DELIVERABLE T1.2.1

D.T1.2.1 - Baseline inventory - SOTA of 3D city modeling and related applications | **10/2017**

D.T1.2.1: Baseline inventory - SOTA of 3D city modeling and related applications

A.T1.2 Creation of realistic 3D building models

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1. Introduction and aims

The deliverable T1.2.1 reports a state-of-the-art (SOTA) of existing solutions and lesson learnt for generating 3D city models & related applications (e.g. PV potential estimation, energy efficiency (EE), energy losses mapping, etc.). The aim of the SOTA is thus to present technical details about existing methodologies for 3D building modeling as well as an analysis of implemented projects (EU FP7, EU H2020, Interreg CE, etc.) and relative outcomes. The document is restricted to project partners (PP), reviewers and JS.

2. What is a 3D city model

3D city models are a digital approximation, based on 3D geometries, of a real urban environment where urban features are modelled with a particular Level of Detail (LOD) and certain elements are simplified or omitted. Nowadays cities around the world are increasingly adopting 3D city models to better document, manage and control expansions and urbanization. Many people and local governments are indeed realizing that 3D city models are providing further added value and additional efficacy over standard 2D geodata (i.e. maps or orthoimages), for making and taking decisions, improving the efficiency of governance, better planning actions, simulating hazards or noise propagation, etc. The growing interest of cities for using 3D models encourages standardisation processes like the European INSPIRE (Infrastructure for Spatial Information in the European Community) initiative and the development of interoperable 3D formats (i.e. CityGML) to manage and store 3D spatial data. By merging geometrical, topological and semantic aspects, OGC (Open Geospatial Consortium) CityGML[1] standard specifications for 3D city models enables various analysis, particularly useful for different applications related e.g. to buildings management, transport networks, energy efficiency, etc. (Section 3).
The quantity and mixture of building aspects and contents are normally driven by the intended use of the digital city model, the data acquisition technique and source, the employed methodology, budget and spatial scale. The amount of detail that is captured in a 3D building model, both in terms of geometry and attributes, is collectively referred to as the level of detail (LoD), indicating how thoroughly a spatial extent has been modelled (Fig. 1). As a result, the LoD is an essential concept in geographical information science (GIS) and 3D city modelling. The LoD concept describes 3D city models in five levels: starting from the LoD0 – Digital Terrain Model (DTM), the LoD1 – buildings as extruded footprint, the LoD2 – buildings with roof shapes, the LoD3 – very detailed buildings with facades details, to the LoD4 – interior structures.

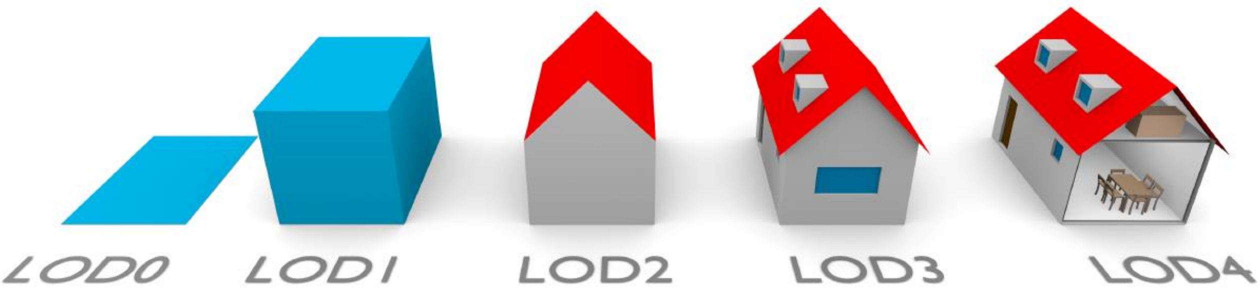


Figure 1: Different Level of Detail (LoD) in 3D building models (source: TU Delft).

[1] Gröger, G., Kolbe T. H., Nagel C., et al., 2012: OGC City Geography Markup Language (CityGML) Encoding Standard, Version 2.0.0. Open Geospatial Consortium Inc

3D geometries in city models are very often display as large textured polygons (Fig. 2a), without separations among buildings and with no semantics (e.g. Google Earth). Such 3D models are fine for visualization and entertaining purposes whereas the LOD approach is suitable for various applications (Fig. 2b – Section 3).

