TopoGeo: a data model for elaboration of cadastral survey plans and land register documents

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Abstract. *The deed description and the survey plan properly georeferenced in a geodetic system are essential items in the process of demarcation of urban or rural properties and land tenure regularization. Although there are several regulatory instructions for carrying out the survey of these properties, there is still no standardization regarding the storage of the land surveying collected data, as well as in the process of preparing its technical documentations. In order to meet this need, TopoGeo modelling was developed in this work, being implemented in Geopackage, a format developed by the Open Geospatial Consortium (OGC), as it is considered a suitable repository for the storage in a GIS the geographic features of a property, when compared to CAD formats like DWG and DXF. The Python programming language, on the other hand, made the use of this model more flexible and enhanced in QGIS, allowing it to perform specific tasks demanded by each type of work. This article, therefore, aims to present the TopoGeo model, describing its main feature classes and demonstrate the possibilities of application in QGIS with the use of the "LF Tools" plugin for the preparation of the necessary documentation for the land regularization process. Such implementations have ensured a better standardization for sharing the land surveying collected data, greater efficiency, better quality and, mainly, the reduction of costs with software licenses. The method developed in this work has already been applied in Brazil and can also be applied or adapted to other countries' specifications.*

Resumo. *O memorial descritivo e a planta topográfica devidamente georreferenciados a um Sistema Geodésico são itens essenciais no processo de demarcação de imóveis urbanos ou rurais e regularização fundiária. No Brasil, embora existam diversas instruções normativas para a realização do levantamento topográfico dessas propriedades, ainda não há uma padronização quanto ao armazenamento dos dados levantados topográfico, bem como no processo de elaboração de suas documentações técnicas. Para atender a essa necessidade, a modelagem TopoGeo está sendo apresentada neste trabalho, sendo implementada em Geopackage, um formato desenvolvido pelo Open Geospatial Consortium (OGC), por ser considerado um repositório mais adequado para o armazenamento em um SIG das feições geográficas de um imóvel, quando comparada a formatos CAD como DWG e DXF. A linguagem de programação Python, por outro lado, tornou o uso*

deste modelo mais personalizável no QGIS, permitindo a realização de tarefas específicas para cada tipo de trabalho. Este artigo, portanto, tem como objetivo apresentar o modelo TopoGeo, descrevendo suas principais classes de feições e demonstrar as possibilidades de aplicação no QGIS com a utilização do plugin "LF Tools" para a preparação da documentação necessária ao processo de regularização fundiária. Tais implementações têm garantido uma melhor padronização no compartilhamento dos dados levantados em campo, maior eficiência, melhor qualidade e, principalmente, a redução de custos com licenças de software. O método desenvolvido neste trabalho já vem sendo aplicado no Brasil e pode ser aplicado ou adaptado às especificações de outros países.

1. Introduction

Properly georeferenced cadastral survey plans and the deed description are essential documents for the regularization of properties and to get the title of property (Brasil, 2018; DEC, 2018). These documents hold the limits of the property and its boundaries, assuring protection of this property against claims for land tenure considered illegal and wrong ownership, being essential items for the solution of land conflicts (Vranić, 2014).

The Deed Description is a document that contains a natural language description of the limits of an urban or rural property, including its perimeter, parcels, boundaries and the area it occupies based on the technical data surveyed on the ground (DCT/DEC, 2010), with each limit point on the ground by its plane coordinates correctly georeferenced in the national geodetic system.

The survey plan is a type of specialized land parcel map, designed mainly to present the measurements and characteristics of a property through its azimuths, distances, areas and boundaries.

Buildings and other important features within or close to the property can also be represented in the plan. However, to consider the plan a georeferenced document and with a solid legal importance, the coordinates of the property's vertices must be evident in the plan, usually in a table called a synthetic deed description.

Nowadays, the main Brazilian official institutions responsible for cadastral survey and land regularization do not have a centralized solution for making survey plans and deed description for surveyed areas, either in the use of standard software or in the management of land survey collected data (França et al., 2020).

According to França et al (2020), topographic plans and other documents that compose the land survey are usually produced in proprietary software such as DataGeosis, Topograph, MicroStation or AutoCAD, which greatly limits its use due to the cost of maintenance and license update.

