Methodological cadastral baseline for the multipurpose physical survey of real estate using SFM-CRP photogrammetric techniques for 3D reconstruction.

Yosef CORTES, Melixa GOMEZ and Johan AVENDAÑO, Colombia

Key words: 3D reconstruction; vertical component; three-dimensional cadaster; multi-purpose cadaster; SFM-CRP.

SUMMARY

With the adoption of the Multipurpose Cadaster Public Policy, Colombia seeks to strengthen property information under the principles of greater legal certainty and efficiency in the real estate market. To achieve this, it is necessary to strengthen both institutional and technological capacities to obtain reliable and interoperable data. However, the limited technological resource to inventory the physical dimension of the properties has not favored the complete identification and characterization of their attributes, adding to the demand of effort required in the field to carry out a massive property survey. This leads to the deepening of the use of low investment tools that provide accurate and multidimensional data to fill the gaps in cadastral information, especially in its vertical component. One of the 3D modeling proposals is the Structure from Motion technique based on close-range (SFM-CRP), implemented in this research for the three-dimensional reconstruction of facades for cadastral purposes at the scale of sidewalk and municipality. The mean square error of the 3D reconstructions showed values from 0.000008 to 0.09 meters, proving its feasibility to consolidate a high-rise cadaster.

RESUMEN:

Con la adopción de la Política Pública de Catastro Multipropósito, Colombia busca fortalecer la información predial bajo los principios de mayor seguridad jurídica y eficiencia en el mercado inmobiliario. Para lograrlo, es necesario fortalecer las capacidades tanto institucionales como tecnológicas para obtener datos confiables e interoperables. Sin embargo, el limitado recurso tecnológico para inventariar la dimensión física de los inmuebles no ha favorecido la completa identificación y caracterización de sus atributos, sumándose a la demanda de esfuerzo requerido en campo para realizar un levantamiento predial masivo. Esto lleva a profundizar el uso de herramientas de baja inversión que proporcionen datos precisos y multidimensionales para llenar los vacíos de información catastral, especialmente en su componente vertical. Una de las propuestas de modelado 3D es la técnica *Structure from Motion basada en close-range* (SFM-CRP), implementada en esta investigación para la reconstrucción tridimensional de fachadas con fines catastrales a escala de acera y municipio. El error cuadrático medio de las reconstrucciones 3D mostró valores de 0,000008 a 0,09 metros, demostrando su viabilidad para consolidar un catastro de rascacielos.

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1. INTRODUCTION:

With the adoption of the Multipurpose Cadaster Public Policy, Colombia seeks to strengthen property information under the principles of greater legal certainty and efficiency of the real estate market. In this sense, the national government establishes in the National Development Plan 2023-2026, to update cadastral information by 70% by 2026, in order to minimize conflicts in the process with registry effects and consolidate the comprehensive rural reform, which articulates the processes of value, tenure, land use and development, environmental management and infrastructure development [1]. In order to achieve this goal, it is not only necessary for the different entities responsible for the work to work together and synergize, but also to strengthen both institutional and technological capabilities to obtain reliable and interoperable data. In addition, it should be considered as one of the links that will facilitate the migration from a traditional cadaster to one with a multipurpose approach, which integrates physical, legal, fiscal and economic aspects.

Precisely, CONPES 3859 denoted the main obstacles that impede the scope of a modern cadaster. The limited technological resources to inventory the physical dimension of the properties have not favored the complete identification and characterization of their attributes [2]. However, with the entry into force of CONPES 3958 of 2019, the aim is to reduce the information gaps in and between each component of the cadaster, by promoting the use and incorporation of efficient instruments that contribute to streamlining the collection of property information [3]. Massive land survey requires a great effort in the field. For years, it has been carried out with conventional techniques based on direct methods, which has a taxing impact on cost and time variables. This causes institutional wear and tear when it comes to prioritizing resources and geographic locations for cadastral management. Although this inventory of the country has been achieved with traditional procedures, especially 2D cartographic applications, there are still gaps in the altimetric representation of real estate [4].