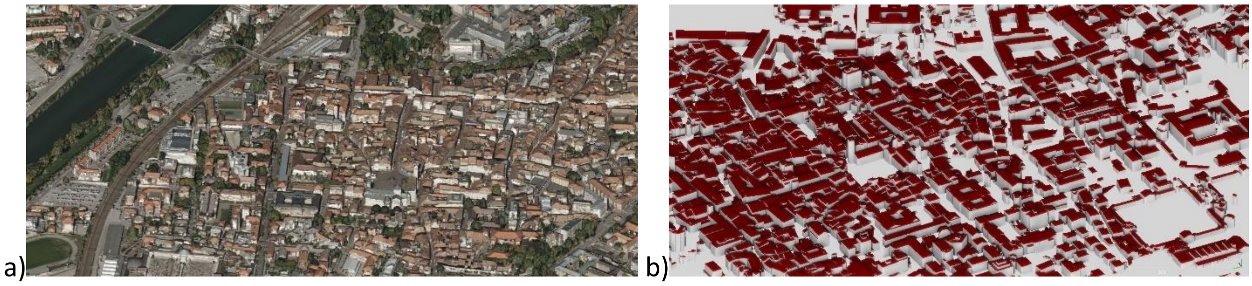


Figure 2: Different representation of a 3D city model: large and unique polygonal model with texture (a – source: FBK), single polygonal models in LOD2 (b – source: FBK).

3. Needs and applications for a 3D city model

The most common applications[2] requiring 3D building models are reported in Table1, considering various fields like energy, security, emergency, cadastre and real estate.

Use case and action	***Need and application***
Visibility analysis	Finding the optimal location to place a surveillance camera Security
Estimation of solar irradiation and shadows	Determining the suitability of a roof surface for installing photovoltaic (PV) panels Determing solar envelops and accesses
Classification of building types	Semantic enrichment
Estimation of energy demand	Assess the return of a building energy retrofit
Estimation of volumes, floorspaces and density	Assess the building's value Urban studies
Visualization	Real estate adv Entertainment / movies
Urban planning and routing	Designing new areas Understanding encumbrances and accessabilities
Emergency response	Planning evacuation Crisis management
Lighting simulation	Planning lighting Security
Change detection	Urban studies and inventory
Thermal analysis	Estimation of heating loses

Table 1: Some use cases where 3D buildings are necessary to perform particular applications.

[2] Biljecki, F., Stoter, j., Ledoux, SH., Zlatanova, S., Çöltekin, a., 2015: Applications of 3D City Models: State of the Art Review. ISPRS International Journal of Geo-Information, Vol. 4(4), pp. 2842-2889.

Requirements for 3D geometries of building (including possible LoD) comes from the final user and applications. We can distinguish three main classes of building geometries according to their final use:

- Low accuracy but high visual quality (e.g. for visualization purposes, web, entertainment, etc.);
- Middle accuracy and middle visual quality (e.g. for city planning, energy flow visualization, visibility analyses, etc.);
- High accuracy and high visual quality (e.g. for 3D cadastre, PV estimation, etc.).

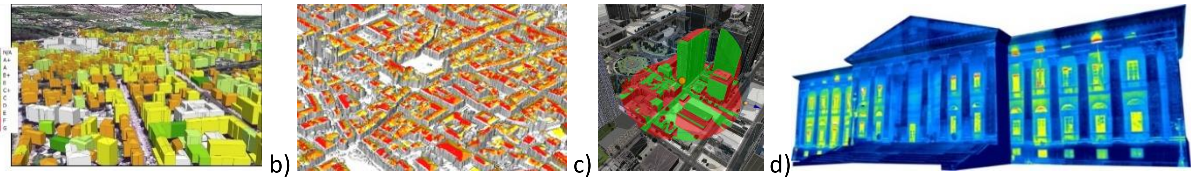
a) b) c) d)


Figure 3: Examples of possible applications of 3D city models: visualization of energy classes (a – source: FBK), computation of PV potential (b – source: FBK), noise pollution map (c – source: ESRI), heat loses (d – source: FBK).

4. Methodologies for generating 3D city modeling

There exist various approached to produce 3D geometries, either starting from surveyed data or creating 3D contents using rules or hybrid methods[3]. There is not a winner among the generation methods as the 3D geometries are created based on the available data (e.g. point clouds, maps, etc. – Fig. 4), as explained in the following sections.

