"Turin digital twins: initiatives and challenges"

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Volume 3

Earth Observation: current challenges and opportunities for environmental monitoring

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Preface

Since its foundation 1986, the Italian Society of Remote Sensing (Associazione Italiana di Telerilevamento – AIT) has been engaged in the dissemination of knowledge of remote sensing and Earth Observation (EO), with a particular effort in fostering scientific and operational consciousness about their exploitation.

AIT is specifically committed to:

(i) create a network connecting people from Research, Academia, hi-tech Companies, Administrative Institutions and Professionals involved in territory management and involved, or interested, in the development of Earth Observation methods, techniques and applications;

(ii) promote and coordinate initiatives to foster the exploitation and the technology transfer of remote sensing technologies, like the organization of congresses, conferences, workshops and thematic Summer/Winter schools;

(iii) promote the exchange of knowledge and cooperation among its members to "shorten" the technology transfer chain;

(iv) serve as the Italian national representative and reference player on matters pertaining to remote sensing and Earth observation-related issues for institutions, agencies, and companies, at the national and international levels;

(v) maintain an ongoing observation of technological and scientific advances, with particular attention to datasets, products and services from open, or commercial archives, to ensure a conscious and proper exploitation by users;

(vi) draft guidelines for the definition of possible standards about data quality, data processing, validation methods and accuracy metrics related to EO.

As AIT President for 2023-26, I specifically encouraged the Executive Board to focus on points (iv-vi), whose inner meaning have to be better specified.

Concerning point (iv), the 2023 AIT Congress, from which the contributions of this volume were derived, made evident the high expectations that Institutional players have in respect of the EO scientific community, especially related to the ongoing post-pandemic Italian National Plan for Recovery and Resilience (PNRR). The newly programmed Italian IRIDE Program for EO, supported by ASI and ESA, and the various territorial needs discussed along the congress sessions, definitely highlighted the strategic role of EO in this framework.

Discussions at the 2023 AIT Congress also highlighted we are experiencing a too-fast technology advancement, paradoxically slowing down the technology transfer. In fact, low-cost and user-friendly tools are continuously made available, providing users with the illusion of operational autonomy despite their domain knowledge is low or non-existent. This situation makes it extremely difficult to recognize applications based on a solid and proved EO-, or more generally, Geomatics-related knowledge, thus introducing a high degree of unreliability of results and deductions, especially when quantitative measures are required.

The EO and Geomatics scientific communities may have reacted too slowly and disjointedly to this phenomenon and now need to regain a new role in supporting a proper (reliable) technology transfer. I retain that the main reason about this failure relays on the new and reverted relationship linking the Applied Sciences with the technological market. Today, more than ever, technology often anticipates applied sciences requirements, proposing solutions to problems that have yet to be solved. The feeling is that scientists and scholars are currently being asked to go back along the supply chains to obtain proper technical specifications needed to consciously experience new devices (or products and services) and test them under the right conditions. In most of the cases, they are also called to find a suitable and valuable application that the newly proposed low-cost technology can be useful for.

A further, recent new challenge is coming from the unstoppable introduction of Artificial Intelligence in our life, including EO and Geomatic processes. The 2023 AIT Congress proved that the EO context is one of the mostly involved sectors from this point of view. But, is this really healthy for Science? Is this safe for a sustainable development? AIT opinion is that scientific societies and Academia are called to slow down this trend where an immediate exploitation of new continued technological advances has to come. A new paradigm has to be introduced where the ongoing "continuous" technology transfer has to move to a "discrete" one. This means that, at the application level, the technological (and algorithmic) level have to be fixed at a certain point and reconsidered/updated after a time step consistent with the time of: (i) engineering of processes; (ii) definition of controlled (by reference subjects) procedures for both data processing and validation of results; (iii) validation of global data/services at the local level. This would permit a proper ingestion and exploitation of the technological advances that we are ordinarily stimulated about, and a proper development of users' consciousness needed to prepare a more effective advance in the next evolution step. AIT, under my leadership, supports a SLOW, but conscious, SCIENCE.

