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The 3D Metric Survey for the Digital Cartographic Production to Support the Knowledge of the New Municipality of Mappano

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18 November 2026



The Urban Book Series

Grazia Brunetta
Patrizia Lombardi
Angioletta Voghera *Editors*

Post Un-Lock

From Territorial Vulnerabilities to Local Resilience

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Post Un-Lock

From Territorial Vulnerabilities to Local Resilience

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Preface

This book is the first result of the "Post Un-Lock" research project, funded by the Interuniversity Department of Regional and Urban Studies and Planning (DIST) of the Politecnico di Torino, a three-year work involving the collaboration of a large number of researchers belonging not only to different departments and institutions but also to diverse disciplinary areas.

The research involves teams from the Department of Environmental, Land, and Infrastructure Engineering (DIATI) of the Politecnico di Torino (such as environmental and geomatics engineers), the Department of Mathematical Sciences "Giuseppe Luigi Lagrange" (experts in mathematical statistics), and the Department of Medical Sciences of the Università di Torino (researchers in the field of medical statistics and epidemiology), committed to reflecting on the territorialization of the pandemic and the effects of pollution on health in cities.

The Post Un-Lock research took shape in the last months of 2020, triggered by the scientific impulse of the international goals of sustainability and resilience in the perspective of the post-carbon city and the overcoming of environmental, economic, social and health crises. Scholars have collaborated and tested on case studies methodologies, approaches, and tools capable of re-imagining cities and regions to overcome vulnerabilities and to innovate the socio-ecological system on the basis of the ideal-typical model of Local Resilience Unit.

With this in mind, we would like to thank, in addition to the authors of the chapters and their collaborators: the partners of the research such as the Interdepartmental Centre Responsible Risk Resilience Centre (R3C), the SDG11LAB, the S3+Lab (Urban Sustainability and Security Laboratory for Social Challenges), the CED PPN (European Documentation Center on Natural Park Planning), the Living Lab and the PIC4SER of Politecnico di Torino. We would also like to thank the external supporting institutions such as IUGA of Grenoble, University of South Denmark, CMCC (Euro-Mediterranean Center on Climate Change), and the administrations involved in the case studies, whose suggestions provided crucial support for the outcomes of this publication. Other institutions and people we would like to thank are: Nicola Tollin, Professor with special responsibilities in Urban Resilience, UNESCO Chair at University of Southern Denmark (SDU), ITI,

Civil and Architectural Engineering; Joe Ravetz, Co-director of the Collaboratory for Urban Resilience and Energy at the Manchester Urban Institute, University of Manchester; Jordi Morató, Director UNESCO Chair on Sustainability at Polytechnical University of Catalonia; Michele Talia, Istituto Nazionale di Urbanistica (INU); Stefania Crotta, Direzione Ambiente, Energia e Territorio of Regione Piemonte; Milena Maule, Associate Professor of Medical Statistics and Epidemiology at Department of Medical Sciences of Università di Torino (UNITO); Egidio Dansero, Professor at Department of Cultures, Politics, and Society (UNITO) and delegate at RUS; Alessio Malcevschi, Professor at Università di Parma, RUS delegate; Stefano Armenia, Senior Research Fellow at Link Campus University, president of System Dynamics—SYDIC; Rosa Gilardi, Director of Area Urbanistica e Qualità dell'Ambiente Costruito, Città di Torino; Gilles Novarina, Laboratoire Architecture Environnement and Cultures Constructives at Université Grenoble Alpes—École Nationale Supérieure d'Architecture; Guglielmo Filippini, Direzione Risorse Idriche e Tutela dell'Atmosfera at Ufficio Pianificazione e Controllo delle Risorse Idriche of Città Metropolitana di Torino.

Turin, Italy
January 2022

Grazia Brunetta
Patrizia Lombardi
Angioletta Voghera

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Chapter 12
The 3D Metric Survey for the Digital Cartographic Production to Support the Knowledge of the New Municipality of Mappano

Egle Beani, Elisabetta Colucci, Luigi La Riccia, Andrea Maria Lingua, Paolo Felice Maschio, Francesca Matrone, Alberto Possa, and Ammj Traore

Abstract The complexity of the territories and cities is the genesis of the need to carry out spatial analyses, simulations of complex phenomena and urban planning, requiring an evolution of very large-scale numerical cartography. The representation of cities has not to ignore some essential aspects as well as: the three-dimensionality of the land and all its natural and artificial objects, the multi-scale of geometric and descriptive information to allow different levels of detail and granularity according to the operational purposes, and the interoperability, which enable sharing of map data among various stakeholders and applications for complex analysis. The outcome