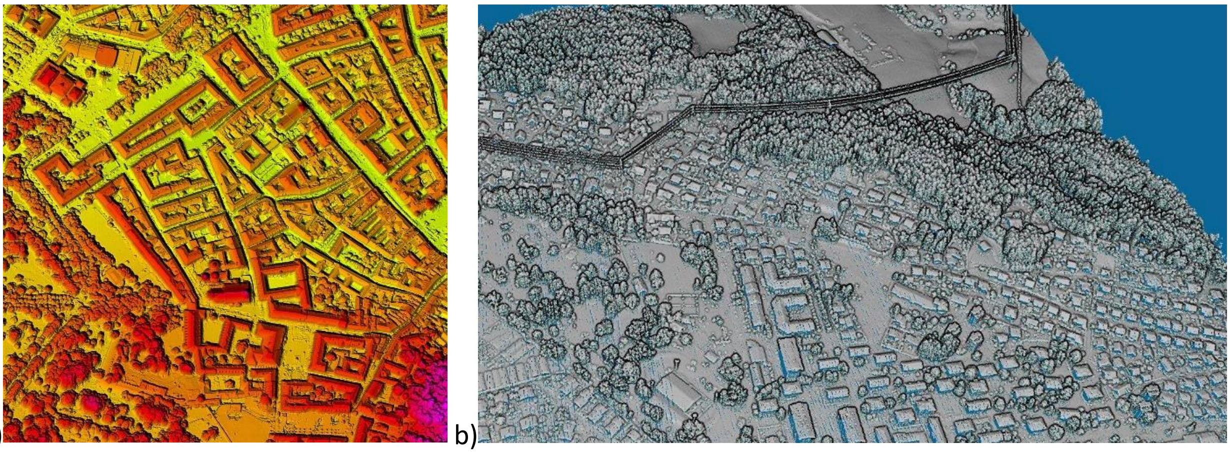
a) b)


Figure 4: Example of photogrammetric point cloud derived from aerial images (a – source: FBK) and acquired with airborne laser scanning / LiDAR (b – source: Municipality of Velenjie).

[3] Haala, N. & Kada, M. 2010: *An update on automatic 3D building reconstruc*tion. ISPRS Journal of Photogrammetry and Remote Sensing, Vol.65, pp. 570-58; Zhang, W., Wang, H., Chen, Y., Yan, K., Chen, M., 2014: *3D Building roof modeling by optimizing primitive's parameters using constraints from LiDAR data and aerial imagery*. Remote Sensing, Vol. 6 (9), pp. 8107-8133; Frommholz, D., Linkiewicz, M., Meissner, H., Dahlke, D., Poznanska, A., 2015: *Extracting semantically annotated 3D building models with textures from oblique aerial imagery*. Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(3), pp. 53-58; Tomljenovic, I., Höfle, B., Tiede, D., Blaschke, T., 2015: *Building extraction from airborne laser scanning data: An analysis of the state of the art*. Remote Sensing, Vol. 7, pp. 3826-3862; Toschi, I., Nocerino, E. Remondino, F., Revolti, A., Soria, G., Piffer, S., 2017: *Geospatial data processing for 3D city model generation, management and visualization*. Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 42(1/W1).

4.2 3D building models from surveyed data

This approach is normally referred to as “reality-based” 3D modeling as it starts from real data, surveyed with dedicated sensors (aerial cameras or LiDAR) and then processed to create the geometries at a specific LoD (Fig. 1). Airborne 3D point clouds, generated using photogrammetry or laser scanning (D.T1.1.1), are the general starting point (Fig. 5). They are processed to extract building shapes or polygonal/mesh models using different approaches and, often, integrated with terrestrial data to close possible gaps due to occlusions.