Deepening the application of low-investment tools that provide accurate and multidimensional data has become a necessity in order to respond to the complexities of the urban densification process and move towards a three-dimensional cadaster. Thanks to the theoretical and technical foundations provided by the different photogrammetric techniques, the challenge of extracting three-dimensional information from objects is becoming more agile; in fact, with the technological boom, advances have been made in artificial vision. One of the 3D modeling proposals is the Structure from Motion (SFM) technique, based on the reconstruction of the scene from its movement [5]. This is achieved, with photographs taken from different distances and angles, facilitating the translape without knowing the positions in X, Y, Z [6]. In addition to obtaining a relative three- dimensional model, it is possible to extract it in absolute coordinates from control or known points [7].

Jover et al. (2016) indicate that, with this technique, scene geometry, camera positioning, orientation and deformations are solved by means of computational calculations, favoring the extraction of metric and geometric parameters from the 3D information obtained (scaled and georeferenced). Its ease of application and accessibility from the economic point of view, makes it more attractive to develop three-dimensional modeling at a detailed scale. Even, the implementation of SFM based on Close-Range Photogrammetry (CRP) has been widely used in Europe for architectural reconstruction purposes [9].

Conventional photogrammetric methods have been potentially employed in the abstraction of information through the use of aerial photographs or satellite scenes. Its principle lies in the identification of homologous points from different angles, from which a three-dimensional restitution can be obtained. From there, the idea of applying short-range SFM-CRP photogrammetry for the three-dimensional reconstruction of real estate with low-cost sensors arises, making possible the physical cadastral survey.

In Colombia, related research has also been developed. Muñoz (2017), for example, generated a three-dimensional model using images captured with a cell phone camera; and supported by MATLAB programming language, re-constructed the scenes identifying the characteristics of the studied element. Along the same lines, Cortes et al., (2022), made a very interesting contribution, as they implemented the SFM-CRP technique for cadastral purposes, achieving the physical identification of six real estate properties by obtaining photograms captured with a cell phone camera. Although it is a great advance, it must be recognized that it is still necessary to deepen its implementation, especially when thinking about the goal projected in the National Development Plan, by virtue of the cadastral update of the country. Therefore, it is necessary to implement these techniques on a larger scale. In this research, the SFM-CRP technique was chosen to be applied at both the rural and municipal levels, and the results and discussions will be shown for each of them.

2. MATERIALS AND METHODS:

2.1 Study Area:

In irder to evaluate the versatility and wide applicability of the 3D reconstruction technique, a village in the municipality of Cumaral, Meta, was taken as a pilot plan. San Nicolás is located at latitude: 4.16631, lonhitufe: -73.39, to the southwest of the municipality and 40 kilometers from Villavicencio. It is an area woth a flat slope because its average elevation is 295 meters. The village is made up of a total of 319 properties, 120 of which are located in the town center. For the purposes of this research, information was collected from the blocks where an urban sprawl was identified; this includes control points, videos of the facades, height data and measurements of the width of the facade for validation of the 3D property reconstruction. Another area studied corresponds to the municipality of Sesquilé.

It is located at latitude 5.045, longitude -73.797, 45 km northeast of Bogota, with an average altitude of 25951 meters above sea level. In addition, it is made up of a total of 362,194 predates according to the information contained in its 2015 cadastral base. The data collection was carried out in specific areas of the municipal capital to demonstrate that the methodology can be implemented in places with steep slopes.

