L1.2 Semantic City Models

Lecture Notes

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Summary

This lecture focuses fully on semantic models as the state-of-the art-approach of the city modelling and basis for applications like smart cities and digital twins. It goes through advantages of models with semantic information and explains how such models are created. In the last part, the lecture shows several examples of existing semantic models as well as of their use in societal planning.

Learning outcomes

At the end of this lecture, the learner is expected to be able to:

Explain the semantic part of the city models and differences compared to graphical 3D models

Summarize the main steps of semantic model creation

Name examples of existing models as well as of their possible applications

Co-funded by the European Union

Expected competences when entering the lecture

Intermediate GIS knowledge

L1.1 Concepts of 3D Modelling

Expected workload

17 slides with learning content, approximately 3 hours

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What is Semantic City Model?

In the last lecture, we saw that highly detailed graphical 3D city models can be automatically produced by dense matching of aerial images. Anyway, these mesh models are just “pictures”. They do not provide any information about what a building is, or a street or a tree, neither what properties they have.

Surely, a human can look at the mesh model and count the trees in a given street or number of windows of a building of interest. But a computer sees only a series of triangles with a texture attached to them. That is why the computer needs to define distinct objects which represent real-world things: the houses, streets, trees and others.

These realistic objects are labelled with their meaning. Of course they can have attributes attached to them. And even interrelationships with other objects within an area.

These structured 3D models with clearly defined realistic objects are referred to as the semantic models.

Objects in the semantic models

Just to remind us, the semantic models are digital representations of the objects, their properties as well as interactions among them. The objects can be both natural and human made.

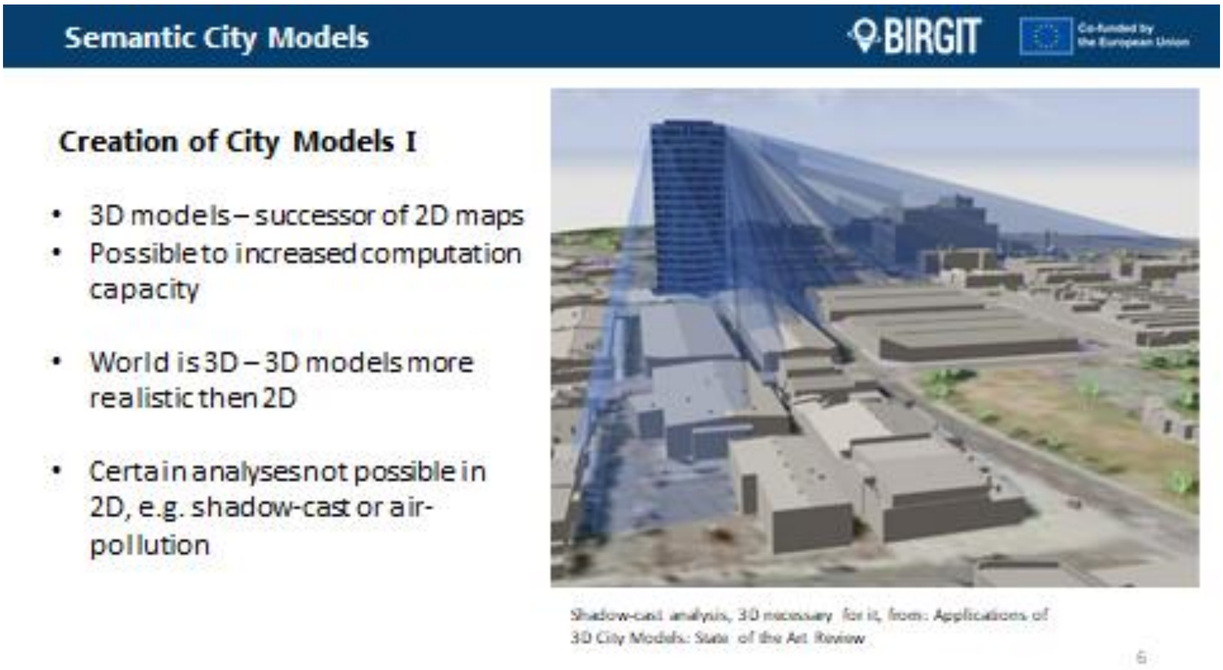
The natural objects (or features) are e.g. the digital terrain model (DTM), vegetation or water bodies.

The man-made constructions are houses, bridges, streets and so on, combined with smaller objects like benches, trash-bins, traffic-lights, lamppost and other features.

Complex objects are typically further decomposed. For example, a house can be decomposed into building parts and these again into roof, walls or ground surfaces.

Walls can further contain windows and doors. As we see, this aggregation (decomposition) is hierarchical (as a building is composed of parts, which are formed of walls, which have windows).