In this context, due to the rapid information systems evolution, QGIS, a free and open-source software, which has become an easy to use and open for implementing alternative solutions to achieve tasks. When using free software, it is possible to take the benefits and advantages of it, for instance: being able to use, copy and redistribute the software, without legal restrictions and save money on application license costs (Passos & França, 2018).

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Regarding the land survey collected data organization and structuring, QGIS allows integration with the Geopackage format, recently developed, and standardized by the Open Geoespatial Consortium (OGC, 2020). The adoption of this format is an adequate alternative for the storage of geographic features, when compared to the DWG or DXF formats, commonly used in CAD softwares.

In this work, the TopoGeo model was deployed using the Geopackage format, taking to consideration the Brazilian Spatial Data Infrastructure (*Infraestrutura Nacional de Dados Espaciais* - INDE) and the Technical Specification for Structuring Vector Geospatial Data (*Especificações Técnicas para Estruturação de Dados Geoespaciais Vetoriais* - ET-EDGV), version 3.0 (CONCAR, 2017). However, the ET-EDGV vector model had to have some amendments by adding new classes to the conceptual model to allow the storage of features used to define the property's boundaries.

The use of this specification has several advantages, as: the portability of files; the convenience of aggregating new data and updating information; the possibility of inserting thematic information to the cartographic data storage; the simplicity of building converting programs to extract data structured in other format standards.

Another advantage of using the TopoGeo model in QGIS is that its interface allows writing codes in the Python programming language, in order to enable the development of Scripts and Plugins for the automatic generation of technical components such as deed description, area/perimeter report and geodetic mark report, in addition to guaranteeing the quality of the collected data through validation rules (França 2018; França et al., 2018; França et al. 2020).

Based on the advantages showed above, this team has developed a method which uses QGIS for the elaboration of survey plans, data storage and automatic generation of technical documentations for surveys of property areas.

Given the above, the main objective of this work is to present the TopoGeo modelling and describe the usage of this model in the "LF Tools", a QGIS's plugin, to generate survey plans and documentations such the deed description.

Although the TopoGeo model and the LF Tools plugin were designed to assist in the regularization of properties in Brazil, a country with a large territorial dimension and old problems of land tenure regularization, the methodology presented in this work also serves as an azimuth for other countries with similar problems.

2. Methodology

This work had the following stages: the creation of the TopoGeo geospatial data model for storing survey data in a Geopackage file, the construction of Python Function for the automation of the survey plan elements and the implementation of processing tools in the "LF Tools" plugin. for the generation of the documentation inherent to the Survey (Figure 1).
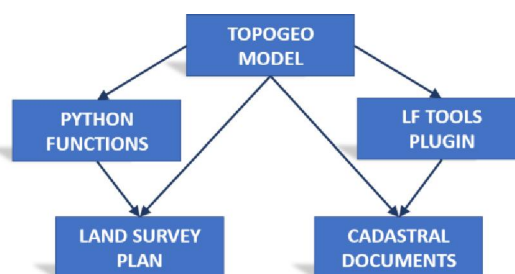
Figure 1. Workflow.

The database and the Python scripts used in this work were based on the QGIS 3.16 software, being tested with land surveys data.

2.1. TopoGeo Model

The processing, which starts from the land data survey to its storage, must guarantee the integrity of the elements and the communication between the various users of territorial information (Silva et al., 2018). However, currently the legacy data storage system does not guarantee the integrity of the elements, and, in some cases, it is not performed by automatic processes in which the documents are organized in a decentralized way in folders or files, creating a database that is difficult to manipulate and manage.

As geographic data is linked to terrestrial representations and it is described by its coordinates, the storage of these types of data must be performed through a geospatial database, which relates the descriptive information with their respective representation in the real world (Silva et al., 2018).

In this context, the TopoGeo model was deployed as a database, bringing together a set of conventions for storing spatial data in the Geopackage format, whose file extension is (.gpkg), an open and platform-independent standard (OGC, 2020).

Feature classes group instances of geospatial data with common characteristics and behaviours (CONCAR, 2017). These classes were deployed in Geopackage to reach the categories that are most worked on a survey plan, according to their functionality (Table 01).

