LiDAR data integration for 3D Cadastre: some experiences from Brazil

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Key words: Cadastre, Cadastre 3D, LiDAR data.

SUMMARY

The processes of acquisition, storage, processing and representation of spatial data had a lot of changes in recent decades, which led to new possibilities in the use of spatial information, especially with 3D models generation of objects. From these models is possible to understand the dynamics of some phenomena and to define action strategies for interventions. In this way, the cadastral information also was influenced by this process, which has led many researchers to verify the demands and impacts on the cadastral system of so-called 3D Cadastre. This work aims to contribute to proper procedures for the incorporation of 3D information to the Urban Cadastre from the existing structure, especially in where there isn't a cadastral model that is the Brazilian case. It is proposed to use a model for the spatial parcel using a square cylinder of revolution and a cloud points with attributes. The experiments with data obtained from LASER scanning sensors (aerial and ground platforms) to assist in the incorporation of 3D information to Cadastre were satisfactory, not only for the use of cloud points attributes for Cadastre, but by the integration of the LASER point cloud air and ground. To make the studies, test areas were selected in São Paulo and Curitiba. In developing the thesis, C++ libraries were used, implemented by research groups in the area of Photogrammetry and LiDAR data manipulation. The results for the labeling of points with attributes using mathematical models of the cylinder show promise for the discussion of spatial Parcel model for Cadastre, and allow incorporate 3D data to Cadastre even without Cadastral Model.

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1. INTRODUCTION

The study of the urban context, together with its attributes, has been the main function of the Urban Technical Cadastre, mainly in its multipurpose characteristic. Although not all the Cadastre's problems have not been solved by the researches developed to date, the 3-dimensional representation of the parcels and their attributes are now considered, which leads to a rethinking of the Cadastre model adopted in many countries.

Although at the time its was launched, by the International Federation of Surveyors (FIG), the 2014 Cadastre did not discuss the issue of three-dimensionality, some initiatives in this aspect were explained, especially when talking of the exact definition of the limits of the territorial unit (KAUFMANN; STEUDLER, 1998). Despite not explicitly citing the issue of three-dimensionality of the parcel's limits, the 2014 Cadastre foresees a broad cadastral reform not only in the aspect of data acquisition and storage, but also a broad reform in the legislation in effect on the Cadastre and the registration of real estate, following the technological evolution.

In the search to define a better territorial unit for the Cadastre and registration of real estate, some countries started to incorporate orthometric altitude as a parcel attribute, generating a new concept of territorial unit, the spatial parcel (SHOSHANI, 2005).

Several technological research and development groups have turned their attention to the issue of three-dimensionality of the Cadastre. There are projects being developed in countries like Holland, Sweden, Norway, Israel, China, Australia, Greece among others, each one studying proposals and models to adapt the structures of their cadastral systems to incorporate the spatial issue. Oosterom et al (2006) present an introduction on the time aspect in the Cadastre, including a fourth dimension of the Cadastre.

From this context, this works aims to contribute with the discussions regarding three-dimensionality of the parcel of the Cadastre, discussing means of acquiring, modeling and representing the cadastral parcel, exclusively in the urban environment, considering paradigms of the Cadastre, mainly the presence or not of the Cadastre defined.

2. THE Cadastre AND THREE-DIMENSIONAL INFORMATION

Before treating the three-dimensional information directly in the Cadastre, note an important aspect of the terminology used for the Cadastre in the three-dimensional issue. Although literature and even the author of this work have used the expression 3-D Cadastre, it is sometimes not used correctly. This is because the Cadastre is an abstract concept, therefore, dimensionless. It is different from the cadastral parcel, which is regarded as an object and has dimensions. It is not the Cadastre that is 3-D, but rather the cadastral parcel, whether it is called a lot, land or real estate.