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resulted in the evolution of traditional cartography into numerical cartography toward new instruments and applications such as digital twins. They constitute a virtual replica of physical, potential, and actual resources equivalent to objects, processes, people, places, infrastructures, systems, and devices related to the city and the territory. The case study selected for this research is the recent municipality of Mappano, in the metropolitan city of Turin. The methodology consists of a semiautomatic extraction of cartographic information and geometry essential for defining a digital twin. It has been developed investigating the existing Piedmontese regional geoportal (BDTRE) datasets and data models, and the Geographic Information System (GIS) standard specification for 3D city models, CityGML, mainly considering the first three levels of detail (LoD). The methodology and the resulting spatial data application have been validated by in-loco surveys and digital tools in GIS environment. The starting base map entities derived from a high-resolution acquisition from drone photogrammetry (UAV, Unmanned Aerial Vehicle, platforms have been adopted). The outputs of the aerial survey, orthophotos, and dense altimetric models (DTM, Digital Terrain Model and DSM, Digital Surface Model) were essential to extract various cartographic information.

Keywords 3D metric survey · GIS · Geo-topographic database · Digital cartography · 2D/3D city models

12.1 Introduction

Smarting the city is an intricate process due to the complexity of a city. The city is not an automated system that can be easily understood and predicted, but rather a living system that evolves every day through variations and developments of its physical constructs, economic and political activities, social and cultural settings, and ecological systems (Shahat et al. 2021). The knowledge of a territory is strongly related with the accessibility to a complete and detailed digital cartography in which quantity and quality information can be collected and organized. Data harmonization must play a key role to guarantee interoperability of these data, and hence, policies have been advanced at European and global levels to pursue this aim. Data standardization is part of the process for better planning and policy evaluation, more efficiency, optimization and innovation. Furthermore, the creation of a European data infrastructure can simplify the sharing of spatial information between public administrations, facilitate public access to environmental spatial information throughout Europe, and assist in decision-making processes relating to the environment and the territory (Geoportale Nazionale 2021).

The infrastructure for geographic information (GI) is the set of spatial data, metadata, network services and technologies, policies and institutional agreements aimed at sharing, accessing, and using to facilitate the availability and homogeneity of geospatial data. Legislative Decree of January 27th, No. 32/201022 for "Implementation of Directive 2007/2/EC, establishing an Infrastructure for Spatial Information in

the European Community (INSPIRE)"[1] was published by Italy aimed at the creation of a national infrastructure for spatial information and environmental monitoring allowing the Country to participate at INSPIRE. Services are available to the public free of charge, but the State might limit (art. 13) public access to spatial datasets and services for many reasons such as public security or national defense.

Moreover, also at the international level, the GIS standard data model for 3D city representation is CityGML. It extends the GML, by adding the semantic values for the 3D representation of city objects (Gröger et al. 2012). The standard implements five levels of detail (LoD) for a multi-scale model of spatial entities representation. LoD 0, deals 2D or 2.5D objects (scale about 1:50,000—1:10,000). LoD 1 represents buildings in 2.5D or 3D (1:25,000—1:10,000). LoD2 and LoD3 represent city district or architectural models (1:10,000—1:5000 and 1:2500, 1:2000 in Italy—1:1000). Finally, LoD 4 is dedicated to the interior building (1:1000 or 1:500) (Biljecki et al. 2016).

In the national framework, each Italian Region must own spatial datasets, related to the specific geographic area of pertinence, collected in a geoportal providing public access to these services organized in standardized spatial information of the territory. Piedmont region has BDTRE, initials of spatial database reference for the authorities—Base Dati Territoriale di Riferimento degli Enti—which is the geographical database of whole Piedmont promoted by the Piedmont region authority, whose contents are structured according to the national "Technical rules for the definition of the content specifications of the geo-topographic databases" (MD 2011/11/10) primarily aimed at supporting the planning, governance, and protection of the territory. The BDTRE therefore assumes the role of shared and free-to-use storage of all spatial data, from which Regional Technical Cartography (CTR) derives. The region has published a standard's specification document, to produce topo-cartographic database pursuant to the MD 2011/11/10 and to support cartographic productions, which constitutes a base for public administrations on spatial information, according to Art. No.59 of Legislative Decree. No. 82/2005 (Digital Administration Code[2]).

All municipalities must guarantee the development of a database (DB) containing spatial and semantic information of their objects. This set of data help also the different stakeholders of the city involved in many activities such as urban planning, policy-makers actions, restoration, and revitalization of marginal areas. Therefore, the tasks of the newly formed municipalities include the creation of a geodatabase containing all the related information. During the DB design, all the three-dimensionality objects in the land and all its natural and artificial objects have to be considered. Moreover, the datasets have to be structured with a multi-scale, multi-level, and multi-granularity approach. The result is a numerical cartography designed with innovative methods, instruments, and applications such as digital twins, a digital representation of the reality, in 2D or 3D.

[1] "Implementation of Directive 2007/2/EC, which establishes an infrastructure for territorial information in the European Community (INSPIRE)".

[2] Code of digital administration.