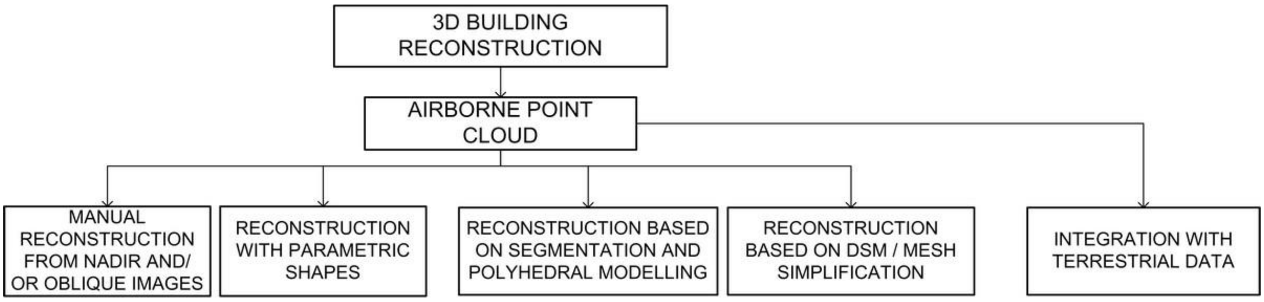


Figure 5: 3D building geometries from airborne point clouds: various methods to derive 3D gemetries, e.g. through manual reconstruction, using parametric shapes, based on polyhedral modeling or applying a mesh semplification.Often terrestrial 3D data al also integrated..

According to the geometric resolution of the point cloud (e.g. 10 points/sqm), LoD1-2-3 can be generated. In case building footprints are available, they can be used to constrain the location of the building envelop.

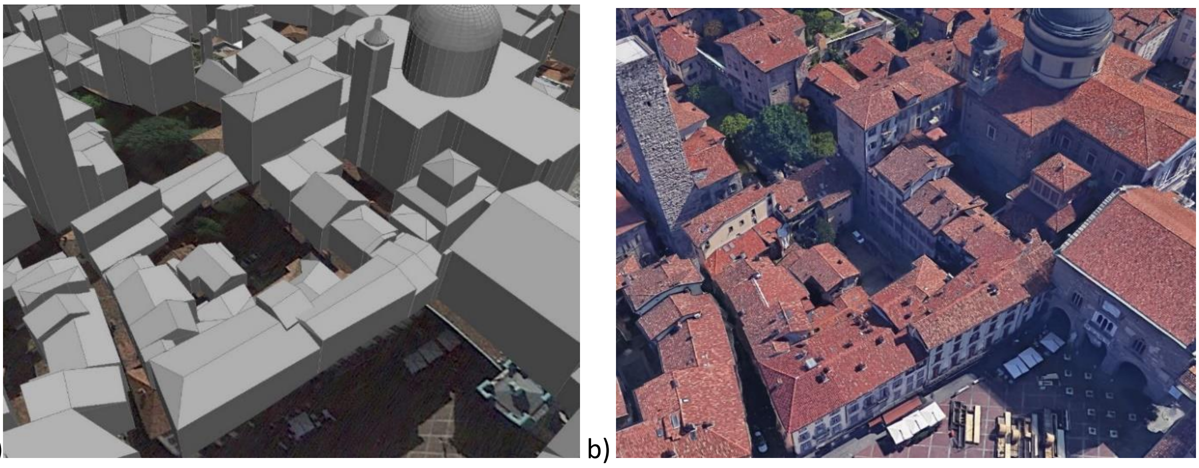
a)  b)

Figure 6: 3D building geometries (LoD2) derived fitting geometric primitives on point clouds (a: source: FBK) wrt polygonal mesh model (b: source Google Earth).

In case methods based on parametric shapes are applied, difficulties can arise due to complex roof shapes and as roof libraries are not containing all possible roof shapes (Fig. 7).
Available tools include Tridicon, 3DFier, VirtualCitySystem BuildingReconstruction, etc.

a)

b)

c)