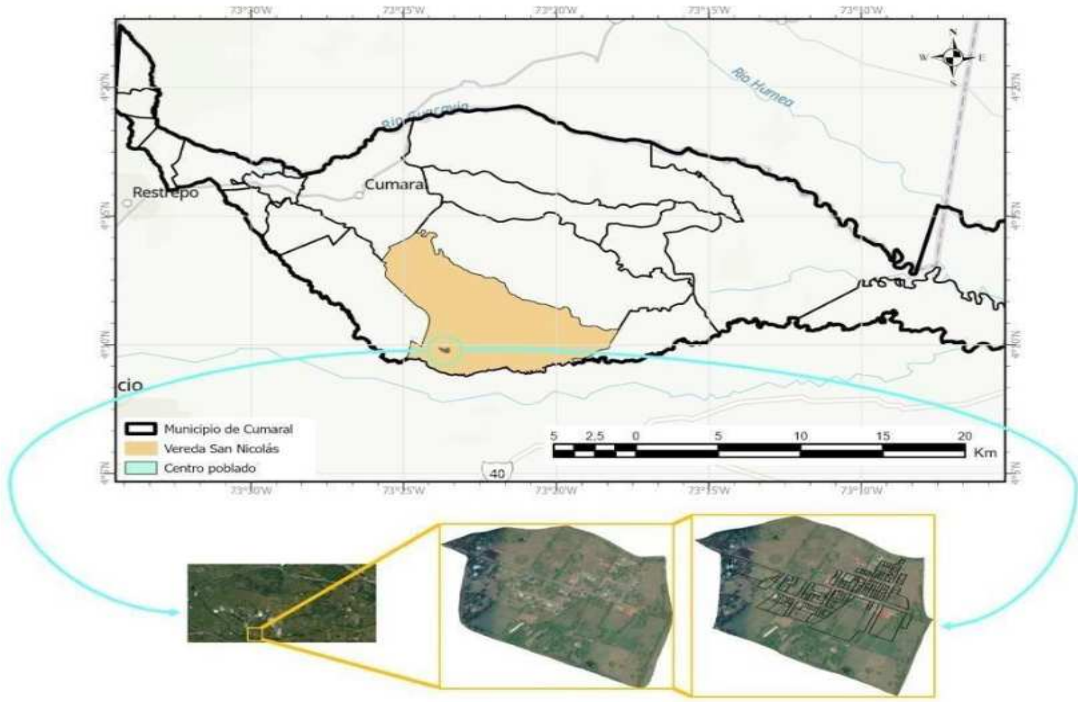

Figure 1. Pilot Area: Vereda San Nicolás (Municipality of Cumaral).

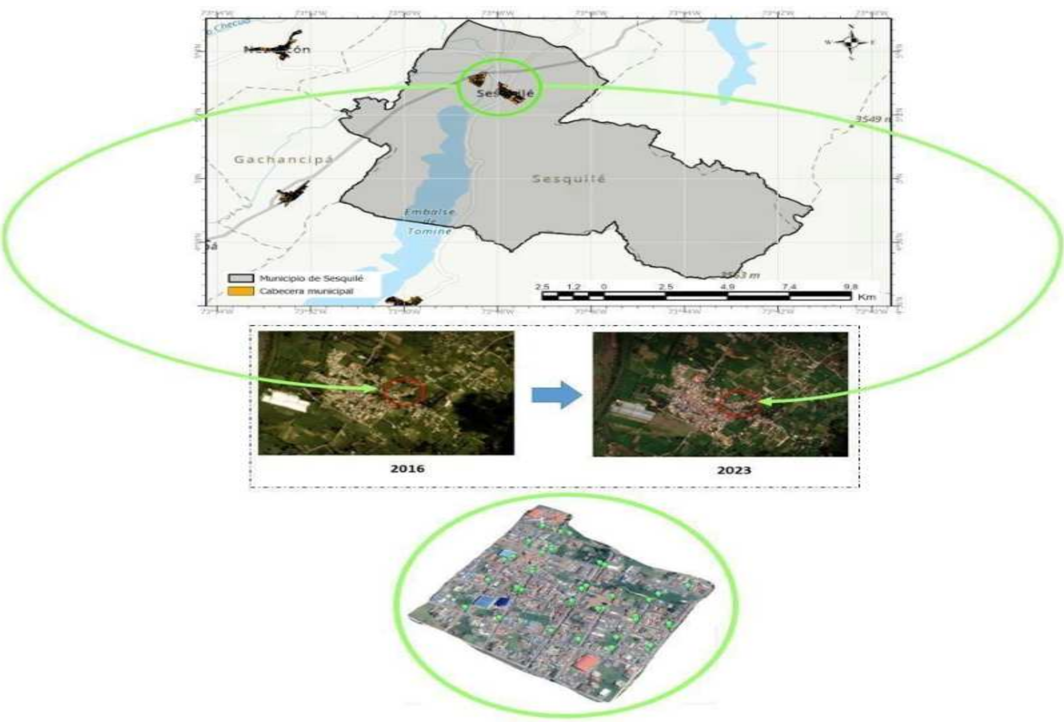

Figure 2. Study Area: Municipality of Sesquilé.

