The potential use of laser scanner in urban contexts

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Abstract. 3D laser scanner is an instrument that employs LiDAR technology to map out objects in space by means of remote detection. In Architecture, digital mapping through 3D laser scanning mainly aims at creating digital surface models based on instant recordings of still objects, whereas lived spaces such as squares, streets, and urban surroundings presuppose the presence of people on the move. This paper presents some preliminary results of an investigation on the use of 3D laser scanning in urban contexts. It seeks to examine experimental data on moving people obtained in point clouds and discuss their operationalization possibilities and limitations. The main goal of this investigation is to assess the potential of this technology for use as a research tool and in city-scale design processes.

Keywords: 3D laser scanning technology, motion modeling, geometrical modeling, computational tools, urban survey.

1 Introduction

The use of digital technologies in architecture and urbanism has given rise to research on several fronts. Close examination of paths followed by today's design and production processes indicates that fast prototyping devices, such as 3D printers and laser cutters, have had a huge impact on them, especially at laboratories of Architecture and Urban Planning programs. Moreover, their use can also be found beyond the academic walls for various purposes.

Different, however, are the features of LiDAR (light detection and ranging) technology, whose application to everyday processes is less common and still restricted to specific niches of expertise and whose potential is only now being widely explored by researchers and scientists. LiDAR is an optical technology that enables tracking and modeling objects in space through remote sensing, that is,to determine the distance, dimensional properties and/or other information about a distant object. The 3D laser scanner is one of the equipments that scans surfaces of objects by means of laser beams and promptly provides accurate data about their geometry.

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Research aimed at the use of 3D laser scanning technology for mapping and creating a DSM (digital surface model) is being conducted in the fields of archeology, geomorphology, geomatics engineering, historical and cultural heritage preservation, geography, geology, forestry, remote sensing, and atmospheric physics as well as in the military context. It is different from other tracking and image-based modeling methods, i.e., photogrammetric processes or surveys with other equipment such as GPS (global positioning system). Studies employing 3D laser scanning technology aim at exploring its potential and improving its prospects of use in specific contexts, but, as it often happens with research designs that employ any given technology, investigations that use 3D laser scanners share some advantages and disadvantages inherent to this tool. Among the relevant advantages is its submillimetric accuracy in obtaining 3D geometries by means of automated fast measurement processes. One of the downsides is the price of this equipment, comprising the laser scanner itself and a computer capable of processing point clouds, which constitute the main graphic representation it provides. In addition, its operation is time-consuming since in spite of its digitalization process being fast, subsequent data pre-processing, which includes segmentation, grouping of point clouds, modelling, optimization, model edition, and exporting products in several formats according to proposed ends is work-intensive [1].

The applicability of technologies involving the use of 3D scanners in the field of architecture has been continuously improved as regards the scale of the object and/or building, especially in areas of historic preservation, as indicated by Gomes, Bellon, and Silva [2] and Fassi et al. [3], and more recently with digital scan-edit-print processes for various purposes. Notwithstanding, 3D scanning appears to have been little explored in connection with urban scale, especially when it comes to digital mapping and modeling of urban fragments to support design processes in the field of urban design. Urban spaces are lived spaces; they often presuppose the presence of people on the move. However, when employed to digitally map and model spaces such as squares, streets, and urban environments in order to collect information to support design processes on this scale, 3D scanning usually eliminates moving objects, for example, vehicles, bicycles, pets, and especially people, from the scenes.

This paper presents some preliminary results of an investigation on the use of 3D scanning on the scale of urban fragments, conducted atNóLab, a laboratory of the Architecture and Urbanism Department at Universidade Federal de Viçosa, Brazil. It depicts an experiment aimed at scanning a road closed to cars for exclusive pedestrian use downtown a mid-sized Brazilian city. The fact that this street has been closed to vehicles greatly improves the possibility of reading and systematizing data obtained by this means from the perspective of moving objects, as people.

