3D Cadastres for Complex Extra-Legal and Informal Situations

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Key words: informal tenure, 3D cadastre

SUMMARY

3D cadastre research and development is most often directed at high valued urban land. The value of the land and the economic activity generated from transactions in this urban space potentially support the cost and time spent on establishing and maintaining a 3D cadastre. Data acquisition for construction and maintenance of the 3D cadastre is also simpler in the regular and formally planned and surveyed structures of the high value urban environment. Low-income, urban areas of informal tenure and informal development, however, also need and can benefit from a land administration system supported by a 3D cadastre but are neglected in the 3D cadastre research. This paper explores the need for 3D cadastres in low-income but densely structured urban settlements, using the example of a case study in Trinidad and Tobago. Mechanisms are required for quick and cost effective construction of a 3D cadastre in this type of area to support land management and regularisation procedures. LiDAR is examined to differentiate structures in densely occupied environments where limited information and limited resources must be able to be used for managing the land and also protecting informal rights. The difficulties of manually or automatically discriminating between close and overlapping structures and boundaries are highlighted and it is found that there is still a need for adjudication and verification of boundaries even when physical features can be discerned.

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1. INTRODUCTION

In most instances the 3D cadastre is directed at condominiums and apartments in urban areas where the high value of the land drives the need for, and supports the cost of precise positioning of cadastral boundaries in initial demarcation and subsequent redefinition (Oldfield et al 2018; Griffith-Charles and Edwards 2014; Griffith-Charles and Sutherland 2013; Rajabifard 2014; El-Mekawy, Paasch and Paulsson 2014; Kalantari and Rajabifard 2014). These land units are usually regular in shape and conform to planning standards. However, dense living and occupation spaces occurring in informal urban areas also require precise capture of boundaries to prevent conflict in regularisation, and land readjustment. The cost of the data acquisition for a 3D cadastre, in these instances, is high and is not justified by the value of the land but can be justified by the value to the society for reducing conflict, improving well-being, and providing for sustainable development and the achievement of the SDGs and the Urban Agenda.

Despite the value of the data capture to the state as a whole, there may still be insufficient resources to acquire data comprehensively over the urban area. Procedures for data acquisition and construction of the 3D cadastre can be facilitated in the formal sector by statutory processes where the cost is borne by the applicant who supplies the parcel boundary data, such as in the building construction and facilities management, (Mekawy M. and A. Östman. 2012) building permit (Oldfield et al 2018), land subdivision (Thompson et al 2018), or parcel sale or mortgage transaction processes. This reduces the burden of cost on the state for construction and maintenance of the cadastre. However, informal occupants do not interface with or abide by the formal administrative processes and usually cannot afford to. If a comprehensive 3D cadastre is desired for all its positive characteristics for land management and land administration, then other means of data acquisition will need to be explored.

It is now accepted that the cadastral system may be comprised of various datasets of variable quality integrated together in a fit-for-purpose whole (Thompson et al 2018). The LADM provides a model for formal legal land objects while the related STDM provides the flexibility that can accommodate less precise physical and conceptual definition of extent of land rights (Griffith-Charles 2011). Both datasets can be woven together to provide equitable support for tenure in a land administration system. However, in dense urban settings greater precision is required than the minimum allowable in the STDM. In this research, the main objective is to determine a method for developing as precise as possible definition of the physical extent of the individual land units of an informal settlement using LiDAR and photo imagery data. These data, acquired since 2014 together with a DEM, were used to determine the possibilities for a system to be used for land management. The case study area is a hilly area in Laventille, in Trinidad and Tobago. While the use of LiDAR and other methods of data acquisition for formal registration of parcels has already been accomplished in some developed countries such as the Netherlands (Stoter et al 2016), for the many developing countries the need for other mechanisms for data acquisition and the possibilities of use for land management in informal settings need more examination as proposed here.

