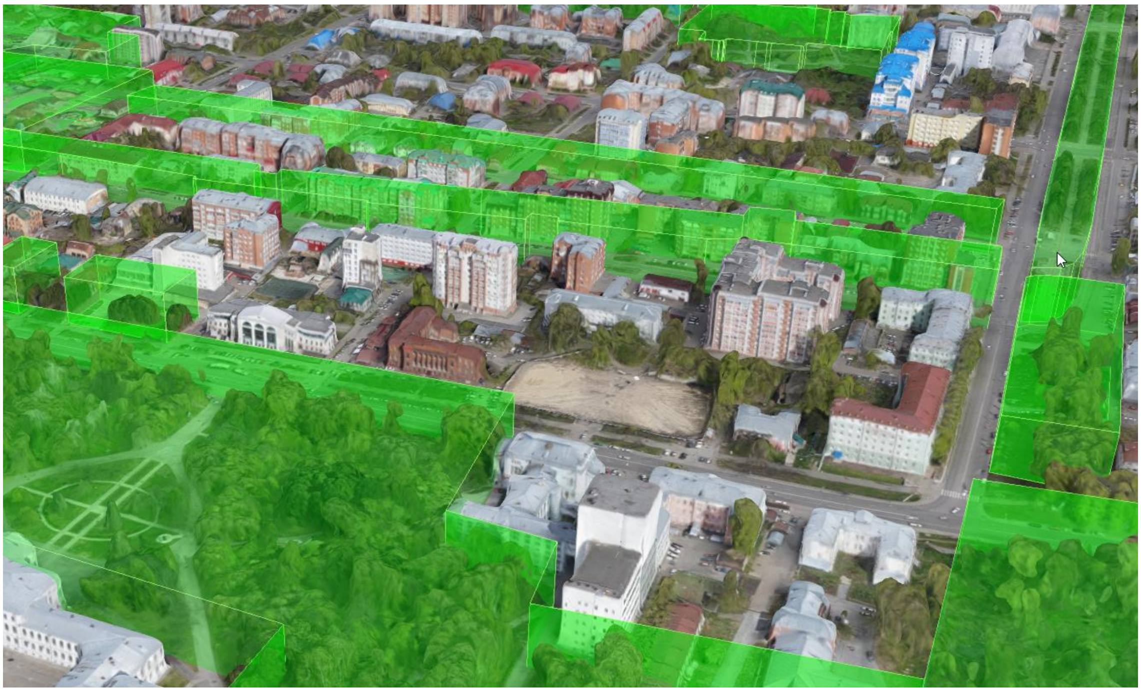

Figure 17. Tomsk 3D city model – parks and recreations marking (Tomsk 3D 2016).

The portal is organized in such a way that it allows any interested person - developers, investors, designers or citizens - to register and receive the necessary information and take part in joint work (Geoscan Group 2017).

As the Tomsk city model – is a mesh model, it allows to easily get the data about the terrain profile. This function is shown in the Figure 18.

Figure 18. Tomsk 3D city model – terrain profile dimensioning (Tomsk 3D 2016).

The model shows historical buildings, allows to calculate volumes and areas, profile of the surface, shows public spaces, monuments, and more.

4.2 Dubna 3D city model

In 2012 by order of the administration of the city of Dubna, the group of companies "NEOLANT" has implemented the municipal GIS of the city (GIS "Dubna"). The system is a complex integrated solution based on different software products. The first version of GIS "Dubna" used Autodesk MapGuide 6.5. In the future, the system was relocated to more modern software - Autodesk Infrastructure Map Server and AutoCAD MAP 3D and received many new features (creating models of utility networks, importing and exporting data in common exchange formats, etc.).

General look of the model is represented in the Figure 19.

Figure 19. Dubna 3D city model – general look (Neolant 2015).

To create a 3D representation of the city, the Autodesk InfraWorks platform was used. It allows, in the presence of 2D spatial data with attributes (height) and correct geometric contours, to create 3D models of territories on their basis. And in a matter of days, the contours of the rivers were filled with water, the buildings stretched upward and became voluminous, and the roads acquired coverage. All objects were given clear textures depending on the building material from which they are made. With 3D city model it became possible to visually present and evaluate projects for reconstruction and development of territories, taking into account the existing infrastructure (Spivak & Yurchenko 2012).

Figure 20 shows that the manual added information about the buildings can be reached from the model.

Figure 20. Dubna 3D city model – buildings data (Neolant 2015).

The system is available to all employees of Dubna local self-government, which is almost 200 people, including employees of geographically distributed divisions. For the most part, users work through the clients available in any Web browser and interact through a local network.

The most active users of the system are: architecture and urban planning authorities, the property management committee, the trade and services department, the housing and communal services department, the investment department, and deputy heads of administration. In addition, the data in the system are used by employees of organizations operating city engineering networks (water, heat, electricity) that is shown in the Figure 21 (Neolant 2015).

Figure 21. Dubna 3D city model – outside communications data (Neolant 2015).

Being a single platform for a large number of different services and departments, GIS "Dubna" contains and combines disparate information about urban land and property into a single database on a single cartographic basis, integrated with the 3D Autodesk InfraWorks application. This allows to make the procedure for making land decisions more transparent and faster, to reduce the number of urban planning errors, and also opens up new opportunities for spatial analytics, report generation and the development of related systems that need a single digital geo-base. As a result, the city administration received a single tool for supporting decision-making at a qualitatively new level, and city bodies and services - a single topical base for accounting for their economy.

4.3 Yarolslavl 3D city model

Architectural company Vimania created a 3D model of Yaroslavl. The model was originally created for the production of panoramic videos for tourism purposes and the main emphasis in detailing the model was placed on the UNESCO zone. Also, the central part of the model, the UNESCO area, was used to develop the augmented reality mobile application - Yaroslavl 3D (available on Google Play). Currently, as part of the creation of the Augmented Reality Laboratory at the Yaroslavl Architectural Institute, it is planned to develop an information system based on a city model, which allows to embed architectural projects of buildings into the real environment of the city. At this stage, it is planned to add a semantic component in a model (Rastorguev 2020). General view of the model is presented in a Figures 22 and 24.

Figure 22. Yaroslavl 3D city model – general view (Vimania 2018).

As an initial data were cared the topographic survey of the city, models of buildings were built according to their real heights. For individual buildings and facades photogrammetric construction was used. In all other cases, building textures created from real photos.

Also, the company created a 3D model of the pre-revolutionary Yaroslavl. It is made for augmented reality application as well. So, anyone can try walk around 20th-century Yaroslavl through virtual reality glasses. The fragment of the historical model is presented in the Figure 23. The historical version of the model was made on the basis of archival data: plans, building facades and photographs, most of which were found in open sources (Rastorguev 2020).

Figure 23. Yaroslavl 3D city model – historical variant (Vimania 2018).

Full assembly of the model was carried out in Cinema 4D software. It is a 3D modelling complex and mostly used in the product visualization, architectural, medical, advertising, and game industries. Modeling of individual blocks and buildings were carried in Trimble SketchUp (Rastorguev 2020).

Figure 24. Yaroslavl 3D city model – general view (Vimania 2018).

In the creation process were taking into account the peculiarity of using the model, so maximum optimization and reduction of the number of polygons was required. At the moment the model exists in C4D format. The simplified version is publicly available in the mobile application (Rastorguev 2020).

5 St. Petersburg City Model

3D city model of the urban space of St. Petersburg was developed by LLC “Institute of Territorial Development” (LLC “ITR”). Customer of the model - Committee for Urban Planning and Architecture under the Government of St. Petersburg. The model includes information about buildings and structures, elements of hydrography, road network, railways, green spaces and terrain.

The basic requirements for the model were necessary in consideration of it as a high-precision geoinformation tool intended for effective use by both state authorities and legal entities and individuals. The requirements are follows (Avrutin 2009):

- The need and sufficiency of information resources, the sets and combinations of which will allow solving the problems of public administration in the field of territorial development and providing a compromise between the initiative of a particular investor and the interests of the whole society.
- The prevalence and general availability of software tools that provide, among other things, multi-user access, access based on WEB-resources and stable work with industrial Database Management System (DBMS).
- Versatility of formats for presenting information resources to ensure the possibility of exchange with other GIS and computer-aided design tools.
- Compliance with the requirements of secrecy.
- Accuracy.
- Methodical approach to creation a 3D model as a geodatabase for the subsequent development of the city model itself, forming standards and, possibly, technical regulations for a three-dimensional representation of the real world (at the federal level).

The model was created on the basis of the current topographic plan M1: 10000 with the specification of the plan-height characteristics of individual elements according to remote sensing data. The general view of the model is represented in the Figure 25.