Table 1. Categories and respective Feature Classes

Category	Feature Class
Limits	limit_point_p, boundary_element_l, property_area_a.
Reference	reference_point_p, border_construction_l.
Analysis (optional)	litigation_area_a, security_area_a.
Artificial Features (optional)	airstrip_a, building_a, curb_l, dam_a, deposit_a, energy_tower_p, field_court_a, grandstand_a, highway_l, housing_building_a, pipe_line_l, pool_a, power_line_l, railway_l.
Natural Features (optional)	altimetric_point_p, contour_line_l, drainage_line_l, flooding_land_a, vegetation_a, water_body_a.

2.1.1. Limits Category

This group refers to the classes: "Limit Point", "Boundary Element" and "Property Area". They are responsible for a property delineation.

The Limit Point class is used to define the vertices of the boundary lines of the perimeter of a property. The Boundary Element class is defined as the boundary line between the surveyed property and its neighbour, while the Property Area class is a single Polygon that delineates a property and that contains the main attributes about that property.

Tables 02, 03 and 04 show the attributes of the classes limit_point_p, boundary_element_l and property_area_a, respectively.

Table 02. Attributes' description of the class limit_point_p

Attribute	Type	Description
type	text(5)	CodeList: 1: Benchmark with identification; 2: Measured point and materialized, e.g., fence or wall; 3: Virtual point, not materialized and not occupied.
sequence	mediumint	Correct sequence of points that describes the polygonal.
code	text(11)	Name given to the vertex

Table 03. Attributes' description of the class boundary_element_l

Attribute	Type	Description
adjoiner	text(255)	Adjoiner's name
adjoiner_ label	text(80)	Abbreviation of the adjoiner's name for presentation on the map (optional).
start_pnt_ descr	text(255)	Short description of the starting point of the border (this information will appear in the deed description).
authorizer	text(255)	Name of the person responsible for signing the consent (optional).
authorizer_ id	text(14)	Authorizer's ID, if necessary (optional).
adjoiner_ registry	text(255)	Transcript or code of the adjoiner's property registry.

Table 04. Attributes' description of the class property_area_a

Attribute	Type	Description
property	text(200)	Property name or code.

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registry	text(100)	Property registration code.
transcript	text(255)	Transcript of the property registry.
owner	text(200)	Name of the property's owner.
address	text(200)	Location address or description.
county	text(150)	county or municipalty where the property is located.
state	text(2)	state where the property is located
survey_date	date	Date on which the survey was carried out.
surveyor	text(255)	Responsible for field survey.
tech_manager	text(200)	Technical manager.
prof_id	text(50)	Professional identification.
area	real	Property area in square meters.
perimeter	real	Property perimeter in meters.

2.1.2. Reference fixation Category

This category consists of the Reference Point and Physical Delimitation classes and represents the fixation of features on the ground. Both classes come from ET-EDGV 3.0.

According to CONCAR (2017), the Physical Delimitation class is defined as a natural or artificial structure that serves to delineate, separate, or protect an area. While the Reference Point class is a reference point, fixed on the ground, used in geodetic and topographic processes.

It should be noted that the attributes of these classes were amended to also store the information necessary for the automatic generation of the geodetic mark report information, and the perfect representation, according to the Brazilian specifications for topographic survey NBR13.133 and IR50-08 (ABNT, 1994; DCT/DEC, 2010).

2.1.3. Analysis Category

This category is composed by the Litigation Area and Security Area classes, which are optional for use, depending on the purpose of the plan. The Litigation Area class, in a legal context, refers to the polygon referring to areas of property rights conflict, and the Security Area class refers to features that involve road, railways, pipelines, and power lines, being characterized as a domain range to ensure security limits.

2.1.4. Artificial Features and Natural Features Category

The Artificial Features category is made up of classes that are used to contextualize the plan and to present features that were created or modified by man.

Classes in the Natural Features category are also used to contextualize the plan, representing natural characteristics of the land surface and around the property.

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These classes in both categories follow the same model as ET-EDGV 3.0 and, therefore, more information about the concepts and characteristics of these classes can be found in Annex A of that specification (CONCAR, 2017).