2.2 Application of the SFM-CRP technique:

This applied research project was developed in: A). The construction of the frame of reference, B). Structuring of a methodological proposal for 3D reconstruction with a physical-predial approach, C). Implementation of the SFM-CRP technique for 3D reconstruction-village level. And, D). Implementation of the SFM-CRP technique at a municipal level. The workflow was the same for each of the study areas, both at the village and municipality level. The process began with the capture of information in the field, corresponding to the taking of videos and control points. Also, to validate the results of the reconstruction with respect to the real values, measurements were made of the frontal distances and the heights of some facades. Figure 3 illustrates the procedure for the three-dimensional reconstruction of faces for cadastral purposes.

The first step is to enter the video captured in the field and the coordinate system with which the control points were taken into the specialized processing software. Subsequently, the geolocation of the images is provided by entering an output coordinate system. The software performs a point matching process (internal and external orientation), linking the parameters of: coordinates of the main camera point, camera position in space, the main distance, the center of projection, camera end point coordinates (omega, phi, kappa) and lens distortion; giving the result as a cloud of crossing points with which it is possible to mark the control points (X, Y, Z). Subsequently, the cloud of passing points is reoptimized to obtain a geo-referenced cloud. This is subjected to a densification process and then depurated. The product corresponds to a point cloud classified into coverages: soil, buildings, vegetation and other elements. Finally, from the densified cloud, the physical identification of the buildings and the linkage with the information contained in the cadastral base is performed.

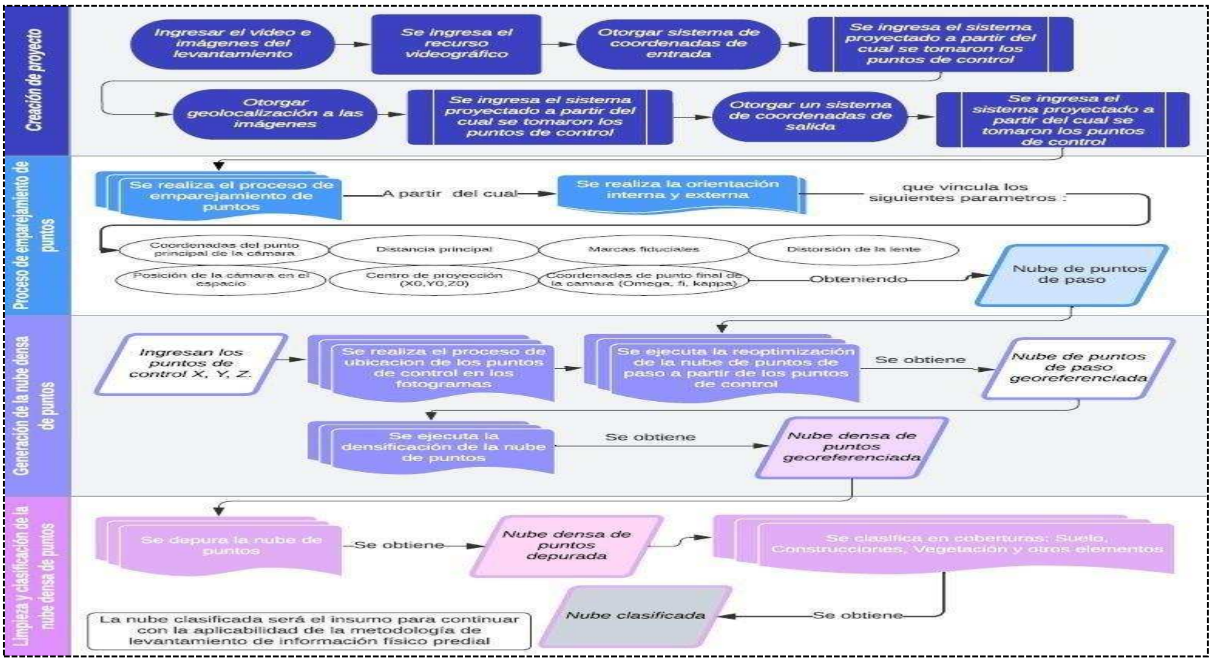

Figure 3. Methodology for 3D reconstruction of facades for cadastral purposes using the SfM-CRP technique.

3. RESULTS:

3.1 Implementation of the SFM-CRP technique in San Nicolás (Cumaral):

The three-dimensional reconstruction of the San Nicolás district was achieved with the generation of 600 frames per block, and georeferencing, by means of 21 control points taken in the field at ground level. For the latter process, the reference system was WG84 / UTM Zone 18N. Regarding processing times, the densification of the point clouds took 30 minutes and the generation of the textured mesh took 40 minutes. It should be noted that these times do not include the time taken for the classification of the point clouds, which depends on each photo-interpreter and the number of densified points.

