BUILD-IT2023 Workshop

3D feature recognition for the assessment of buildings’ energy efficiency

Daniela Cabiddu, Michela Mortara, **Chiara Romanengo**, Andreas Scalas

CNR – IMATI Genova

Istituto di Matematica Applicata e Tecnologie Informatiche "E. Magenes"

imati

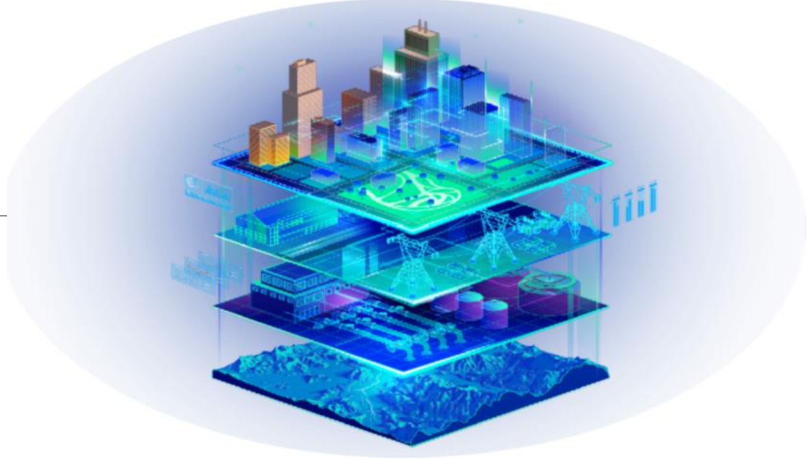
Alice Bellazzi, Lorenzo Belussi, Ludovico Danza, Matteo Ghellere

CNR – ITC Milano

Istituto per le tecnologie della costruzione

ITC

Motivation



The real assets, procedures, systems, and subsystems of a city can be virtually represented through an **urban digital twin (DT)**, which integrates heterogeneous data to learn and evolve with the physical city, offering support to monitor the current status and predict possible future scenarios

Accompanying salient urban elements with all kinds of information related to them allows reasoning on multiple levels and inferring qualitative or quantitative attributes about the state of the element

↓

We focus on the **geometric layer**, which represents the morphology and physical features of the city, and its integration with the **energy consumption layer** to compute and map the building **energy efficiency**, e.g., to support urban planning

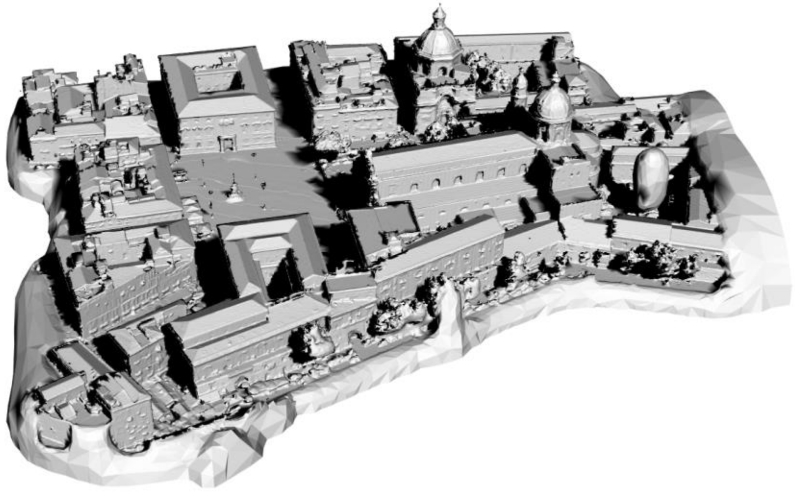
Castelli G., et al. *Urban intelligence: A modular, fully integrated, and evolving model for cities digital twinning*. In Proceedings of the 2019 IEEE 16th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT), Charlotte, NC, USA, 6–9 October 2019; pp. 33–37

Motivation

- The **energy efficiency assessment** of the built heritage within the DT passes through the interaction between the **geometric layer** (3D model of the city) and the body of knowledge related to the energetic analysis of the built heritage, that is, the **energy consumption layer**
- The integration concretely happens through the mechanism of **annotation**
- The **energy layer** defines the **properties of elements** that concur to the computation of efficiency (e.g., building exposed surface, roof orientation) and interrogates the geometric layer to get these properties
- The **geometric layer** consists of a 3D model, that is a triangle mesh representation of buildings
- The geometric layer runs geometry analysis algorithms to automatically compute these dimensions