It is interesting to distinguish this because some terminologies used become inadequate such as, for example, the so-called 4-D Cadastre. There is no fourth dimension in the Cadastre, rather there is an analysis of the behavior of the cadastral parcel over time. In addition, 3-D does not necessarily mean that one is considering the coordinate (X, Y, Z) or (E, N, h), since each dimension can receive the attribute of interest. If the terminology is adopted as 3-D, 4-D, etc., one must consider it as n-D Cadastre, since each theme applied to the Cadastre like health, education, among others, would be a dimension. In this work, the object of study is the cadastral parcel, which in the text will be referred to as spatial parcel with three dimensions referring to the system of coordinates (X, Y, Z). Thus, in this work, the 3-D Cadastre considers the parcel in 3-D.

In the context presented, a spatial parcel model that meets the incorporation of three-dimensional information must take some important aspects into account. The main thing is that not all countries have a well established Cadastral model. In the case of Brazil, for example, there are several parcel standards, also called lot. The lack of a standard for the parcel makes the Cadastre management a problem in a city, without allowing the use of solutions for several places.

To work with a data acquisition strategy and spatial parcels for places without defined cadastral model becomes advantageous, since one is not limited to a pre-established standard and inclusion of such data in a later model to be adopted will not be a problem. Many countries do not have an established Cadastre model and therefore, using a strategy that is not limited to one model is interesting to keep the data updated without detriment to the observance of models.

The models of spatial parcels proposed by Stoter & Oosterom (2006) included 4 basic structures: tetrahedron (**Fig.** 1), polyhedrons (**Fig.** 2), polyhedron with cylindrical and spherical parts (**Fig.** 3) and models obtained from CAD from CSG (*Constructive Solid Geometry*), breakdown into cells and curved objects (**Fig.** 4).

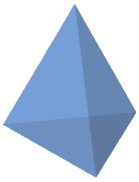


Fig.** 1 - **Model of a tetrahedron

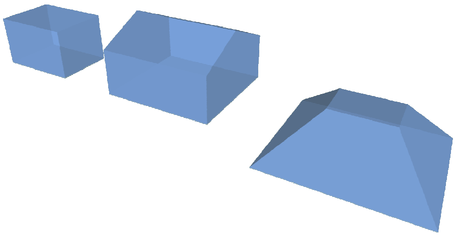


Fig.** 2 - **Set of polyhedrons

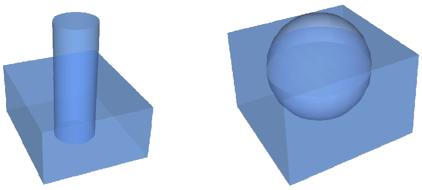


Fig. 3 - Polyhedron with a cylinder and with sphere

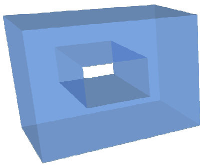


Fig. 4 - Model based on CSG formed by the subtraction of two polyhedrons

Ekberg (2007) proposes the use of triangular features to recompose the objects in 3-D as polyhedrons, for example. . He breaks down the spatial features into triangles to improve the topological consultations. **Fig.** 5 illustrates this concept.

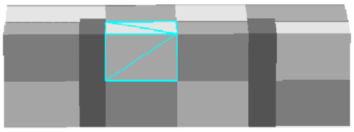
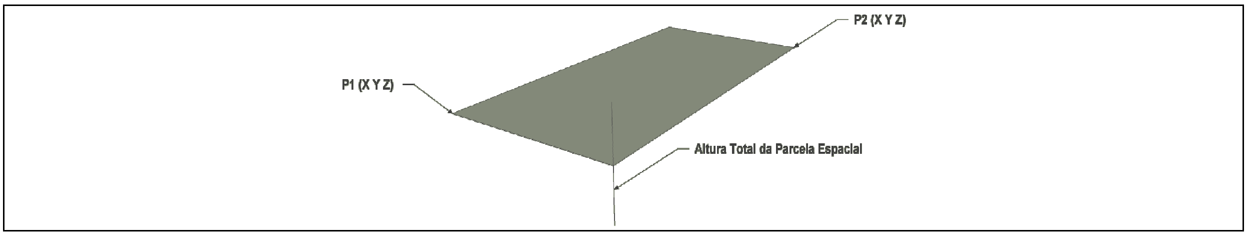


Fig. 5 - Representation of spatial parcels with triangular features

All these alternatives of the model of spatial parcels took into account the technical feasibility of implementation in database, CAD and GIS. Thus, even if not ideally, these models have guided the use of three-dimensional information for GIS as well as for the Cadastre. The polyhedron is the model that stands out the most due to its easy implementation, however, the topological relations with objects contained in it are not so trivial (ARENS et al, 2005).

