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ARTICLE

An Automated Process of Creating 3D City Model for Monitoring Urban Infrastructures

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ABSTRACT

This paper describes the process of designing models and tools for an automated way of creating 3D city model based on a raw point cloud. Also, making and forming 3D models of buildings. Models and tools for creating tools made in the model builder application within the ArcGIS Pro software. An unclassified point cloud obtained by the LiDAR system was used for the model input data. The point cloud, collected by the airborne laser scanning system (ALS), is classified into several classes: ground, high and low noise, and buildings. Based on the created DEMs, points classified as buildings and formed prints of buildings, realistic 3D city models were created. Created 3D models of cities can be used as a basis for monitoring the infrastructure of settlements and other analyzes that are important for further development and architecture of cities.

1. Introduction

The need for visualization of populated places, and especially the objects in them, has been present since ancient times. There are various forms of visualization of objects and buildings, starting from two-dimensional (2D), three-dimensional (3D), all the way to multidimensional visualization. At the same time, three-dimensional visualization has become indispensable in spatial planning and city management. The need for the third dimension and spatial analysis arises especially as a result of the construction of large buildings and complexes. Also, there is the idea of smart cities that relate to the modern and

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urban future, and as such require a third dimension [1,2]. In addition, many settlements and cities contain a large number of buildings of different classes, different models and structures, and are most often divided according to the degree of detail of the display of the building-level of detail (LoD) [3-5]. Object models are created on the basis of data obtained from various sources (photogrammetry, LiDAR imaging, remote sensing, etc.).

Due to the increasingly frequent requirements for credibility and timeliness in the display of 3D cities and buildings, there is a need for mass and fast data collection. At the same time, the manual data processing procedure is in principle time consuming and it is impossible to repeat procedures with the same results, primarily due to subjectivity in the work. Automated procedures enable a larger amount of data that needs to be processed in the shortest possible time and credibly. Also, the fields of application of 3D models of cities are quite different, such as planning and construction of infrastructure facilities, environmental monitoring (air pollution, noise propagation), observation of roads and green areas, solving emergencies [6].

Recently, space data can be obtained by active and passive sensors in the form of point clouds (LiDAR recording). Point cloud data represent a specific surface geometry using an object-independent distribution of points with uniform quality. However, this form of representation is not suitable for many applications. Some more sophisticated tasks require generalization and simplification of data models. The process of generating 3D models of buildings and structures are just such a case.

The ideas and approaches taken to aid the problem of geometry construction have two strands: the creation of imagined geometry for virtual worlds and the reconstruction of geometry as it exists in the real world from measured data. Both commercial and academic spheres of research have investigated the automated reconstruction of geometry from point clouds [7-12].

New approaches to boundary detection employ different properties of the data. Some authors make use of LiDAR data to automatically extract the boundary of water bodies [13]. They present two algorithms for boundary detection. For the first, the centroid of the region of interest is computed and an imaginary line is generated between the centroid and the farthest point. Then, more imaginary lines are generated between the centroid and each point in the region of interest. The angle between the main line and each generated line is computed to create a range between 0° and 360°, then for each degree the furthest point from the centroid is assigned as a boundary point. The second algorithm converts the cloud data into an image format. The resulting image is transformed into a binary representation and after that the pixels between the white and black colors are assigned as the object boundary [13]. The collected data are further processed to obtain fully developed photorealistic virtual 3D city models. The goal of this research is to develop a virtual 3D city model based on airborne LiDAR surveying and to analyze its applicability to Smart Cities applications [14]. They identify each roof patch from the LiDAR dataset firstly and secondly an improved Canny detector is used to extract the initial edges from the imagery data. Finally, the boundary is computed by fusing the roof patches with the initial boundary segmented from the images [15].

Automatic object modelling from point cloud data spans across a wide variety of domains. Multiple attempts use different segmentation methods with varying results. It seems that the more promising methods employ a combination of segmentation methods and semantic information, with a boundary extraction component. The boundary extraction component may be used to aid in segmentation of objects with the characteristic shape where segmentation methods based on local descriptors may exceed object boundary resulting in improper segmentation [6,9,16,17].