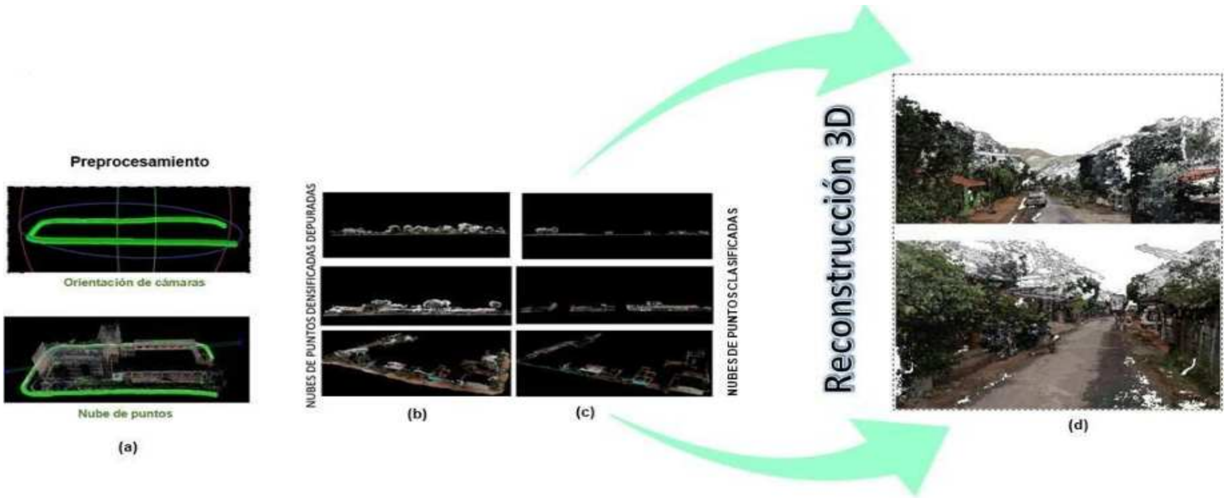

Figure 4. Point clouds of the San Nicolás village: (a) georectified point clouds, (b) densified point clouds, (c) classified point clouds and (d) result of the three-dimensional reconstruction.

Six (6) densified and classified point clouds were obtained for the village. The values of the ground pixel size (GSD) and root mean square error (RMS) are presented below. As for the positioning errors of the terrain control points, values approximately between 0.000037 to 0.20 meters in X, 0.00003 to 0.27 in Y, and 0.000008 to 0.09 in Z were obtained.

Table 1. GSD and RMS values of the densified point clouds - San Nicolás village.

# Cloud	GSD (cm)	RMS Error X*	RMS Error Y*	RMS Error Z*
1	1.21	0.003146	0.005241	0.000976
2	1.28	0.197585	0.269953	0.085804
3	0.79	0.006373	0.007185	0.001445
4	0.85	0.030572	0.019747	0.000940
5	0.70	0.013030	0.013737	0.000426
6	3.11	0.000037	0.000029	0.000008

* **The units of measurement for X, Y and Z are in meters.**

3.2 Implementation of the SfM-CRP technique in the municipality of Sesquilé:

The three-dimensional reconstruction of an area of the municipal capital of Sesquilé was achieved with the generation of 750 frames per block, and georeferencing, by means of 47 control points taken in the field at ground level. Likewise, WG84/UTM Zone 18N was assigned as reference system. The densification of the point clouds took 37 minutes and the generation of the textured mesh took 50 minutes.

