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Automatic classification of urban ground elements from mobile laser scanning data

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ABSTRACT

Accessibility diagnosis of as-built urban environments is essential for path planning, especially in case of people with reduced mobility and it requires an in-depth knowledge of ground elements. In this paper, we present a new approach for automatically detect and classify urban ground elements from 3D point clouds. The methodology enables a high level of detail classification from the combination of geometric and topological information. The method starts by a planar segmentation followed by a refinement based on split and merge operations. Next, a feature analysis and a geometric decision tree are followed to classify regions in preliminary classes. Finally, adjacency is studied to verify and correct the preliminary classification based on a comparison with a topological graph library. The methodology is tested in four real complex case studies acquired with a Mobile Laser Scanner Device. In total, five classes are considered (roads, sidewalks, treads, risers and curbs). Results show a success rate of 97% in point classification, enough to analyse extensive urban areas from an accessibility point of view. The combination of topology and geometry improves a 10% to 20% the success rate obtained with only the use of geometry.

1. Introduction

The United Nations estimates that over 70% of the world's population will be living in towns and cities by 2050 [1]. A population increase implies a greater number of urban trips, and pedestrian displacements that make necessary a smart city use [2]. The smart city is a recent concept that integrates multiple information related to the city such as energy, construction, transport, services and resources. The first step to create a smart city is modelling the as-built environment [3]. 3D models are becoming essential to represent cities and the basis for storing and using the information of the as-built environment.

Laser scanning is a consolidated technology for the collection and analysis of three-dimensional data on the as-built status of large-scale civil infrastructures. Urban acquisitions with a mobile laser scanning (MLS) are faster than with terrestrial laser scanner (TLS) and resulting point clouds are obtained with good quality, much higher than with aerial laser scanning (ALS). Laser scanner also can be equipped in UAV providing more detailed information than common ALS [4] and giving a different point of view than MLS, but with less autonomy than both. However, point clouds are composed of massive and raw information that should be processed to extract the information that is useful for the applications they are intended to serve.

Although, intense efforts have been made to facilitate the automatic processing of 3D laser scanning data, the productive modelling of the complete as-built environment is still an unsolved issue. With regard to city modelling, most works focus in façade modelling from Terrestrial Laser Scanner [5,6] or roof reconstruction from Airborne Laser Scanner [7–9]. Other works are focused on modelling the city ground because it is the element that communicates all components in the city: metro station, bus stop, parking with buildings or gardens. Many times, it is supposed that every building is connected to each other without paying attention to the way itself. However, modelling ground urban elements is essential to understand a city and more specifically, it is of great interest for those people that present mobility impairments.

City accessibility is treated indirectly in works aiming to detect curbs for autonomous vehicles [10–14]. Curbs, and others small steps, are also important from an accessibility point of view. For instance, wheelchairs cannot navigate through curbs, acting as an architectural barrier. In this context, Serna and Marcotegui [15] contextualise their work on curbstones detection as a barrier identification from an accessibility point of view.

Actually, architectural barriers are an important problem in urban environments. Many places can only be accessible by stairs or steps, and mobility-impaired and elderly people have problems to access them. In

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this context, different initiatives are being developed to mark obstacles in urban zones [16]. In terms of regulations, the European Union aims to guarantee disabled people rights [17]. Furthermore, International organizations promote standards, such as the ISO-25142 [18], to eliminate architectural barriers and preserve measures in stairs, hallways and ramps and in their proximity.

The aim of this work is to develop an automatic methodology to detect and classify urban ground elements such as stairs, curbs, sidewalks and ramps from point clouds acquired with Mobile Laser Scanner. The methodology is based on segmentation followed by feature analysis and geometric classification in preliminary classes that are verified according to their topology from comparison with a topological graph dictionary. The methodology is tested in four real case studies.

This paper is organized as follows. Section 2 collects related work about urban element classification, topology and graphs. Section 3 deals with the methodology while Section 4 presents the results. Finally, Section 5 is devoted to conclude this work.

2. Related work

This section deals with the review of the recent literature on urban element classification, followed by a discussion about the use of topology and graphs to identify and reconstruct models.

2.1. Urban element classification

Urban reconstruction is mainly composed of three consecutive processes: segmentation, classification and reconstruction [19–22].

Segmentation is the process of dividing a point cloud or range image into a number of disjoint subsets [23,24]. In a classification, these subsets are sorted into classes. And in the reconstruction, the segmented and classified subsets are used to create a new representation of the scene. Segmentation and classification usually appear together and different approaches have been presented in the recent years due to the increasing availability of 3D point cloud data and respective acquisition systems [25].

Methodologies based on rasterizing point clouds are conventionally used to extract façades of urban environments. Hernández and Marcotegui [26] and Serna et al. [27] project points in 2D creating intensity images based on their height. Pixels with high intensity values correspond with vertical elements such as façades and trees. Morphological operations can be applied to improve the images and the position of the elements is finally extracted.