3D models of cities are especially interesting. There are various terms used for 3D city models, some of which are: “Cybertown”, “Cybercity”, “Virtual City”, or “Digital City” [18]. The first 3D city models began to be applied at the end of the last century, accompanied by great difficulties, primarily due to the lack of appropriate application tools as well as standards that prevented the wider use of such models. The City Geography Markup Language Open Geospatial Consortium (CityGML OGC) standard is the first standard in the field and describes five LoDs for structuring the geometric and semantic characteristics of 3D data, however these LoDs have been shown to be ambiguous and limited (Figure 1) [19].

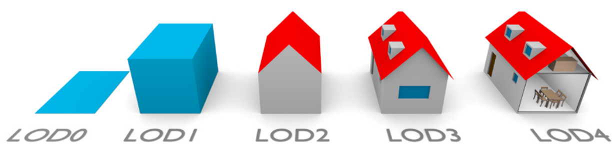

Figure 1. The five LoDs of the OGC CityGML [19]

In the past, virtual city models were most often used for visualization or simple graphical search of urban areas. Today, however, virtual 3D city models provide important information for various aspects of urban area management. Their application becomes extremely important during the construction, use and management of urban infrastructure [18]. The amount of detail that is captured in a 3D model, both in terms of geometry and attributes, is collectively referred to as the LoD. In fact, the LoD concept is important in all steps of a typical 'life cycle' of a 3D city model, even prior to any acquisition has taken place. When creating 3D models of cities, LoD determines the data collection technologies that should be used, because different models are the result of different data collection approaches. For example, LoD defines the minimum point cloud density when using aerial laser scanning technology. When collecting data, LoD serves as the main guide on how detailed the data should be collected [19].

2. Methodology and Technology of the Study

2.1 Case Study Area

Tuborg Havn or Port of Tuborg is a marina and surrounding mixed-use neighbourhood in the Hellerup District of Copenhagen, Denmark. Located on a peninsula on the north side of Svanemølle Bay, just north of the border to Copenhagen Municipality, it is the result of a redevelopment of the former industrial site of Tuborg Breweries which ceased operations in 1996. The marina is operated by the Royal Danish Yacht Club which also has its club house at the site (Figure 2). Other local landmarks include the Experimentarium science centre, the Waterfront shopping centre and the Saxo Bank headquarters [20].

Figure 2. Tuborg Havn area [20]

2.2 Experimental Program

The experimental design was performed in the ArcGISPro software. It supports data visualization, advanced analysis, and authoritative data maintenance in 2D, 3D, and 4D. Also, it supports data sharing across a suite of ArcGIS products such as ArcGIS Online and ArcGIS Enterprise, and enables users to work across the ArcGIS system through Web GIS [21]. It is used to perform raster analysis and work with large sets of LiDAR data in 3D [22]. In ArcGIS Pro, a body of related work-consisting of maps, scenes, layouts, data, tables, tools, and connections to other resources-is typically organized in a project. A project has its own geodatabase and its own toolbox [22].

Model builder is an application within ArcGIS Pro that is used to create, edit and manage models. Models are workflows that combine a number of geoprocessing tools, using the output of one tool as input to another tool. The model usually consists of at least three elements:

- input data (blue circles);
- geoprocessing tools (yellow squares);
- output data (green circles).

Model builder can also be considered a visual programming language for building workflows [23]. Instead of running each tool one at a time, a created model takes the input data, transforms it with a series of tools, and then creates the output data. The tools needed to form a model can be added in two ways. The first is by searching in the Add Tools To Model window and adding tools by double-clicking on the model. Another way is to simply drag the geoprocessing tool into the model from the Geoprocessing window or the Catalog window [24,25].

There is a possibility that several different users use the created model for the same purpose. Therefore, the input data and the output data have completely different names. Instead of static inputs and outputs, they need to be set dynamically as parameters. When input or output data are set as parameters, users can enter their data and set their output paths or storage locations [26].

3. Processing of Data

The created model for performing the task of work can be divided into two parts that are interconnected (Figure 3). The main result of the first part of the model is a digital elevation model (DEM). Within the second part of the model, the classification of point clouds were performed with the aim of obtaining the points of the roofs of buildings and the necessary data processing was performed. The final results of the second part of the model are 3D models of objects and 2D polygons in .shp format with information on the maximum and minimum height of 3D models of objects.