In this framework, AIT supports open and wide-ranging actions involving multiple players and scientific associations at national and international levels. Among these actions, one deals with the education/formation in EO with a special focus on the importance of consciousness of data and methods. In 2020, AIT has strongly supported the launch of the Italian National PhD Course in Earth Observation specifically designed with the main goal of training professional figures with transversal and integrated skills of Earth Observation and Geomatics, and specific application, administrative and legal skills, able to effectively support the wider exploitation and use of the EO programs and related services.

AIT, together with Stati Generali dell'Innovazione - SGI and AM/FM GIS, is supporting the Italian National Copernicus User Forum in collecting Geomatics-related needs from users and providing proper guidelines for conscious exploitation of the available technology and data. The goal is to build a unique solid entity having the scientific strength and the political weight of acting like the accredited interlocutor when a Geomatics-related need arises from institutions (but not only). it is AIT conviction that this would permit an immediate and unambiguous recognition from users of their reference speaker, when a geospatial information-related problem has to be faced. Additionally, this would trigger a virtuous process for even defining standards for data acquisition and processing able to recover a leading role for the Geomatics and EO community in the framework of a conscious and sustainable technology transfer process.

To achieve the above-mentioned goals, AIT operates through the following actions:

(i) it is presently a partner of the Italian National Copernicus User Forum;

(i) it is the reference scientific society of the European Journal of Remote Sensing, an open-access scholarly journal published by Taylor & Francis;

(ii) it is the reference scientific society of the European Journal of Remote Sensing, an open-access scholarly journal published by Taylor & Francis;

(iii) it is one of the 4 confederated scientific societies of ASITA, the Italian Confederation of the Scientific Associations for Territorial and Environmental Information, where EO integrates with the other branches of Geomatics at Italian national level;

(iv) since 2016 AIT started to propose and give its International thematic summer/winter schools mainly addressed to support the conscious exploitation of the Copernicus and ASI (Italian Space Agency) data, products and services;

(v) AIT organizes its Congress every two years. Selected and blinded reviewed contributions from the Congress are gathered and published in a Scopus and WoS indexed book Series named "Trends in Earth Observations (TEO)". These volumes are intended to present a snapshot of the state-of-the-art in several application fields and advice about potentialities and limits from the ongoing trends of EO technology transfer.

AIT President (2023-2026)
Enrico Borgogno Mondino

Contents

TURIN DIGITAL TWINS: INITIATIVES AND CHALLENGES

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KEY WORDS: Digital Twins, LiDAR, Photogrammetry, Smart Cities, Data Integration, 3D modeling.

ABSTRACT

The ability of the Digital Twins (DT) to provide value-added information simplistically has paved a completely new and broader path of opportunities in the field of Remote Sensing (RS) and digital 3D modeling. The presence of state-of-the-art RS techniques like LiDAR, SLAM, close-range photogrammetry, aerial photogrammetry, and their possible integration have even broadened the horizons and scopes for the creation and update of DT. In addition to 3D modelling, DT features the fourth dimension, time, which itself alters the data and the associated semantic information. DT enables the end users with a simplistic browsable and interactive web environment to analyze the past, present, and future of urban dynamics. Urban DT represents the virtual picture of a complex and dynamic physical world with a variety of applications in mobility, planning, energy, and many others. In this contribution, we focus on the ongoing progress and initiative in the project of creating the DT for the city of Turin Italy and deriving products from it. The DT project is aimed at the extraction of the built environment features, land use data, road network, and signs along with the update of the model with time.

1. INTRODUCTION

The concept of Digital Twin (DT) has been developed in the last years as part of the more general discourse on smart cities, with the aim of providing a physical infrastructure, data, information and procedures for the management of complex anthropogenic systems. The traditional association between DT and smart city derives from the ability of the former to analyze big data, provide services and applications and guarantee continuous monitoring, But Digital Twins are way more than just smart cities built in 3D, as they incorporate time as a variable that modify data and semantic information.

There are several applications of urban DT. Representing the virtual simulation of a complex dynamic reality, it can be used efficiently in various fields, for instance: energy, environment, mobility, spatial planning, emergency management and security. A DT can be understood as a bridge between physical reality and the virtual world i.e., a digital replica of physical objects and systems in the virtual world with the inclusion of sensors, smart Internet of Things (IoT) technology, Artificial Intelligence (AI) and dynamic simulations (Lehtola et al., 2022; Lu et al., 2020). In the field of Urban Planning, 3D models for DT are employed at multiple scales ranging from a single building to a regional scale.