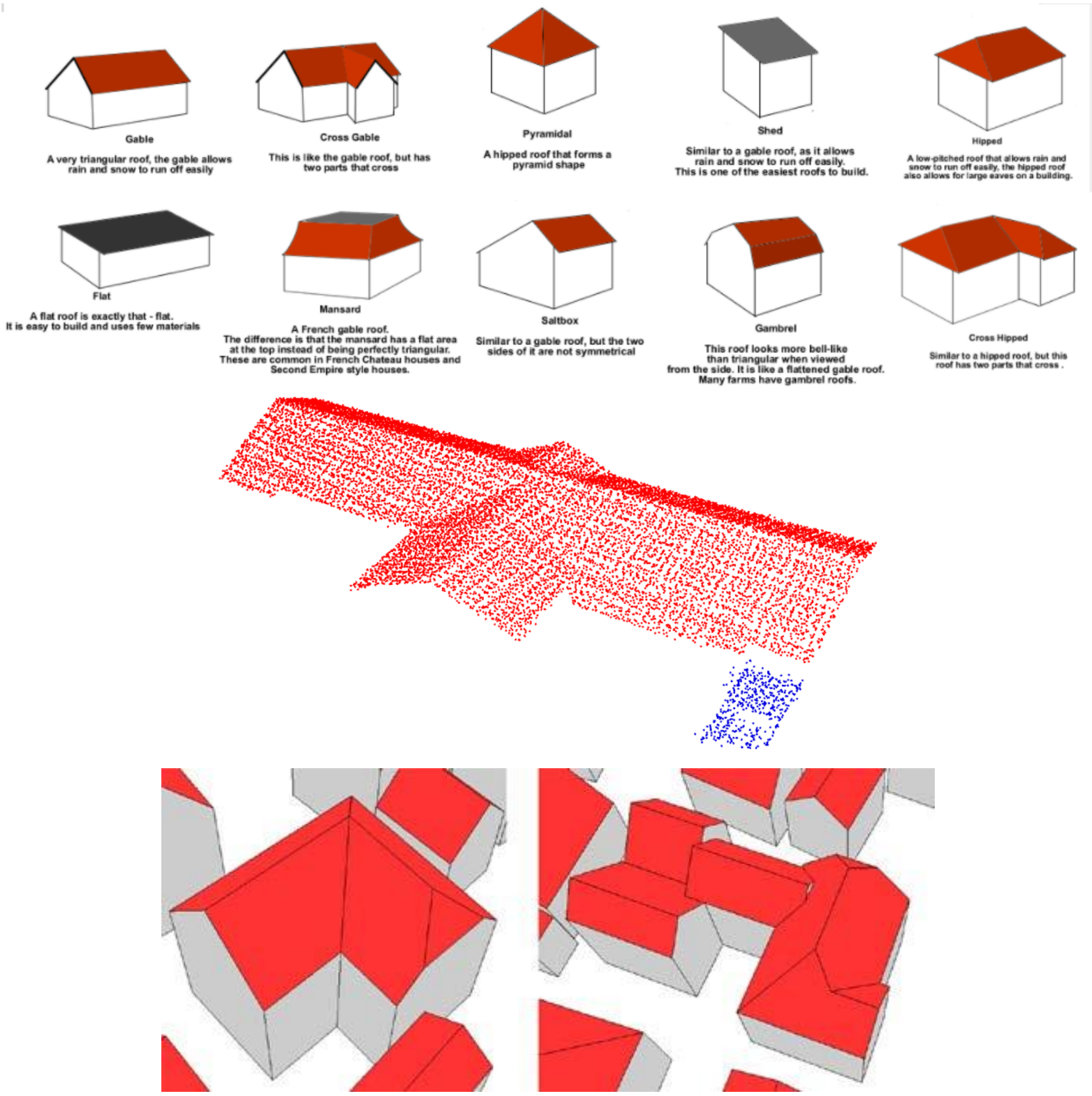


Figure 7: Example of roof primitives (a) which are then fitted onto roof point clouds (b) to derive LoD1 or LoD2 (c) building models (depending on the density of the point cloud and complexity of the roofs).

4.3 3D building models from maps

In case no images nor 3D point clouds are available, 3D building geometries can be generated starting from existing maps. Maps should have a suitable scale and sufficient details based on the needs of the requested 3D building models. Extrusion methods are then applied to create the 3D building according to a given height (Fig. 8). Such height can be inferred or assigned, e.g. from the attributes of the vector data. A limitation of this approach is the fact the workflow does not consider terrain data: this is not critical for flat areas (e.g. Netherlands, Singapore, etc.) but it could be critical for hilly areas, with an impact on the generated 3D geometries. Another limitation is the uncertainty of the height value as it is normally not known to what is referred to (top of the building, central point of the roof, eaves).

Vector data of building footprints can be retrieved from municipalities repositories or open geoportal like OpenStreetMap[4].
Available tools include OSMbuildings, QGis, ArcGIS, etc.

a) b)

Figure 8: LoD1 over the city of Trento (a) and Bologna (b) generated extruding the available vector building footprint to a given height stored in the attributes of the vector data (source: FBK).