The tools used in the model are described below, starting with the first part of the model. Although the model is universal, for a concrete example, a point cloud related to the settlement of Tuborg Havn in Copenhagen, Denmark was used as input data (Figure 4). All data used comes from the Danish government website [27,28] and is also available through the website [29].

Figure 3. Appearance of the created model

Figure 4. Orthophoto of area of interest (Tuborg Havn)

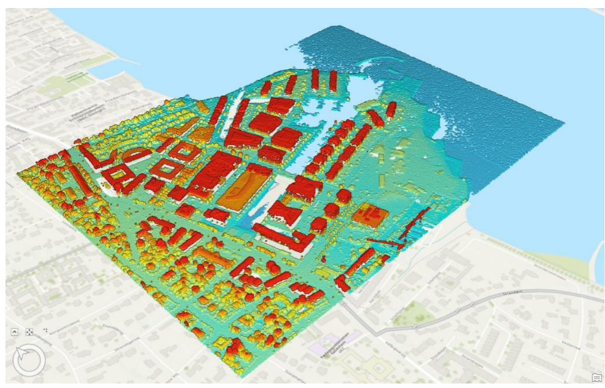

Figure 5. View the created LAS dataset

The point cloud data were split into two files, so it was necessary to merge them into a single file. The two LAS point clouds come from a project managed by the Danish government and resulting in lidar coverage for the entire country. The merging of these two files was done by creating a new LAS dataset. The created LAS dataset called Tuborg_Havn.lasd, which represents the input data is shown in Figure 5.

Prior to the model creation process, a new Toolbox was created in the Catalog called Building_Extraction. tbx. Within the toolbox, a model with the same name Building_Extraction was created. The tools used in the first part of the model are: Classify LAS Ground, Make LAS Dataset Layer, LAS Dataset To Raster, Classify LAS noise (Figure 6).

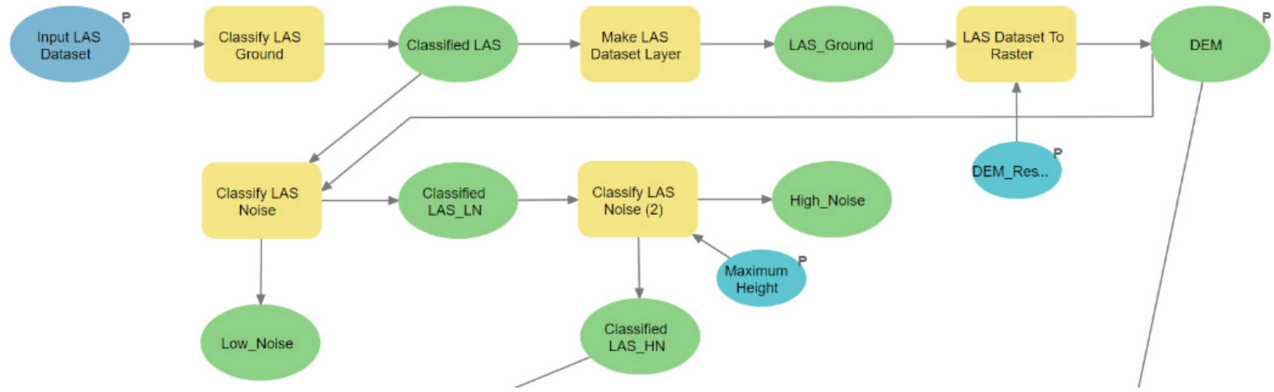

Figure 6. Presentation of the first part of the model

The Classify LAS Ground tool was used at the beginning of the model. The result of the tool is a modified point cloud Classified LAS to which the classification code 2 - Ground has been added (Figure 7).

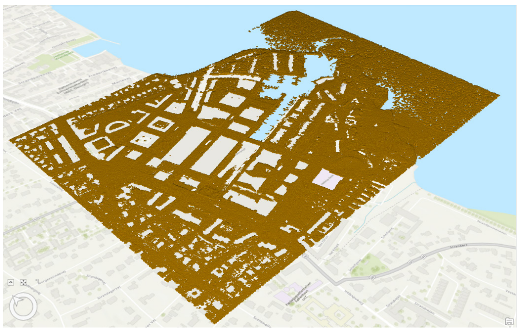

Figure 7. Classification code 2 – Ground

After the ground classification was performed, the Make LAS Dataset Layer tool was used. The output layer LAS_Ground represents the layer to which the filter for classification code 2 - Ground was applied. After filtering the point clouds and creating a layer that represents the ground, the DEM was created using the LAS Dataset To Raster tool. The created DEM is displayed in Figure 8.