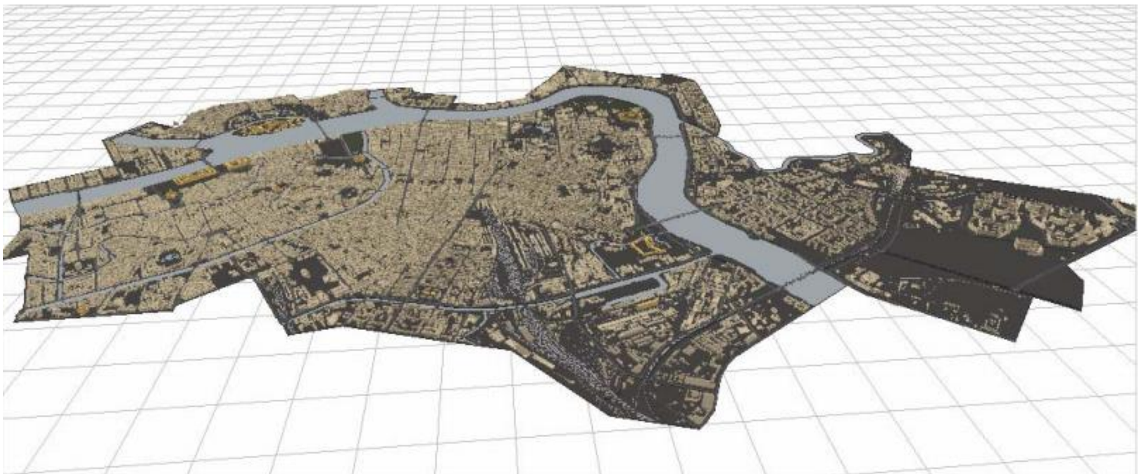

Figure 25. St. Petersburg 3D city model – general view (Lomtev 2009).

5.1 Used standards

At the time of the study, Russia does not have specific standards related to 3D modeling of cities. The creators of the model claim that for this reason they were guided by the highest possible level of accuracy when creating the model (Lomtev 2009).

5.2 Production

Regarding the issues of accuracy, it should be noted that in the absence of any standards and regulation documents about the 3-dimensional models of the territory development in Russia, in a creation process of the model, developers had to use maximum achievable planning and altitude accuracy characteristics in relation to each used information resource (Avrutin 2009).

In the development process were used two main software – ArcGIS and AutoCAD. ArcGIS is a family of geographic information software products of the American company ESRI. They are used for land cadastres, in the tasks of land management, registration of real estate objects, systems of engineering communications, geodesy and subsoil use and other areas. The ArcGIS platform is the optimal solution for creating GIS models of large areas. ArcGIS is built on the basis of open standards of the computer industry (including COM, .NET, Java, XML, SOAP), which provides support for generally accepted standards, the flexibility of the proposed solutions, and extensive editing capabilities for spatial data. A distinctive feature of the applied GIS is its widespread occurrence, as well as the absence of the need for special technical support throughout the entire cycle of generating geoinformation data (Avrutin 2009).

5.3 Terrain

Terrain of the model is realized in the form Triangular Irregular Network – TIN (Lomtev 2009). It is a digital display of surface structure, the simple representation of it is shown on the Figure 26. The surface in that case is modeling as a continuum consisted from points that have altitude values. The points are selected with variable density. The term "Triangular Irregular Network" accurately describes the properties of a TIN, namely (DeMers 1997):

- "irregular" defines the key advantage of TIN in surface modeling - points can be taken with variable density to model areas where the surface relief changes harder;
- "triangular" indicates the triangles that constructed from a set of points; triangles give a good idea of the local part of the surface, because three points (xi, yi, zi), i = 1,2,3, exactly define a plane in three-dimensional space;
- “network” reflects the topological structure that is inherent in TIN - each triangle contains information about neighboring triangles, thus forming a network.

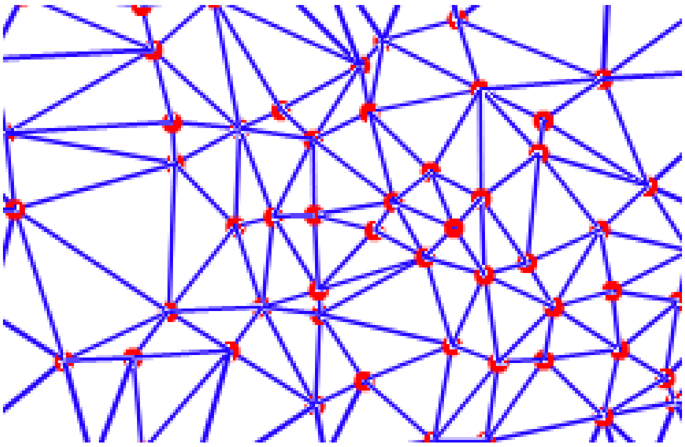

Figure 26. TIN surface (ESRI 2014).

TIN elements are created from points, lines and polygons, which are called mass points, breaklines, and exclusion regions in TIN models (DeMers 1997):

- Mass points are points with known coordinates (X, Y, Z); the density of mass points should vary depending on the degree of surface change: for a flat plain, there is a fairly low density of points, and mountainous relief requires a high density of points, especially in areas of rapid elevation changes;

- Breaklines outline sharp heterogeneity of the terrain; they correspond to natural features such as ridges or artificial features such as roads;
- Exclusion areas represent strictly horizontal sections; usually these are water surfaces (lake, ocean) or the edges of construction sites and other artificially leveled areas; exclusion areas are defined by polygons (polygons are also used to set the project boundary: cut off unnecessary parts of the triangulation).

So, in St. Petersburg city model, terrain is implemented in the form of TIN, the inflection points are the elevation marks of the relief translated from topographic planes of scale 1: 2000. Local relief elements were also taken into account: embankments, ledges, etc. The relief representation of the model is shown in the Figure 27.

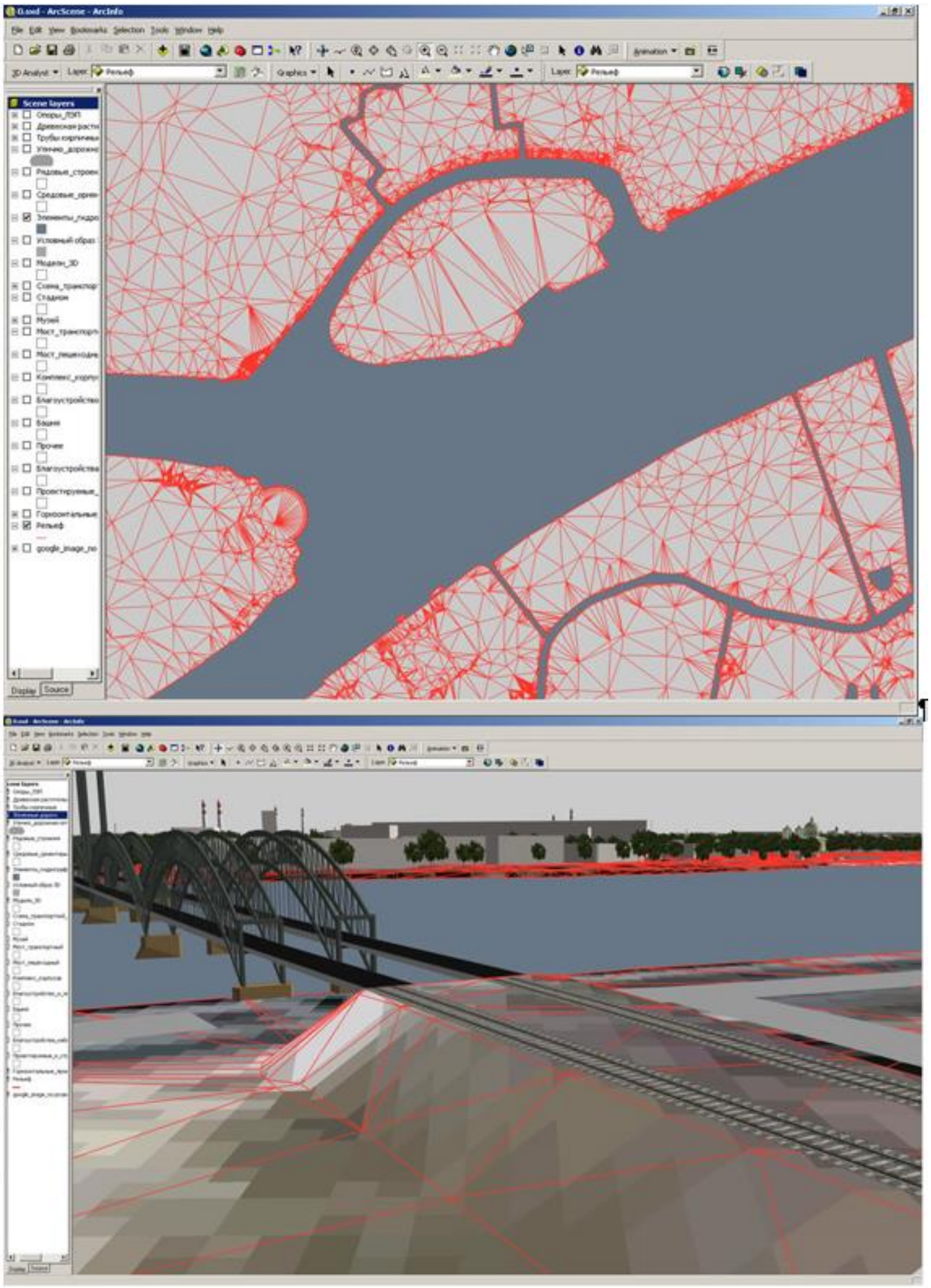

Figure 27. Relief in the form of TIN, railway tracks, engineering structures, elements of hydrography (Avrutin 2009).

