3D FEATURE RECOGNITION FOR THE ASSESSMENT OF BUILDINGS' ENERGY EFFICIENCY

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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. A DT of a city can be organized into layers, which represent specific facets of the city and cooperate to address specific issues. In this work, we present an application scenario in which a geometric layer, representing the 3D morphology of the urban environment, cooperates with an energy consumption layer, providing knowledge of the peculiarities of the building urban area and in particular of the built fabric, to assess their impact in terms of energy efficiency. The analysis of the urban geometries provides quantitative measures as useful input, for instance, to define heat leakage.

Keywords: *urban intelligence*, *geometric layer*, *semantic enrichment*, *energy efficiency*, *urban mapping*

1. Introduction

The geometric representation of the city's physical space, through the enrichment of relevant elements with heterogeneous data, becomes the common place where the integration of different information, "views", or topics actually takes place. Accompanying salient urban elements (single building, block, street, etc.) 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. In this work, we focus on the *geometric layer*, which represents the morphology and physical features (either built or natural) 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.

2. Methodology

The energy efficiency assessment of the built heritage within the DT passes through the interaction between the geometric layer -the 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 runs geometry analysis algorithms to automatically compute these dimensions.

The energy consumption layer aggregates the heterogeneous knowledge of the built heritage that is necessary for the energy efficiency assessment[1]. Building knowledge comes from different sources as periodic censuses, historical and thematic urban maps and other previous studies. The information layer considers both general data and data derived from building and urban morphology. In the first case, general data refers to year/period of construction and the building's intended use, while the latter is the S/V ratio, which indicates how large the surface area S (such as wall, ceiling, roof and window surface areas) is in relation to the building volume V, the urban context surrounding the building and the incidence of window area on the external envelope of the building.

The geometric layer consists of a 3D model - a triangle mesh representation of buildings, generated either by reconstruction from hi-res point clouds produced by specific acquisition surveys, or from low-res data available at national level [2]. In either case, the salient entities, e.g., 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). Hence, we compute specific geometric attributes for a class of elements. For the sake of energy assessment, we focus on the following attributes: (i) exposed surface of buildings; (ii) volume of buildings; (iii) surface, orientation and slope of roof pitches; (iv) window areas.

Concerning the exposed surface, the external area of a single building can be computed straightforwardly by summing up the triangle area annotated as that building. Note that adjacent buildings share walls to some extent and this is an important feature for assessing buildings' heat loss. Therefore, the adjacency relation among buildings can be easily obtained by detecting common vertices in building footprints. The approximated shared surface can be computed as the distance between common vertices pairs multiplied by the difference in the buildings' height; then, the total surface minus the shared surface provides the estimated of exposed surface. Regarding the volume computation, it is sufficient to close each building's annotated portion and apply volume computation as defined in [3] (i.e. creating a tetrahedron for each triangle by connecting each of its vertices to the origin and summing up the corresponding *signed volume*). We refer to figure 1 for a depiction of city geometric models with annotations and characterization.