The necessity to analyze urban dynamics and evaluate them beforehand in order to maximize the effectiveness and influence of new projects is what drives the urbanistic application of this instrument. Furthermore, DT can become an incredibly useful tools for public administration. In the framework of the SDG 11 - Make cities inclusive, safe, resilient and sustainable, in fact, developing a city-DT means not only adopting the principles of security, sustainability, and equity that future urban policies should pursue, but also becoming aware of the climate-altering impacts due to the increasing anthropic pressure on the city–landscape–inhabitant system (Shahat et al., 2021). The data sources for a DT can be satellite images, RGB images, point clouds, and hybrid 3D modelling methods. (Ying et al., 2023). For the image-based DT creation, most applications use the stereo-images based 3D reconstruction providing the detailed geoinformation with a larger coverage (Rothermel et al., 2020). As for point cloud dataset, they can accurately collect high-resolution 3D information of the ground features both in small and large scale urban scenes. Moreover, point cloud provides abundant 3D data and represents the vertical dimension straightforwardly i.e., building heights and surface occlusions from trees and buildings are represented well. The point cloud-based DT are focused on the building reconstruction in boundary classification and feature extraction as point data is enriched with semantic labels (roof, door, window, openings, etc.) (Albano, 2019; dos Santos et al., 2020; Erener et al., 2018) They provide height information and depict the building outline accurately. This adds significant value to DT visualization and semantic information input (Gevaert et al., 2017).

Another possibility for the creation of a DT involves hybrid data sources like 3D city models, 3D GIS, BIM-GIS and a few others. A 3D city DT includes information about the geometry, structure and covering data of numerous morphological aspects, infrastructure, vegetation, and buildings (Julin et al., 2018). The applications of the 3D city DT encompass anything from energy applications to urban spatio-temporal change detection and noise mapping (Zhao et al., 2017; Zięba-Kulawik et al., 2020; Zirak et al., 2020). For instance, low level of Details (LoD) concentrates on extracting large-scale building information (such as volume, height, and density), but high LoD examines nuanced 3D influence, which may be overlooked due to poor data resolution (for example, trees may cast shadows on houses on low-store levels). In addition, the 3D visualization breaks the 2D barrier, which is advantageous for various real estate stakeholders (Biljecki et al., 2016) Figure 1 illustrates the different applications and use-cases of a Digital Twin of a smart city.

Taking into consideration what stated above, the present paper intends to present some first results of the on-going project of creation of the Turin Digital Twin by the SDG11Lab in the DIST Department of the Politecnico di Torino. In the next lines it will be explained in detail the process of acquisition and

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processing of the city-level data used to create the 3D model for the DT. The objective of this contribution is to propose a method for data acquisition which enrich the quality of the final 3D model, thanks to the combined use of Lidar and image data. The proposed outcomes of the Turin DT project are an easily accessible and browsable digital ecosystem that describes the behavior of the real world and its evolution over time as well as the effects of future urban developments.

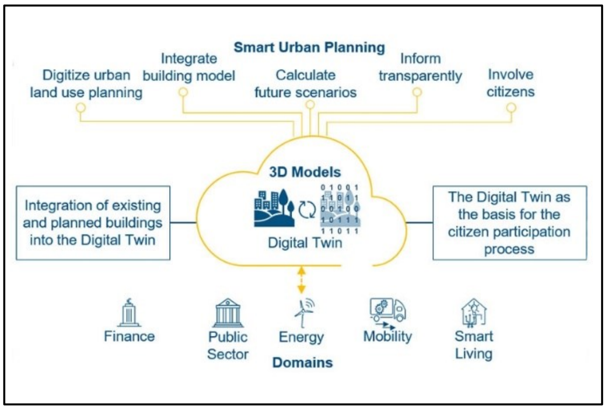


Figure 1: Urban Digital Twins for a smart city (Biljecki et al., 2016)