After determining the ground points, the next step is to identify the noise among the remaining unclassified points. Noise points correspond to points that are too high or low and are probably the result of random errors in lidar data. The Classify LAS noise tool was used for noise determination purposes. The LAS tool classifies points with atypical spatial characteristics as noise. The tool was used twice. The first time for low noises (Low Noise), and the second time for high noises (High Noise).

After the classification of noises, in the second part of the model, the classification of buildings, i.e. points that define roofs, was performed and additional data processing was performed to obtain the final result in a vector format containing 3D models of buildings. The tools used within the second part of the model are: Classify LAS Building, Make LAS Dataset Layer, LAS Point Statistics As Raster, Raster to Polygon, Select Layer By Attribute, Eliminate Polygon Parts, Regularize Building Footprint, LAS Building Multipatch, Multipatch Footprint. Figure 9 shows the appearance of the second part of the model.

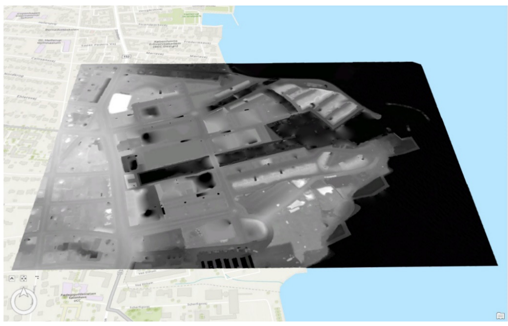

Figure 8. Created DEM resolution 0.5 m

In the second part of the model, the Classify LAS Building tool was used. The tool is used to classify building rooftops and sides in LAS data. The Classify LAS Building tool uses a combination of methods to identify the building points. The ground points must be separated out before running the tool. Among the unassigned points, the tool identifies solid surfaces where there was only one return per laser pulse. In contrast, an area with trees may have several returns per laser pulse because the light reaches and reflects from several levels in the foliage or even the ground. The Minimum Rooftop Height and Minimum Area parameters are also important to make sure that a surface that is too low or too small in the area is not mistakenly classified as a building. The Aggressive method was chosen for the Classification Method. Within this method, points corresponding to the characteristics of a flat roof with a relatively high tolerance to protrusion were discovered. The points identified as buildings are placed in classification code 6 - Buildings (Figure 10).