Geometric layer

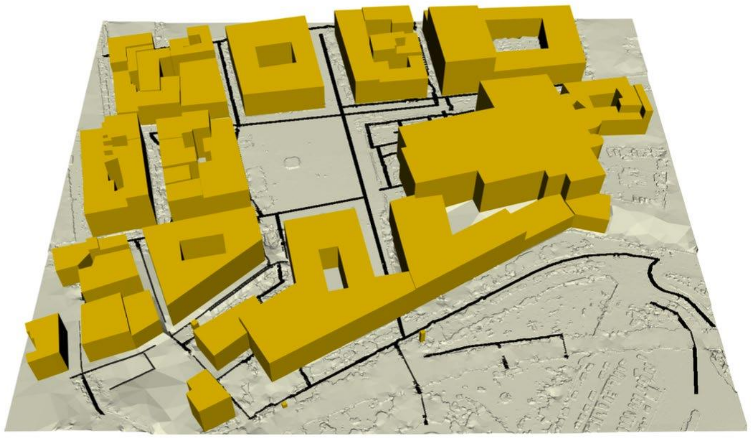
- The **3D model** is generated either by reconstruction from hi-res point clouds produced by specific acquisition surveys, or from low-res data available at national level[2]
- The **buildings** are selected and **annotated** within the undifferentiated triangles of the mesh, using information about the building footprints (e.g., from OpenStreetMap or from cadastral documents)
- For the sake of **energy assessment**, we focus on the following **attributes**:
    - exposed surface of buildings
    - volume of buildings
    - surface, orientation and slope of roof pitches
    - window areas



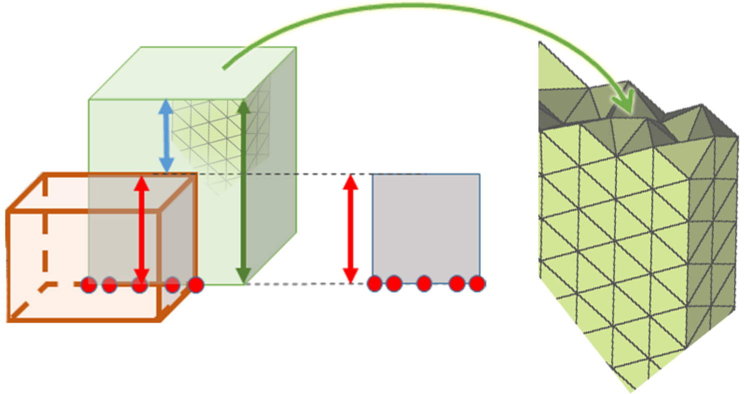
Scalas A., Cabiddu D., Mortara M., Spagnuolo M., *Potential of the geometric layer in urban digital twins*, ISPRS International Journal of Geo-Information, 11 (6), 343, (2022)

Geometric layer - attributes

- Concerning the **exposed surface of buildings**, the external area of a single building can be computed straightforwardly by summing up the triangle area annotated as that building



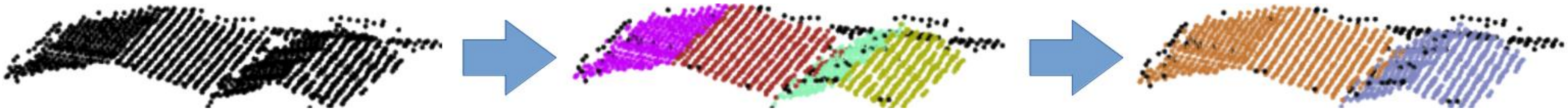
- Regarding the **volume computation**, it is sufficient to close each building's annotated portion and create a tetrahedron for each triangle by connecting each of its vertices to the origin and summing up the corresponding signed volume[3]



Zhang C., Chen T., *Efficient feature extraction for 2D/3D objects in mesh representation*, Proceedings 2001 International Conference on Image Processing (Cat. No.01CH37205), vol. 3, pp. 935–938 vol.3, (2001)

Geometric layer - attributes

- To detect **roof parts** for each building, we apply a feature-recognition method to detect geometric primitives (planes, cylinders, cones, spheres, tori) associating geometric parameters. In the energy analysis scenario, it recognises mesh vertices composing the same roof pitch and provides the fitting plane normal direction, computing the **surface, orientation and slope of roofs**