2.2. Development of Python algorithms in QGIS

The use of computational algorithms that provide optimized solutions has become an excellent alternative to suppress the need for manual operations in the elaboration of survey technical components, due to the productivity gain.

In this sense, a series of tools was developed, based mainly on the Python programming language.

In QGIS, Python can be used in several possibilities such as the creation of new custom functions, scripts, and plugins.

In this work, new functions were developed for the automation of elements of the survey plan and the "LF Tools" plugin for the generation of the following technical documentations: deed description, area/perimeter report, and geodetic mark report.

2.2.1. Python functions for survey plan automation

In QGIS, "expression" is a resource for dynamically accessing and manipulating the values of attributes, geometries, and variables of a project, in order to configure styles based on rules, set label's position, select features, insert data in the map layout, and create virtual fields between other features (QGIS Development Team, 2021).

In this work, for custom expressions, it was necessary to deploy new python functions that could use as parameters both the data available in QGIS Projects and the Geopackage layers for the construction of the survey plan of the property and automatic generation of its items, such as the Synthetic Deed Description, the Survey Data, the Meridian Convergence, and the Scale Factor (k).

Figure 2 shows an example of using an expression to create the synthetic deed description, having as input the class Limit Point, the sequence of the first and last vertex, the title of the table and the font size. The output of this function will be a string built in HTML (Figure 3).
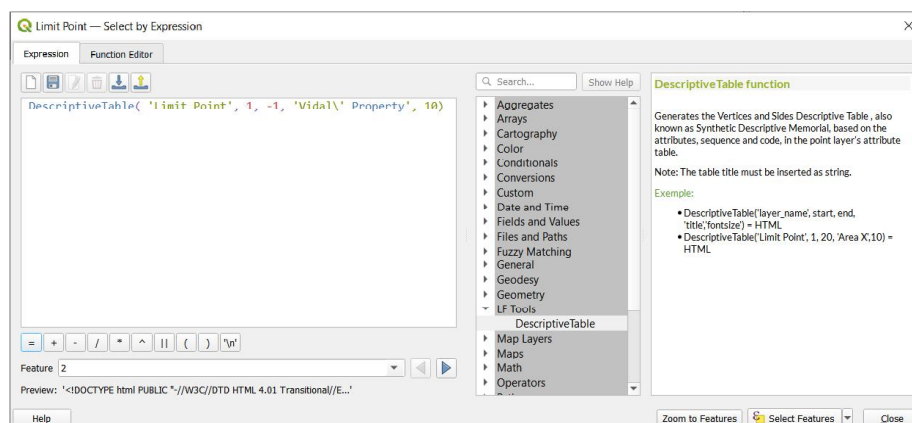