The 3D laser scanning technology is almost exclusively suitable for collecting information and modeling static objects. Moreover, in the context of urban space, this modeling usually leaves out and/or segregates data on moving objects. In the face of that, two questions seem relevant: (1) In addition to providing location and size accuracy, what are the other properties of these data? and (2) What could architects gauge from the data obtained about moving objects, that is people, when operating a 3D scanner in urban spaces? This paper will initially examine these data in detail and then present some perspectives on and limitations to their operationalization.

2 Tracking Multiple People

Despite the existence of other equipment for observing and recording behavior in public space in the field of architecture and urbanism, such as, webcams, photos, behavioral maps, and more recently digital image fusion methodologies, most people-detection research is based on the analysis of motion video images due to its capacity for capturing a target individual's shape and texture. However, high sensitivity to climatic conditions and camera angle limitations can greatly reduce instant accuracy of these methods, in addition to the difficulty in digitally combining data from multiple cameras, which requires a software program capable of integrating algorithms to graphic data for post-processing information adequately.

Several measurement methodologies of this nature have been developed in robotics and automation or computer vision and image understanding algorithms, which integrate algorithms to point clouds when using a 3D scanner for numerical count or identification of individuals in public open spaces [4-8]. However, a 3D laser scanner enables recording of various scenes irrespective of lighting conditions. It is not affected by variations in light conditions, and recording and pre-processing do not take much time. Moreover, a 3D scanner provides dimensional accuracy, exact location of people, distance between them, path speed and direction, among other geometric characteristics of scenes that can support urban design. According to Isaki and Helme [9], *'in some of the early work, visualizations were used to reveal inherent geometrical properties of space, leaving it to the designer to speculate on and interpret the results, based on his or her knowledge and experience'.*

2 .1 Experiment

This experiment made use of the Z+F IMAGER® 5010C equipment (Zoller+Fröhlich), considered to be a terrestrial middle-range laser suitable for detection of buildings and scenes, unlike the short and long-range lasers used for scanning products and in planialtimetric surveys. It addresses the use of static LiDAR technology when equipment cannot be handled during data acquisition, differing from operating a mobile equipment fixed on top of vehicles. A 3D laser scanner operates in active mode by gauging the return speed of laser pulses emitted by a target. The laser scanner employed generates a beam that can go 320 degrees vertically to detect what lies ahead and behind the equipment (horizontal capture of 360 degrees). This beam falls on a material and returns there by providing data to estimate the target individual's distance from the difference of phase between emitted and received waves.

In this study, the evaluation of 3D laser scanner for detecting people was carried out in a real context, and involves two pedestrian streets. Although the equipment is omnidirectional, the axial spaces of the roads in question were chosen because of their potential for mapping circulation flows in addition to providing the benefit of a limited vision angle, initially set at 150º and later at 180º, which favored control of data generated by point clouds. No concurrent mappings were done, since that would have required at least two instruments and post-processing overlap of many point clouds.