- **Windows** are annotated manually or by images

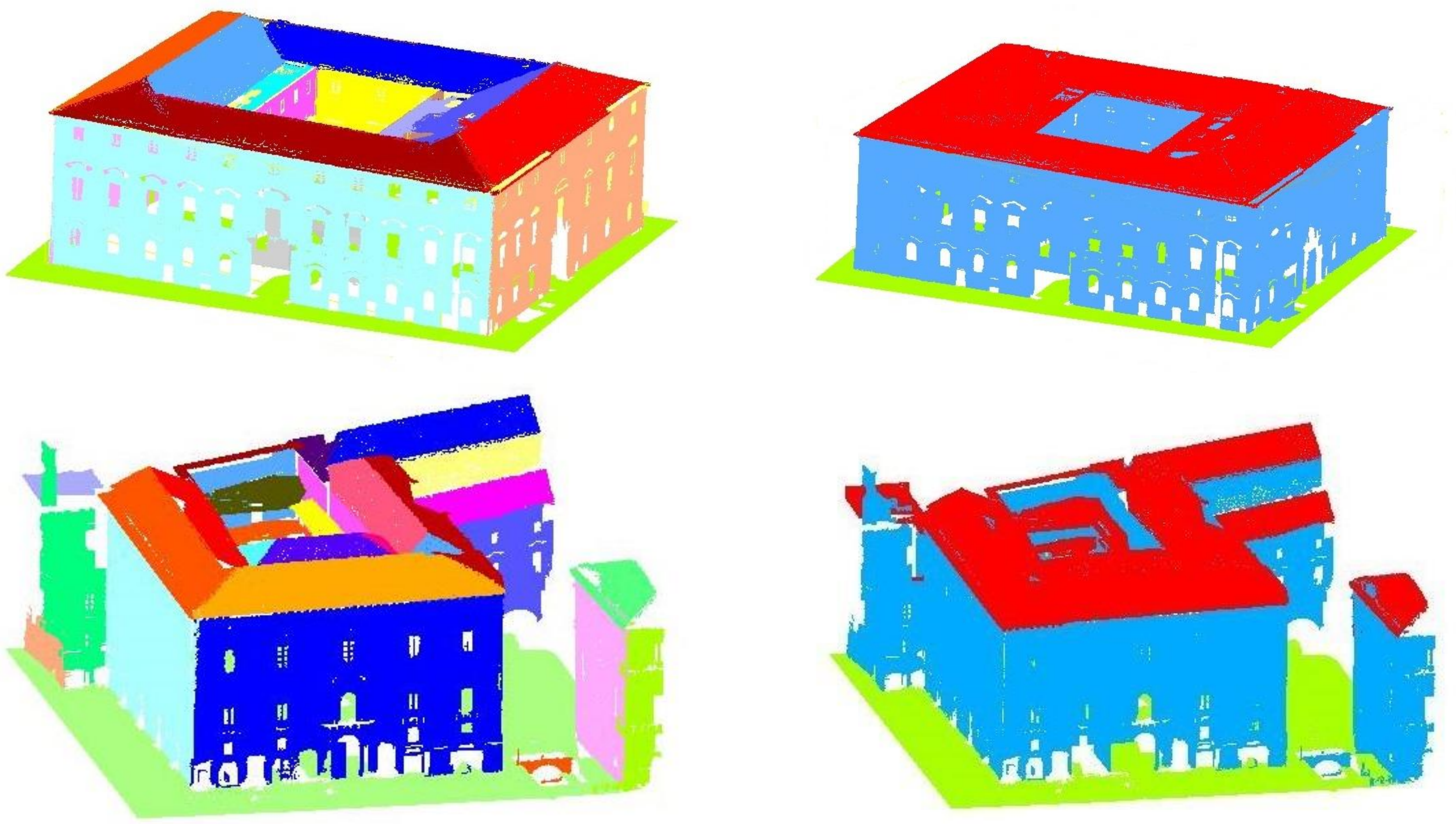
Romanengo C., Raffo A., Biasotti S., Falcidieno B., *Recognizing geometric primitives in 3D point clouds of mechanical CAD objects*, Computer-Aided Design, 157, 103479, (2023)

Energy layer

- The energy layer aggregates the heterogeneous knowledge of the **built heritage** that is necessary for the energy efficiency assessment[1]
- It considers both general data and data derived from building and urban morphology
  - **general data** refers to year/period of construction and the building's intended use
  - **data derived from building** is the S/V ratio, the urban context surrounding the building and the incidence of window area on the external envelope of the building
- The association of **historical data** allows deriving for each building HVAC (**Heating, Ventilation and Air Conditioning**) and **lighting systems data** as layout, yearly hours of operation, system efficiency, energy carrier used and building envelope thermal properties

Ghellere M., Belussi L., Barozzi B., Bellazzi A., Danza L., Devitofrancesco A., Salamone F., *Energy and environmental assessment of urban areas: an integrated approach for urban planning*, Building Simulation 2021, vol. 17, pp. 77–85, IBPSA, (2021)