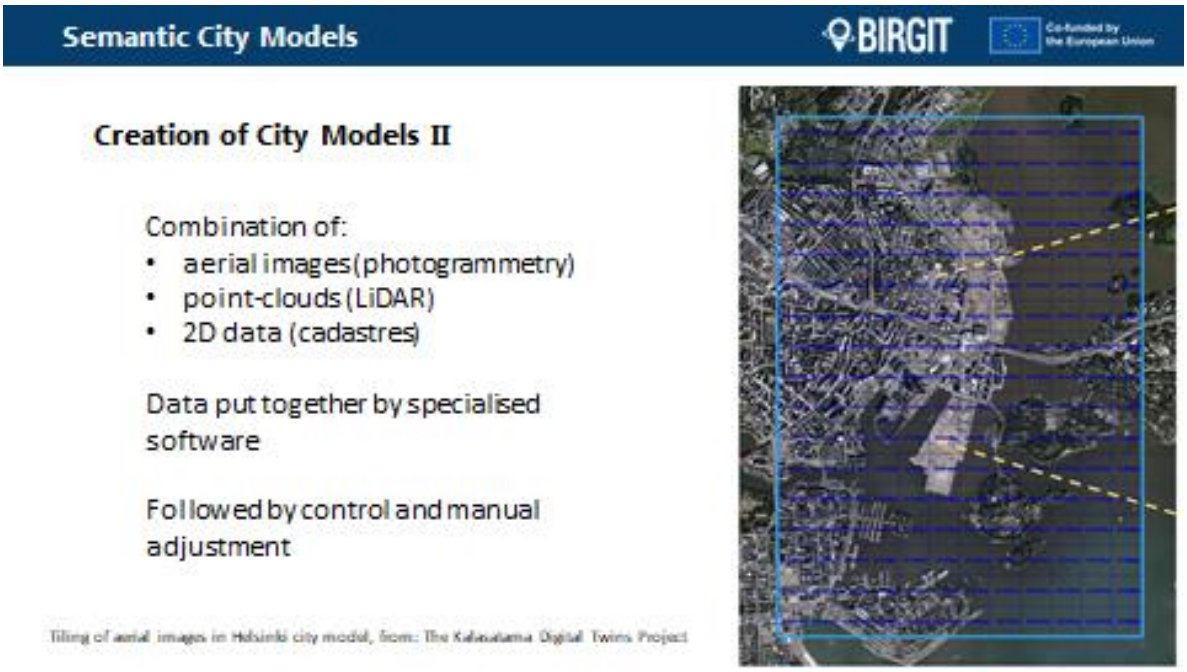
The features can have attributes on all aggregation levels. These attributes can provide all relevant information – e.g. on the location, visual appearance, thematic attributes, functional aspects, their interrelationships, just to name a few.



Creation of City Models I

We can see the 3D city models as the successor of traditional 2D maps.

Progress from 2D to 3D depended on the development and decreasing price of both scanning techniques as well as of computational capacity. As the world is in 3D, the 3D models provide more realistic information about reality, compared to 2D maps. Certain analyses are possible only in 3D space, for instance shadow-cast or air-pollution analysis.



Creation of City Models II

How are such 3D models created? In general, the models are based on aerial images, point-clouds and 2D data, optimally combining these techniques.

The images can be obtained by diverse photogrammetric techniques, the point-clouds origin from laser scanning (LiDAR) and the 2D spatial data from registries and cadastres, for instance.

From these data, specialised software can generate the city models automatically. It can go fast and it is cost-effective. Of course, the input data must be of good quality and properly harmonized.

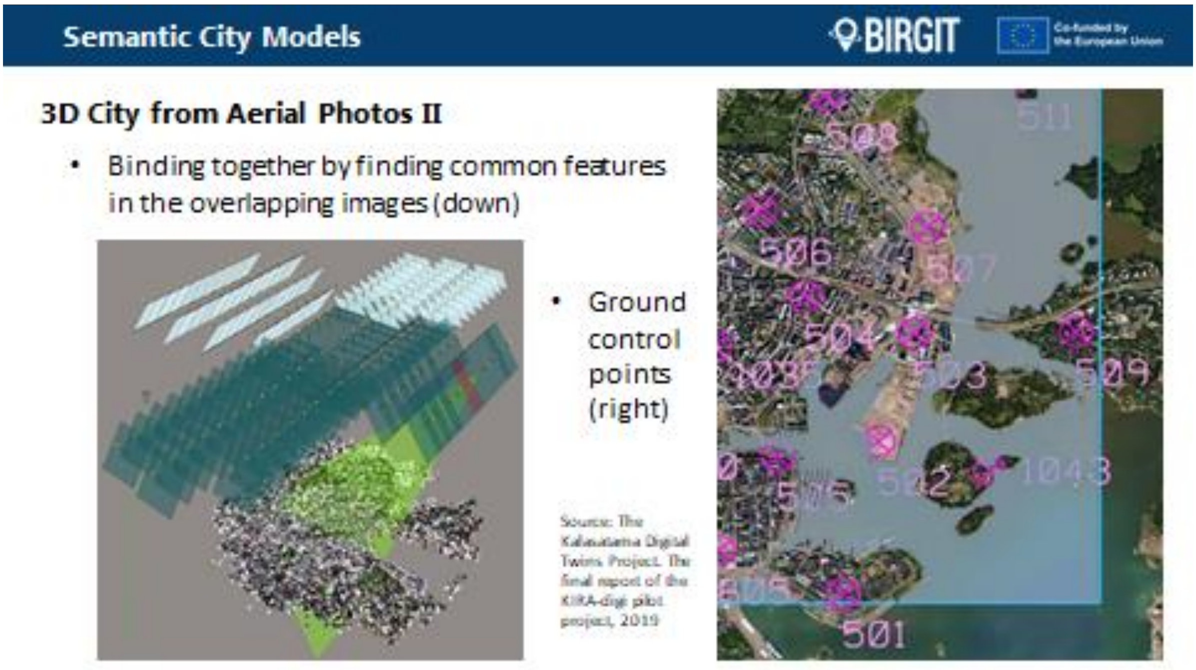
Obviously, the user is able to define settings of the model calculation. And the output models can be adjusted manually later on, if it is needed for their final application.

Let’s look at the creation process a bit closer and with examples.

3D city from aerial photos I

2D images from different viewpoints can be enough to obtain a mesh model.

The source data consists of several partially overlapping photographs of the object to be modelled.