The development of accurate and precise large-scale numerical 2D cartography integrated with the production of 3D city models is increasingly studied worldwide and required by public administrations. Therefore, the municipalities have a digital model of the territory, also in 3D, of significant potential.

The methodology here presented consists of a semiautomatic extraction of cartographic information and geometry essential for defining a digital twin. The cartographic production derived from a rigorous 3D metric survey after an accurate analysis of the Piedmont regional geoportal (the BDTRE, Base Dati Territoriale di Riferimento degli Enti piemontesi[3]) datasets and data models, and the GIS standard specification for 3D city models, CityGML. The case study selected for this research is the recent municipality of Mappano, in the metropolitan city of Turin. The methodology and the resulting spatial data application have been validated by in-loco survey and digital tools in GIS environment. The starting base map entities derived from a high-resolution acquisition from drone photogrammetry (UAV, Unmanned Aerial Vehicle, platforms have been adopted). The outputs of the aerial survey, orthophotos, and dense altimetric models (DTM, Digital Terrain Model and DSM, Digital Surface Model) were essential to extract various cartographic information.

12.2 The Case Study

Mappano is a town in the first belt of the metropolitan city of Turin not far, less than five kilometers, from the Turin Stura railway station. It is characterized by being defined as the youngest municipality in Italy as it was officially formed in 2017. Mappano was born from "the supremacy of the local identity [which] is the main driver of social actions. […] Until the time of the referendum in 2012 there was no official, unique, or shared definition of what the territory of Mappano is, a conurbation that extends over the territory of the municipalities of Borgaro Torinese, Caselle Torinese, Leinì, Settimo Torinese, and Torino" (Pileri and Scalenghe 2016). The actual boundaries of the city were established after the referendum on November 11, 2012 (Ibid.). This "administrative fragmentation," occurred with the birth of a small new municipality, brought environmental issues up, since at greater number of units governing a territory, each of them maximizing its own goal on a small territory, increase the need for inter-agency dialogue and coordination (Ibid.) other than difficulties in finding a shared line of planning view, time, and costs.

As above mentioned, due to the necessity to organize and spread a digital cartography of the municipality, Mappano has signed a collaboration agreement with the DIATI and DIST departments with the aim of creating a highly accurate, updated, and complete cartography, essential for the implementation of its first General Town Plan (Italian *Piano Regolatore Generale*). At the basis of this commitment, there is the recent born of Mappano and therefore the consequent assignment of adopting a General Town Plan, as provided by law no. 1150 of 1942. Correcting the flaws of the

[3] https://www.geoportale.piemonte.it/cms/bdtre/bdtre-2.

forced coexistence of the plans of four municipalities (Caselle Torinese, Borgaro, Leinì e Settimo Torinese) has been the starting point of the plan. Hence, the differences of quality among the composed Mappanese cartography have increased the interest in harmonizing the existing data and acquiring a new one. The methodology here presented describes this process.

12.3 Methodology

As shown in Fig. 12.1, the workflow of the methodology is divided into three main phases: the data acquisition, the processing, and the definitions of outputs. The first step consisted of a 3D metric survey adopting traditional topographic methods (GPS/GNSS) and photogrammetry techniques. The first step was measuring the topographic network to obtain the vertices coordinates. Then, UAV aerial photogrammetry has been adopted considering different details and scale representation levels. For this reason, two different drones have been adopted: the fixed-wing drone eBee Plus by senseFly for the territorial acquisition and the DJI Phantom 4 RTK for the city objects survey. After the acquisition phase, the data have been processed following consolidated approaches to generate 3D models in point clouds, meshes, digital models, and orthophotos. The data outputs, as described below, are all the outcomes of the post-processing phase: the spatial objects (both vectors and rasters, such as digital terrain models) included in the new digital twin from the BDTRE Geo-topographic database of the Piedmont region.

12.3.1 Data Acquisition

The initial inspection of the area allowed to proceed with the preliminary phases of the photogrammetric survey. First of all, markers on the ground that make up the topographic network were placed uniformly on the area to be surveyed. These markers, also named ground control points (GCPs), are essential for returning the final data, allowing the correct scaling and georeferencing of the outputs. In this case, 60 × 60 cm panels in semi-rigid plastic or high-strength PVC fabric were used, characterized by high-contrast colors that allow them to be easily recognized from the UAV images (Fig. 12.2a). Where possible, natural points have been used, such as manholes, manhole covers, or fixed objects that are clearly identifiable and permanently present in the surveyed area (Fig. 12.2b).

Figure 12.2c shows the final distribution of control points materialized in the field, in particular 30 GCPs evenly distributed over the area. The position of those GCPs was acquired using a GNSS receiver (Fig. 12.2c). In particular, ItalPOS SmartNet GNSS network was used: a service owned by Leyca Geosystems which offer the correction of measurements for positioning in RTK with fixed bases throughout the national territory.