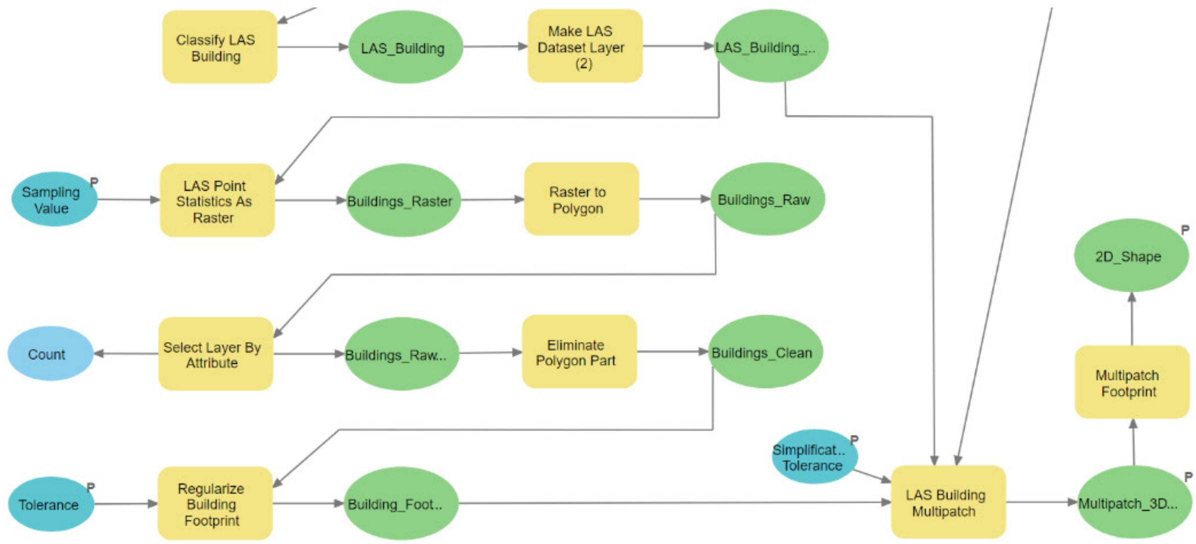

Figure 9. View second part of the model

Figure 10. Classification code 6 – Buildings

After classifying the points of the roofs of the buildings, it was necessary to separate the 2D contours of the buildings. Figure 11 shows the points identified as buildings.

Figure 11. Classification code 6 - Buildings i orthophoto (2D)

Orthophoto provides insight into what real buildings look like. However, the perspective in a photograph can make it difficult to achieve a complete visual match between the contour of the building (or the LAS points of the building) and the building below it. In the continuation, a raster was formed that corresponds to the location of the LAS points of the building. Before forming the raster, the Make LAS Dataset Layer tool was used again to create the layer LAS_Building_Layer. The LAS Point Statistics As Raster tool was used to form the raster Buildings_Raster. The next step was to convert Buildings_Raster to a polygon layer. The Raster to Polygon tool was used for this process. A polygon named Buildings_Raw has been created that contains defects. The first step in eliminating the defects was to eliminate the smallest polygons based on the value of the Shape_Area attribute. Based on the analysis of all facilities, 70 m^2 was selected for the limit value. Then, polygons larger than that value selected and the others were eliminated. The polygon selection procedure was performed using the Select Layer By Attribute tool. The next step was to remove the cavities within the polygon using the Eliminate Polygon Part tool. In this case, cavities with an area of 50 m^2 or less were eliminated. The next tool used is the Regularize Buildings Footprint tool. This tool is used to correct the stepped edges of polygons, i.e. to eliminate errors in their geometry. The Right Angles method was chosen for the method, which focuses on buildings with clean right angles. The result of the tool was a feature class called Buildings_Footprints (Figure 12).

Figure 12. Buildings_Footprints

The LAS Building Multipatch tool was used to create realistic 3D models of objects. The tool is used to create models of buildings derived from roof points recorded in lidar data. The building model is generated by constructing a triangulated irregular network (TIN) from selected LAS points located within the building contour. The contour is embedded in this TIN as a truncated polygon whose height is defined by the lowest point of the LAS within its range. The ground height is the foundation of the building and can be reported either from the field in the attribute polygon attribute table or from the elevation surface (DEM). The created data were used for input data: DEM, LAS dataset points classified as buildings (LAS_Building_Layer) and building contours (Buildings_Footprints). The result is a multipatch layer, a format that can store complex 3D vector characteristics.

At the end of the model, the Multipatch Footprint tool was used. The tool is used to create 2D polygon object contours in .shp format, created within a multipatch variable. The attributes Z_min and Z_max are added to the existing attributes based on the height of the created object models. The layout of the created polygons is the same as Buildings_Footprints, but with added attributes. The name of the output .shp file is user-defined. Figure 13 shows a pop-up window with information showing the attributes that have been added.

For the created model to be universal and to be able be used with different input data, certain input and output data are set as parameters. When input and output data are set as parameters, users can enter their data and set their output paths or storage locations. After saving the model with parameters, the model can be launched by double-clicking within the Toolbox in which it is located, as well as other tools (Figure 14).