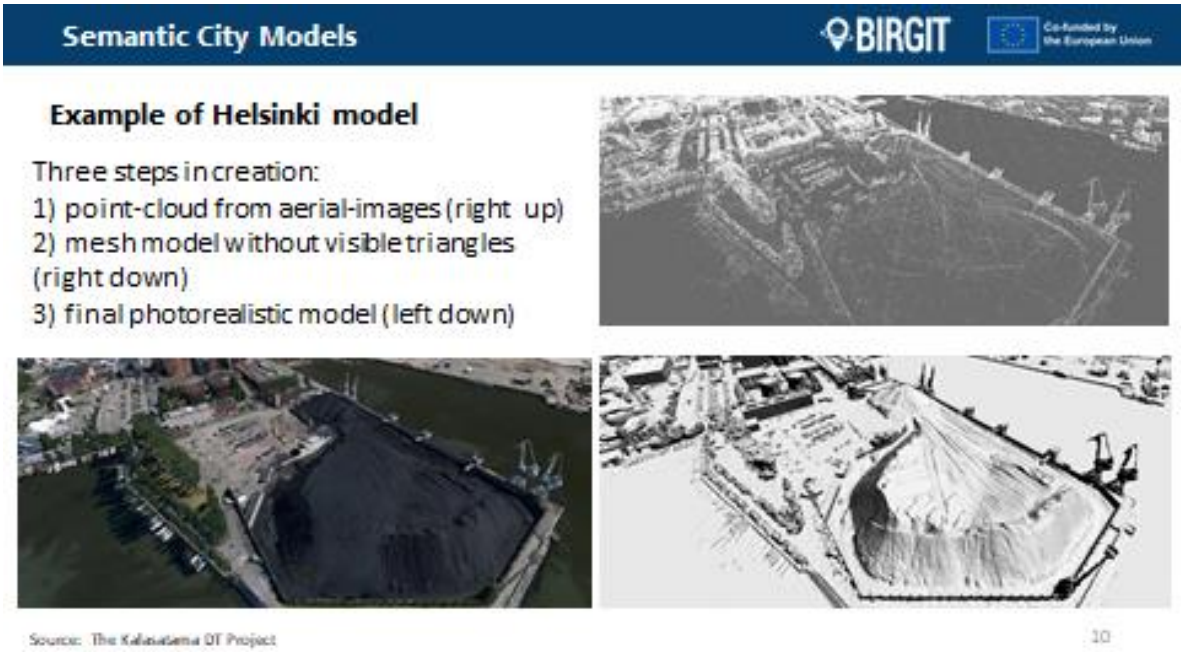


3D city from aerial photos II

These data are then automatically triangulated. The aerial images are bound together by finding common features in them.

To anchor the 3D model to reality, one needs to define ground control points and specify their X, Y and Z coordinates. These ground points represent easy-to -distinguish places, such as road crossings. Their location must be determined manually so that they both cover and encloses the entire area.

The resulting model looks highly realistic, and its quality can be checked by visual inspection or by comparing the model to the laser scanning data. We can see an example of the Helsinki model on the next slide.



Example of Helsinki 3D model

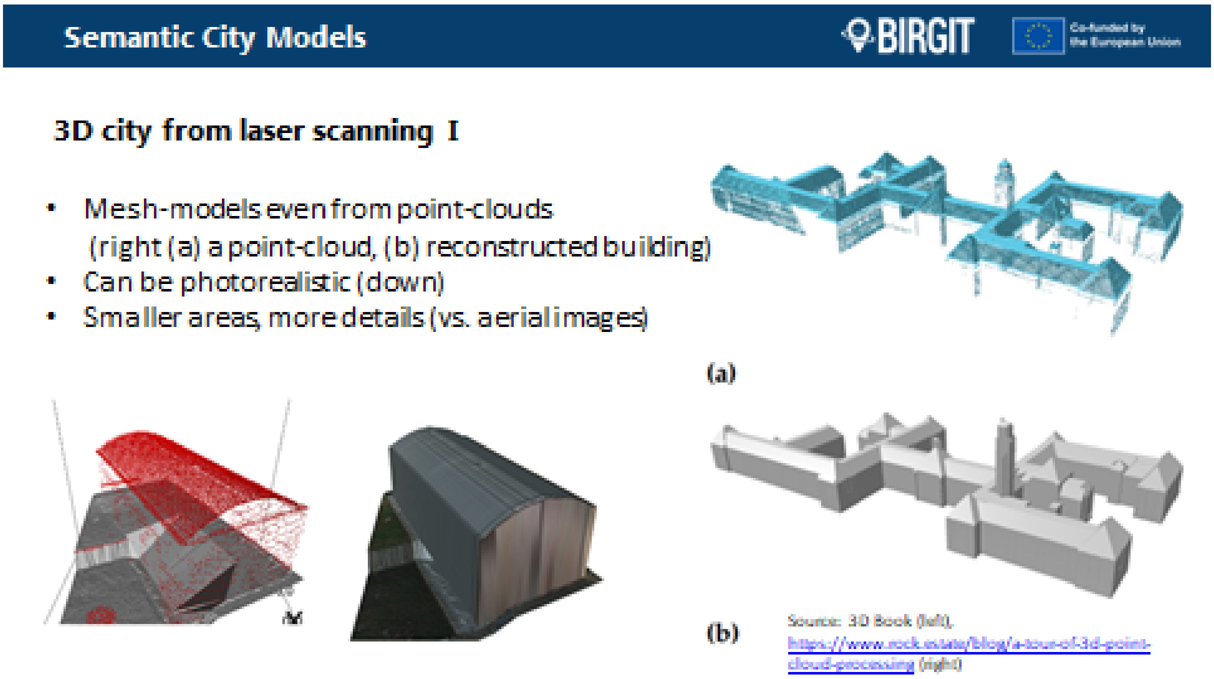
The slide demonstrates the three steps in creation of Helsinki mesh model based on aerial images.