One of the difficulties of establishing primitive geometrics for the Cadastre is the irregularity of the boundaries of the parcels on the land surface. In many regions, there is no established standard, which can lead to inconsistencies in information. Thus, there will always be an overlapping of spatial parcels or spaces in a square that does not legally belong to any property.

Lack of definition of the parcel boundaries compromises the use of volumes for the cadastral model, since these need at least two coordinates and a height to establish the upper and lower boundaries of the surface in question. **Fig.** 6 shows a diagram of a polyhedron's construction from these parameters to represent a spatial surface.



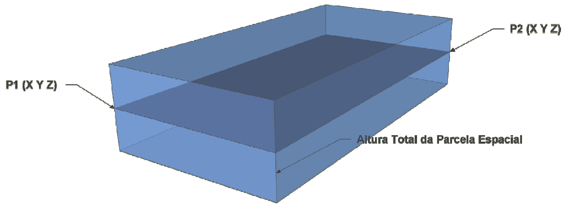


Fig. 6 ***- Criteria for formation of the spatial parcel***

Note in this case that the polyhedron considered is regular, which is not always so in reality. Thus, definition of the spatial parcel depends on seven parameters, considering the level of the land as starting plane. Considering the constructions existing in the spatial parcel as subparcels, these would also depend on other parameters to be reconstructed. In the case of spatial subparcels, it is possible to reconstruct the polyhedrons from the Cadastre files that have the ground floor plan of the property and database information on the number of floors (FILLIN et al (2008)). Even then, this modeling would not be faithful to the reality, since the forms used may not correspond to the geometry of the constructions.

To find a suitable model to represent and use the spatial parcels is important for the Cadastre. However, it should not be mistaken for the modeling of virtual cities, whose purpose is different. Although both borrow concepts from each other, they differ in use.

The paradigms of virtual modeling of cities are based on two main aspects: 3-D geometrical modeling and modeling based on images. (NEBIKER et al., 2010). Both have characteristics that help understand the use of three-dimensionality for the Cadastre and help in its incorporation to the cadastral systems.

The geometrical modeling has the advantage of being based on CAD and GIS concepts, using the same standards, formats and tools. This allows great interoperability among various systems for edition and viewing of models. Another great advantage is flexibility of the modeling that allows anything to be modeled using the principles of B-rep (*Boundary Representation*) and CSG. The disadvantage in this case is not the method itself, but the complexity of urban environments. The breaking down of some complex structures into geometrical primitives demands a great time of editing, which leads to some inconsistences between what the user expects from the model and what the producer achieved (NEBIKER et al., 2010).

On the other hand, the modeling based on images has the advantage of allowing a realistic construction of the landscape, but limited to the point of view of the scene's acquisition. There is also need to make the brilliance values of the pixels compatible. The *Google Street View* is an example of this approach. In general, a combination of both approaches is used in more consolidated virtual city systems, applying brilliance values obtained in the images as elements of textures in the geometrical models modeled.

Both approaches illustrate the problem of obtaining 3-D models from objects in the urban scenario. For the Cadastre, there is the need to establish the spatial parcel as an object, although it is not actually materialized. In addition, the information for the Cadastre must be current, which requires greater speed in data acquisition and consequently a faster construction of models. In this aspect, both approaches are not so fast, due to the time of editing required to construct the model. For the Cadastre, there is no need for such a realistic modeling, only for specific themes like Historical Heritage Cadastre.