One of the main objectives of this work is to equip the public administration with a privileged tool to plan the future of the city and to manage past, present and future information at the same time.
First step to achieve these objectives is the construction of a digital model, integrating different sources, and the realization of a virtual environment where it is possible to visualize and to analyze different kind of data. Another goal is represented by the extraction of the built environment features, like land use data, road network, public infrastructure, buildings and green areas. Compared to a static 3D model, this application allows to reduce time for simulation and testing and opens the way to real time experience. Another end goal of the Turin DT project is the update of the model over time, , with a planned acquisition plan with different kind of sensors. This is necessary for the digital environment to maintain consistency over time and, at the same time, to bring the attention to a multitemporal and multiscale approach.

2. PRODUCTION OF DT

To build up this digital environment we analyzed a 3d web platforms that reflect an ever greater interest to Open Source (OS) software, interoperability and collaboration standard, in order to work in openness ecosystem. The next paragraph will explain the methodology of acquisition and processing of the city-level data that were used to create the 3D model for the Turin Digital Twin.

2.1 Data collection and study site

Turin is the third-largest city of Italy located in the North of Italy and is home to numerous UNESCO heritage structures. The location of the city of Turin is shown below in Figure 2. The dataset used to model the Turin DT is acquired on January 28-29, 2022, using the new Leica City Mapper-2 (Figure 3), a hybrid digital sensor onboard an aircraft and is composed by optical images as well as LiDAR point cloud. Figure 4 below shows one of the captures from the data acquisition phase in Turin.

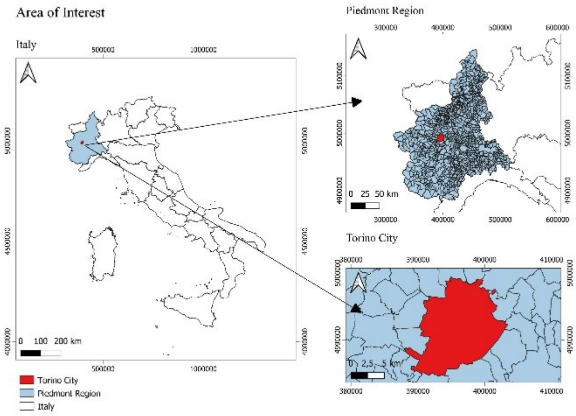


Figure 2: Location of the city of Turin

Figure 3: Data acquisition for Turin DT project with Leica CityMapper-2

Figure 4: Dataset acquisition systems and acquisition schema

For the optical imagery data 20.291 images were acquired over the city of Turin at a flying altitude of around 1 km. For every capture location, one Nadir and four oblique images were acquired, as it is shown in the data acquisition schema in Figure 3. The photogrammetric takens was characterized by a GSD of 5 cm, 60% of lateral images overlapping and 80% of longitudinal images overlapping. Moreover, the sensor is equipped with two different cameras: the Camera NIR Lens 71 for nadir and multispectral acquisition and the Camera RGB Lens 112/145 for oblique acquisition. The scheme of acquisition was based on a traditional grid with nadir and oblique taken. The LiDAR data was collected simultaneously to the images, with a point density of 30-40 m^2. with an acquisition angle of 20°. This system is characterized by a conical scan pattern that allows vertical surfaces in the resulting point cloud in all direction.

2.2 Data management and data processing

The optical imagery and LiDAR data with initial orientations and trajectories were processed with Agisoft Metashape and nFrames SURE to derive classified dense point clouds, 3D mesh, precise and detailed orthophoto, DTM and DSM for the city of Turin. The use of combined dataset aims to improve the quality of the final model, as for instance the use of oblique images and LiDAR system represent an advantage for the modelling of vertical surface or provide additional information like the intensity, useful for point classification (Figure 5). In fact, while with the image data the classification regards only the land-use and land-cover visible on the images, with the LiDAR data we can classify the ground, the vegetation and the buildings. Furthermore, a complementary benefit of using the LiDAR – which is an active sensor – in combination with image data is the possibility to compensate the necessity of the sunlight with the ability to acquire in the shadows and under the vegetation.