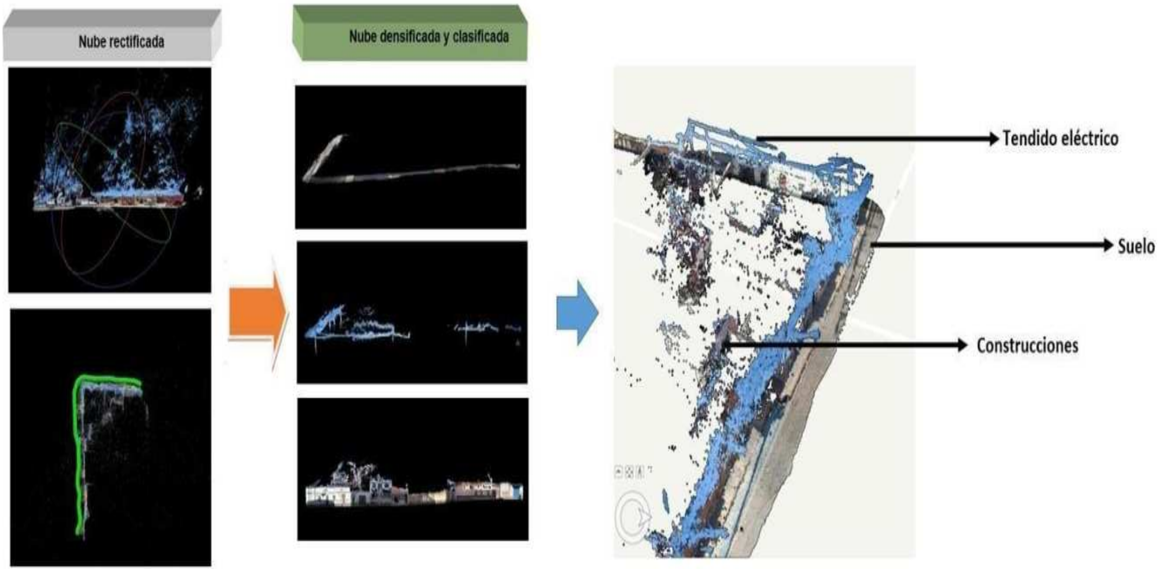

Figure 5. Densified georectified and classified point clouds - Sesquilé.

Figure 6. Unified Densified Point Clouds – Sesquilé.

The reconstructed area comprised a total of nine (9) densified and classified point clouds. GSD and RMS values are presented below. Regarding the positioning errors of the terrain control points, values were obtained approximately between 0.001 to 0.019 (m) in X, 0.0012 to 0.0068 in Y, and 0.000099 to 0.013 in Z.

Table 2. GSD and RMS values of the densified point clouds - Sesquilé municipal seat.

# Cloud	GSD (cm)	RMS Error X*	RMS Error Y*	RMS Error Z*
1	0.56	0.011005	0.006805	0.013039
2	0.70	0.002557	0.004645	0.000099
3	0.62	0.001519	0.003076	0.000161
4	0.62	0.002276	0.001721	0.000148
5	0.81	0.018958	0.004078	0.000787
6	0.71	0.001000	0.001200	0.000200
7	0.67	0.007263	0.004065	0.0028468
8	0.67	0.007263	0.004065	0.0028468
9	0.59	0.0012595	0.0014605	0.0001235

***The units of measurement for X, Y and Z are in meters.**

3.3 Validation of metrics in vertical and horizontal component

For the validation of the metrics, the values taken in situ were compared with those of the software. In the case of the San Nicolás neighborhood, there were no variations in height. With respect to the measurement of facades, differences of 1 to 4 cm were identified. For the municipal seat of Sesquilé, a difference in the frontal measurement of 1 to 2 cm was obtained, and for the vertical component, no changes were recorded.

Figure 7. Validation of metrics for the San Nicolás trail.

Figure 8. Validation of metrics at the Sesquilé municipal seat.

3.4 Identification of cadastral management processes for the San Nicolás district:

However, given the high degree of cadastral outdatedness, it was decided to record the physical changes associated with the cadastral codes with respect to the obstruction by number of floors, lots without construction to lots with construction, character of dwellings, lots that continue to be lots and conservation in height.