In the set of input data to build the resulting TIN, various inflection lines, clipping lines were introduced heights, describing the spatial characteristics of local relief elements. At the same time, the general situational context of the existing environment was taken into account, - placement of railways on embankments, the adjacency of coastlines with ledges, etc (Lomtev 2009).

5.4 Buildings

Buildings in the model are represented as the 3-dimensional objects, made by extrusion from their contours on the city plan. The heights of each building are determined with the help of photogrammetry. The photogrammetry was produced by orthophoto maps at digital photogrammetric stations by specialists of FSUE "Center" Sevzapgeoinform". Orthophoto plan is nothing more than a map of the area. The only difference from ordinary photography is that this map is "assembled" from many pictures taken vertically down from a given height (Avrutin 2009).

The initial information in the form of photographic images, made by shooting from any aircraft device, is subjected to special processing in a photogrammetric program (Lomtev 2009). In aerial photography, the frame overlay method is used. With this technique, the same areas of the surface appear simultaneously on several frames – Figure 28. And upon further actions, based on the coincidence of characteristic features, they are glued together, becoming a single orthophoto. To process the images, engineers use special equipment, like a digital photogrammetric stations. The program defines common points between each pair of images. After that, the complete photogrammetric equation is solved with the definition of the terrain (Kalinin 2017).

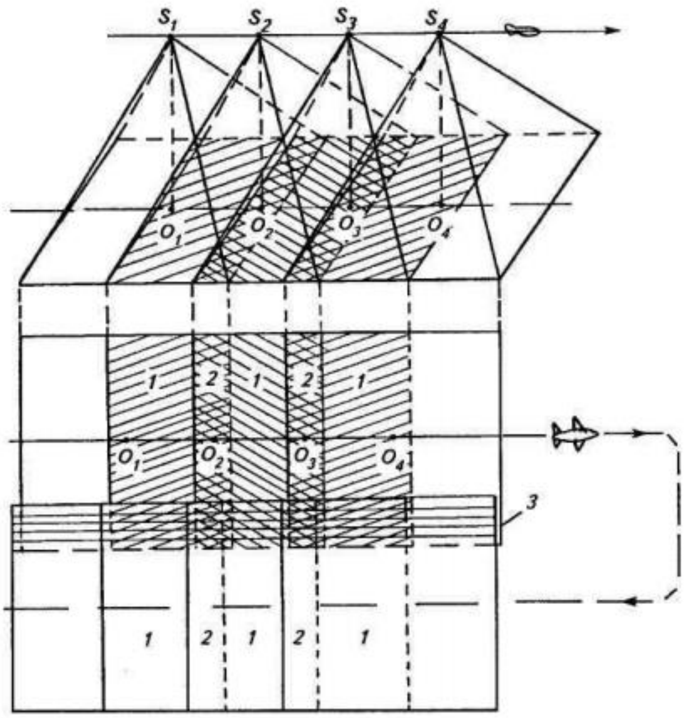

Figure 28. Aerial photo scheme. 1 - double longitudinal overlap of images; 2 - triple longitudinal overlapping images; 3 - transverse overlap of images; $S_1, \ldots, S_4$ - the position of the centers of photography; 0_1, ..., 0_4 - their projections on the ground surface (Kalinin 2017).

After the pictures have been taken and linked, they are decrypted. The main task of decryption is the identification of objects (phenomena, processes) on the image and determination of their characteristics. To identify objects in images, geometric and the optical characteristics of these objects are direct deciphering signs: the shape and size of objects in plan and in height; general (integral) tone of black and white (achromatic) or color of color (chromatic) images as well as the texture of the image (Kalinin 2017).

Form in most cases is a sufficient indication for separation of objects of natural and anthropogenic origin. Human-made objects are usually configured correctly. So, any buildings and structures usually have regular geometric shapes. The same can be said about canals, highways and railways horns, parks and squares, arable and cultivated forage lands and other objects.

Determination of the spatial shape of a relief object is facilitated by its own shadow, which covers a part of the surface of the object itself that is not illuminated by direct sunlight, and a shadow falling on the earth's surface from towering objects. The sizes of the decrypted objects in most cases value relatively. The relative height of objects is judged directly from their images at the edges of images obtained using wide-angle imaging systems. About sizes, as well as about the shape of the height can be judged by the shadows falling from the objects (Kalinin 2017).

As a result of photogrammetry, were determined the height points of the buildings – Figure 29.

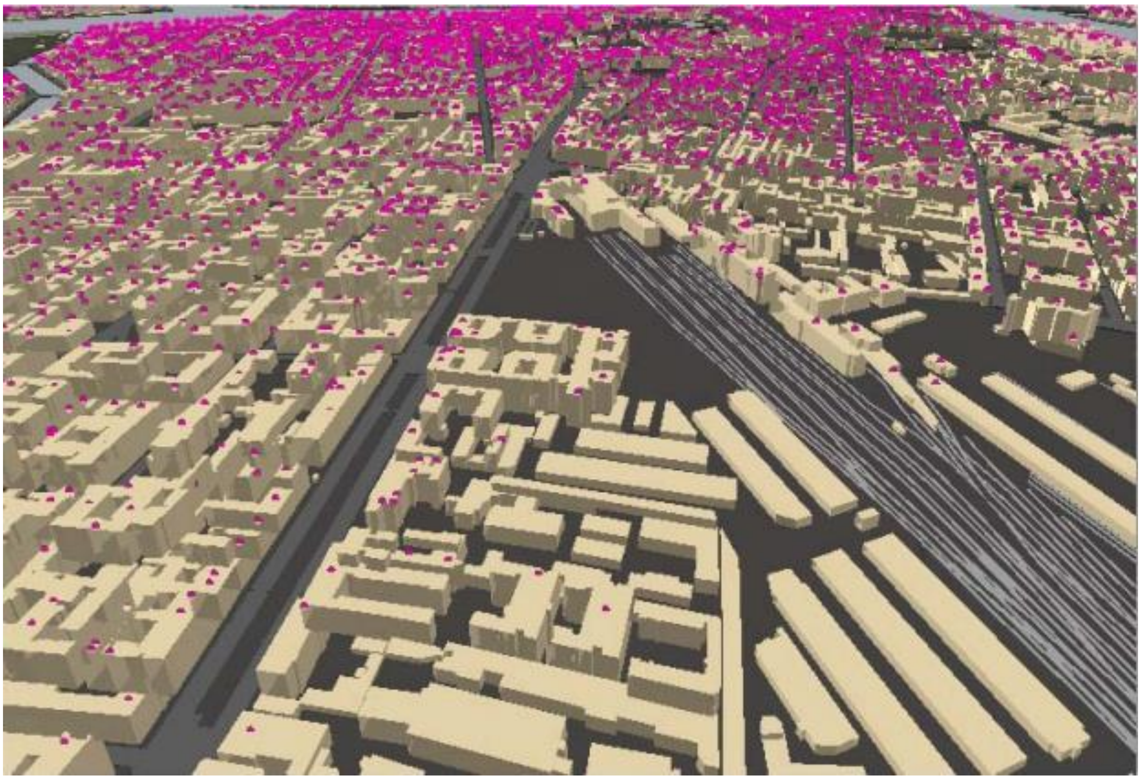

Figure 29. Photogrammetry points of the buildings heights in SPb city model (Lomtev 2009).

The most significant historical buildings and structures with complex architecture are presented in the form of detailed complex three-dimensional models. For a number of buildings that are critical visual barriers when assessing visibility from the historic center of St. Petersburg and located on the embankments of the river Neva, were carried additional clarifying measurements of heights using a reflectorless electronic total station Sokkia 530KT with their subsequent modeling – Figure 30 (Lomtev 2009).

Figure 30. Building models measured with an electronic total station in SPb city model (Lomtev 2009).

The vegetation elements presented in the model are also made as a form of TIN, breakline points of which are determined by photogrammetric and geodetic measurements and controlled by the results of photofixation. Then they there were presented in the form of 3D tree symbols, scaled according to the height characteristics (Avrutin 2009).