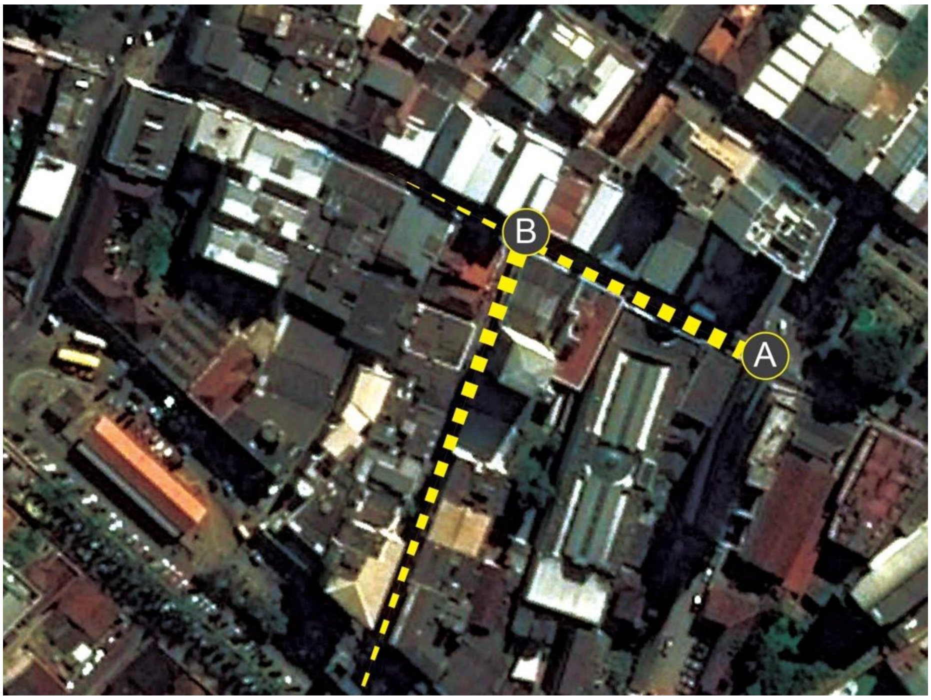

Fig. 1 Axes indicate road and positions A and B of laser scanner during experiment.

Table 1. Data regarding settings of point clouds resulting from captures at different resolutions for laser scanner positions A and B.

	Resolution	Lines	Precision (at 10m)	Time (min)	File Size	Points displayed (thousands)
Position A	Preview	522	50.3mm	00:21	1.3Mb	223
	Low	1043	25.1mm	00:43	4.8Mb	887
	Middle	2085	12.6mm	01:25	16Mb	3563
	High	4168	6.3mm	02:50	60Mb	14342
Position B	Preview	626	50.3mm	00:25	1.5Mb	245
	Low	1252	25.1mm	00:50	6Mb	990
	Middle	2501	12.6mm	01:39	20Mb	3892
	High	5001	6.3mm	03:19	77Mb	15372

At position A (fig. 1), the equipment was placed on a 6-meter high balcony. The 3D laser scanner was set to map a 153°-wide enclosed area and the system was tested at four different standard resolutions: preview, low, middle, and high, which produced several recordings lasting from 20 seconds to 3 minutes (table 1). It is well known that not only do these varying resolutions affect the quality and number of points that compose the clouds, but they also affect the scanner rotation speed during mapping. It was necessary to perform several captures at different speeds in order to improve accuracy of instant recordings of moving people and/or probable traces suggested by continual movement recorded by the scanner linear beams.

At the first position, the 3D laser scanner recorded above the pedestrian level, thus increasing both the distance between passers-by and the in-depth recording range. The intent of this oblique and high mapping in relation to the street axis at the ground level was to avoid possible data loss due to barriers created by people crowding in front of the equipment, although previous studies are based on data obtained at the time of the observer or on the level of ankles. As aforementioned, the equipment was positioned in such a way to capture recurring linear flows of people at an angle, which could favor captures parallel to the laser beams (Fig. 4).

At position B (Fig. 1), the scanner was placed at 1.8 meters above the pedestrian street crossing with the intention of recording flows both orthogonal and parallel to the laser beam, thereby improving the mapping of intersecting flows occurring there. A 180° field of vision was thus selected, which allowed the recording of people's paths in the main directions of flow on both streets.