The upper left image illustrates the first step, i.e. a point-cloud obtained from the aerial-images.

Next image below the first one shows the mesh model, in this case without the visible triangles.

The final photorealistic model, with projected aerial photographs, is shown by the last image down on the right side of the slide.

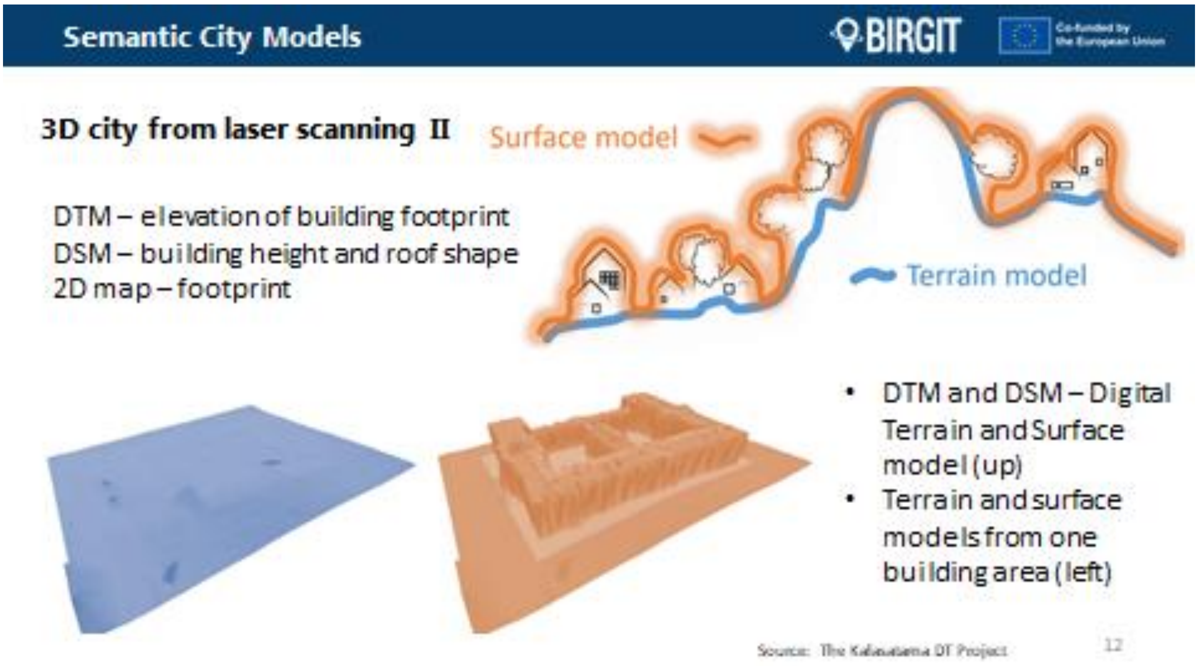
We can see that the model is highly realistic. However, the individual objects are not defined yet.



3D city from laser scanning I

Mesh models can originate even from point clouds from laser scanning. In general, this method is suitable for smaller areas and can result in more detailed models, compared to the image-based method.

It is even possible to project photos onto the model to get it photorealistic.

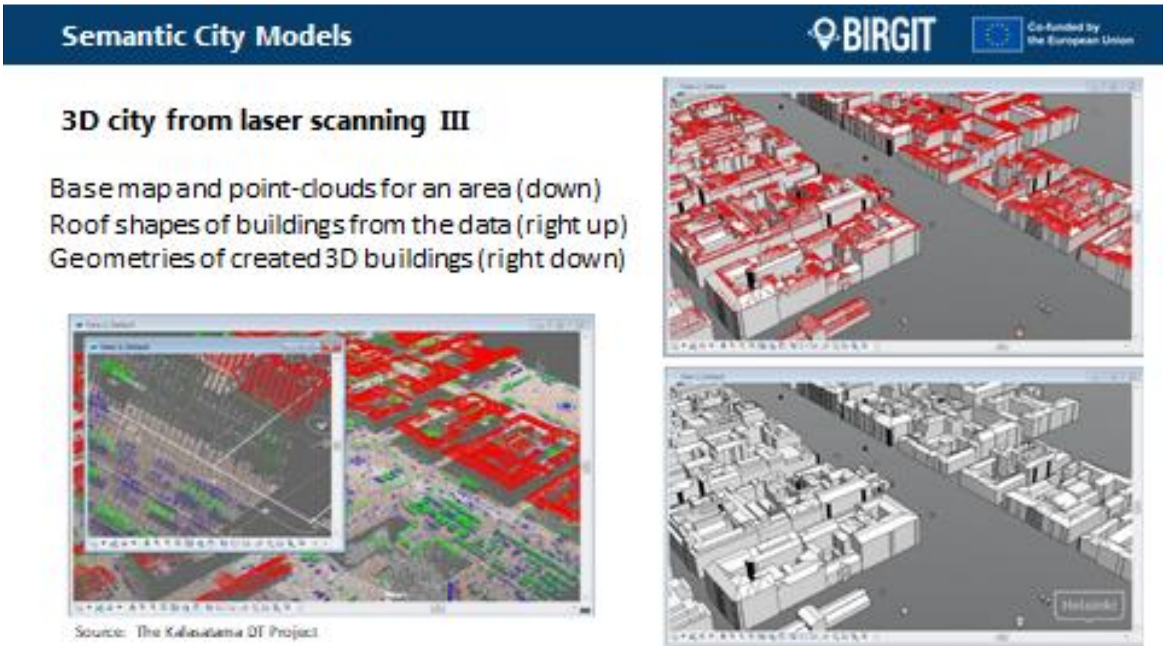


3D city from laser scanning II

Great examples of LiDAR-based point-clouds are Digital Terrain Model, DTM, and digital surface model, DSM. These are often freely available for users and can be used to generate city models from them.