4.4 3D building models with hybrid methods

With this approach, the two previously methods are fused: maps are used to define the building envelops whereas heights are derived from elevation data (such as point clouds from LiDAR) and not from vector attributes. This approach is normally providing LoD1 building models.
Available tools include 3DFier, ArcGIS ArcScene, etc.

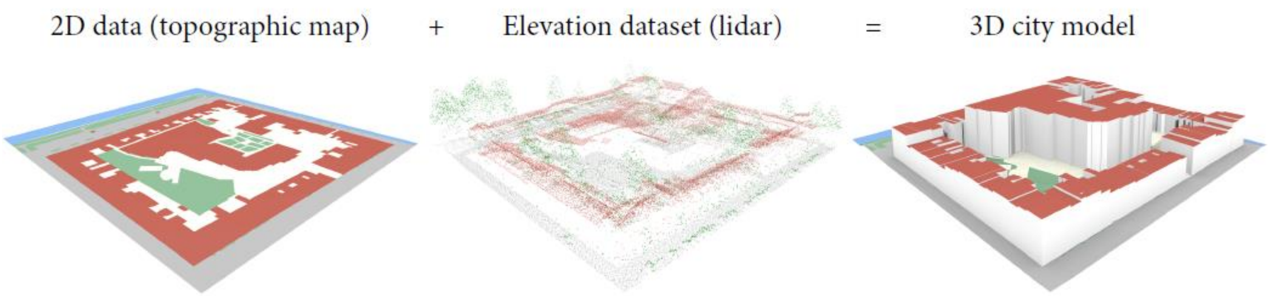


Figure 9: An hybrid approach to generate 3D building models: building polygons/footprints are extruded up to the height provided by a DSM (e.g. acquired with LiDAR)

4.5 3D building models with procedural modeling

Procedural modeling is a computer graphic method based on shape grammar that generates procedural variations of a building mass model (e.g. a cube or parallelepiped) using volumetric shapes. Then it proceeds to create façade detail consistent with the mass model. Context sensitive user-based rules ensure that entities like windows or doors do not intersect with other walls, doors give out on terraces or the street level,

[4] Over, M., Schilling, A., Neubauer, S., Zipf, A., 2010: G*enerating web-based 3D City Models from OpenStreetMap: The current situation in Germany*. GeoVisualization Digit. City Special Issue Int. Cartogr. Assoc. Comm. GeoVisualization, Vol 34, pp. 496-507

terraces are bounded by railings, etc.[5] Procedural modeling approaches can use maps to start the generation of 3D geometries but they don't use measurements nor reflect reality. They are normally employed for visualization or gaming or entertainment purposes.
Available tools include ESRI CityEngine, RamdomCity, Houdini, etc.

5. Past projects and activities related to 3D city modeling and applications

3D city models were already used for R&D and application-oriented projects related to energy efficiency, energy audit and heat looses computation/visualization, PV estimation, etc. In the following table we report the most recent and effective activities with their characteristics in order to build upon past actions and outcomes.

Title	SENECA (Smart and sustaiNablE City from Above)
Co-funded by	CARITRO (Cassa di Risparmio Trento e Rovereto)
Duration	06/2015 – 06/2017
About	SENECA aims at developing a reliable methodology for the processing of aerial imagery and the derivation of high quality 3D data for visualizing energy audits. The project delivers innovative procedures and advanced solutions for the distribution of useful services to citizens and public administrations based on geospatial information.
PP involved	FBK
Employed data	aerial images, topographic maps, illumination data
Final output	3D city models, energy audit, web-based visualization

Title	3D Solar Web: A solar cadaster in the Italian alpine landscape
Co-funded by	Alpine Space Program, Autonomous Province of Trento
Duration	2012-2014
About	The project aims at providing reliable results in a cost-effective way for the accurate and detailed estimation of photovoltaic (PV) potential of building roofs. Reliable models and algorithms for the estimation of the incoming sun radiance are adopted and a WebGIS is set up for the interactive calculation of the PV potential in a raster-based form.
PP involved	FBK
Employed data	low resolution LiDAR data, high resolution aerial images
Final output	PV estimations, web-based tool

Title	ENERCITY - Reducing energy consumption and CO2 emissions in cities across Central Europe
Co-funded by	Interreg Central Europe
Duration	02/2010 - 02/2013
About	Enercity aims at contributing to the reduction of energy consumption and CO2 emissions of cities through measuring the heat loss of urban buildings by aerial thermography. These data are used to show heat losses and prepare strategies for the