Figure 2. Function for creating synthetic deed description (*click on the picture to see it in full size*).
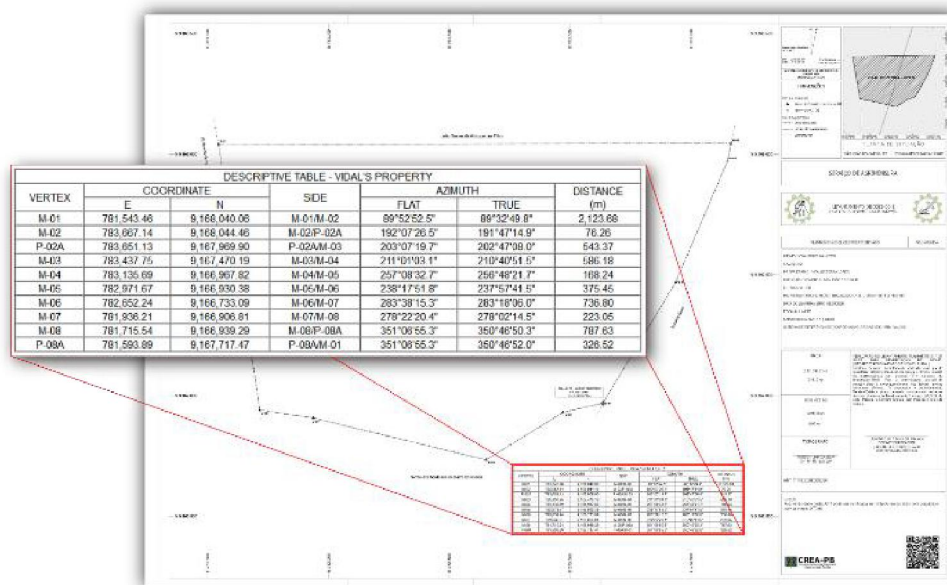
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| VERTEX | COORDINATE | | SIDE | AZIMUTH | | DISTANCE |
	E	N		FLAT	TRUE	(m)
M-01	781,543.46	9,168,040.06	M-01/M-02	89°52'52.5"	89°32'49.8"	2,123.68
M-02	783,667.14	9,168,044.46	M-02/P-02A	192°07'26.5"	191°47'14.9"	78.26
P-02A	783,651.13	9,167,969.90	P-02A/M-03	203°07'19.7"	202°47'08.0"	543.37
M-03	783,437.75	9,167,470.19	M-03/M-04	211°01'03.1"	210°40'51.5"	586.18
M-04	783,135.69	9,166,967.82	M-04/M-05	257°08'32.7"	256°48'21.7"	168.24
M-05	782,971.67	9,166,930.38	M-05/M-06	238°17'51.8"	237°57'41.5"	375.45
M-06	782,652.24	9,166,733.09	M-06/M-07	283°38'15.3"	283°18'06.0"	736.80
M-07	781,936.21	9,166,906.81	M-07/M-08	278°22'20.4"	278°02'14.5"	223.05
M-08	781,715.54	9,166,939.29	M-08/P-08A	351°06'55.3"	350°46'50.3"	787.83
P-08A	781,593.89	9,167,717.47	P-08A/M-01	351°06'55.3"	350°46'52.0"	326.52

Figure 3. Table with vertices and sides (synthetic deed description) created automatically in HTML (*click on the figure to see it in full size*).

2.2.2. *Cadastral documents by the LF Tools QGIS plugin*

The tools deployed in the LF Tools plugin for the automatic creation of cadastral documents are as follows: deed description, area/perimeter report and geodetic mark report.

The Deed Description must also contain the textual description of the boundary elements and the notorious limit points in the terrain, in addition to the coordinates, azimuths and distances. Therefore, for the deed's generation, it is necessary that the attributes of the Limit Point (point), Boundary Element (line) and Property Area (polygon) classes are previously correctly filled.

Another document that must be present in the land survey works is the Area and Perimeter report, where all vertices in geodetic plane coordinates, azimuths, and measurements on each side, in addition to the final calculation of perimeter and area.

The documentation of the geodetic marks of a property is an essential procedure in the work of geodetic surveys. That is why they can be reoccupied as a basis for future GNSS placements or total station position. For this reason, a tool was also implemented to automate the preparation of this document.

The geodetic mark report tool basically has the Reference Points layer and a string as input parameters, indicating exactly the code (or name) assigned to the mark that the document description is to be created.

Figures 4, 5 and 6 illustrate and exemplify the input parameters for each tool. In all cases, the output file will be in HTML format, which can be a temporary file or the path where it will be saved on the machine. In both situations, the generated file can be viewed and printed directly in QGIS, as well as being able to be opened in any text