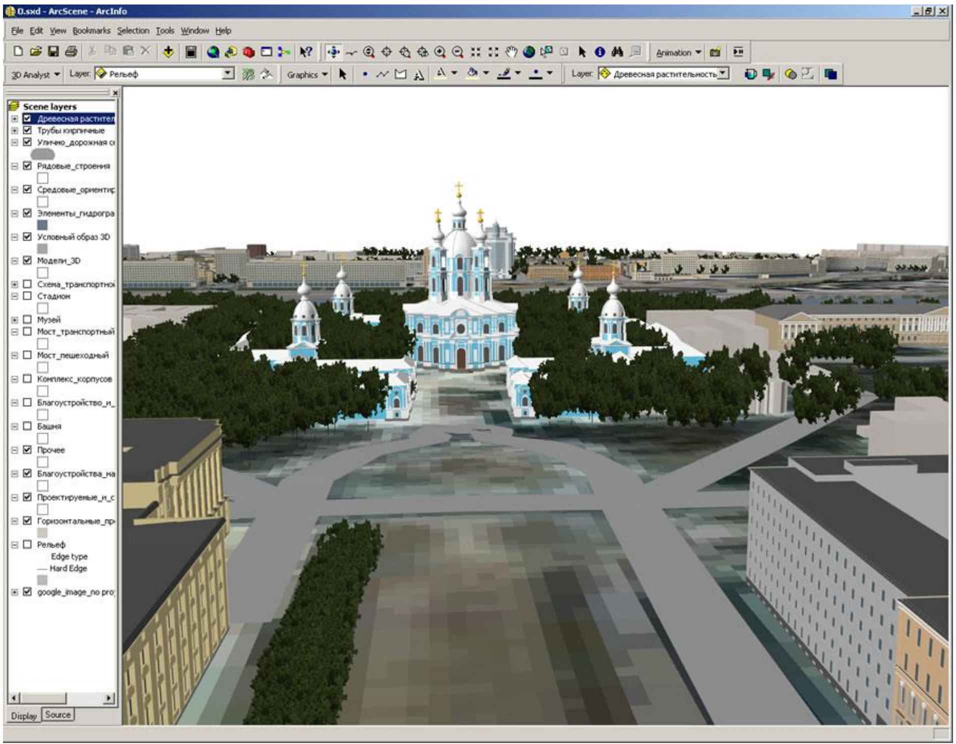

Figure 31. Vegetation example in SPb city model (Avrutin 2009).

In the model also presented: supports of overhead power lines (Fig.35), chimneys (Fig.33), bridges (Fig. 34) and the road network elements (Fig.35).

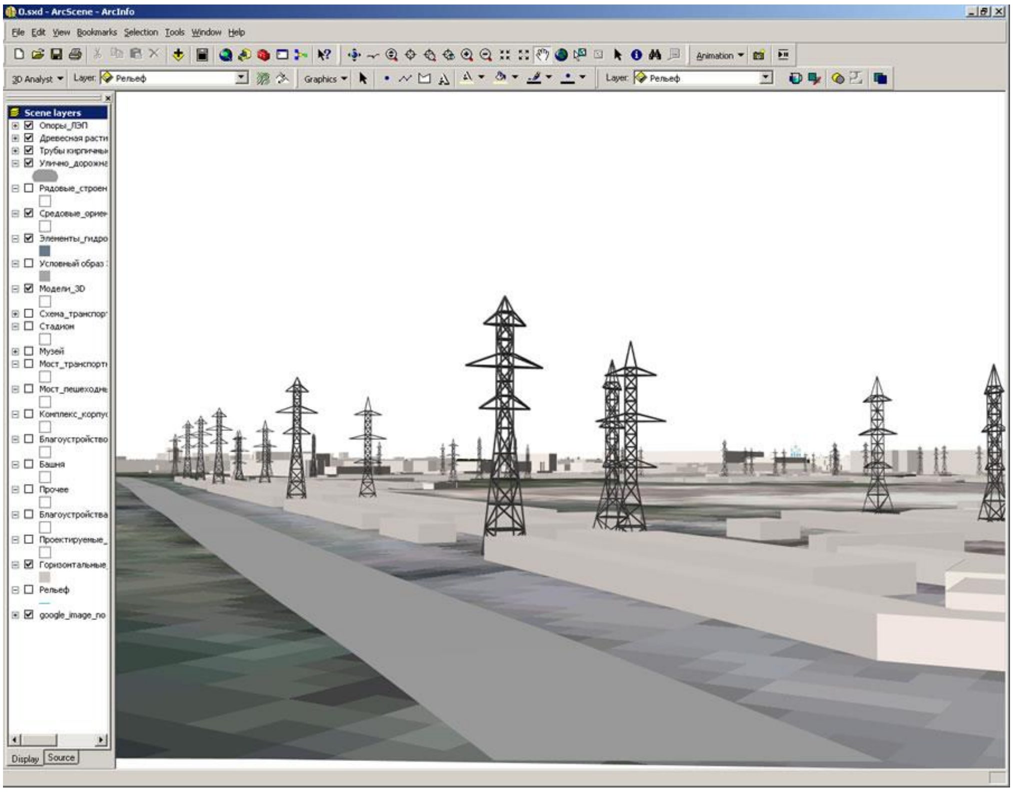

Figure 32. Supports of overhead power lines in SPb city model (Avrutin 2009).

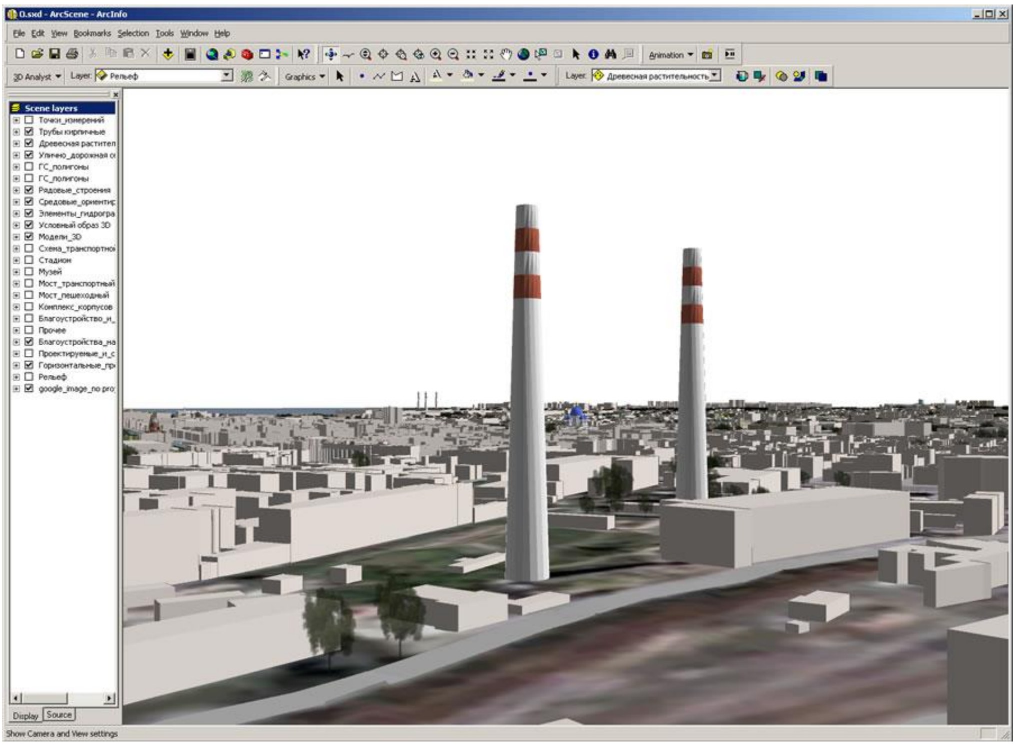

Figure 33. Chimneys in SPb city model (Avrutin 2009).

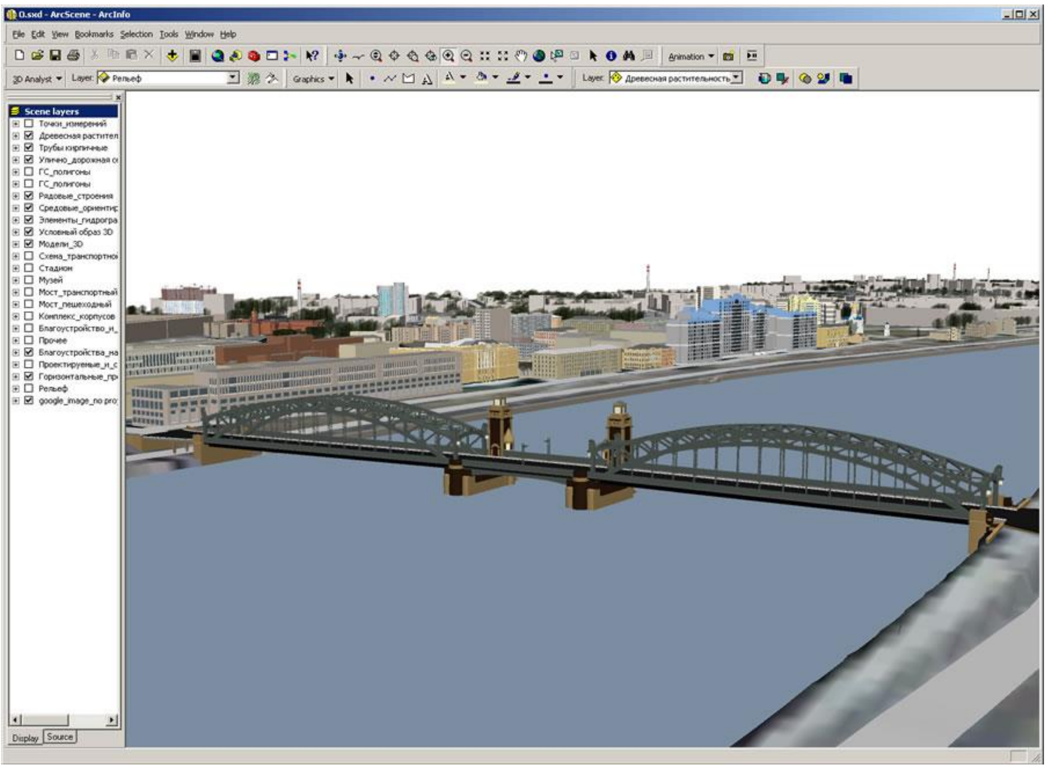

Figure 34. Bridge model (Bolsheokhtinsky bridge) in SPb city model (Avrutin 2009).