In light of this context, concepts of a new city modeling paradigm were used in this work, called *Rich point clouds (RPC)* (NEBIKER et al., 2010). The term's translation in Portuguese would not have the sense it has in English, which h is a cloud of points with various attributes, like intensity, RGB value, classification and others of interest. In general lines, the LASER points have information on position, return pulse, time, among others.

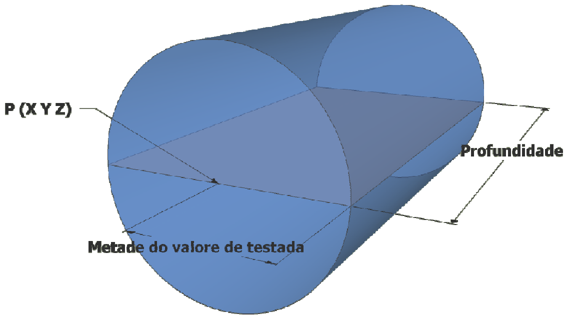
With these new concepts, one can attribute to each point of the cloud several pieces of information such as, for example, the type of construction it is part of or even the property's cadastral enrollment. In addition, RAVADA et al (2009) states that the point cloud structure can be supported in database, giving the *Oracle Spatial 11g* as example.

3. METHODOLOGICAL PROCEDURES

To meet the objectives, we propose, to incorporate the three-dimensional information to the Cadastre, a hybrid spatial parcel model, using concepts and paradigms of City Modeling and primitive geometrics that can be represented in the database. Thus, each spatial parcel will be represented by a geometrical structure and the objects by point cloud.

Something that must be highlighted is that the spatial parcel is an abstract object. It cannot be measured completely, only the part that is on the land surface, which generally corresponds to the plane that divides the spatial parcel into two equal parts. While the subparcels, which in this case are the constructions or structures contained in the spatial parcel, are physical objects.

The geometrical structure proposed for the spatial parcel is the cylinder instead of the polyhedron. Although Stoter & Oosterom (2006) have placed limitations in the use of cylinders for the database, technological advancements allow this structure to be used. With regard to the polyhedron, the cylinder has 5 (coordinates (X,Y,Z), depth and facing) parameters to determine the parcel instead of 7 (two coordinates (X,Y,Z) and height of the spatial parcel), highlighting that both have the ground level as starting plane, that is, the parameters in relation to the lot plane are common to both. **Fig.** 7 illustrates use of the cylinder as spatial parcel, with the continuous or multifaceted cylinder in plane regions.



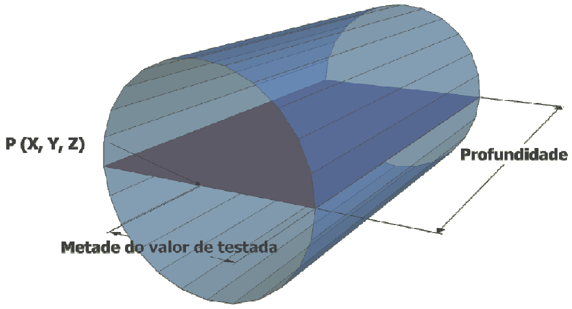


Fig. 7 **- Example of the use of cylinder as spatial parcel.**

Although the cylinder has less parameters than the polyhedron, the mathematical implementation of the verification of structures in its interior is not so simple. According to the methodology proposed, the cylinder is made up of a center, radius and generatrix axis. According to the model proposed, the cylinder center is represented by the coordinates obtained in the average point of the lot facing, the generatrix axis is the depth of the lot and the radius is half the value of the facing. Having defined such parameters for construction of the cylinder, the next stage was to mathematically assure that an object was outside or inside the spatial parcel.

Regardless of the model of the object inserted in the spatial parcel, the consultations on its topology are made in relation to the vertexes, whether these objects are polyhedrons, tetrahedrons, CSG objects, among others. Therefore, once the consultations refer to points, using the concept of RPC becomes valid since verification and labeling of the points do not depend on the total number of input points.