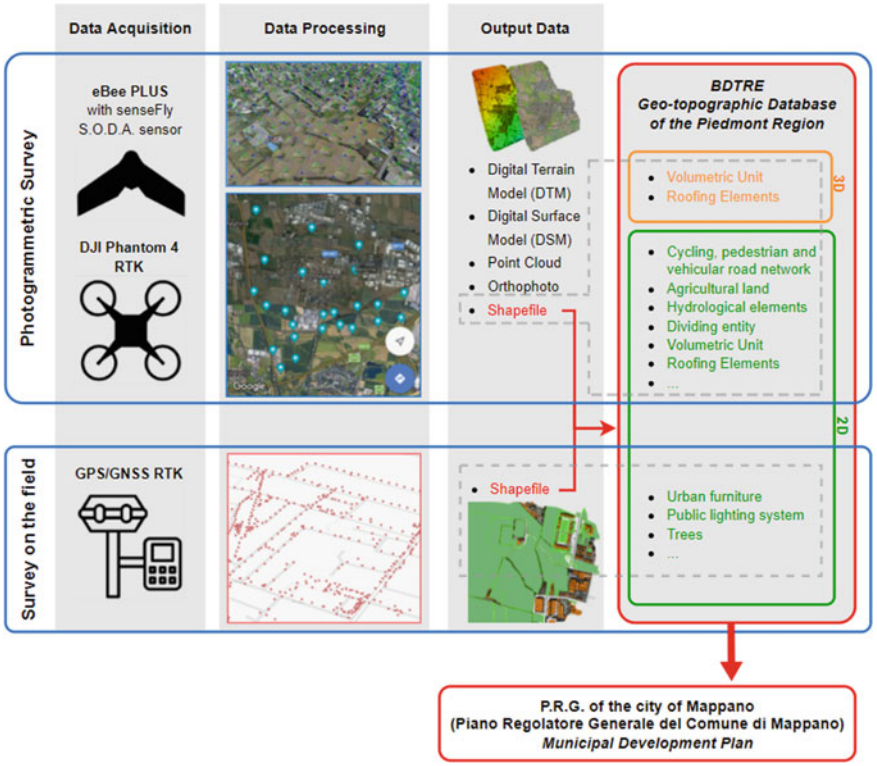


Fig. 12.1 Methodology used for the creation of the new municipal cartographic products. The output data obtained from the photogrammetric and field survey merged into the Geo-topographic database and served as the basis for the definition of the new Municipal Development Plan



Fig. 12.2 GCPs materialized in the surveyed area and GNSS receiver (**a**). Natural point selected as GCP (**b**). Overall view of the GCPs (**c**). (Images from the 3D metric survey carried out by the Geomatics group of Politecnico di Torino)

The coordinates in terms of latitude, longitude, and ellipsoid elevation (with reference to the ellipsoid WGS4 and then converted to geoid) of all the GCPs were thus acquired.

Photogrammetric survey

A strategy of multiple drone flights was implemented to cover the entire area of 11.896 km^2.

The system used consists of a fixed-wing aircraft called eBee Plus produced by senseFly. The aircraft weighs about 1.1 kg including camera and battery, with a wingspan of 110 cm. The cruising speed varies between 40 and 110 km/h, with a wind resistance of up to 45 km/h. The flights have been planned around 40 min, in order to avoid running out of batteries before the scheduled landing.

In this application, the camera supported by the senseFly SODA device was used with 13.8 × 8.8 mm format RGB sensor, 10.6 mm focal length, for a total of 20 megapixels, global shutter, and equipped with dust and shock protection. The mounted camera allows for a theoretical ground resolution of about 2.9 cm/pixel for a flight height of 120 m.

The complete coverage of the municipality of Mappano was achieved through a total number of 13 flights (Fig. 12.3). A total of 5.646 frames were acquired, at a flight height of about 140 m, with a resolution of 3.16 cm/pixel.

During the acquisition phases, the images have been taken from different angles: nadiral and oblique. The latter are used to document the areas not visible from the former (as façades) and to develop the three-dimensional model with a higher level of detail.