3. Discussions and Results

3.1. People Recognition Distances

The distance range for capturing fixed objects with the equipment in question at a satisfactory level of element recognition, such as architectural elements, is approximately 160m. Although distances not exceeding 50m are recommended for conventional use to prevent decrease inaccuracy on millimeter scale, in this study, the maximum distance that the equipment managed to capture buildings was 170m. However, this distance was observed to drop considerably in the case of capturing people and to vary according to the chosen settings. As to the clouds recorded at position A, it was noticed that people could be recognized at high resolution at a maximum distance of 47.9m. At longer distances, it was not possible to identify passers-by accurately since the number of points was not large enough to enable distinguishing them from other elements in the scene (Fig. 2). The image in Figure 3 illustrates the maximum range of people identification based on close analysis of the point cloud at preview, low, and middle modes, whose recognition distances were 13.66m, 28.6m, and 39.14m, in that order. It should be remarked that this analysis implies approximating visualization within the cloud proper and carefully examining the patterns of points. Dispersion of these points over space, which typifies the recording of a moving person within a given period, is further discussed in 3.3 below.

Fig. 2 Analysis of patterns of points enables recognition of people. Image of point cloud showing the farthest person recognized at high mode at position A.

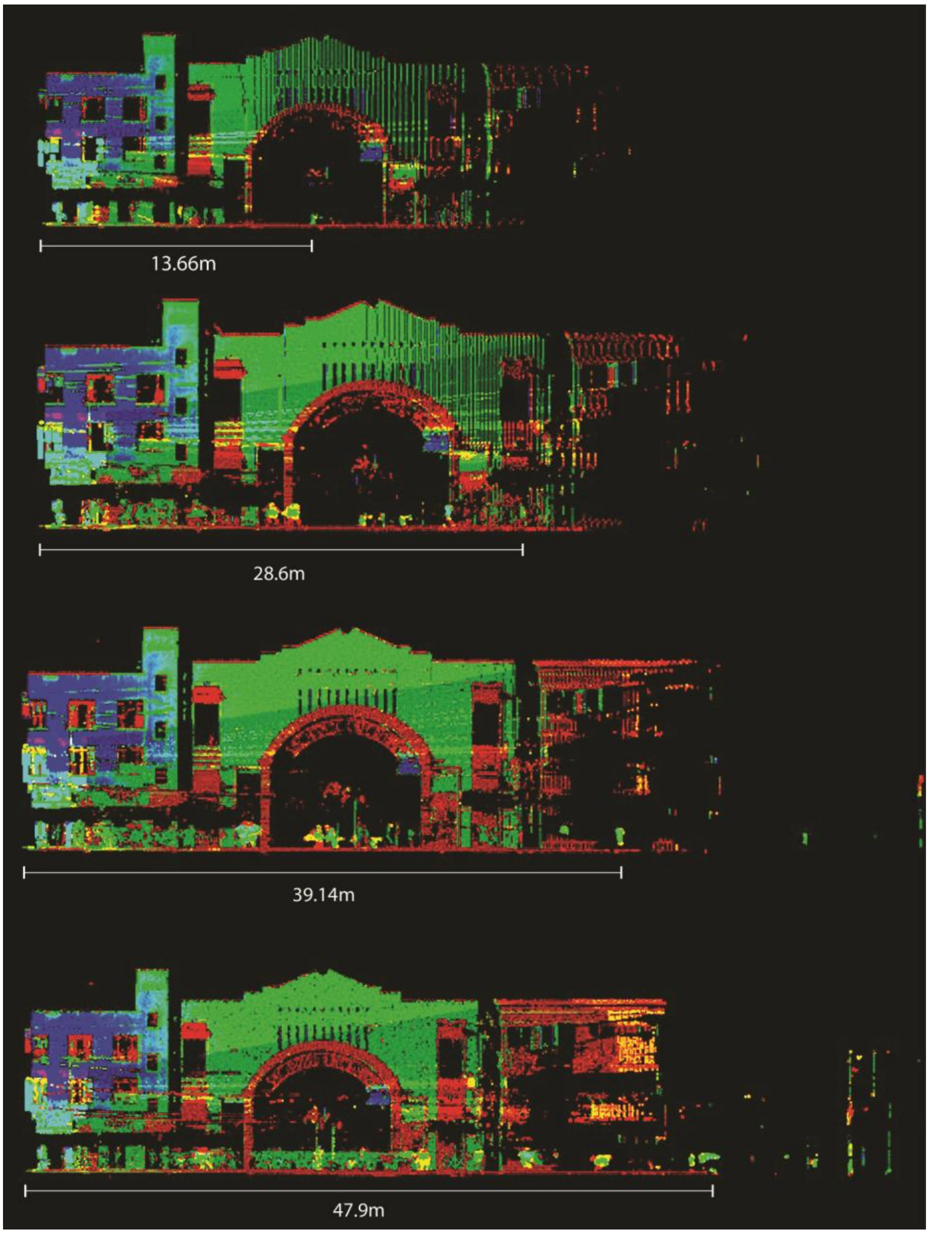

Fig. 3 Maximum recognition distance at standard resolutions preview, low, middle, and high at position A.

3.2. Recording of Moving People

Although previous studies used the laser technology to quantify pedestrian groups in an event, this paper analyzes the recording of moving people in a public space. It was identified that the pattern of recording people on the move depends on the combination of two variables: position of laser beam relative to their paths and speed of flows over space vis-à-vis capture speed, provided by the adopted resolution. In other words, people recording patterns in a point cloud are directly linked to people's path and their speed as compared to the scanner position and capture speed.