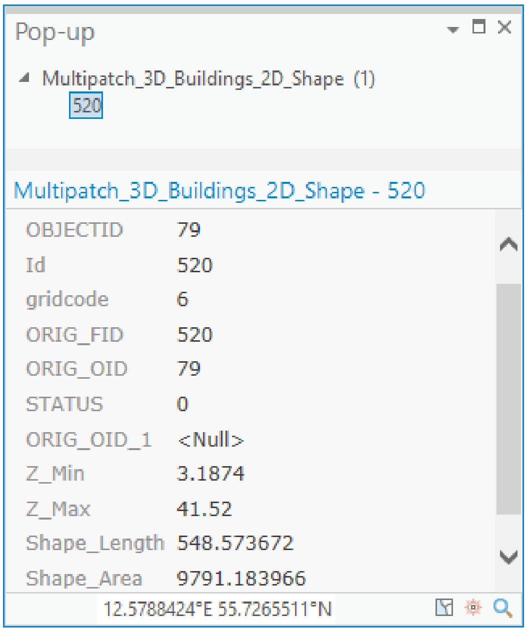

Figure 13. Pop-up window with object information (2D_Shape)

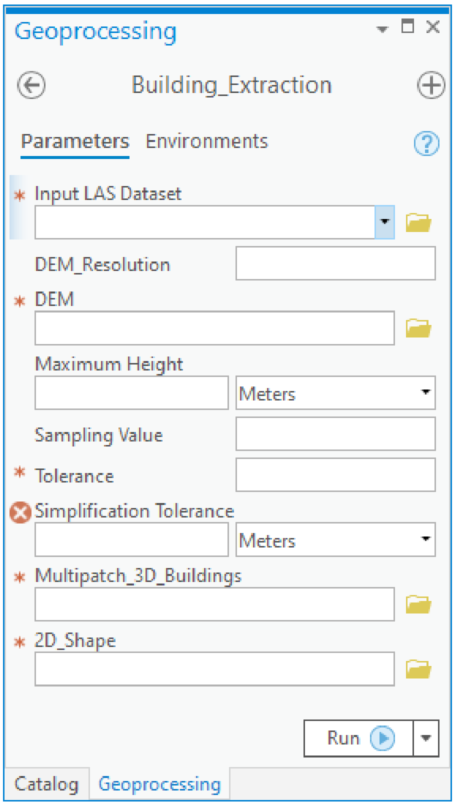

Figure 14. Appearance of the running model window

4. Results and Discussion

The point cloud, obtained by laser scanning, is classified into several classes: ground, high and low noise and buildings. As stated in the paper, after the classification of ground points, a DEM was created, which was further used in the tools in which it was needed. Primarily in the classification of low noise based on the soil surface. After the calcification of noise inside the cloud of points, the classification of roofs of buildings was performed, i.e. facilities. Then, a raster was created from those points, and after that a polygon to which certain tools were applied in order to obtain the most realistic contours of the objects. The last step was to create realistic 3D models of objects, as well as 2D polygons obtained from point clouds. To create the final result, the previously obtained results in the model were used, and they are: DEM, points classified as buildings and contours of buildings, i.e. facilities.

The results of the work are models or tools for the automated process of creating 3D models of objects based on the raw point cloud. Within the tool, the classification of point clouds was performed, a DEM was created, and after that, the geometry of the objects was extracted. The last step was to create 3D objects. The final results represent a set of 3D objects, i.e. buildings in vector format, as well as 2D polygons of created 3D objects. The created multipatch layer with realistic 3D models of objects and with the created DEM set as a reference of the ground surface is shown in Figure 15.

Figure 15. Multipatch_3D_Buildings

Some of the buildings are located just above ground level. This is because they are generated using the created DEM as a reference for the ground level. Because the DEM is created from very precise lidar data, it represents a slightly different and more detailed terrain than the default WorldElevation3D / Terrain3D layer used within the display scene to model the ground in 3D. For a more accurate view of the terrain within the Contents window, below Elevation Surfaces, the created DEM has been added for Ground using the Add Elevation Source option and selected as a ground surface reference. A zoomed view of the created 3D object models is shown in Figure 16.

Figure 16. Multipatch_3D_Buildings, close-up

Within the tools in the model, the values obtained by the analysis of the localities for which the data were collected were used. Although the model is universal, one should still take into account the locality and characteristics of the objects within it. The main advantage of the created tool is the possibility of automatic data processing, based on the parameters defined by the user.

5. Conclusions

In this paper, a model was formed, and later a tool for creating an automated procedure for creating a 3D city model based on a raw point cloud. The main intention was to create a tool that is universal for designing. In this way, the tool can be used by all users who need it. Also, there is a possibility for free choice of input and output parameters, and most importantly the input LAS dataset, i.e. point clouds.