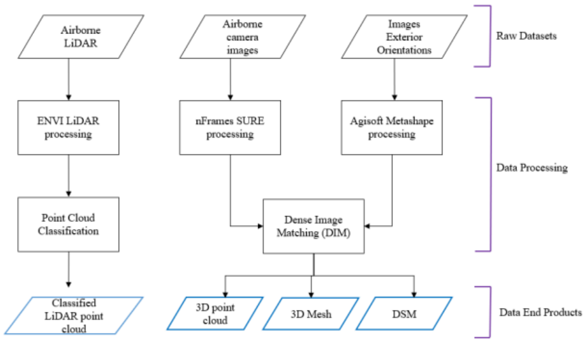


Figure 5: General Data Processing Methodology

Moreover, for 3D mesh the combining of LiDAR and image it's essential because one is used during the geometrical modelling end the other to texturing the 3D model.
The processing phase on nFrames Sure (Figure 6) combine LiDAR data and image data, this software offers the possibility to use LiDAR data to improve the 2.5D and 3D product. The LiDAR point clouds is useful where the geometry of the surface is difficult to reconstruct only from the images, in particular where the density of the city is very high or where the images is affected by shadow areas or occlusion. The following scheme shows the nFrames workflow.

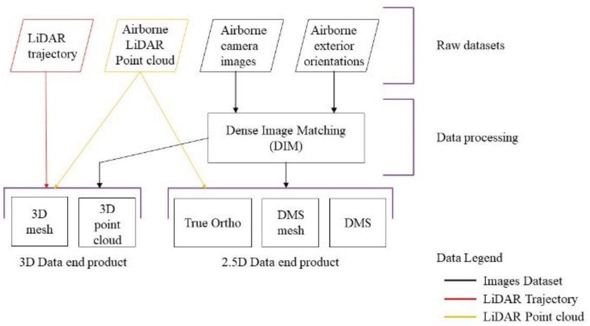
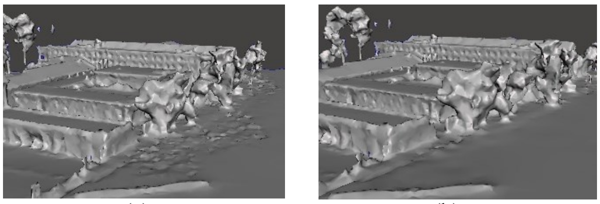


Figure 6: nFrames Sure workflow

The integration of the photogrammetric data with a LiDAR data, as shown in the figure 4, took place during the processing phase, so it is important that the initial data already match. The first step is called Dense Image Matching (DIM), and regard only the images. In this phase the images and the relative orientations were processed in order to obtain a 2.5D output.

After the DIM, LiDAR data are used only to reach a 3D output, like 3D mesh and 3D point cloud, and to enrichment the True Ortho.
Adopting LiDAR point cloud as a complement to the image data, the final 3D model result more complete and geometrically improved, as it allows to correct typical photogrammetric errors, during surface reconstruction phase. The following images show the difference between an image-based model and an integrated model in a zone afflicted by a shadow due to trees foliage.



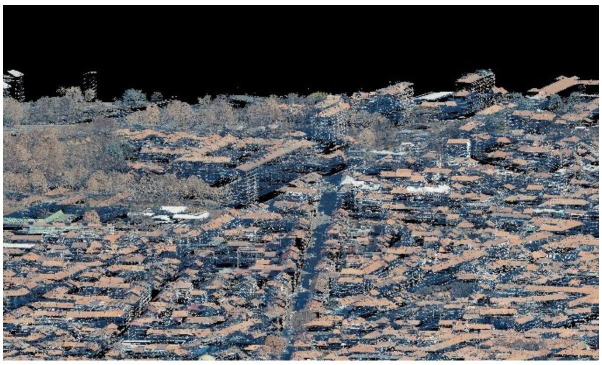
(a) (b)

Figure 7: Difference between (a) image-based model and (b) integrated model

The data were georeferred using the initial trajectory of the flight. The Leica City Mapper-2 is equipped with a multi-frequency and multi-constellation GNSS (Global Navigation Satellite System) receiver and IMU (Inertial Measurement Unit) gyro and accelerometer measurements. The absolutely accuracy of GNSS positioning with the stability of IMU generate a 3D navigation solution, used to georeferencing the data.