For the mathematical model used in the labeling process of the points to meet the objectives proposed, some initial considerations were required. The first approach used the concept of distances within the cylinder, but the labeling process generated a sphere due to the countless directions that the distance vector could assume, which rendered such use unfeasible.

Henceforth, the approach used was to define a system of local coordinates X'Y' in the XY plane with origin fixed in the average point of the facing in front of the parcel, which coincides with the center of the cylinder circle. The system was defined such that the Y' axis would coincide with the alignment of the lot facing. **Fig.** 8 illustrates the position of the new system of coordinates in relation to the spatial parcel. In continuous line is the original system of coordinates, in blue the transfer of the axes to the center of projection of the cylinder and in red is the system resulting from rotation θ, with the X' axis coinciding with the cylinder's axis. The X and Y values can also assume the values of E and N of the UTM system.

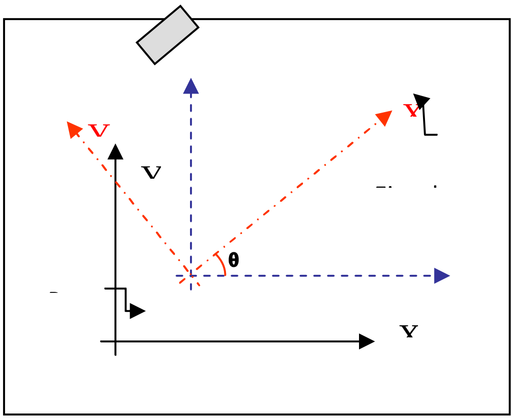


Fig. 8 - ***Positioning of the local coordinate system in relation to the original system***

The parameters of transfer to the new system of coordinates would occur by subtracting the point of origin of the cylinder from the point of interest being tested. While the parameter of rotation would need more than one point beyond the point of origin of the spatial parcel. This is due to the fact that the parameter of rotation is obtained from the factor of inclination of the equation of the straight line that passes through the cylinder's point of origin.

To solve this problem, there is the need to obtain the central point of the nearest spatial parcel that is in the same alignment. With two points, one thus determines the straight line equation and finds the angle of rotation θ of the new system of coordinates in relation to the system of origin. It is important to study the sign of the angle of rotation because it is obtained through the tangential arc function and has impact on the coordinate system's direction.

With the transfer and rotation parameters defined, the equations for the new system of coordinates are given by equations 4 and 5.

$$X' = (X - X_C) \times \cos\theta + (Y - Y_C) \times sen\theta \tag{4}$$

$$Y' = -(X - X_C) \times sen\theta + (Y - Y_C) \times \cos\theta \tag{5}$$

Where
X’ Y’ are coordinates of the points in the new system;
X_C Y_C are coordinates of the cylinder's center;
X Y are coordinates of the points being tested;
θ is the angle of rotation between the systems of coordinates.

The consultation conditions to know if the point is planimetrically within the cylinder are given by equations 6, 7 and 8.

$$X' < 0$$

$$X' < depth \tag{6}$$

$$Y' < radius \tag{7}$$

(8)

The information on the depth and facing are obtained in the database or can be measured in the field also, remembering that the value of the cylinder's radius is obtained through the value of the facing.

For altimetric verification of the point being tested in relation to the cylinder, the equation of the circle in the Y'Z plane was used. Where the equation's result to be less than or equal to the value of the radius established, the points would be inserted in the cylindrical spatial parcel. Equation 9 shows the consultation condition for the points.

$$(Y')^2 + (Z - Z_C)^2 \leq radius^2 \tag{9}$$

Where

Z is the coordinate of the point being tested;

Y' is the coordinate of the point tested in the local system;

Z_C is the coordinate of the central point of the cylinder.

Therefore, the point being tested must meet the conditions of equations 4.3, 4.4, 4.5 and 4.6 to be labeled with the attribute desired, in this case the cadastral enrollment. As already cited, whether the point originates from a point cloud or from polyhedrons, the mathematical model is consistent and can be used.