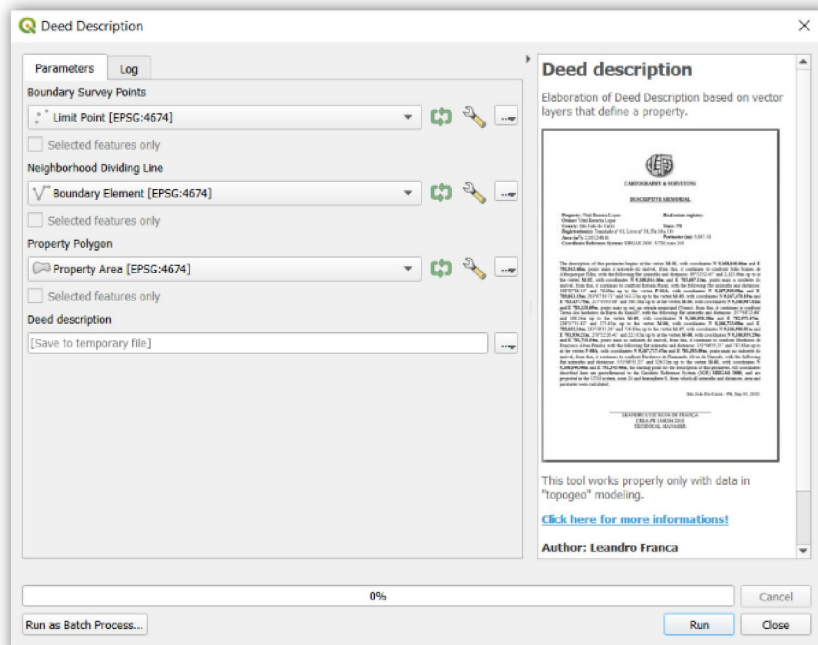editor such as Libre Office Writer or Microsoft Word for further adjustments and formatting.

Figure 4. Tool to create the Deed Description (*click on the picture to see it in full size*).
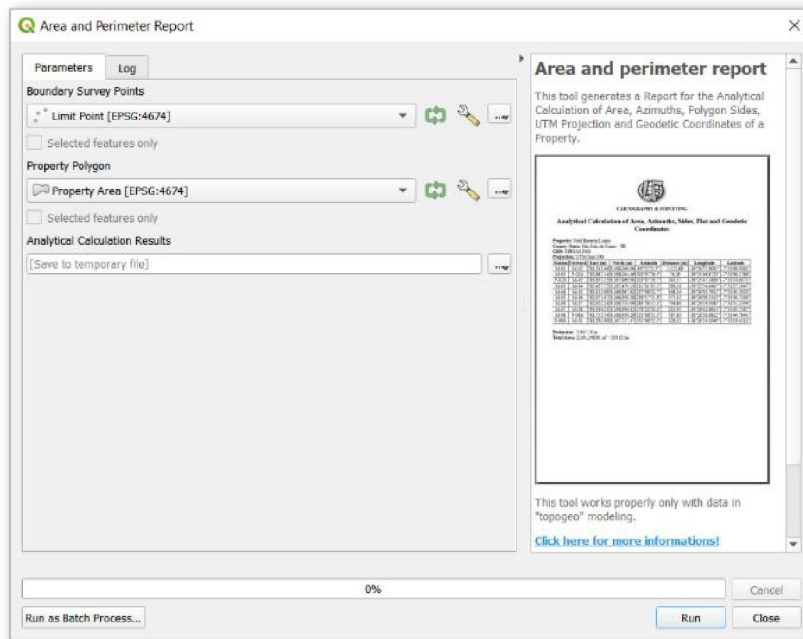

Figure 5. Tool to create the Area and perimeter report (*click on the picture to see it in full size*).
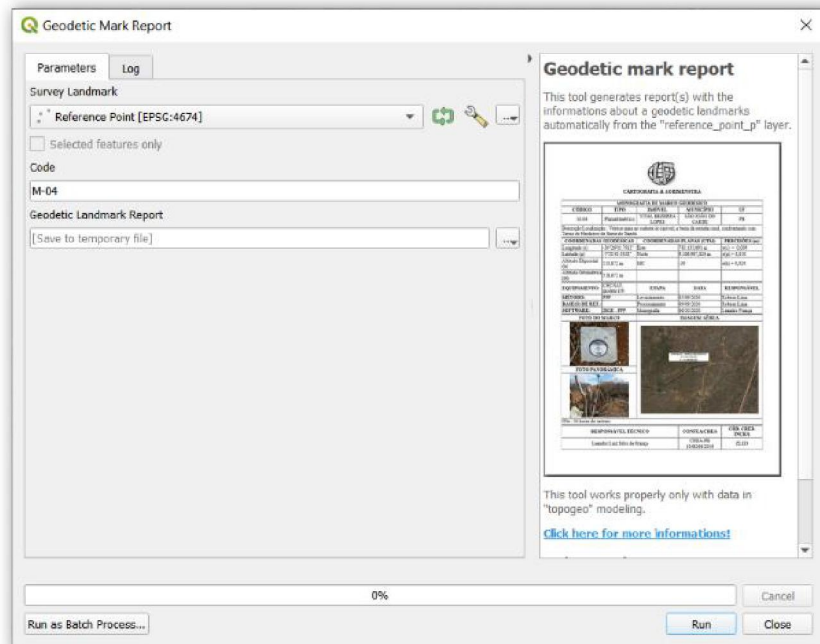
Figure 6. Tool to create the geodetic mark report information (*click on the picture to see it in full size*).