The terrain model determines the elevation of the building's footprint; the surface model identifies the height and roof shape, and the footprint is available in any 2D map.

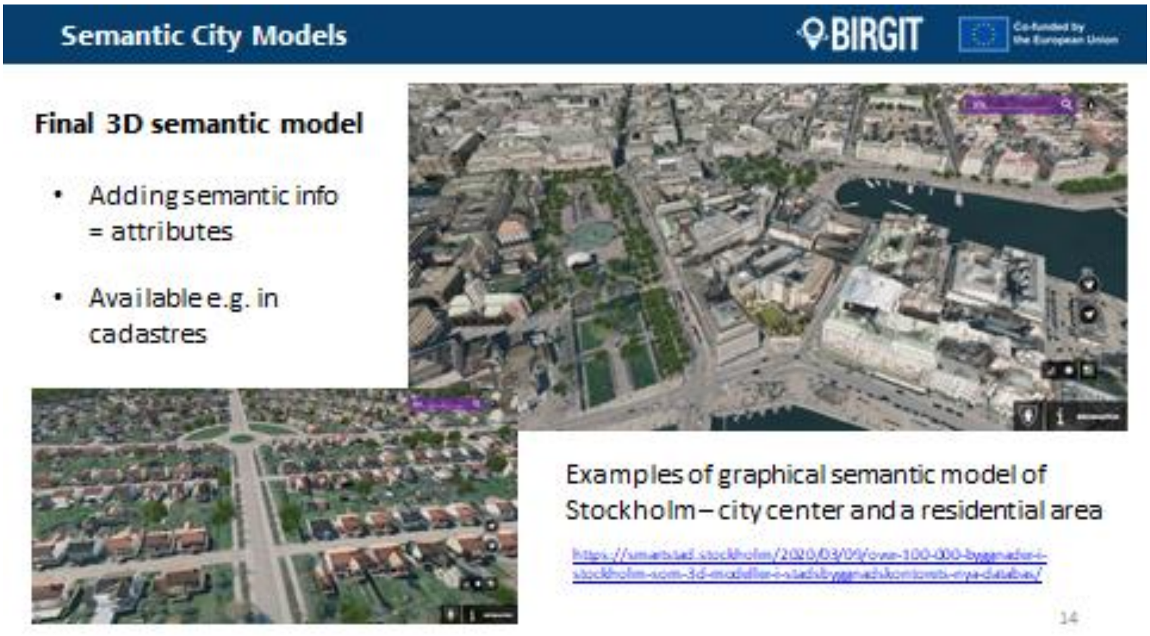
With the height, roofs and footprints available, it is possible to identify individual city objects as well as to assemble the walls. And even this can be processed more or less automatically.



3D city from laser scanning III

The figures on this slide demonstrate the process of object creation and identification, as describe in the previous slide.

The area example is again from the Helsinki 3D model.



Final 3D semantic model

Following the steps from the previous slides, a city-model with individual objects gets ready. Obviously, it is possible to project air-photos onto the model in order to get realistic façade appearances.

How such a model looks like in the end can be seen on the slide, this time as examples from Stockholm.

But to get a real semantic model, we also need to add the attributes, that is to say the semantic information. It can be everything from object owner and usage to number of persons living at the given address. This information is available in cadastres, for instance, so all that needs to be done is to connect it with the model.

Abstraction in 3D city models

We have seen that 3D modelling is done through a series of abstractions of the real world. Some information gets loss, but, hopefully, the remaining information is more structured and meaningful in the end.

The abstraction can remove unnecessary parts, such as interiors in a city model, and can work at different levels.

The semantic 3D models are typical examples of high abstraction level with the world divided into discrete objects. All these objects should have globally unique identifiers, stable over the entire object-lifetime. This allows both for keeping track as well as for updating the objects in different applications.

Mesh models based on triangulation represent a lower abstraction level, but are faster and cheaper create. As discussed, it can be the first step of the 3D-modelling, which can be followed by semantic decomposition later on.

In general, the first generation of the city models were based on the meshes. Nowadays, some cities upgrade their models into semantic ones that could serve as a basis for a digital twin. Of course, the more a city's model is enriched with information, the more functional and useful its digital twin becomes.

There is a specialised course on Digital Twin in this Course module (3D GIS).