2. LIDAR IN CONTEXT

LiDAR data capture and processing are more expensive and more time consuming than photographic image capture and photogrammetric extraction of data. While the data capture itself can be quite rapid depending on the extent of the area being captured, the errors, occlusions, and magnitude of the datasets of point clouds make the entire process from data acquisition through classification of points, segmentation of discrete objects, and recognition of component features very complex whether it is manually or automatically done (Xing 2018). Virtual Geographic Environments (VGE) technologies are now more adept at extracting precise data from LiDAR point clouds and can even automate to some extent the data extraction including classifying and recognising features. In most instances, however, manual interventions are required to correct errors in classification and recognition for similar features. Xing et al (2018) examine the complications of designing the semantic reasoning that would allow automatic differentiation of features. Specific rules for a particular environment that would define the various objects of walls, roofs of different architectural styles, and even atypical features such as outhouses, sheds, and water tanks would need to be described semantically to allow for automated extraction. This includes geometric descriptions of the dimensions of the features such as length, and breadth, geometric properties of the relationship between features such as perpendicularity, and topological relationships between features. Familiarity with the particular environment is important for constructing the semantic rules. Kada and McKinley (2009) use standard geometric shapes to which to compare the point cloud. When a sufficient number of dimensions coincide, the standard shape is put in place to visualise the real structure.

The use of UAV systems has reduced the cost of the process when small areas are targeted for acquisition at low altitudes. The cost can be lower than conventional surveying on the ground for dense data acquisition especially since the LiDAR has the advantage of remote capture of data. This is important where there may be several difficulties attached to accessing the ground for direct surveying purposes for example, in areas of conflict or resistance to intrusion.

LiDAR primarily acquires height data. For 3D visualisation of condominiums, the ground level is accepted as the datum as differentiation between adjoining parcels occur within the confines of one building. However, for densely populated areas of hillsides, conflict and overlap can occur between adjacent buildings, necessitating more careful determination of datum. For this reason, a defined datum other than ground level is required. Mean Sea Level or ellipsoidal datum or other national datum should therefore be used.

The LiDAR data presents positioning of the tangible and visible physical features on the ground. The location of the 3D legal boundaries with respect to the physical features must also be semantically defined so that the boundaries can be visualised (Griffith-Charles and

Edwards 2014; Griffith-Charles et al. 2016). The many opportunities and possibilities for visualisation in the most meaningful way for the purpose of the cadastre needs to be decided on (Pouliot et al. 2018)

3. CASE STUDY

Trinidad and Tobago has several densely populated areas where both tenure and development standards are informal and where living quarters are in close juxtaposition and, especially in elevated areas, overlapping. Conflict over informally held land is frequent and often settled violently since recourse to the legal system is too costly and time consuming to be considered. What is required for land management in these areas is precise location of these intricately interwoven spaces by cheaper methods of crowd capture by perhaps the ubiquitous cell phone or UAV image acquisition. Figure 1 shows such a scenario where, besides horizontal and vertical positioning of boundaries above the ground, elevations above the national or at least a local community datum are required. Figure 2 shows the same area in plan view where the densities and overlaps of adjacent rooftops are apparent and the lack of cadastral information can be observed in Figure 3. Trees are interspersed in the area and may relate to legitimate boundaries and ownership, further densifying the number of features that need to be captured using any remote sensing process. Figure 2 also indicates how difficult capturing data using photogrammetric procedures can be since the ground is obscured over long distances. LiDAR can provide vertical differentiation, which, together with orthophoto imagery can allow for some measure of 3D visualisation.

