Artificial Intelligence for the analysis of Cultural Heritage point clouds

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Motivation

In Digital Cultural Heritage (DCH) domain, the ever-increasing availability of three-dimensional data, deriving from LiDAR (Light Detection And Ranging), MMSs (Mobile Mapping Systems) or UAVs (Unmanned Aerial Vehicles) platforms, provides the opportunity to rapidly generate detailed 3D scenes to support conservation, restoration, safeguarding and maintenance as well as activities of built heritage. Historical Building Information Modeling (HBIM) deals with the management of these manifold types of heritage data that allows to enrich the geometrical representation of the asset, thus creating a complete informative data collector [1], [2].

Achieving this result is not trivial, as HBIM models are generally based on scan-to-BIM processes that enable the generation of parametric 3D model from the point clouds [3]. These processes, although very reliable since they are done manually by domain experts, introduce two obstacles: firstly, they are very time-consuming, and then they rely on a large amount of data derived from an uncountable amount of information to describe a parametric object.

The use of Artificial Intelligence (AI) techniques for the automatic recog- nition of architectural elements from point clouds can thus provide valuable support to expedite these processes. Moreover, Semantic segmentation of her- itage 3D data would help the community in better understanding and analysis of digital twins (digital twins), facilitate preservation operations, and support many other activities related to this field.

Related Work

To date, there are many research papers in which Point Clouds are used for the recognition and reconstruction of geometries related to BIM models [7], and first attempts to apply this methods to DCH have been proposed in recent years. However, these studies are still limited, even if, accord- ing to [9], these methods had great potential to this regard. Deep Learning (DL) techniques are suitably adopted for directly handling the raw data of point clouds. without an intermediate processing that allows a more regular representation. An example is the work of Malinverni et al. [5] that exploited PointNet++ [11] to semantically segment 3D point clouds of CH dataset.

Research Gap

The lack of benchmark for semantic segmentation of CH point clouds has hindered the development of automatic classification solutions in this field. Our heritage 3D data and point clouds represent complex geometric structures with uncommon classes, thus preventing the simple implementation of already available methods developed in other fields or for other types of data. Cultural assets are in fact characterized by complex geometries, different even within the same class and describable only with a high level of detail, making consequently much more arduous to apply DL strategies to this domain. A newly dataset was specifically collected to deal with CH data and manually labelled by domain experts: ArCH dataset [6]. It includes datasets and classification results for better comparisons and insights into the strengths and weaknesses of different machine and deep learning approaches for semantic segmentation of the heritage point cloud, as well as promoting a form of crowdsourcing to enrich the already annotated database.

Proposed Approach

The specific goal of this project was to demonstrate the effectiveness of a DL framework specialized in point clouds semantic seg- mentation to tackle with CH-related point clouds. Inspired by the great results obtained in [12], which introduced a module called EdgeConv, that constructs a local neighborhood graph and applies convolution-like operations and developed a new DL model named DGCNN (Dynamic Graph Convolutional Neural Network), dynamically updates the graph, changing the set of k-nearest neighbors of a point from layer to layer of the network, we have made extension of the previous work and exploited the novelties offered by the DGCNN. Thus in [9] we proposed a modified version of DGCNN by adding relevant features such as normal and HSV encoded color. This improved version aimed at facilitating the management of DCH assets that have complex geometries, extremely vari- able and defined with a high level of detail.

The lack of literature in this field is to be found in the need of a large scale well annotated dataset that limits the development of robust DL framework for processing CH point cloud data. This important issue prevents the research in this direction. In particular, classification and semantic segmentation is noticeably challenging in historical and classical architecture, due to the varieties and the complexity of CH goods, which make difficult the DNNs training. A first attempt to solve this obstacle is the use of Generative Networks (GANs) since their ability to generate novel suitable data as well as learning [10]. In CH field, encouraging results have also yielded by synthetic datasets as already done for urban point clouds [8].

Significance of Our Approach

This approach facilitates safeguard and cataloging operations (e.g., in case of disaster as earthquake or wars) and sup- port many other activities related to this sector. Moreover, we have started to pave the basis in the discussion on algorithmic decision-making (ADM) [4]. We considered fairness as one of the most prominent values in the Ethics and Artificial Intelligence (AI) debate and we have started to design an ethical framework specifically developed for CH domain.

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