The constructions in this proposal can be represented by a vertical cylinder or the point cloud itself of the construction. When the case, one can opt for a hybrid model between these two approaches. Although, likewise the polyhedron, the cylinder has problems with regard to the boundaries, note that no model represents the reality and, therefore, one must choose the one that is best for the application of interest. For the Cadastre, a realistic or geometrically faithful representation is not always the best solution since one cannot execute measurements of the Registration of properties in models by the legislation in effect. The three-dimensional information in the Cadastre contributes mainly toward the urban planning area and legal area. It can also be used for the real estate Cadastre, except in the limits of the spatial parcel, since these are not materialized. In addition, the Cadastre data can be used in the so-called 3-D GIS, for tourist and geomarketing applications.

The choice for the cloud point was to facilitate the topology of the structures within the parcels. With use of the *RPC* concept, the points may have various attributes. In addition, it is much easier to control the point within a cylinder than another volume. The idea is to use the range of attributes to facilitate the topology and identification of properties. Although acquisition of the points is somewhat burdensome, technological progress tends to minimize these costs with time. The model proposed uses the point clouds obtained by aerial and land LASER, with integration of both.

4. EXPERIMENTS AND RESULTS

The test area is located in the Polytechnic Center of Universidade Federal do Paraná (UFPR), Curitiba - PR. This area was chosen due to availability of the aerial LASER point cloud and the possibility of conducting a field survey with the land LASER. **Fig.** 9 shows an image of the test area.

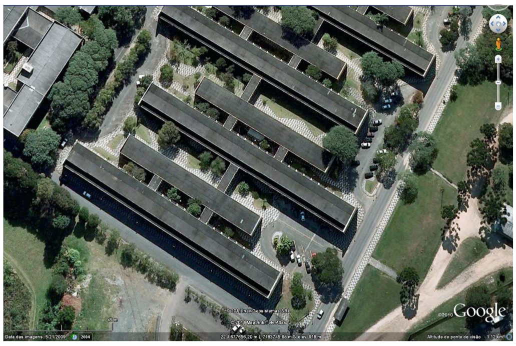


Fig.** 9 - **Polytechnic Center of UFPR

SOURCE: *www.googlemaps.com*

The aerial LASER data of the test area was provided by Prof. Dr. Daniel Rodrigues dos Santos, from the Geometrical Department of UFPR. This point cloud was elaborated by Instituto LACTEC of Paraná. **Fig.** 10 below shows the point cloud of the aerial LASER.

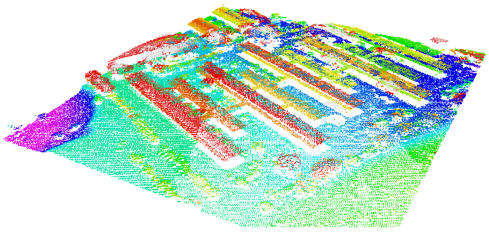


Fig.** 10 - **Aerial LASER point cloud of the test area

The data survey with land LASER was done in December 2010, using an equipment granted by the Geology Department of UFPR. The initial idea was to collect a point cloud, uniting various scenes that would model several walls, especially corners of the constructions. However, on the day scheduled for the survey, there was rain, preventing the survey. The scenes were collected the next day, but not in the configuration previously established due to the time conditions and equipment availability. **Fig.** 11 shows the cloud of points collected.

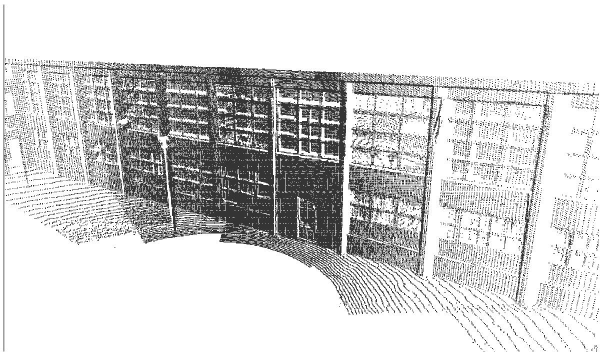


***Fig.** 11 - Land LASER point cloud of the test area*

The first step to integrate both point clouds was to outline the strategies to verify the points common to both clouds. As already mentioned, it is impossible to know a priori if a point is present or not in the aerial and land LASER point cloud at the same time.