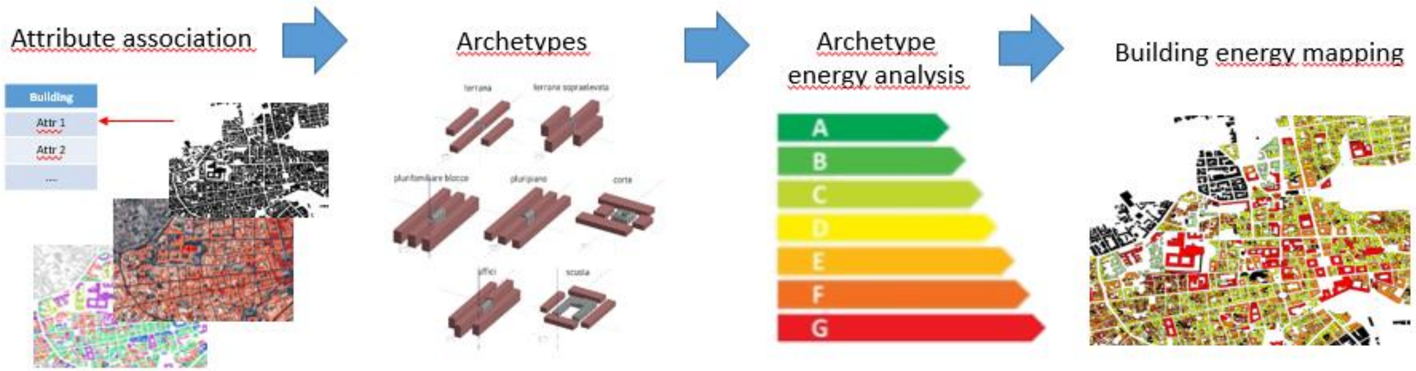
Results (Catania case study)



Romanengo C., Cabiddu D., Pittaluga S., Mortara M., *Semantic segmentation of high-resolution point clouds representing urban contexts*, Smart Tools and Applications in Graphics 2023, accepted

Results

- Thanks to the annotated data, it is possible to estimate the primary energy need (PE) and of the CO2 emissions (MCO2) produced per square meter of building archetype floor through building energy simulation (BES)



- A final additional semantic association links each building of the DT to the correspondent archetype, inheriting PE and MCO2 values and allowing their punctual mapping over the city territory

- From the integration of this information at a higher scale, an estimation of the energy consumption of all buildings, or in a portion of it, in the municipal area can be generated to assess potential energy savings as a result of urban regeneration management policies

Conclusions

- The proposed methodology provides the DT of the built heritage and a mapping tool for the energy efficiency of the city buildings
- The first goal of the DT is to carry out an analysis of the peculiarities of the built fabric from the energy consumption point of view, starting from the 3D model
- The second goal of the DT is to support public authorities in evaluating the impact of land transformation decisions and driving future urban policies
- The accuracy of the computed quantitative properties depends on the resolution of the input point cloud
- The current research is seeking to recognise and annotate more features, such as windows, as automatically as possible

Reference Publications

- *Ghellere M., Belussi L., Barozzi B., Bellazzi A., Danza L., Devitofrancesco A., Salamone F.,* **Energy and environmental assessment of urban areas: an integrated approach for urban planning**, Building Simulation 2021, vol. 17, pp. 77–85, IBPSA, (2021)
- *Scalas A., Cabiddu D., Mortara M., Spagnuolo M.,* ***Potential of the geometric layer in urban digital twins***, ISPRS International Journal of Geo-Information, 11 (6), 343, (2022)
- *Zhang C., Chen T.,* **Efficient feature extraction for 2D/3D objects in mesh representation,** Proceedings 2001 International Conference on Image Processing (Cat. No.01CH37205), vol. 3, pp. 935–938 vol.3, (2001)
- *Romanengo C., Raffo A., Biasotti S., Falcidieno B.,* **Recognizing geometric primitives in 3D point clouds of mechanical CAD objects**, Computer-Aided Design, 157, 103479, (2023)
- *Castelli G., et al.* **Urban intelligence: A modular, fully integrated, and evolving model for cities digital twinning,** In Proceedings of the 2019 IEEE 16th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT), Charlotte, NC, USA, 6–9 October 2019; pp. 33–37
- *Romanengo C., Cabiddu D., Pittaluga S., Mortara M.,* **Semantic segmentation of high-resolution point clouds representing urban contexts**, Smart Tools and Applications in Graphics 2023, accepted

Thank you for the attention!

This work has been supported by the project "Programma Operativo Complementare Città Metropolitane 2014-2020 - Ambito II - Progetti Pilota - Progetto: Urban Intelligence Science Hub for City Network". We wish to thank the city and municipality of Catania, direct beneficiary of project outcomes, for the support during the 3D survey.