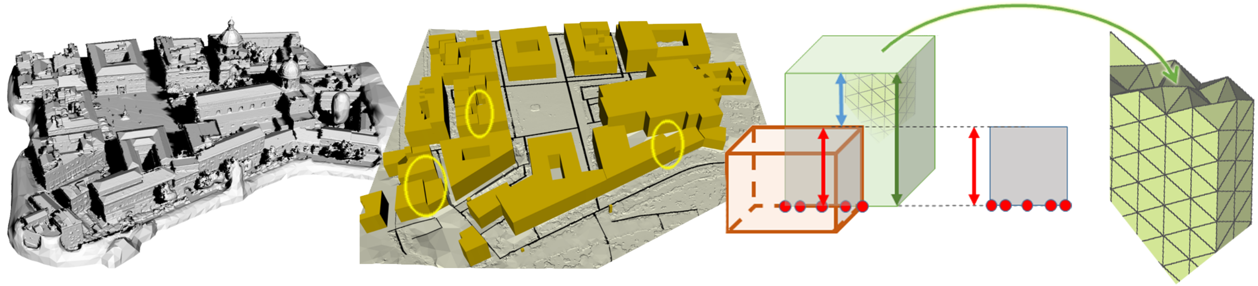

Figure 1: 3D models of Piazza Duomo in Catania, Italy. From left to right: detailed reconstruction from hi-res data; block reconstruction from low-res data and semantic annotation of buildings (in yellow) and streets (black); estimated shared surface between adjacent buildings; volume computation on the corresponding tetrahedral mesh.

To detect roof parts for each building, we extended the feature-recognition method in [4] to the urban context. This approach is designed to recognise geometric primitives (planes, cylinders, cones, spheres, tori) and their associated parameters in point clouds representing CAD objects; it can be naturally extended to the urban context, since the main urban elements can be identified by such types of surfaces. It can be also used to find relationships among the recognised parts (see Figure 2), and it is robust to noise and outliers in the geometric data. In the energy analysis scenario, it recognises mesh vertices composing the same roof pitch and provides the fitting plane normal direction. Then, the computation of roof surface, orientation and slope is straightforward. The same approach cannot be applied to windows, as the window plane mainly coincides with the external walls. Thus, windows are annotated manually or by images.

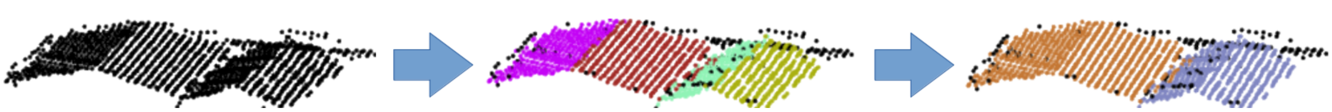

Figure 2: Feature-recognition method applied to urban context. (left) part of the point cloud representing a city. (center) the points that belong to different recognised planes are highlighted in several colours. (right) the geometric parameters associated with the recognised planes can be used to determine if two planes belong to the same roof.

3. Results

While the geometric layer can provide information such as the extent of dispersing surfaces, air-conditioned volume, type of roof, number of pitches, and orientation/exposure, 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.

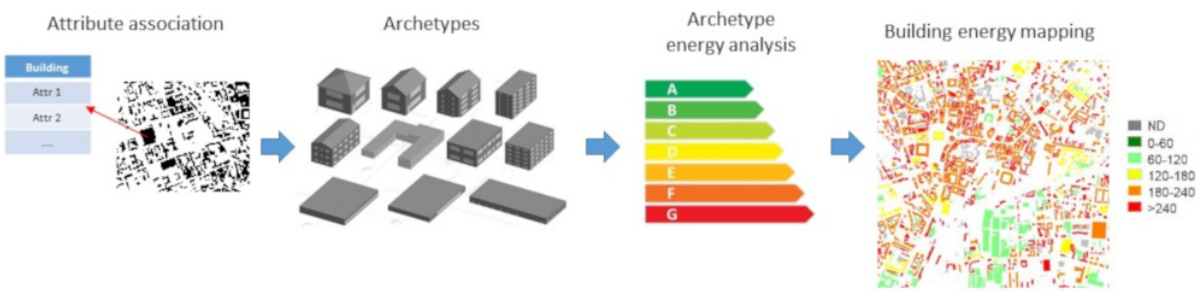

Figure 3: Building energy efficiency analysis after the semantic enrichment.

Considering the unique thermal characteristics of each real building and the number of buildings belonging to the city, some simplifications and a minimum level of energy calculation uncertainty are necessary for mapping purposes. On the basis of morphological and non-morphological annotated data, a set of building archetypes representing the building stock is defined. With the previous data, the estimation of the primary energy need (PE) and of the CO2 emissions (MCO2) produced per square meter of building archetype floor area is assessed 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.

4. Conclusions

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

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