Aijazi et al. [28] present a method based on segmenting a point cloud in voxels. Then, the voxels are joined into super-voxels to form objects according to their attributes such as the geometrical centre, the mean of the RGB value of the constituting 3D points, etc. Finally, they are classified into buildings, roads, poles, cars and trees based on their local descriptors (surface normals, geometrical shape, barycentre, etc.). Another octree-based voxelized methodology to segment urban elements is introduced by Vo [29]. In this case, point clouds are converted to voxels and segmented according to their orientation.

Currently, machine learning is a very popular instrument to classify elements. Weinmann et al. [25] compare different number of neighborhoods, features, values and classifiers searching an optimal façades, ground and vegetation detection. This methodology gets good results in extensive point clouds, but it also needs big samples to train the machine learning and it is not exempt of some false positives.

More specifically related to urban floor classification, most of the existing literature is focused on curbs. Using vehicle trajectory, Wang et al. [13] detect salient points near to MLS trajectory and consider them as curbs. Others authors [10,12] design methods to work in real-time. They implement more sensors than a LIDAR, such as high-resolution cameras to use density, geometry information towards the detected curbs or other lateral obstacles such as barriers and walls.

Related to raster methods, Liu et al. [11] transform the point cloud in a local Digital Elevation Map (DEM) and search elevation gradient variation that correspond with curbs. Then, they extract curbs pixel to a new image where they apply Hough transform and RANSAC to extract lines of the curbs. In a similar study, Serna and Marcotegui [15] also use a raster image, but they interpolate it to create a new image without occlusions to enable the detection of curbs. They can be partially occluded by parked cars so it is necessary to reconnect them. This approach is very important because they study accessibility of an extensive area, with independence of occlusions during the acquisition.

Other ground elements very important for accessibility diagnosis and navigation planning are stairs and ramps. Most literature involving addressing stairs and ramps detection is related to indoor environments. Oßwald et al. [30] and Luo et al. [31] detect vertical and horizontal planes that forming stairs and extract their geometric parameters. Both papers use humanoid robots climbing and scanning stairs. This method is applied to point clouds in which stairs are isolated from the rest of the environment. Sanchez and Zakhor [32] detect stairs using RANSAC from inclined planes segmented with PCA. After, they extract six parameters (number of steps, reference point, tread depth, riser height, step width and azimuth) to create a model from the stair.

Schnabel et al. [33] search in point clouds graphs with geometry and topology information from their previous designed models to recognize basic elements like stairways, dormers and columns. This study illustrates the potential of the graphs and their negative part: isomorphism problem. This is the most restrictive limitation in comparing graphs, which consists in determining which graphs are equivalent or if a graph A can be included into a larger graph B. It is a problem called hard-NP [34] and their unique solution is an exhaustive search, with their cost in computing time and resources.

2.2. Topology and graphs

Topology studies proximity and consistence relations between different elements [35,36]. These relations can be represented through graphs. Although topology relations and graphs have also been used in few applications, like Schnabel et al. [33], who employ graphs to classify different elements independently of indoor or outdoor environments, for example, columns are connected at both ends, and dormers on roofs or stairs have specific query graphs. Most of applications deal with roof reconstruction, modelling and network analysis, but not classifying [37,38].

Sampath and Shan [39] extract roof topology from isolated roofs applying Voronoi diagram and define Voronoi neighbourhood to set adjacency relation between points. With these relations, they cluster the points to segment the cloud into roof planes. Elberink and Vosselman [7] add a 2D building map to cluster roof buildings and extract relations of roof planes. Bizjak [40] uses K-neighbourhood with its normal to detect roofs and bounding boxes of roof sides to calculate adjacencies.

Taillandier [41] combines cadastral maps and aerial images to create 3D graphs with normal vectors of roof shapes and he uses them to model building. These basic graphs, called roof-topology graphs will be used and extended for many authors: Elberink and Vosselman [7], Perera et al. [8], Xiong et al. [42] and Verma et al. [9] among others. Out of roof applications, Dörschlag et al. [43] complete adjacency graph with geometric information (parallel and right-angles) between parts of a polygon building to coarse level detailed models.

Some authors use graphs after classification or reconstruction phase. They extract topologic information (adjacency and inclusion) to different applications such as energy or navigation purposes. Cao [44] extracts room topology in indoor environments, previously reconstructed from a grammar-based methodology [45], to create a graph which relates rooms as nodes with the doors and the walls between them as edges. Zhou and Neumann [46] simplify geometric reconstructed models using topology information. Topologic models are proved to be more coherent than geometric models. The graphs also can be used to store different data types. In Becker [47] a six level

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