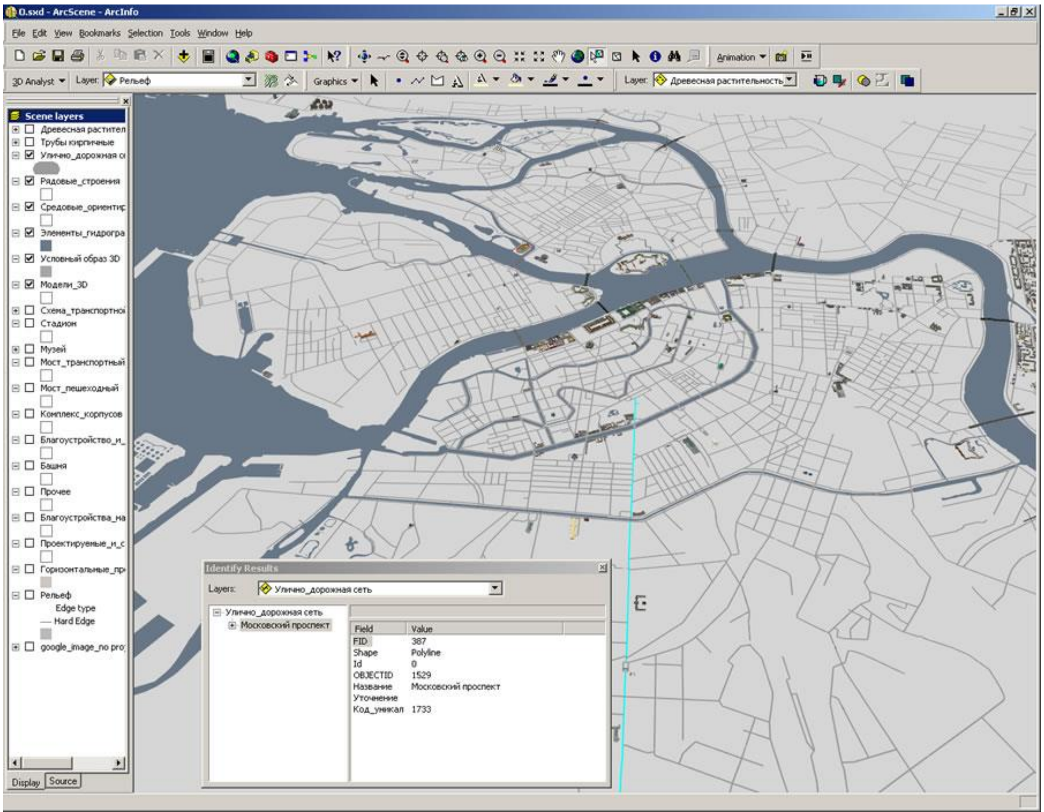

Figure 35. Hydrographic elements, road network (the information window shows the attributes of the selected object of the road network) (Avrutin 2009).

5.5 Usage of the model

The main use purpose of the model is assessing the perception of projected objects in the alignment of panoramas protected in accordance with the current legislation and against the background of surrounding buildings (Avrutin 2009). The example of the application is shown in the Figures 36 and 37.

According to the law of St. Petersburg 19.01.2009 No. 820-7 "On the boundaries of the united protection zones of cultural heritage objects located on the territory of St. Petersburg, land use regimes and requirements for urban planning regulations within the boundaries of these zones" , the city has the status of a historical settlement of federal significance on the basis of a joint order of the Ministry of Culture and the Ministry of Regional Development July 29, 2010 No. 418/339 "On the approval of the list of historical settlements". Of course, all works on the design and restoration of architectural monuments and garden and park art are performed by companies licensed by the Ministry of Culture in accordance with the requirements of federal legislation. Currently, the St. Petersburg law "On the boundaries of the united protection zones of cultural heritage objects located on the territory of St. Petersburg'' establishes the standard of protection of the historical city panoramas for 6 kilometers.

So, when planning the development, the height of the object will need to be calculated based on the need to preserve valuable historical panoramas 6 km from the boundaries of the protected area. And for this task the city model is very suitable.

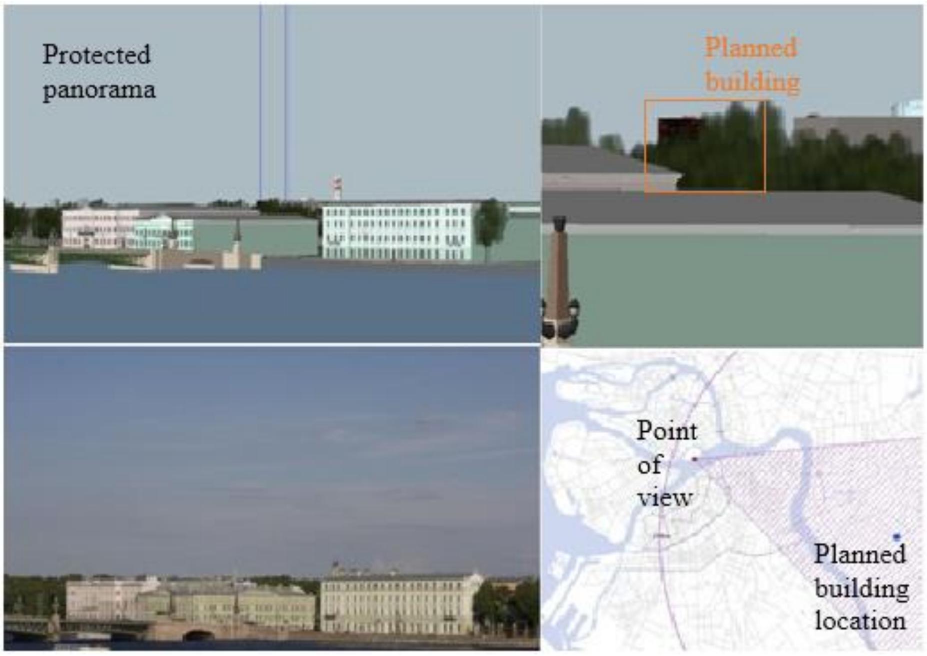

Figure 36. Assessment of the perception of projected objects in the alignment of protected panoramas (on the left -protected panorama of the city; on the right – planned building and its location) (Avrutin 2009).

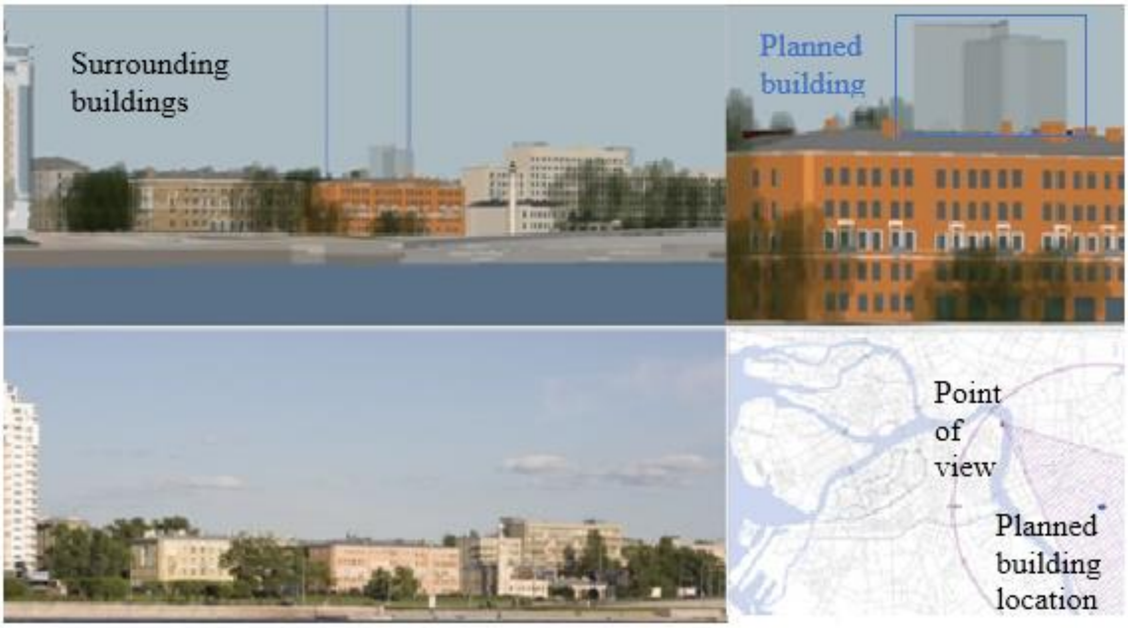

Figure 37. Assessment of the perception of the projected against the background of the surrounding buildings (Avrutin 2009).