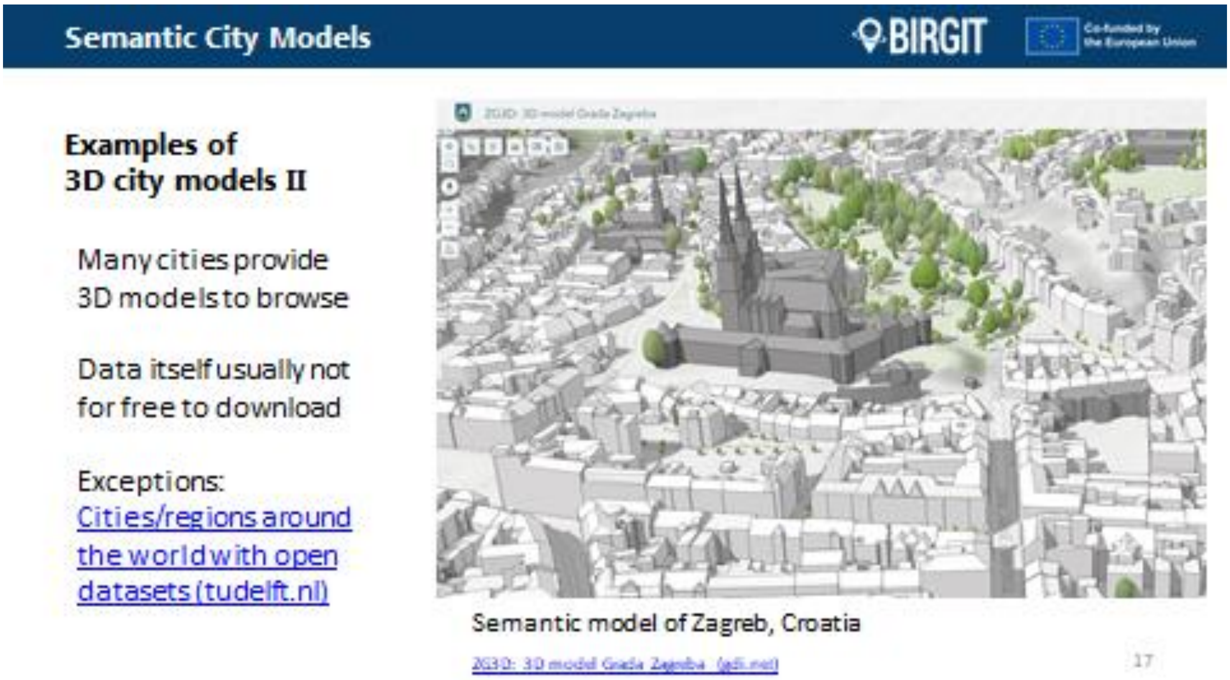
Examples of 3D city models I

To remind us, the 3D city-models can be seen as successors of traditional 2D digital maps. This advance was possible thanks to the increase of both computing and storage power, as the 3D model contains significantly higher amounts of data, compared to the 2D maps.

The majority of semantic city models are created and maintained by mapping departments on municipal level.

Anyway, 3D city models are also produced by commercial companies as well as by initiatives like the Open Street Map project. These are often graphical, not semantic, though.

The first freely available city model was that of Berlin, published in 2015. It was automatically generated from 2D cadastre and airborne laser data, with textures automatically extracted from aerial images, as we explained above.



Examples of 3D city models II

The Berlin model, mentioned above, is open. Similarly, there are other models of diverse cities from many countries. For a list of them, see a list provided by Delft Technical University:

[Cities/regions around the world with open datasets (tudelft.nl)]

These open models are in diverse formats, but only a minority of them are semantic, though.

The majority of cities are creating their own 3D models nowadays. However, they do not provide them for free, or at least not in higher LOD (e.g. LOD1 can be open data, but one has to pay for LOD2).

Swedish examples of advanced semantic models are those of Stockholm and Göteborg.

Stockholm 3D

Digital tvilling - Göteborgs Stad (goteborg.se)

The figure on the slide illustrates semantic LoD2 model of Zagreb, Croatia.

ZG3D: 3D model Grada Zagreba (gdi.net)

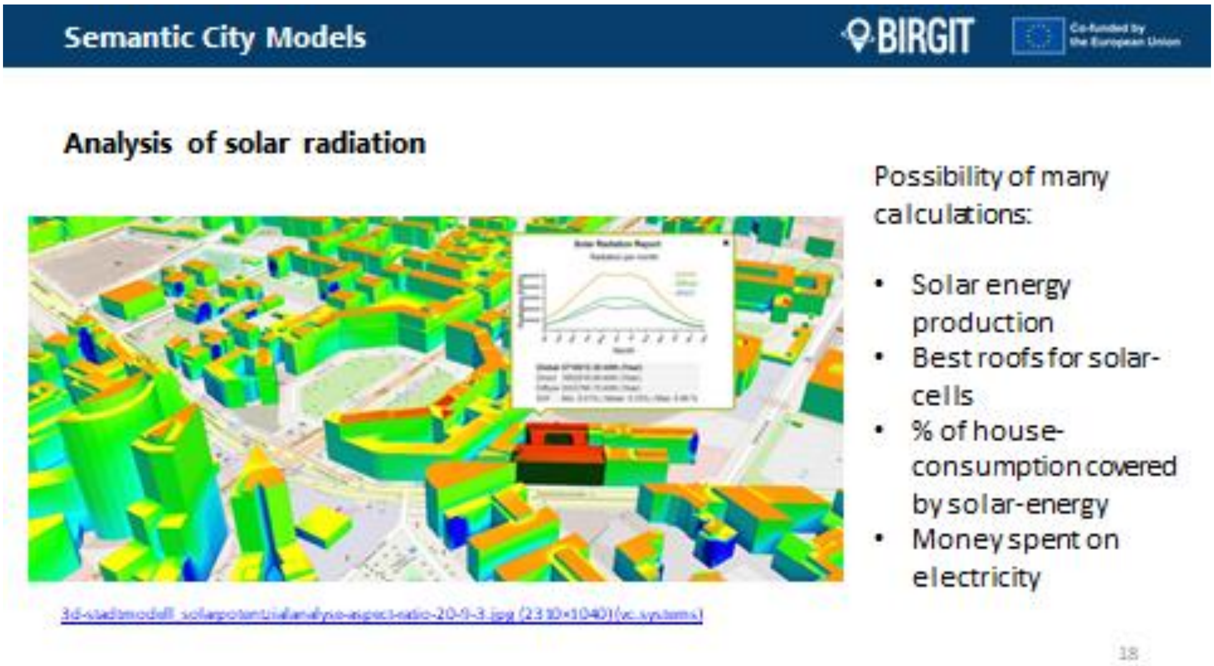
Applications using semantic 3D models

There are many possibilities for how to use the 3D city models.