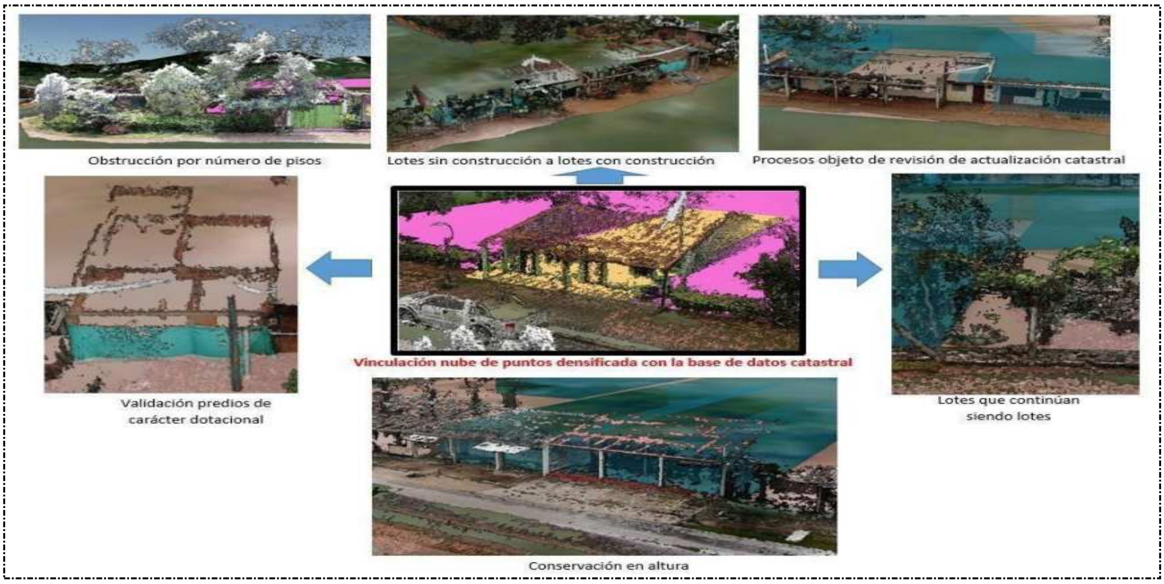

Figure 9. Identification of physical changes in the San Nicolás rural district.

Thanks to the three-dimensional reconstruction of 42 properties for the San Nicolás district, it was possible to identify those that could be subject to cadastral revision and conservation. Table (3) lists the number of properties for each case.

Table 3. Cadastral management processes identified in the San Nicolás district

Identified cases subject to cadastral review: 42 pre-God	Identified cases subject to cadastral conservation
Registered with 0 apartments that with cadastral update. The number of properties would be 1 floor: 26 properties,of which 2 are presumed to be for use by the public.	10 plots
Registered as 1-story properties, which are currently lots without construction: 2 lots.	
Registered with 0 apartments that with cadastral update pa-2 floors: 1 property	
Possible disengagements: 3 properties	
Possible encompasses: 1 property	

In addition, there was evidence of an increase in the built-up area of a property, giving way to a mutation and possible invasion of public space.

Figure 10. Identification of the main cadastral changes in Sesquilé.

3.5 Identification of cadastral management processes at Sesquilé.

In the case of the municipal capital of Sesquilé, a total of 74 pre-gods were reconstructed, of which 24 were identified as the object of cadastral revision, 3 of formation and 47 of conservation. Table (4) shows a breakdown of the cases observed:

Table 4. Cadastral management processes identified in Sesquile

CADASTRAL MANAGEMENT PROCESSES		
Cases identified and subject to cadastral review: 24properties	**Cases identified for training cadastral**	**Cases identified for preservation cadastral information**
Registered with 0 floors than with update would be upgraded to 1 floor: 2 Properties	3 plots	47 plots
Registered as 1-story properties that arecurrently- The lots are not built-up lots: 0 properties.		
Registered with 0 floors than with update would be upgraded to 2 stories: 5 properties		
Registered with 1 floor than with upgrade would be upgraded to 2 stories: 7 properties		
Registered with 2 floors than with upgrade cadastral would go to 3 floors: 9 properties		
Possible disengagements: 1 Disengagement of the property (2573601000000002100420000000000) from 1 to 3 2-story houses each		
Possible encompasses: 0		

4. DISCUSSION:

Resolution 471 of 2020 and its amendment, Resolution 529 of 2020, established the minimum technical specifications that must be met by the final products of the basic official cartography in Colombia: orthoimages, digital terrain models (DTM) and the vector cartographic database. However, the standard does not stipulate those associated with a three-dimensional cadastre. One of the technical specifications of ISO 19157:2013, adapted in the Colombian regulatory framework to evaluate the quality of geographic information is the absolute positional accuracy. Resolution 529 of 2020 defines the root mean square error (RMS) as the method for evaluating positional accuracy in the horizontal and vertical components. The latter, specifically for the

DTM. Although explicitly, the three- dimensional reconstruction is not a digital terrain model, its most relevant attribute is the height component.