In accordance with foresaid, the model can be used to address the issues of considering volumetric-spatial solutions for the development of individual areas of the city and individual buildings and structures at the stages of preparation, as well as monitoring the General Plan of St. Petersburg and the Rules for Land Use and Development of St. Petersburg. As well as in territory planning documentation, design documentation for the construction (reconstruction) of individual objects, granting permits for deviations from the limiting parameters of permitted construction, reconstruction of capital construction objects in terms of the maximum height of buildings and structures. And, of course, when considering these issues at public hearings, meetings of the town planning council and the commission on land use and development (Avrutin 2009).

Also, ArcGIS software allows to determine limit of the height of the projected buildings, according to the foresaid restrictions (invisibility of the building from the historical center in the context of tasks related to the clarification of the altitude regulations St. Petersburg) (Lomtev 2009).

This problem was solved with a few steps (Lomtev 2009):

- Was constructed a current model of heights of the existing buildings of the historical center of the city;
- Were selected the observation points within the historic center, 52 pieces;
- The maximum angle of a circular view was calculated with a step of rotation 0,5 degrees caused by existing buildings in the historic center, as visual obstruction for every vantage point. Were created the space vectors in accordance with certain vertical corners;
- The vectors were extrapolated for the rest of the city to a certain limit with subsequent division into equal segments and calculation height values for the vertices of the line segments – Figure 38;

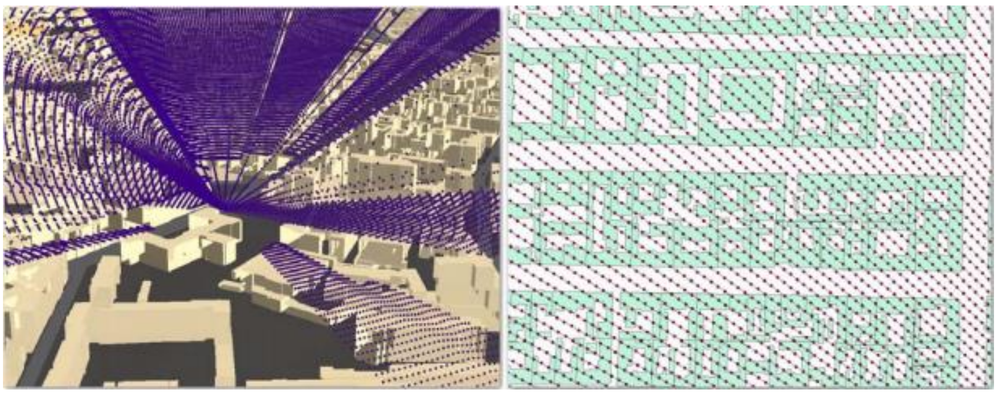

Figure 38. The illustration of the step 4 (Lomtev 2009).

- Based on the obtained set of heights were constructed the GRID-surfaces for each observation points – Figure 39;

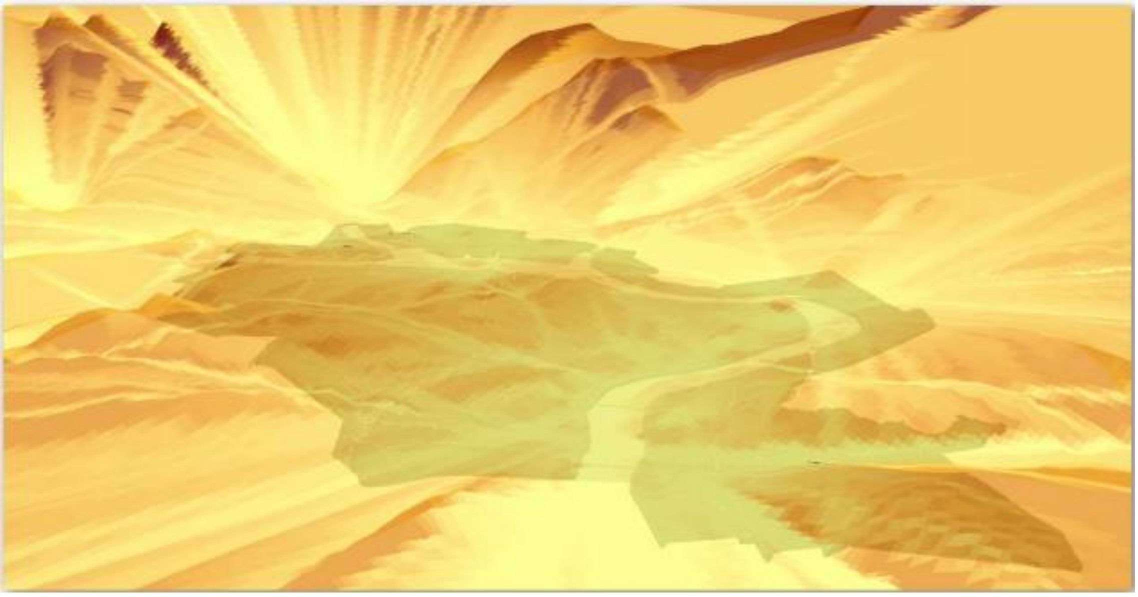

Figure 39. The illustration of the step 5 (Lomtev 2009).

- As a result, was constructed the resulting GRID-surface for all observation points, according to the minimum heights for target points simultaneously determined from different observation points;
- Was constructed the TIN-surface by the triangulation method based on the resulting GRID-surface;
- Was constructed a three-dimensional surface and then combined with a three-dimensional model of the city.

The model was used by the Committee for Urban Planning and Architecture and the Commission on Land Use and Development of St. Petersburg as the basis for assessing the permissible values of "local increases in the maximum height of buildings, structures," as part of the Land Use and Development Rules of St. Petersburg.

6 Implementation and results of the municipal survey

6.1 Survey design and implementation

In the survey data is collected in a standardized way and the respondents to the survey are themselves a sample. Standardization reflects the fact that all participants in a survey must be asked about the subjects to be researched in the same way. The survey was chosen as the way to conduct current research.

This research method has both positive and negative sides. It can easily cover a large number of people, and the survey itself can be made complex. Questionnaire research is also often effective in the point of view of the researcher, both in terms of time and effort. The questionnaire allows to collect a wide range of information, such as facts, values, attitudes, opinions and actions. However, questionnaire research is not appreciated as a very deep way of research, since the material obtained remains easily superficial. One of the drawbacks of a survey is that it is impossible to be sure how serious survey recipients and respondents accepted it. In addition, it can be difficult to assess the correctness of the answer choices provided in the survey before interviewing of the respondents.

But the survey success can be improved if it is properly designed. All of the respondents have to clearly understand all of the questions. Besides the common types of questions such as multiple choice questions, survey also has the open-ended questions. The survey is shown in the next chapter.

For this research was chosen online survey – it is a quick and modern way to proceed it. The advantages of an online survey are the ease of submitting and returning a survey response form. But there are also some complexes in it – for example, process of collecting contact information of the respondents.

The purpose of the research is to find out needed information about 3D city modelling in city of St. Petersburg. Conduction of the survey was proceed through the Google Forms – it’s quite simple in use and safe platform. As the respondents were selected specialist from the different building companies of St. Petersburg, working in a different areas of the building industry. Link on a survey was sent to the potential respondents via email, hiding other recipients from recipients message. The offer of joining the survey was supplemented by the cover letter, which is shown in appendices. The survey was conducted anonymously.

6.2 Survey results

Of the 60 companies to which the survey was sent only 11 responded. From each company there is one representative – respondent. When interpreting the answers, it should be noted that the respondent could have skipped the question and gave several answers to some of the questions.

The study was divided into several blocks. The first of them allows to collect background information about the survey participants and allows to find out if the respondents are aware of the existence of such a model. The second block concerns the model of St. Petersburg itself. Questions were asked here about the experience of using the model. The third block deals with the topic of creating a new open model of St. Petersburg. Here the respondents answered what information they would like to see in the future model and expressed their comments regarding urban modeling in Russia in general.

6.2.1 Background of the respondents

Questions 1, 2 and 3 of the survey concerned the respondent's background information. Most of the respondents represented the field of industrial and civil construction - 5 respondents. In second place are representatives of road construction - 4 of them. Then, one representative of bridge construction. And also a company for the transportation of oversized cargo took part in the survey.

Only one respondent of the survey used a 3D model of St. Petersburg in their work, and six respondents did not even know about the existence of such model.

6.2.2 The existing model of St. Petersburg

In this block of questions, respondents which are familiar with the St. Petersburg city model were asked to answer questions about their experience of using it.

Question 5 was aimed to finding out how the respondents learned about the existence of the St. Petersburg model. As it was an open question, the participants had the opportunity to show how different sources of information they have. The question is shown in the Table 2

How did you know about the existence of the model?

5 answers

I found out on forums on the Internet

A similar model exists on Google Earth and covers the entire planet. The development of the St. Petersburg model lags behind European cities, and has been going on for several years. However, we are actively monitoring digitization.