The entire process is fully automated. The main disadvantage of the tool is the need for very high quality input data. The processing of different data sets showed that in order to achieve high-quality object models, it is necessary to use a very dense point cloud as an input. The application of a sparse point cloud results in the creation of lower quality object models. As stated in the paper, the obtained 3D models can be used for various purposes such as flood simulation, noise estimation, solar energy estimation, visibility analysis, spatial planning and many others. Advances in data collection methods and technologies for the automatic realization of 3D models are evolving very rapidly, which will make it easier to describe spatial data and their photorealism in the future [16,30].

A procedure was created to perform the task, which was later converted into a tool within the Model Builder application, in the ArcGIS Pro software environment. The input data are an unclassified point cloud obtained by the LiDAR system, which is subsequently structured through the application. Based on the classified point cloud, a DEM was created, object geometry was extracted, and realistic 3D object models were formed in the form of a multipatch layer, a format that can store complex 3D vector features.

References

[1] Ostrowski, W., Pilarska, M., Charyton, J., Bakuła, K., 2018. Analysis of 3D Building Models Accuracy Based on The Airborne Laser Scanning Point Clouds. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2.
DOI: https://doi.org/10.5194/isprs-archives-XLII-2-797-2018

[2] Billen, R., Cutting-Decelle, A.F., Marina, O., de Almeida, J.P., Caglioni, M., Falquet, G., Leduc, T., Métral, C., Moreau, G., Perret, J., et al., 2014. 3D City Models and Urban Information: Current Issues and Perspectives. European COST Action TU0801, EDP Sciences.
DOI: https://doi.org/10.1051/TU0801/201400001

[3] Gröger, G., Plümer, L., 2012. CityGML-Interoperable semantic 3D city models. ISPRS Journal of Photogrammetry and Remote Sensing. 71.
DOI: https://doi.org/10.1016/j.isprsjprs.2012.04.004

[4] Wang, R., Peethambaran, J., Chen, D., 2018. LiDAR Point Clouds to 3D Urban Models: A Review. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 99.
DOI: https://doi.org/10.1109/JSTARS.2017.2781132

[5] Biljecki, F., Ledoux, H., Stoter, J., 2016. An improved LOD specification for 3D building models. Computers Environment and Urban Systems. 59.
DOI: https://doi.org/10.1016/j.compenvurbsys.2016.04.005

[6] Hron, V., Halounová, L., 2014. Automatic Generation of 3D Building Models from Point Clouds. Conference: Symposium GIS Ostrava 2014 - Geoinformatics for Intelligent TransportationAt: Ostrava, Czech Republic.

[7] Thomson, C., 2016. From Point Cloud to Building Information Model: Capturing and Processing Survey Data Towards Automation for High Quality 3D Models to Aid a BIM Process. PhD Thesis.
DOI: https://doi.org/10.13140/RG.2.2.19058.71366/1

[8] Andriasyan, M., Moyano, J., Nieto, J.E., Antón, D., 2020. From Point Cloud Data to Building Information Modelling: An Automatic Parametric Workflow for Heritage. Remote Sensing. 12(7).
DOI: https://doi.org/10.3390/rs12071094

[9] Căluşer, A., Cristian, G., 2018. Semiautomatic Building Information Modelling from point clouds, Master's Thesis, Department of Development and Planning, Aalborg University, Denmark.

[10] Rusu, R.B., Blodow, N., Marton, Z.C., Dolha, M., Beetz, M., 2007. Towards 3D Point Cloud Based Object Maps for Household Environments, Robotics and Autonomous Systems. Volume 56.
DOI: https://doi.org/10.1016/j.robot.2008.08.005

[11] Awrangjeb, M., 2016. Using point cloud data to identify, trace, and regularize the outlines of buildings. International Journal of Remote Sensing. 37(3).
DOI: https://doi.org/10.1080/01431161.2015.1131868

[12] Zahn, C.T., 1996. A formal description for two-dimensional patterns, Stanford Linear Accelerator Center Stanford University, Stanford, California. pp. 621-628.