[5] Parish, Y.I.H., Mueller, P., 2001: Procedural modeling of cities. Proc. 28th SIGGRAPH Conferece, pp. 301-308; Musialski, P., Wonka, P., Aliaga, D.G., Wimmer, M., Gool, L.V., Purgathofer, W., 2013 A survey of urban reconstruction. Computer Graphics Forum, Vol. 32(6), pp. 146-177.

	reduction of energy consumption and the consequent increase of energy efficiency in buildings stocks and urban agglomerates.
PP involved	-
Employed data	Thermal aerial data, satellite imagery
Final output	Web-based tools, energy and heat loss maps, spatial decision support system (SDSS), strategies.

Title	UP-RES - Urban Planners with Renewable Energy Skills
Co-funded by	Intelligent Energy Europe
Duration	09/2010 - 02/2013
About	The project focused on creating favorable conditions for energy-wise urban and regional planning through (i) the creation and delivery of continuing education programs for practicing professionals, (ii) the modification of some existing energy planning tools and (iii) the finding of best practices in renewable energy systems with particular focus on urban and regional planning.
PP involved	-
Employed data	Polygon layer of building outlines, building type property, number of floors.
Final output	A GIS-based tool which generates a grid-based map of the annual energy demand for room heating and hot water in a city. Training material package of 10 modules, translated in 10 languages, including good practice in energy-efficient urban and regional planning and six tools to calculate e.g. energy use and emissions.

Title	EFFESUS - Energy Efficiency for EU Historic Districts' Sustainability
Funded by	EU FP7
Duration	09/2012-08/2016
About	EFFESUS aims to develop and demonstrate through case studies a methodology for assessing and selecting energy efficiency interventions in historic buildings and districts, based on existing and new technologies that are compatible with heritage values. The project will develop a multiscale data model for the management of energy. In addition, new non-invasive, reversible yet cost-effective technologies for significantly improving thermal properties are also developed.
PP involved	-
Employed data	Urban data, national policies, database of structured categorisation method for historic building.
Final output	Best practices, Energy efficiency solutions repository, Decision Support System.

Title	SimStadt
Funded by	German federal Ministry of Economic Affairs and Energy
Duration	2013-2015
About	The project aims to realize a variety of energy analyses for city districts, whole cities or regions. Via the simulation of building refurbishment and renewables energy supply scenarios, this urban simulation environment aims at assisting urban planners and city managers with defining and coordinating low-carbon energy strategies for their cities.
PP involved	-
Employed data	3D city models
Final output	heating demand, CO2 emissions, primary energy and energy saving potentials

Title	KLIMA-SEK II
Funded by	German Ministry of Economy and Technology
Duration	-
About	The project aims to deliver a methodology for urban heat demand analysis which enables the calculation at national scale of the building heating demands, based on 3D city model (available in whole Germany since 2013) and on national-available databases (ALKIS database and European census data).
PP involved	-
Employed data	CityGML 3D city model, building physics properties
Final output	heating demand of each heated building

Title	Energy Atlas Berlin
Funded by	Various private partners and private institutions
Duration	2011-2013
About	The project aims to generate a 3D semantic city model of the entire city (more than 550,000 buildings)
PP involved	-
Employed data	CityGML 3D city model, building physics properties
Final output	3D utility network from the enrgy providers, consideration of energetic correlations in a regional context

Table 2: Summary of past projects and activities employing 3D building models.

6. 3D city models in the consortium countries and pilot areas

At the moment of the delivery of this document (Oct. 2017), the pilot areas have no 3D city model available. Nevertheless, within the consortium countries there might be some large cities where municipalities have adopted 3D geometries for planning, management and other purposes. 3D building models in the pilot areas will therefore be generated using available geospatial data collected by the PPs (D.T1.1.1), harmonized and integrated (D.T1.1.2) and applying the developed methodology (D.T1.2.2).

7. Conclusions

3D city models, produced either from surveyed data or extruding maps at verified heights, are a valuable geo-product useful for numerous applications, even in the energy sector. BOOSTEE-CE will leverage on these kinds of products within the project platform OnePlace in order to share energy information and promote energy efficiency activities. The project pilot areas will have 3D geometric reconstructions (D.T1.2.3) based on a dedicated methodology (D.T1.2.2).