Two recurring situations may be identified in the recordings: people's paths perpendicular to the scanner rotation path and people's paths orthogonal to the scanner capture axis (frontal). When people cross the scanner-captured 'scene', that is, when their path is perpendicular to the laser beam, the point cloud will record the exact moment of intersection. In this case, there are two variables interfering with mapping results: their movement direction and speed. The scanner rotation is always clockwise in that pedestrians whose path is counter clockwise will be recorded as line fragments. However, when their movement is clockwise, they will be recorded as traces as shown in Figure 4. In these cases, the closer the pedestrian's speed is to that of the scanner, the longer the trace is. Not with standing, it should be remarked that in both directions, an individual's speed that is higher than that of the scanner will be recorded as line fragments in the point cloud. In the case of paths orthogonal to the scanner capture axis, regardless of their direction and coinciding with the equipment rotation or not, people are recorded as accurately as static objects are, the quality of register in the point cloud being affected only by the adopted resolutions.

Figure 5 shows several identified recording situations: highlighted in yellow is the trace of a path in the same direction as that of the scanner rotation at a speed close to the rotation speed; in orange are fragments of people whose paths were perpendicular to the scanner laser beam at higher speeds than that of rotation; whereas in red are recordings of people whose paths were orthogonal to the laser beam, which provided the largest number of data in the point cloud and, as a result, the most accurate identification of the human body shape.