The first is the visualisation, both of the existing buildings and of the planned ones. This is illustrated by the figure on the slide, showing a newly planned neighbourhood in Helsinki. This is of course highly useful in city-development.

But one can get much more information out from the semantic models, as all city objects can be enriched with thematic data. It is possible to query, for instance: “How many lamp-posts are in a street” or “How many windows of a house are oriented to a square” or “How many buildings consume more energy than 100 kWh/m^2/year “. The queries can be as complex as the semantic information and LOD allow.

One can also perform diverse analyses and simulations, as well as test different development-scenarios in that way. Results of such analyses can even provide new semantic information. Many of the analyses are already used in practice, even if definitely not in all the cities.



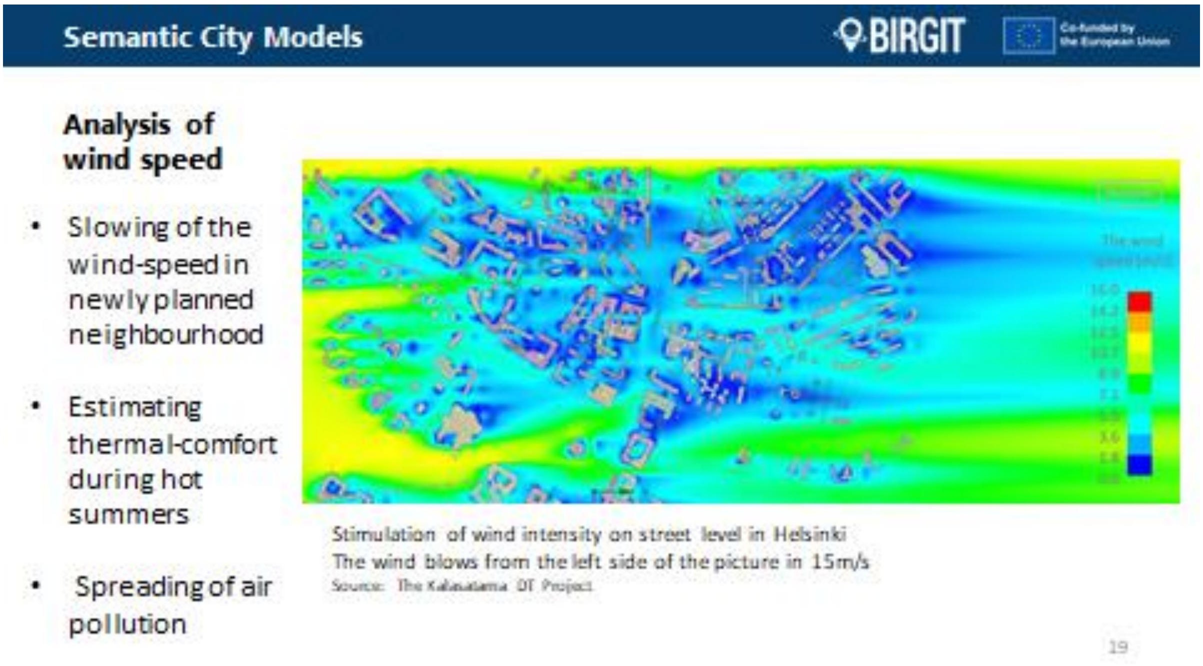
Analysis of solar radiation

We are going to look at some concrete application examples.

Figure on the slide shows estimated solar radiation on roofs and facades in a German town. From that number, it is possible to count how much solar energy can be produced in the area, or which roofs are the most suitable to mount solar-cells on.

If we know how much electricity houses consume, we could count the percentage of the consumption covered by the solar-cells or even how much money a household can spare yearly on electricity-bills. It is also possible to see if the house can become a net-zero-energy building, with or without improvement of its thermal insulation parameters.

As we see, the analyses might be highly complex, if the model provides relevant semantic information.