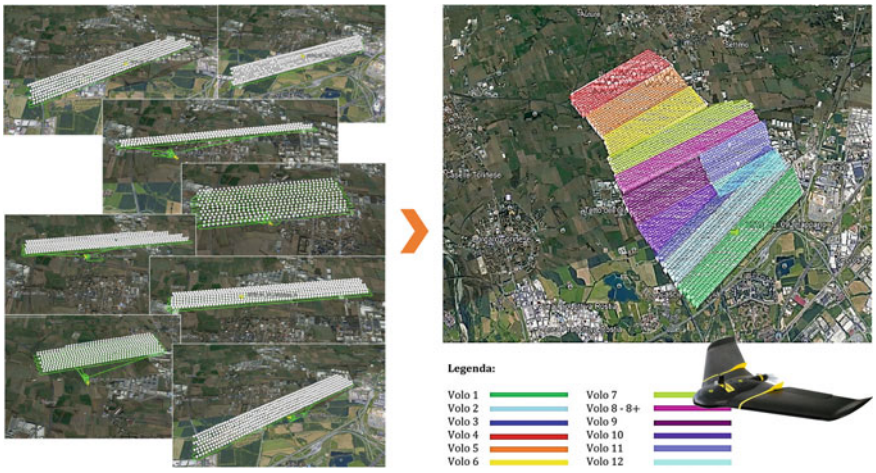


Fig. 12.3 Examples of flights performed for the survey (left) and their union (right). On the right bottom, the eBee Plus UAV used. (Screenshot from the software used for the planning of the UAV survey)



Fig. 12.4 On-site survey in Municipal of Mappano took place in January 2021 and it involved the direct team, scholarship holders, and PhD students from DIATI. (Images from the 3D metric survey carried out by the Geomatics group of Politecnico di Torino)

Survey on the field

An on-site survey was necessary to acquire all those elements not detectable from the orthophoto analysis, such as street/urban furniture (MN_ARR), vertical road signs, single trees, and artifacts such as traffic lights, control groups (MN_INT), electrical network/gas cabins (MN_IND) (Fig. 12.4). To this aim, Leica GS14 and GS18 GNSS RTK rover were used, fixing the position when under 4/5 cm of accuracy.

12.3.2 The Geo-Topographic Database

As anticipated, the Data Catalog (Simplified Operational Specifications for Geo-topographic DBs for use by public administrations—Piedmont Region, Version 2.2.1, April 5, 2017) can be considered as a real translation of the structure illustrated in the CityGML model, since the reference structure is also in this case constituted by the *class*, which defines the representation of a specific typology of territorial objects: the properties, the data structure, the acquisition and structuring rules and the relationship with the other objects. Within this framework, four levels are identified to define the topological land cover (Fig. 12.5):

urban level,
traffic level,
water level,
vegetation level.

There is also a fifth level for non-topological classes and three further levels for graphs and addresses: viability graph level, hydrography graph level, and address level.

To distinguish the type of attributes, identification codes have been used within the specifications, determining the creation of an external *dictionary*.

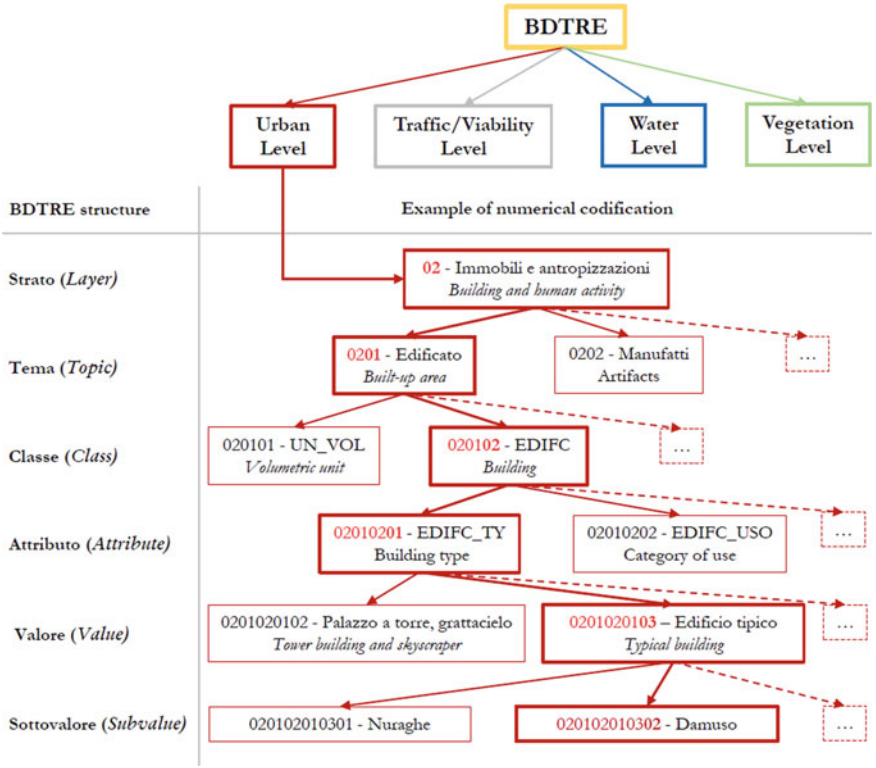


Fig. 12.5 BDTRE structure followed for the data output. (Schema designed by the authors)

Urban level

Within the urban level, there are multiple classes such *as equipped areas, buildings, minor buildings, industrial artifacts, architectural details, street furniture,* and so on. Specifically, as regards the Building Class (EDIFC—020,102), the related attributes that have been inserted are:

the building type (02,010,201 EDIFC_TY): generic '01', tower building '02', typical building '03', etc.;
the category of use (02,010,202 EDIFC_USE): residential '01', administrative '02, public service' 03 ', military' 04 ', etc.;
status (02,010,204 EDIFIC_STAT): under construction '01', ruined '02', or built '03'.