To determine the points that may be common to both point clouds, the *convex_hull* algorithm was applied in the aerial LASER point cloud. The interest in this case is not in the contour of the construction, but rather in the points that define the straight line segments that define the contour. From the straight line equations of these points, their points of intersection were defined.

After determining the points of interest in the aerial LASER point cloud, planes were then extracted in the land LASER point cloud. Points were collected manually through the *Cyclone* software for definition of the planes. Since the density of the points is high, a threshold of 5 cm was chosen to separate the planes, distinguishing planes from windows, pillars, floor and walls. **Fig.** 12 illustrates the result of this process, showing the plane of the walls (red), of the pillars in light green, of the floor in green and of a lateral wall in orange.

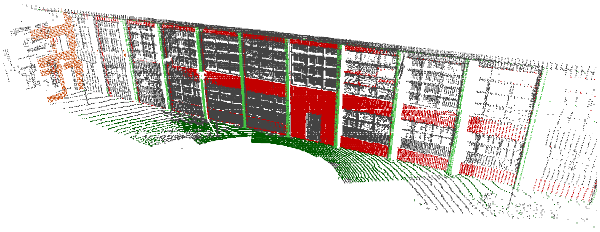


***Fig.** 12 - Point cloud with the planes in highlight*

Using the result of the intersection of planes, 3 points corresponding with the aerial LASER were found. With the points chosen, the parameters of transformation between the point clouds were obtained using the transformation of similarity. **Table** 1 below shows the parameters of transformation and the standard deviation.

***Table** 1 - Parameters of transformation between the point clouds*

Parâmetro	Valor do parâmetro	Desvio-padrão

Rotação X (em radianos)	0,553341	0,002804
Rotação Y (em radianos)	-0,052737	0,006131
Rotação Z (em radianos)	0,111036	0,013127
E (em metros)	677670,487342	0,059906
N (em metros)	7183789,101412	0,068592
h (em metros)	915,478115	0,104128
Escala	1,009331	0,002765

From the parameters found, the inverse transformation was applied in the points of the land cloud, placing both in the same reference, in this case, geodesic. With regard to test area 2, one notes that the standard deviation of the points were better, that is, the correspondence of the points found by intersection of planes and straight lines was more adequate, even with different points of density. **Fig.** 13 below shows the result of the integration.

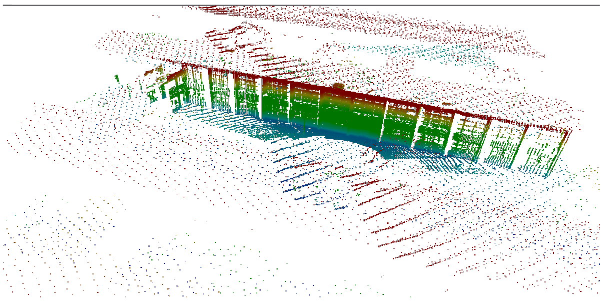


Fig.** 13 - **Result of the integration of point clouds

After the integration of point clouds, the points were labeled as of the concept established for the spatial parcels. Since the situation is not ideal, two cylinders were established for the methodological test, dividing the region of the study area into two cylindrical spatial parcels. The intention in this case was to simulate two adjacent lots, dividing the point cloud. The radius used for the cylinder was 11.5 meters, resulting from a 23-meter facing. The depth used was 20 meters. The centers generated for the cylinders are defined by the points of **Table** 2.

Table** 2 - **Parameters of the cylinders used in test area 3

Cilindro	E(m)	N(m)	h(m)	Raio(m)	Profundidade(m)
Cilindro 1	677658,26	7183788,28	913,42	11,5	20
Cilindro 2	677679,35	7183778,44	913,44	11,5	20

Fig. 14 shows the result of the point labeling in two cylindrical parcels in red and blue. In this case, the *LASEdit* application was used to view the labeled clouds.