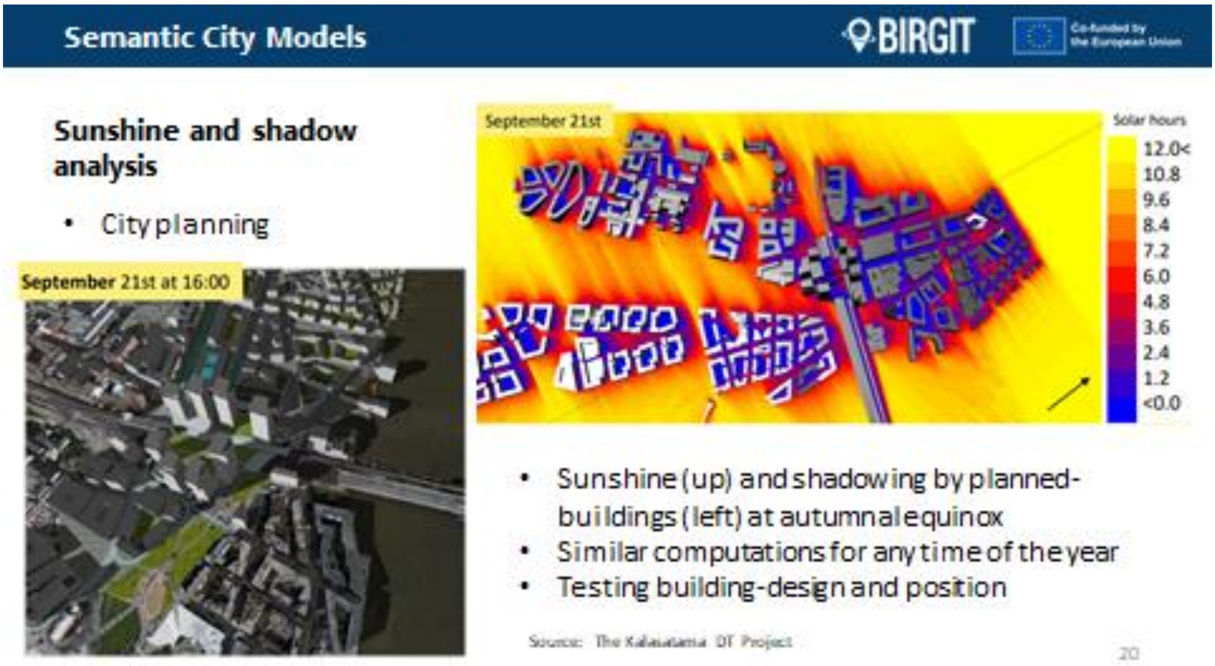
Analysis of wind speed

With the next application examples we come back to Helsinki, to the newly planned neighbourhood of Kalasatama.

The figure shows how a strong wind from the sea would be slowed down by the planned buildings and how pedestrian wind-comfort would be.

Similarly to the solar radiation, wind-speed and direction can provide data to numerous other analyses. For instance, one can count thermal comfort and wind cooling effect in cities during the hottest days, which is important in the cities with increasing maximal temperatures and lethal heat-waves.

Wind speed and direction is also crucial when simulating air- and noise pollution, as required by European Noise- and Air Quality directives. (More about that in the third block of this course).



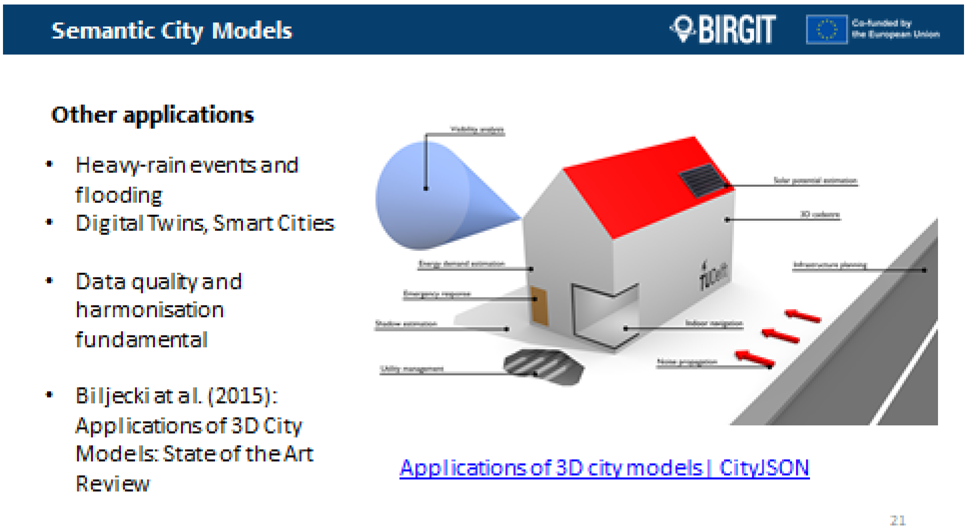
Sunshine and shadow analysis

The next example is again from the Helsinki Kalasatama neighbourhood.

The figures visualise the results of sunshine analysis and how the shadows of the newly-planned houses will appear at autumnal equinox.

Of course such an analysis can be conducted at any time of the year. It reveals which yards and streets have very little or no sunshine in different seasons.

It is possible to test different scenarios of the building disposition and design, in order to choose the most suitable variant.



Other applications

Another important application in city-planning is flooding analysis, where one can test different scenarios of heavy rains and see if the locality will become inundated or not. This is increasingly important as extreme-weather events will become more and more common.

Then, there are the concepts of Digital Twins and of Smart Cities. The idea is that diverse sensors would collect information in real-time and provide immediate feedback on city functions. It can include everything from regulation of traffic jams and air-pollution to smart trash-bins, asking themselves to be emptied when they get full.

Other applications are still in the beginning, like to use the models for navigation and training of autonomous cars or use VR-googles to provide a virtual walk through newly planned developments.

Of course, there are many other applications. An overview paper from 2015 describes more than 100 of them.

[Applications of 3D city models | CityJSON]

Whatever application one would run, it is important to know that preparatory work is fundamental. If information in the model is structured in a consistent way and includes aspects that are really needed for the application, the simulation itself can run more-or-less automatically.

References

The Kalasatama Digital Twins Project. The final report of the KIRA-digi pilot project, 2019

Biljecki at al. (2015): Applications of 3D City Models: State of the Art Review, ISPRS Int. J. Geo-Inf. 2015, 4, 2842-2889; doi:10.3390/ijgi4042842

Ken Arroyo Ohori, Hugo Ledoux, and Ravi Peters (2020–2022): 3D modelling of the built environment, available at: [Releases · tudelft3d/3dbook (github.com)]