Traffic/viability level

Within the traffic/viability level, different classes are identified corresponding to the different types of traffic areas: vehicular (AC_VEI), cycle path (AC_CIC), pedestrian (AC_PED), mixed (AR_VMS), and so on.

Water level

The Water level of the BDTRE database is defined as the classes that provide a representation of the hydrographic system of the Piedmont region. This level has been identified different elements such as river/stream or canal (EL_IDR), the different types of standing water (SP_ACQ) and the water node (ND_IDR), i.e., the point of intersection between water elements.

Vegetation level

In the vegetation level, the classes relating to the different types of vegetation present are identified: green areas (AR_VRD), agricultural crops (CL_AGR_TY), forest (BOSCO_TY) and pastures and uncultivated (PS_INC_TY).

12.4 Results

12.4.1 Cartographic Products

As regards the processing of photogrammetric data, it took place at the Geomatics Laboratory of the Department of Environmental, Territory and Infrastructure Engineering of the Polytechnic of Turin. Agisoft Metashape and Pix4D were chosen as processing software, allowing a data comparison (Beani 2019). The procedure followed is rather automatic, since it consists of sequential steps (generation of sparse point cloud, dense point cloud, DEM, orthomosaic and eventual 3D textured mesh); however, it requires a careful check on the residual errors of the 24 GCPs used. This workflow provided mean errors of 2.15 cm with accuracies of around 1.52 cm and 1.4 cm for the horizontal coordinates (x and y) and 0.6 cm for the vertical coordinate (z), allowing to generate large-scale cartographic products up to 1:1000.

The above-described pipeline outputted the required cartographic products in terms of dense cloud (12.424.864 million points), orthophotos (Fig. 6a), and digital surface model (DSM) (Fig. 6b) with a resolution of 4 cm/pixel. The processing of this data required a computational time of about 5 h to obtain the dense cloud in *average* quality, 18 h for the orthophoto, and 33 min for the DSM. Once obtained the DSM, a digital terrain model (DTM) was created through the automatic point cloud classification of the Metashape software. This latter tool allowed to speed up the exclusion of categories such as buildings, vegetation, or vehicles, in order to keep only ground points; however, a manual intervention was anyway required.

The DSM (coordinate system WGS 84 / UTM zone 32N, EPSG: 32,632) has a color legend from red to blue that identifies the altitude of the points of the territory from the highest in the north-west to the lowest in the south-east, in correspondence with the area of the hydraulic work known by the community as the "spillway."

In general, an average GSD of 316 cm was obtained for the whole area.

In addition to these products, data have been processed from on-site survey. Hence, street furniture was classified following BDTRE standards in one data (MN_ARR).

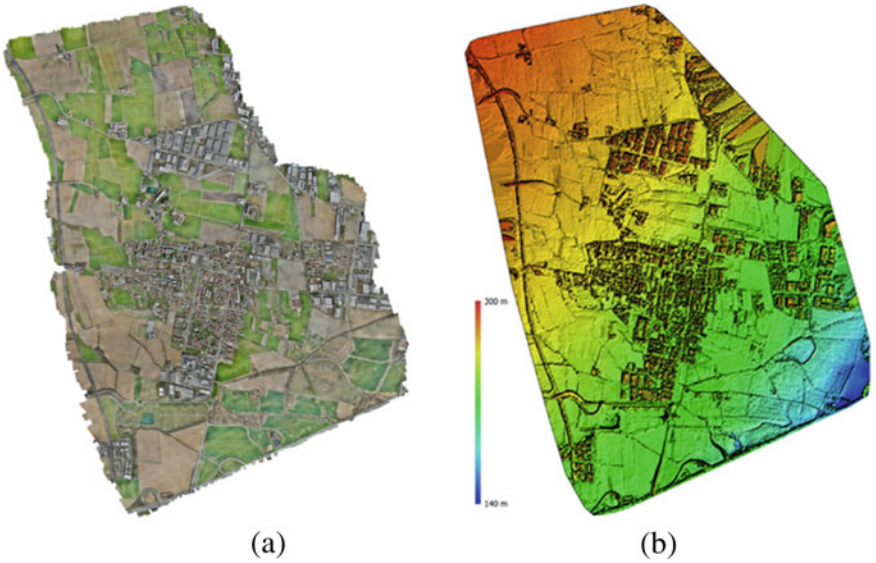


Fig. 12.6 Orthophoto (**a**) and corresponding DSM (**b**). (Data products from the post-processing carried out by the Geomatics group of Politecnico di Torino)

Figure 12.7 shows the result of this process. This information can be used for a plurality of tasks such as updating the level of maintenance of each artifact and their extension on the territory.