In this sense, the results of the village and municipal level are compared with the values of RMS (m) regulated to evaluate the vertical accuracy. The mean square error given by the software yielded values from 0.000008 to 0.09 meters for the San Nicolás district of the municipality of Cumaral and from 0.000099 to 0.013 (m) in Sesquilé, Cundina- marca. These ranges are within the margin established in the standard, since from the detailed to the semi-detailed scales, the RMS for Z should be: 0.3 meters for 1K, 0.6 (2K), 1.5 (5K), 3 (10K) and 7.5 (25K). Another point to be conceptualized in the discussion is the result of the comparison between the metrics taken in the field and those of the software. The null changes in height (z) and the minimum changes in the horizontal component (x, y) allow us to consider the validity of the SFM-CRP technique for the 3D reconstruction of facades, since the differences are below the values of the margin determined in the current regulations for products that present the variable (z).

All of the above allows us to deduce that three-dimensional reconstructions using the SfM-CRP technique are significant for consolidating a high-altitude cadastre. This technique achieves optimal results due to its minimal accuracy errors. In addition, its ability to interoperate with different geographic information systems facilitates the storage of information. On the other hand, the overlapping of the videographic resource allows an adequate fragmentation of the images, making possible the identification of points in multiple images, due to the repeated sequence of the frames. Finally, with the 3D reconstructions at the scale of the village and municipality, the association with alphanumeric data contained in the cadastral base was achieved, resulting in the identification of properties that can be subjected to cadastral management processes. This information is extremely valuable in the framework of the implementation of the multipurpose cadastre.

5. CONCLUSIONS:

With the development of this research project, it is concluded that 3D reconstruction provides valuable information for the multipurpose cadastre, by providing an approximation of the exterior aspects of the buildings, specifically the facade and finishes. This, when associated with alphanumeric data from the cadastral database, made it possible to identify the properties that are the object of cadastral management processes in the San Nicolás (Cumaral) district and in the municipal capital of Sesquilé. Likewise, the accuracies obtained in the vertical and horizontal components provided assurance of the veracity of the applied technique. The RMS values are within the range established in the current regulations for cartographic products that include the height variable.

However, with the generation of the 3D reconstruction, the absence of regulations for a three-dimensional cadastre became evident. Finally, the methodological proposal was implemented at different scales (village and municipality) and topographic terrain conditions, demonstrating its versatility, flexibility and low cost of application. Therefore, it can be considered as a potential indirect method to move from a two-dimensional cadastre to a three-dimensional one.

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Ph.D. Johan Andrés Avendaño Arias

Geographer of the Universidad Nacional de Colombia (UNAL), Cadastral Engineer and Geodesist of the Universidad Distrital Francisco José de Caldas (UDFJC), Specialist in Public Policy Analysis. Master's degree in Territory, Space, and Society, and Ph.D. in Geography, Development, Territory, and Society from the École des Hautes Études en Sciences Sociales (EHESS) of France. University lecturer and researcher, with extensive experience as a consultant and analyst in areas such as public policy, cadaster, planning, poverty, and territorial management. Current Director of the Directorate of Research and Perspective of the IGAC.

Yosef Harvey Cortes Millan
Cadastral Engineer and Geodesist. Official Researcher at the Institute of Geography Agustín Codazzi (IGAC).

Kellith Melixa Gómez Urrego
Environmental Engineer. Official researcher at the Institute of Geography Agustín Codazzi (IGAC).

CONTACTS:

Yosef Harvey Cortes Millan
Institute of Geography Agustín Codazzi
(IGAC)
Carrera 30 # 48-51
Bogotá DC., Colombia
Tel. +57 312 5549960
Email: yosef.cortes@igac.gov.co
Website: https://www.igac.gov.co

Kellith Melixa Gómez Urrego
Institute of Geography Agustín Codazzi
(IGAC)
Carrera 30 # 48-51
Bogotá DC., Colombia
Tel. +57 311 2973162
Email: kellith.gomez@igac.gov.co
Website: https://www.igac.gov.co

Johan Andres Avendaño Arias
Institute of Geography Agustín Codazzi
(IGAC)
Carrera 30 # 48-51
Bogotá DC., Colombia
Tel. +57 312 3677415
Email: johan.avendano@igac.gov.co
Website: https://www.igac.gov.co