[13] Canaz, S., Karsli, F., Guneroglu, A., Dihkan, M., 2015. Automatic boundary extraction of inland water bodies using LiDAR data, Ocean & Coastal Management, Volume 118, Part B. pp. 158-166.
DOI: https://doi.org/10.1016/j.ocecoaman.2015.07.024

[14] Jovanović, D., Milovanov, S., Ruskovski, I., Govedarica, M., Sladić, D., Radulović, A., Pajić, V., 2020. Building Virtual 3D City Model for Smart Cities Applications: A Case Study on Campus Area of the University of Novi Sad. ISPRS International Journal of Geo-Information. 9 (476).
DOI: https://doi.org/10.3390/ijgi9080476

[15] Li, Y., Wub, H., Ana, R., Xua, H., Hea, Q., Xua, J., 2013. An improved building boundary extraction algorithm based on fusion of optical imagery and LIDAR data. Optik - International Journal for Light and Electron Optics. 124(22).
DOI: https://doi.org/10.1016/j.ijleo.2013.03.045

[16] Bellakaout, A., Cherkaoui, M., Ettarid, M., Touzani, A., 2016. Automatic 3D Extraction of Buildings, Vegetation and Roads from LIDAR Data. Remote Sensing Spatial Inf. Sci., XLI-B3.
DOI: https://doi.org/10.5194/isprs-archives-XLI- B3-173-2016

[17] Nys, G.A., Poux, F., Billen, R., 2020. CityJSON Building Generation from Airborne LiDAR 3D Point Clouds. ISPRS International Journal of Geo-Information. 9(9).
DOI: https://doi.org/10.3390/ijgi9090521

[18] Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., Çöltekin, A., 2015. Applications of 3D City Models:

State of the Art Review. ISPRS International Journal of Geo-Information. 4(4).
DOI: https://doi.org/10.3390/ijgi4042842

[19] Biljecki, F., 2017. Level of detail in 3D city models, PhD thesis, TU Delf. pp. 353.
DOI: https://doi.org/10.4233/uuid:f12931b7-5113-47ef-bfd4-688aae3be248

[20] C.F. Møller Architects. https://www.cfmoller.com/p/tuborg-nord-general-og-bebyggelsesplan-i215.html. (Accessed 06 October 2021).

[21] ESRI, ArcGIS Pro. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview. (Accessed 06 October 2021).

[22] ESRI, ArcGIS Blog, Available online: https://www.esri.com/arcgis-blog/products/3d-gis/3d-gis/arcgis-pro-reinventing-desktop-gis/. (Accessed 06 October 2021).

[23] ESRI, ArcGIS Pro, What is ModelBuilder? https://pro.arcgis.com/en/pro-app/latest/help/analysis/geoprocessing/modelbuilder/what-is-modelbuilder-.htm. (Accessed 07 October 2021).

[24] ESRI, ArcGIS Pro, Use ModelBuilder. https://pro.arcgis.com/en/pro-app/latest/help/analysis/geoprocessing/modelbuilder/modelbuilder-quick-tour.htm. (Accessed 07 October 2021).

[25] ESRI, ArcGIS Pro, Add and connect data and tools and modify elements. https://pro.arcgis.com/en/proapp/latest/help/analysis/geoprocessing/modelbuilder/add-connect-and-modify-data-and-tools-in-a-model.htm. (Accessed 07 October 2021).

[26] ESRI, ArcGIS Pro, Model parameters. https://pro.arcgis.com/en/pro-app/latest/help/analysis/geoprocessing/modelbuilder/model-parameters.htm. (Accessed 07 October 2021).

[27] Styrelsen for Dataforsyning og Effektivisering. https://kortforsyningen.dk/. (Accessed 07 October 2021).

[28] Styrelsen for Dataforsyning og Effektivisering, Danmarks højdemodel – Punktsky. https://dataforsyningen.dk/data/3931. (Accessed 07 October 2021).

[29] ArcGIS, Building_Extraction. https://www.arcgis.com/home/item.html?id=d0966e35258847e1903e3d4525786b40. (Accessed 07 October 2021).

[30] Learn ArcGIS, Extract 3D buildings from lidar data. https://learn.arcgis.com/en/projects/extract-3d-buildings-from-lidar-data/ (Accessed 05 February 2022).