3. Results

As results, the Survey Plan, the Deed Description, the Area and Perimeter Report, and the Geodetic Mark Description were automatically prepared.

The plans can be created in different paper sizes using SVG templates, which follow the standardization of IR50-08 (DEC/DCT, 2010).

Figure 7 is an example of a plan drawn up in QGIS in paper size A1 resulting from the survey of a rural property.
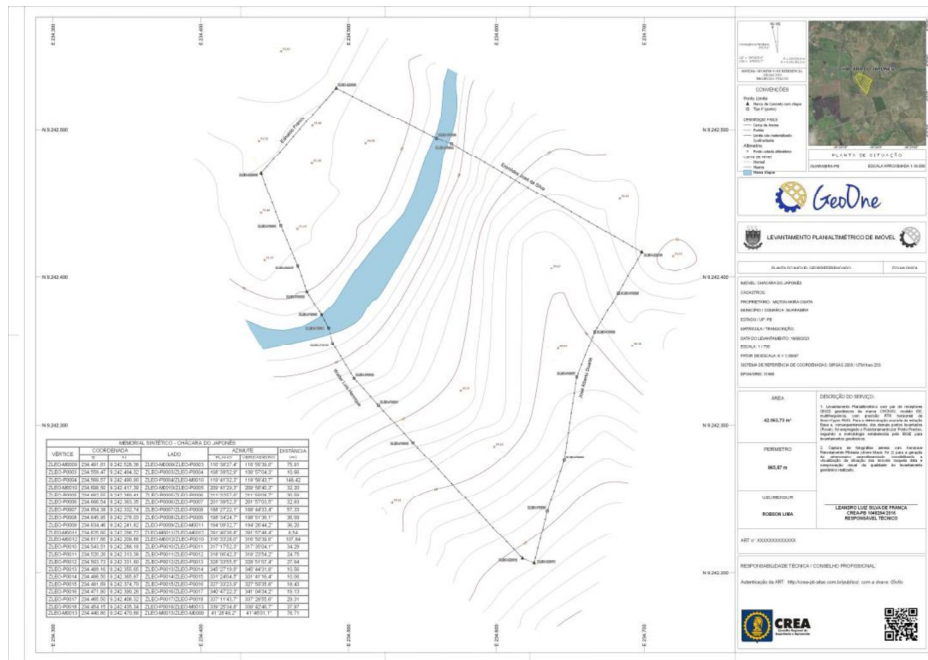
Figure 7. Survey plan prepared at QGIS (*click on the picture to see it in full size*).