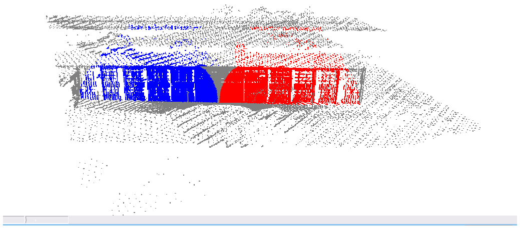


Fig. 14: Cloud Points with visible parcels

5. FINAL CONSIDERATIONS

Incorporation of the 3-D information to the Cadastre is not a trivial task and, therefore, requires careful analysis of the objectives one seeks to attain and the purposes of this information. It does not suffice to add a data on the altimetry of parcels or constructions. The three-dimensional objects must be inserted in a well defined Cadastre model, where reference systems used are clear.

This work proposed to work with the 3-D information even in situations where the Cadastre model does not exist or has not yet contemplated the three-dimensionality of objects, mainly in the urban context. In this aspect, the results presented were satisfactory, actually incorporating the 3-D information to the parcels existing in the database, since the algorithm classifies the point cloud with the attributes of interest, mainly the cadastral enrollment. Although Brazil still does not have a well defined urban Cadastre model, the general guidelines of the Cadastre of the Ministry of Cities launched in 2009 guide the basic principles of the organization of the Cadastre and its basic information, but still do not clearly contemplate the use of 3-D information for the urban Cadastre. Note, however, that this situation is not exclusive to Brazil, since finding a Cadastre model for the most varied situations is not among the most trivial tasks. Therefore, the results of this work contribute toward discussion of the Cadastre basic model, in discussion of work groups of FIG (Commissions 3 and 7).

Use of the cylinder as spatial parcel is an important contribution to the Cadastre as it opens range of possibilities not only for representation of objects in space, but also new possibilities of topological relationships. The characteristic of the cylinder proposed in this work makes use of information present in the Cadastre or that can be acquired in the field, and establishes based on the facing value the use limits of the spatial parcel above and below the surface. It is evident that the use limit of the parcel above and/or below the surface does not depend on a criterion, but using the facing value can contribute toward the impact study of the spatial parcel's use.

Another important aspect to highlight is the matter of limits of the parcel. The model proposed in this work is not a model for the Legal Cadastre or Property Registration, since for these, all the limits must be materialized. Even the polyhedrals used in literature do not have their limits materialized, which is also not the case with the cylinder. The only advantage of the cylinder in this aspect is that since it is a revolution solid, its surface is tangent to the planimetrical limits of the parcel.

The mathematical model proposed for use of the cylinder and the conditions for its use are consistent, showing that mathematically it is possible to use the quadratic cylinder of revolution as spatial parcel. The labeling procedures of the points depend on the minimum parameters for execution and the points surveyed in the field for the procedure are of easy access, there being no need to enter the parcel to survey the limit points.

The topological verifications of the 3-D objects in the cylinder are also possible, and as shown mathematically in the work, regardless of the format of the objects, since the model works exclusively with points, whether they originate from point clouds or solid vertices like the tetrahedron, polyhedron and others. The labeling procedure is also satisfactory, it being possible to not only use information from the database but to also include it.

The RPC concept opens an excellent opportunity for use of the point cloud for various applications. In this work, the attribute of interest used was cadastral enrollment, although many others may be incorporated. Viewing of the point cloud is still a pertinent question, however, with use of the *LAStools* library and commercial software, it is possible to view the points in LAS format, also showing some attributes.

An important recommendation is to test use of the cylinder as a storage structure of the spatial parcel in database and possible implementation of topological consultations. Thus, it will be possible to compare the results with structures proposed by Stoter & Oosterom(2006), like the polyhedron. In this wise, there are works correlated to this being developed for the organization from the 3-D information from the Cadastre in Databases.

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