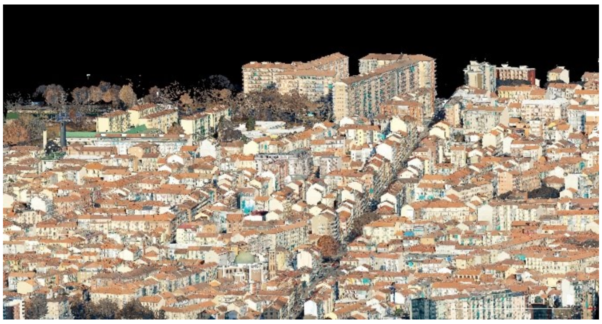
2.3 The 3D mesh model

The 3D model developed in the first phase of this work represents the base for future application of the Digital Twin.
Thanks to the synergy and integration of different technologies, the previous stages allow to obtain a metrically correct model of the city, which will be useful to analyze and describe all the different feature of the urban environment. For instance, with the 2.5D DSM is possible to establish the high of the building and to extract the topography features, while the 3D Point cloud is used to classify the points in different class, like building and roof shapes, high and low vegetation, ground and road infrastructures. Moreover, the 3D model can be used for visualization and dissemination application on the web. All these applications can be translated into virtual layers that describe the city of Turin and that can be enriched by semantic content.

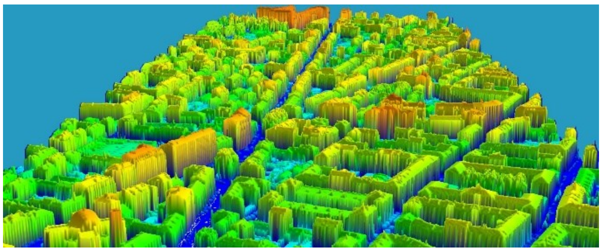


(a)

(b)



(c)



(d)

Figure 8: Processed Data Products (a) LiDAR point cloud (b) 3D point cloud from Photogrammetry (c) 3D mesh (d) DSM for the locality Corso Palermo in Turin

3. CHALLENGES AND OPPORTUNITIES

There are several challenges associated with this research project, related both to technical and semantic aspects. As for the technical aspect, the challenge consists in the processing of larger datasets or their cost-efficiency factor. Relating to the semantic aspects, there are issues concerning the rapid rate of growth and development of the city and the complexity of the solutions, which support the need for further research in the area of multitemporal updating of the model. Many are the solution that exist for the integration of 3D models from different sources for DT, but the key problem is still to have an operational and simplistic product that can be understood and implemented by the direct stakeholders. In this way the 3D model represents a key product which is at the base, in general, of DT.

Regarding the technical aspects, one of the challenges with 3D LiDAR and photogrammetry datasets is the requirement of stronger computational hardware for the processing. A workstation with moderately high computational strength is required for processing and visualization of 3D point cloud datasets from LiDAR and Photogrammetry. Also, when using airborne data along with ground based Close Range Photogrammetry (CRP), Terrestrial Laser Scanning (TLS) and SLAM, wide attention must be made to georeferencing errors that come from the integration of different data sources.

Another key challenge with a city level DT is the solution for sharing with the stakeholders. An open-source solutions would be optimal but it provides a limited storage capacity.

Not only challenges but also great opportunity come with this project. The development of an urban 3D model in an Open-Source system in fact could represent the chance for public administrations to have access to interactive analysis and simulation on the urban environment. Furthermore, particular attention can be paid to model update with collaborative and crowdsourcing solutions, with the perspective to develop a community able to use and update the 3D model.

Further experimentations will regard data integration for improvement of the model: not only ground-based Terrestrial Laser Scanning (TLS) data with aerial photogrammetry point cloud, but also crowdsourced data.

4. CONCLUSION AND FUTURE PERSPECTIVE

The proposed outcomes of the Turin DT project are an easily accessible and browsable digital ecosystem that describes the behavior of the real world and its evolution over time and an environment simulating the effects of future urban developments on the digital copy of reality.

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