Working

from lectures

Information appeared in the media periodically. While studying at the university, the teacher also talked about the students who created a model of St. Petersburg in the ArcGis program

Table 2. Question 5 - How did you know about the existence of the model?

As it shown in the answers, respondents almost equally know about the model existence from the internet resources or from the university courses.

The next question helped to find out that only 1 respondent used the existing model in their work. Therefore, in this block, its experience of use will be described.

Thus, to work with the model, the respondent used the KML extensions, in which any projects of Autodesk products are saved. The model was used to create snapshots of the designed objects. The respondent also mentioned that the widespread use of the model is not yet carried out – Table 3.

What information was found in the model most useful for your work?

1 answer

All the advantages of the work have yet to be picked up, since the widespread use of the digitized area is not yet carried out

Table 3. Question 7 - What information was found in the model most useful for your work?

The respondent also commented that at the moment work concerning modelling of the communication systems is in process – Table 4.

How do you think this model needs to be improved?

1 answer

At the moment, the professional community of St. Petersburg is actively digitizing underground engineering networks. This information is very much in demand for its use.

Table 4. Question 9 - How do you think this model needs to be improved?

In conclusion, the respondent answered that he considers it necessary to introduce the model into open use.

6.2.3 Creation of a new open model of the city of St. Petersburg

Out of 11 respondents, 10 respondents consider it necessary to create a new 3D city model that will be open to use. The result is shown un the Figure 40.

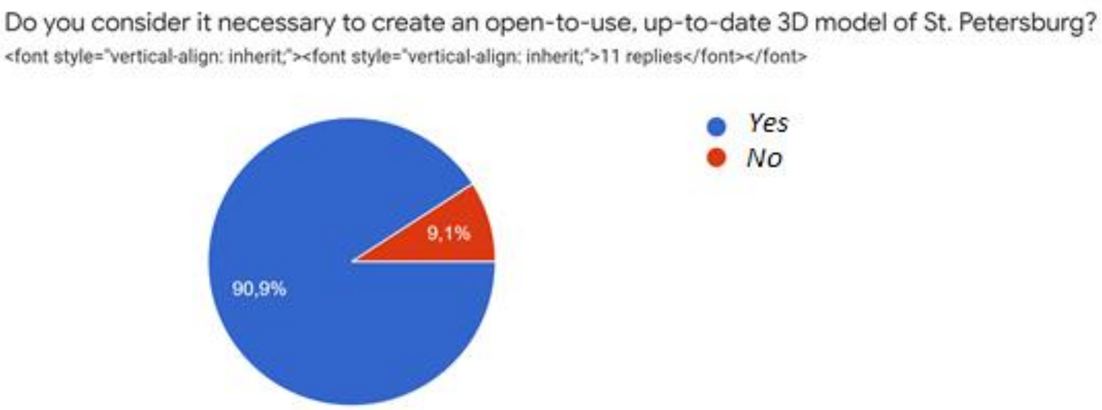

Figure 40. Question 11 - Do you consider it necessary to create an open-to-use, up-to-date 3D model of St. Petersburg?

At the same time, all respondents would be most interested in using models of buildings and structures when working with the new model. Also of great interest appear the relief, territorial boundaries of land plots, as well as the data about the location of communication networks.

In addition, two respondents also provided their own answer options. Firstly, it is the digitization of the movement of transport networks with the binding of real objects and their geolocation in real time. And also, one respondent mentioned that the information saturation of the map of the new model should be maximum with the ability to disable layers. The whole question is shown in the Figure 41.

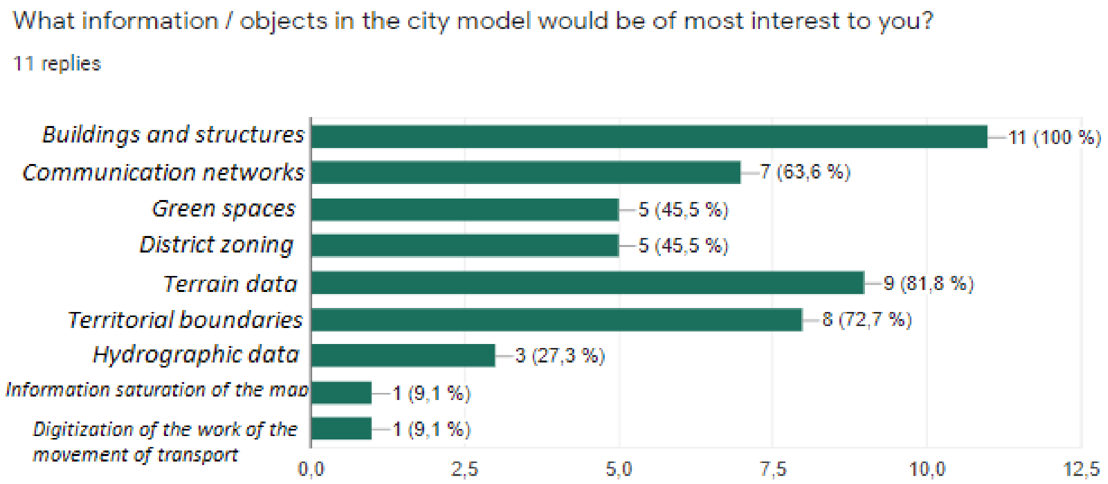

Figure 41. Question 12 - What information / objects in the city model would be of most interest to you?

The next question was aimed to find out whether respondents see potential benefits for construction companies and citizens in using an open city model. 10 out of 11 respondents answered positively – Figure 42.

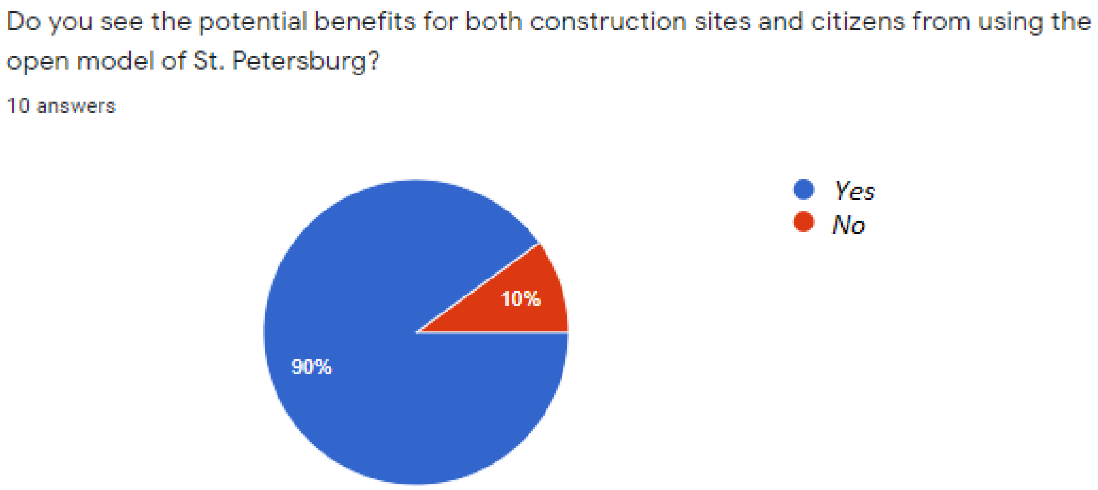

Figure 42. Question 13 - Do you see the potential benefits for both construction sites and citizens from using the open model of St. Petersburg?

The next question was with an opportunity for a detailed answer. In it, 4 respondents explained how they see the benefits of using the 3D model. First of all, the participants sure that with the usage of open digital city model, it will be possible to analyze and make calculations of the new structures more carefully. For example, insolation calculations, urban planning and determination of the influence on the surrounding area. Also cadastral plan open system was mentioned.

But the model will also be useful for the purposes of cargo transportation. The model could be used to assess the driveability (if the model reflects the width of the carriageways, the height of the power lines). In this case, it will be possible to preliminarily assess the possibility of traveling along a particular route. The answers are shown in the Table 5.

The presence of a 3-dimensional model of the city in general, and of specific buildings in private, will allow a more complete analysis of the environment when designing new publications and structures. It will be convenient, for example, when "landing" a new building on the site, to have an idea of the dimensions of the surrounding buildings. This will help to correctly calculate the insolation, determine the volume of the new structure and harmoniously fit its environment.
Analysis of the urban planning characteristics of the site, the possibility of using a model of a new building for the calculation of insolation and initial planting to assess the architectural and urban planning appearance
Technology is developing very rapidly. The use of Roseestra maps with reference to cadastral plans is very useful in work. Zones of negative influence are also used on other resources. Formation of a single space that collects all data together is a very relevant topic
The use of an open model of the city will make it possible to plan in advance the development of the city, as well as its appearance and improvement. From the point of view of usefulness for transportation of bulky goods - the model could be used to assess the possibility of travel (if the model reflects the width of the carriageways, the height of the power lines). In this case, you can preliminarily evaluate the possibility of travel along a particular route. Also, if the model indicates which infrastructure object is in whose possession, this would facilitate the search for owners (sometimes you have to dismantle road signs, power lines, road restraints to get through)

Table 5. Question 14 - If possible, explain the answer you chose.