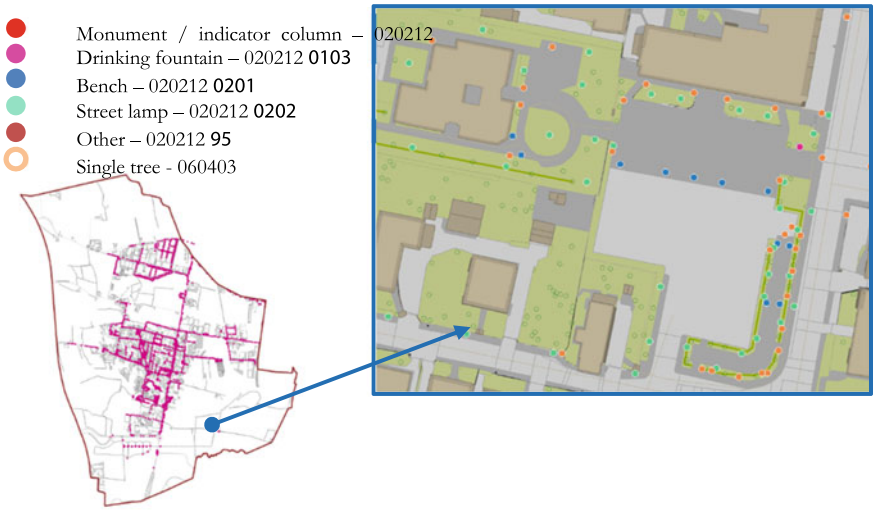


Fig. 12.7 Focus on Piazza Don Amerano showing street furniture's classification result

Then, starting from the results of the photogrammetric data processing process and the survey on the field, in the general context of 3D data generation it is necessary to focus attention on the objective of the project, which envisages obtaining a geo-topographic database based on the Simplified Specification standards proposal for the Territorial Reference Database of Management Bodies within the Piedmont region.

12.4.2 The Digitalization Process and the BDTRE

As regards the geometric definition of the database entities, the outputs of the photogrammetric process and the survey in the field constituted the basis for its digitalization. This operation took place in the work environment of the ESRI ArcMap application.

Starting from the orthophoto, used as a reference image, 2D modeling consists of the generation of geospatial vector data, by defining polygons associated with different layers, which represent the elements relating to the classes of interest. These files, called shapefiles, were the second output of the project.

This is a rather simple manual procedure, but relatively time-consuming. The level of geometric detail for most of the shapefiles stopped at the definition of the contours, therefore a two-dimensional LOD0 (Fig. 12.8). For many of these layers, in the phases following the digital restitution, further inspections were carried out aimed at improving the level of detail, e.g., the insertion of information relating to the balconies (included in the architectural details shapefile—PAR_AR—and not obtainable from the point clouds) or the projections of the roofs, which made it possible to more accurately derive the footprint of the buildings on the ground.

In addition, a 3D shapefile (volumetric units) was also created for the buildings by associating the height interpolated by the DSM with a centroid for each volume, thus obtaining a LOD1. Subsequently, the association of a height interpolated by the DSM to each pitch of the roof was performed and permitted the creation of LOD2. In this way, the roofing system for all the municipality was directly defined in 3D (Fig. 12.8).

Within the same environment, the structure of the desired database was also defined according to the scheme described in paragraph 2.2 and related subsections. The attribute table was defined for each polygonal element modeled, creating the fields relating to level, class, and all the attributes required by the BDTRE Specification.

In this way, at the end of the manual processing in ArcGIS-ArcMap, an exportable and further processable vector data is available, to which the real database is associated (Figs. 12.9 and 12.10), element by element.

Finally, all the data have been arranged for the 3D visualization and query, always keeping the BDTRE structure (Figs. 12.11 and 12.12) and allowing a detailed representation of street furniture, trees, and so on.



Fig. 12.8 GIS project of the Mappano municipality. ArcGISPro screenshot, taken from the GIS project developed by authors for the present research (both in 2D and 3D)