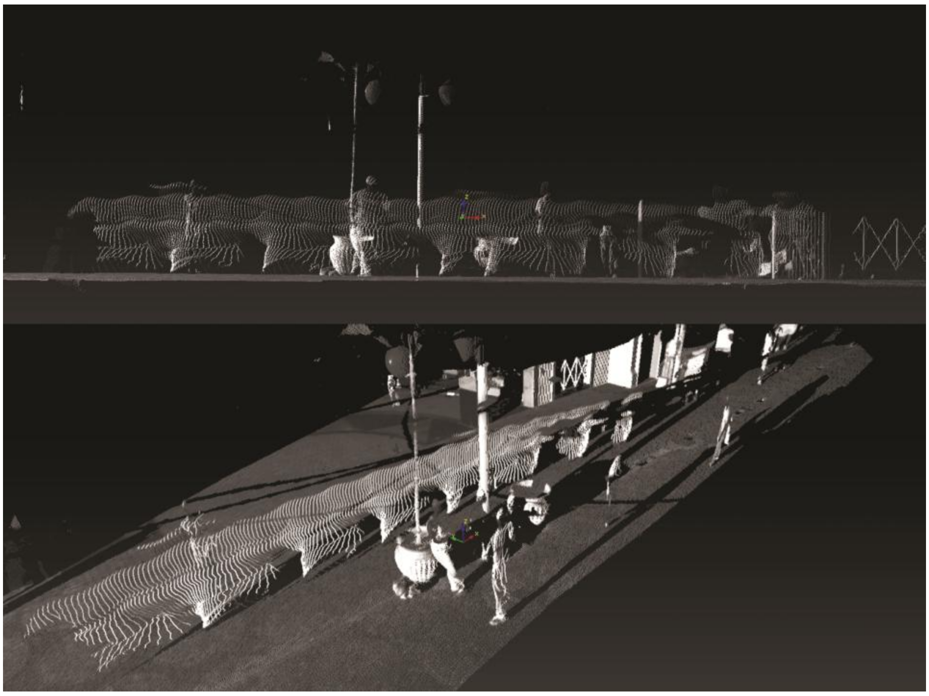

Fig. 4. Recording of a pedestrian’s path walking in the same direction as that of the laser scanner rotation (clockwise) as compared to people in a static position (position A, high resolution).

Fig. 5. Different recordings of people in a point cloud (position B, high resolution).

3.3. People Identification in a Point Cloud

Identification of objects in a point cloud is linked to the density in space of points that determine shapes-surfaces in a given period of capture. One of the ways of distinguishing static from moving objects is by juxtaposing densities of the set of points, especially when some sets only feature line fragments or traces, as mentioned above. For instance, architectural elements are more easily identifiable in a cloud because they provide dense sets of points determining their surfaces, which can be promptly perceived by the laser beams falling on them repeatedly. On the other hand, moving objects are only subject to detection for a very short period of time. As previously shown, the type of recording of passers-by that cross the laser beam transversally cannot produce dense structure-shaping points — just line fragments or traces, irrespective of the adopted resolution. Besides, another way of identifying moving objects is to gauge the position of the sets of points in space—however scattered they may be—by measuring distances in relation to static objects.

At any rate, it is difficult to identify people in a point cloud when there is recordings of the line fragment type are close together. Two very close fragments may indicate the existence of two people walking side by side or just one person’s trace. In this case, there more be more research on accurate ways of identifying the number of people. In any case, juxtaposing densities and verifying the positions of points in space by assessing them in relation to static objects can promote identification of moving people in a point cloud.

4. Future perspectives

Most research conducted in the field of Architecture and Urbanism that employs a 3D laser scanner focuses on preserving cultural and historic heritage. Case studies comprise the majority of research designs and depict the constant development of this technology. On the other hand, there are fewer studies experimenting with this technology beyond its use to capture data on buildings, objects, and urban spaces with the intent of building accurate models. In this study, the use of 3D laser scanners presupposes a specific type of recording, that is, the instant recording of as till object. Therefore, it seems difficult to dispute the argument advanced by Shaw & Trossell [10], that *‘digital versions of space will always be just that – exact lists of numbers, of x, y and z values, the experiential properties lost as pure data’*. However, in the context of this study, which investigates how 3D laser scanning and moving objects/people are related, it also seems pertinent to agree with the same authors when they claim that *‘Scanning offers these challenges to designers. If a digitized version of* *space is uncanny yet cannot compete with the real, how can it enhance it, provoke it, change the way it is used?'* [10].

In this sense, this study provides questions for further research: Could data on people collected by means of a 3D laser scanner add informational or methodological perspectives to conventional processes and equipment for data collection and presentation of a given urban fragment? Is it possible to change the settings of a laser scanner so as to adapt it to register people in interaction with a given space? Is it possible to use these data as parameters to support design processes involving parametric digital modelling as well as generating processes?

Studies of this nature seek to explore mechanisms of 3D laser scanning technology as another tool for analysis of lived space so as to enable parameterization of traces of human relations and interactions in a given context. Apprehending this information can have repercussions to how the built environment is regarded, thereby contributing to design processes novel ways of dealing with people-dependent variables - their behavior and interactions - in space-time.

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