In question 15 respondents were asked to tell what possible research they would like to conduct on the basis of a 3D city model. Three respondents gave a detailed answer.

Thus, it is interesting for the participants to use the model in urban planning and insolation calculations. But for that purpose, participants believes that it is necessary to fill the model with the semantic data. Otherwise the model will have very narrow usage possibility – Table 6.

Assessment of the town planning appearance. Insolation assessment.
3D city map without data filling has a very narrow application. Building files should contain a set of information (or links) to more comprehensive data about projects - the composition of the pavements of the road surfaces, service life, dates of major repairs, logs of maintenance of buildings and structures, and so on.
In addition to estimating the route, the model would be useful for analyzing the possibility of travel in "narrow" places. For example, to find out whether a road train 40 meters long and 5 meters wide will be able to pass at a certain place in the city.

Table 6. Question 15 - What possible research would you like to do based on a 3D model of the city?

Finally, respondents were asked to leave their comments regarding urban modeling in general. Three respondents gave a detailed answer that are shown in the Table 7.

The heights, dimensions and main elements of the building must be accurately indicated in the simulation. Detailed textures are secondary. Also, the relief must be accurately shown, the planned location of all major topographic features.
As described above - 3D city model is not an information model. More in demand is information about buildings and structures, zones of red lines and other use of geolocation applications with reference to real data collected from different resources
The creation of a full-fledged model is essential for the successful development of any city. This will help to see weaknesses in terms of infrastructure, get feedback from city residents, and also make it easier for hundreds, if not thousands, of companies involved in construction and improvement. It is also important that the model is publicly available to everyone.

Table 7. Question 16 - Do you have any comments regarding urban modeling in general?

According to the respondents, the heights, dimensions and main elements of the building should be accurately indicated during the modeling. Detailed textures are secondary. Also, the relief must be accurately shown, the planned location of all major topographic features.

The model is more in demand for information about buildings and structures, zones of red lines and other use of geolocation applications with reference to real data collected from different resources.

It is also interesting to believe that the creation of a full-fledged model is necessary for the successful development of any city. This will help you see weaknesses in terms of infrastructure, get feedback from city residents, and make it easier for hundreds, if not thousands, of companies involved in construction and improvement. It is also important that the model is publicly available to everyone.

6.3 Evaluation of the results of the survey

6.3.1 Validity of the results

The security and anonymity of the survey conducted were implemented reliably. The survey was sent via email and the recipient names were hidden so that no one could see the other survey recipients.

The percentage of respondents to the survey was 18%. The survey was kept short and began with multiple choice questions. Open-ended questions were optional and were left solely at the discretion of the respondent. Thus, the questionnaire page allowed for the submission of responses, although not all of the questions in the survey were completed by the respondent. The respondent could also choose several options for the same question.

Unfortunately, only one respondent answered the questions regarding the real use of the existing model of St. Petersburg. Therefore, there was no variability and alternativeness of the answer in this block. And finally, you have to rely only on the experience of one respondent.

6.3.2 Overview of the results

Analyzing the survey results, it is possible to say that St. Petersburg needs its own open 3D model. The previous model that was reviewed in this study is now obsolete. It has no semantic properties and can only be used in narrowly focused visual activities.

By the answers, the respondents made it clear that the new model of the city should be sufficiently informative and have semantics. And also to be universal - to have a single format that could be used in the work of companies operating in various industries. This is clearly seen in the answers of a respondent from a transport company - the urban model will be useful not only for the construction industry.

Thus, based on the survey, it is possible to identify aspects of use that are important for future consumers.

7 Summary

The results of the study allow to get an idea of the development of three-dimensional urban modeling in Russia, as well as its current state in St. Petersburg in particular. This research was also aimed to find out what problems related to urban modeling are currently facing the cities of Russia.

One of the main indicators of the current situation with urban modeling is the absence of any standards for the production of such models. The consequence of this is the difference in formats and methods of production of existing models, as well as different ways of their use. Taking as a basis the survey conducted in St. Petersburg, it can be noted that the model should perform not only the function of a visual representation, and therefore should be filled with relevant information about communications, geometric dimensions of structures, terrain, cadastral boundaries of sites, and so on. An up-to-date, open model of the city will be useful not only for solving urban planning problems, but also for all areas of activity. And in order to start the widespread production of such models in Russia, it’s needed to start with the development of own standards, or to use uniform international standards.

Summing up the research, it is important to say that it was carried out in order to show the necessity and benefits of using urban 3D models. In the future, it can be used for study to work on the development of concepts and solutions related to 3D modeling of cities in Russia.

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Appendices

Appendix 1. Survey questions

3D model of the city of St. Petersburg

A digital model of a municipal district, displaying its relief, infrastructure, vegetation, landscape design elements and buildings on a three-dimensional scale, is a three-dimensional model of the city. This model is composed of geospatial data and gives an idea of how a city exists in the real world. Since the 3D city model provides a real-world visualization, it can be used for urban planning, risk management, congestion control, energy efficiency and noise assessments, and more.

This survey was created for representatives of companies in various spheres of construction in the city of St. Petersburg. The survey is carried out as part of research work to determine the level of interest of participants in the development of a 3D model of St. Petersburg and its appearance in the public domain. And also to find out what content is required from the urban model in different service sectors and what uses the urban model can have now and in the future.

The survey consists of multiple choice questions as well as several open-ended questions. The survey takes about 10 minutes to answer.

* Required

What company do you represent? *

My answer

In what area of construction is your company engaged? *

- ◯ Industrial and civil construction
- ◯ Road construction
- ◯ Construction of engineering systems
- ◯ Geotechnical construction
- ◯ Other: ____

Do you know about the existence of a 3D model of St. Petersburg? *

Yes

Not

3D model of the city of St. Petersburg

* Required

The existing model of St. Petersburg

How did you know about the existence of the model? *

My answer

Have you ever used this model in your work? *

Yes

Not

Other:

3D model of the city of St. Petersburg

* Required

Using an existing model

What program did you use to work with the model? *

- ◯ 3ds Max
- ◯ InfraWorks
- ◯ ArchiCAD
- ◯ ArcGIS
- ◯ Other: ____

For what purpose was the St. Petersburg model used in your project? *

- ☐ To obtain a building permit near a protected area
- ☐ To create snapshots of a projected object inscribed in urban development
- ☐ For research / analysis of the required indicators
- ☐ Other: ____

What information was found in the model most useful for your work?

My answer ____

How do you think this model needs to be improved?

My answer

Do you think it appropriate for this model to be made publicly available for general use? *

- ◯ Yes
- ◯ Not

3D model of the city of St. Petersburg

* Required

Creation of a new open model of St. Petersburg

Do you consider it necessary to create an open-to-use, up-to-date 3D model of St. Petersburg? *

- ◯ Yes
- ◯ Not

What information / objects in the city model would be of most interest to you? *

- ☐ Buildings and structures (geometric aspect)
- ☐ Network engineering
- ☐ Green spaces
- ☐ District zoning of the city
- ☐ Terrain data
- ☐ Data on the territorial boundaries of land plots
- ☐ Hydrographic data
- ☐ Other: ____

3D model of the city of St. Petersburg

* Required

Creation of an open model of St. Petersburg

Do you see the potential benefits for both construction sites and citizens from using the open model of St. Petersburg? *

- ◯ Yes
- ◯ Not

If possible, explain the answer you chose.

My answer

What possible research would you like to do based on a 3D model of the city?

My answer

Do you have any comments regarding urban modeling in general?

My answer

Appendix 2. Survey cover letter

Hello!

My name is Kseniia Kuznetsova, I am currently doing a municipal survey related to 3D city models in Russia as my thesis. The purpose of the survey is to find out the current situation of municipalities in 3D modeling of the cities and St. Petersburg city model in particular, possible problems associated with 3D modeling and needs for the development of competencies.

The digital model of municipal area that represent it's relief, infrastructure, vegetation, elements of landscaping and building in three-dimensional scale is a 3D city model. That model consist from the geospatial data and gives the representation of the view in which the city exists in the real world. As the 3D city model gives the visualization of the real view, it can be used for urban planning, risk management, traffic jam control, energy efficiency and noise level estimation and etc.

The survey was sent to several building companies in St. Petersburg. The company to which the answers relate will not be mentioned in the study and will only be used for the purpose of structuring the material. The results will be published anonymously in the thesis in January-February 2021. The survey was conducted using a secure electronic Google Form.

The thesis is supervised by the scientific supervisor Timo Lehtoviita, the external client is SOVA 3D Oy.

To get acquainted with the possibilities of using the urban 3D model, I recommend to go to the site of the public web service Kunta3D, created by the SOVA3D company. The open service is available on a link: https://kunta3d.com/ru/kunta3d_ru/ .

It only takes about 10 minutes to answer the survey. I hope that in my thesis I can get an exhaustive example of the situation in St. Petersburg, and I am very grateful for every answer. The response time to the survey is January 31, 2021.You can access the survey from this link: https://forms.gle/hCKwhg5BV28KgTDD8. I will be happy to answer any questions you may have about the survey.

Best regards,

Kseniia Kuznetsova

Education Manager

Timo Lehtoviita