Figure 8 is an example of a plan with orthomosaic created from images captured by Unmanned Aerial Vehicle (UAV), in an urban area to identify parcels in a forensic expertise in cartography.
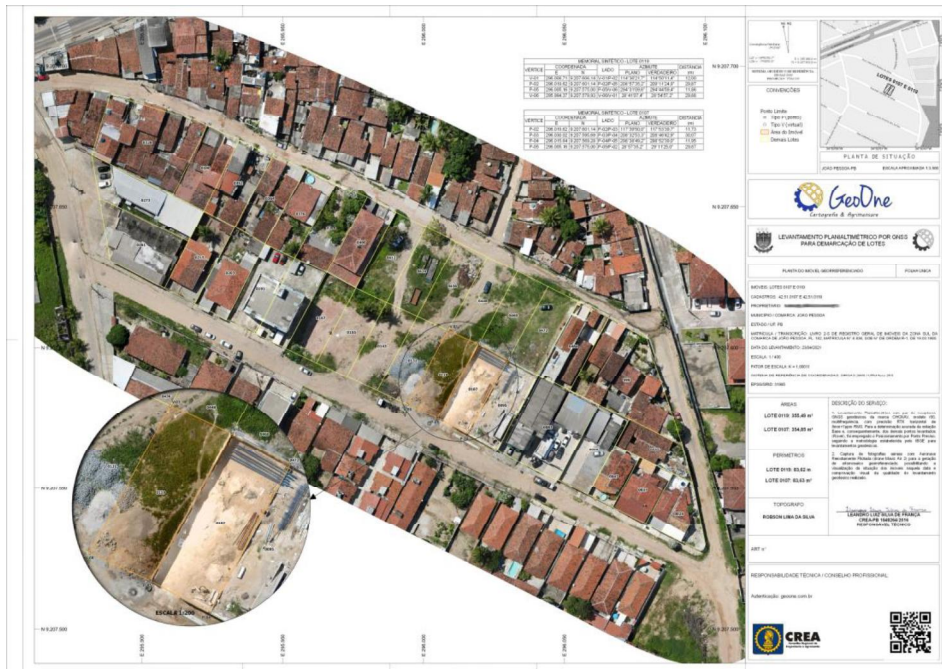

Figure 8. Survey plan with drone's orthoimage (*click on the picture to see it in full size*).

In Figure 9, examples of the documentation generated from the layers of the property's delimitation and fixation of the reference points are presented.
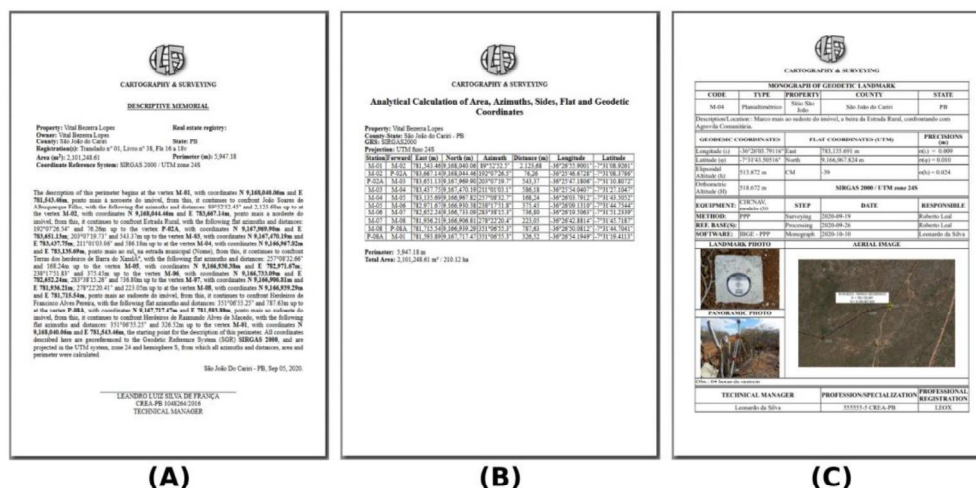

Figure 9. (A) Deed Description, (B) Area and Perimeter Report, and (C) Geodetic Mark Description (*click on the picture to see it in full size*).

4. Conclusion

Based on the results obtained, the TopoGeo model, combined with the documentation tools of the LF Tools plugin, proved to be efficient in the elaboration of the Cadastral Survey and Land Register technical documentation, with productivity gains and cost reduction on the use of proprietary software licenses.

As for the method of Elaboration of survey plan and automatic generation of the survey documentation in QGIS, this has been applied since 2019 in the Brazilian Army (França et al., 2020).

The method developed in this work is also in line with the policies of using Free Software in the Brazilian Government, guaranteeing independence and economy of public resources.

The publication of this methodology also serves as a model for new applications in other cases of properties georeferencing and land regularization by Brazilian and international public organizations.

In addition, the TopoGeo model and the LF Tools plugin are available in English and Portuguese, and the methodology presented in this work can be adapted to the specifications of the user's country, in accordance with its standards such as, for example, Inspire in Europe (Femenia-Ribera, 2021; Bartha & Kocsis, 2011).

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