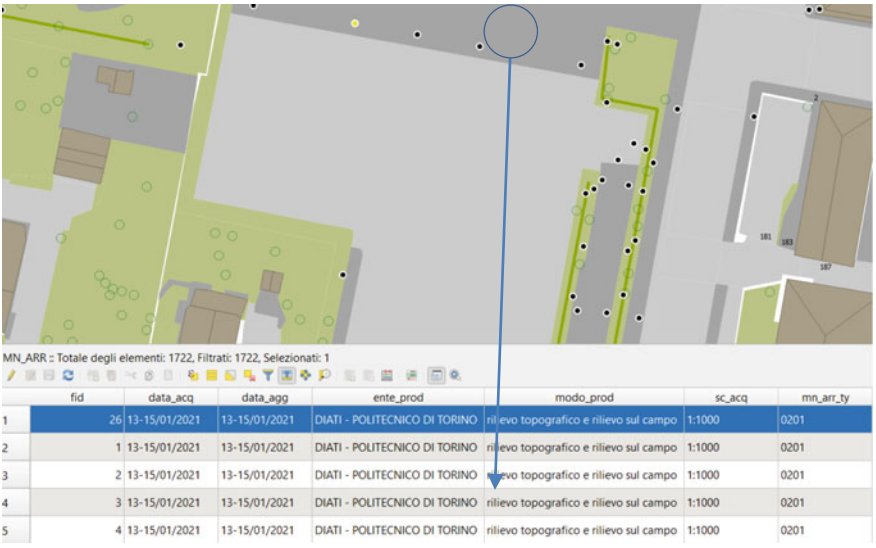


Fig. 12.9 Data query reports information of each geometry. ArcGISPro screenshot, taken from the GIS project developed by authors for the present research (both in 2D and 3D)

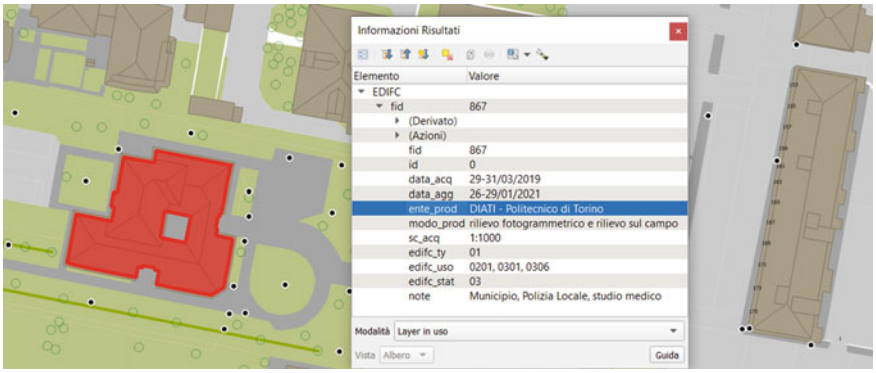


Fig. 12.10 Data query is possible also bypassing the attribute table using the "element information" function. In this case, one single window accounts for the values of one single element. ArcGISPro screenshot, taken from the GIS project developed by authors for the present research (both in 2D and 3D)



Fig. 12.11 3D views in the ESRI ArcGISPro platform of the municipality and urban furniture. ESRI 3D WebApp developed by the authors

12.5 Conclusions and Future Perspectives

The methodology here presented shows an innovative workflow. Thanks to the adoption of 3D metric survey techniques and data outputs, it is possible to help the definition of a high detailed and accurate digital cartography. The digital GIS twin shows the reality in 2D and 3D, representing all the city, land, and territory objects with their information stored into a standard-based geoDB.

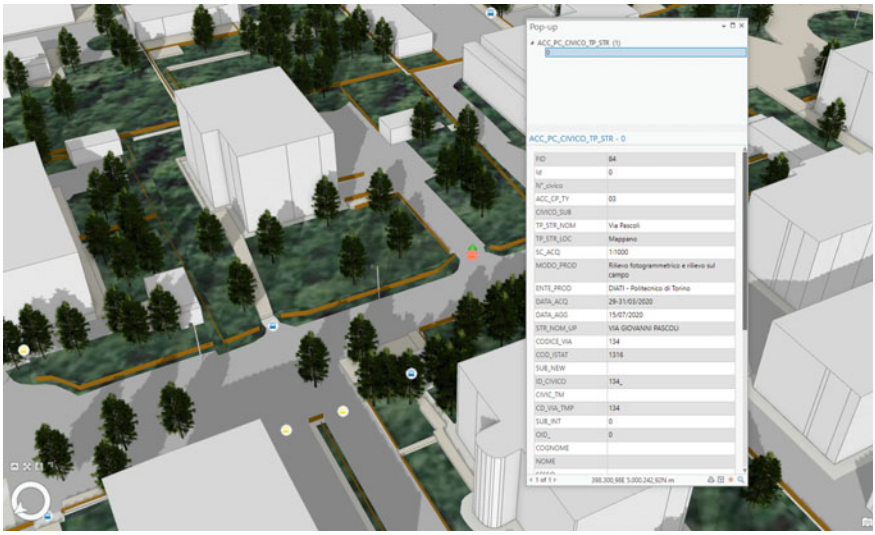


Fig. 12.12 3D GIS query of 3D objects with related information stored into the attribute table for the civic access. ESRI 3D WebApp developed by the authors

Future perspectives and works could include developing user-friendly tools and webGIS applications. It will be possible to query, measure, and analyze the spatial data of the municipality. Moreover, a WebApp map could be adopted by different stakeholders (such as citizens, technicians, public administrations) for various purposes (e.g., energy information of buildings, urban planning, etc.).

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