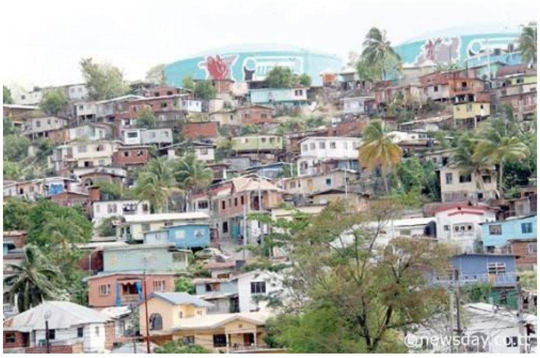

Figure 1. Overlapping and overhanging land objects

State funded regularisation, in these settings, is extremely expensive and more so if land readjustment is contemplated. The Land Settlement Agency (LSA) provides land management support for informal occupants on state land including monitoring, measuring, planning, regularisation, and formalisation into leaseholds from the state. The LSA has stated that it costs the institution TT$130,000 to TT$160,000 per lot to regularise the planning standards of informal occupants on state lands (JSC of Parliament 2016). This figure does not include the cost of regularising the tenure through provision of a Certificate of Comfort and later, a deed of lease. Private land, such as Laventille, does not have this access to state funding and the resources of this institution. In both instances, it is more economically feasible to introduce limited infrastructure without impacting structures that indicate that rights are existing. Figure 4 and Figure 5 show narrow corridors that must accommodate access as well as utilities of water, sewer, drainage without impacting the environment, and rights.

Figure 2. The Laventille area on orthophoto

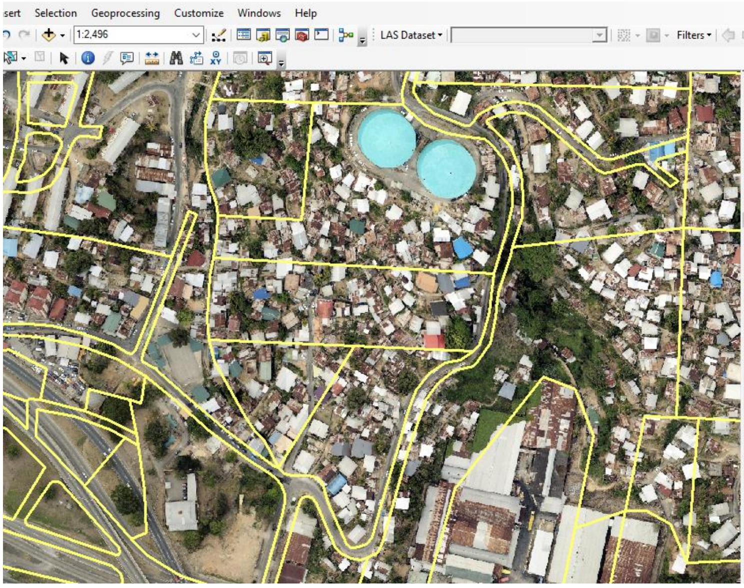

Figure 3. Cadastral layer with only formal rights

Figure 4. Requirement for putting in infrastructure without impacting rights

A 3D cadastre allows for planning for introduction of the infrastructure. Regularisation, like readjustment, involves balancing areas and volumes of space taken from individual land objects with services provided while attempting to ensure that reduced development standards are met.

Figure 5. Infrastructure must be put into tight spaces

In some instances, occupation on state land may overlap private land and it is necessary for the state to determine how much land is encroached on so that the private owner may be compensated. These surveys are required to be accurate enough so that the calculated compensation is not overstated. Where the overlap also includes subsurface minerals or hydrocarbon deposits, as is common in parts of Trinidad and Tobago, a 3D cadastre is required to ensure that surface use is not unduly affected by access rights to the subsurface. Figure 6 shows an area to be regularised with no clear demarcation of the boundaries.

Figure 6. Determining encroachments

4. METHOD

Datasets used in the application were the aerial imagery and LiDAR data acquired between 2013 and 2014 for the entire country by the Surveys and Mapping Division of the Ministry of Agriculture in Trinidad and Tobago at a cost of US$1 million (Ministry of Public

Administration 2015). Both datasets were acquired on the WGS 84 datum/ellipsoid but were transformed to the Naparima 1955 local datum to be compatible with most of the existing cadastral and topographic datasets. The imagery was acquired at 12cm ground resolution primarily to obtain at least 12.5cm orthophoto ground resolution to support cadastral mapping while the LiDAR data was acquired at 1 point per m^2 density to ensure that it met a requirement of 1m vertical positional precision. Classification into only ground and non-ground points was required as the stated purpose of the LiDAR data was to obtain a DEM for the country. Only four returns in the LiDAR data was requested. Precisions and density of data acquisition have implications for the cost of the process and the speed of its acquisition.

Both automated and manual methods were used to identify and acquire individual features from the LiDAR data. The ESRI ArcMap software was used to perform the automated processes. Global Mapper software was also used to perform the same procedures. The point cloud was classified into ground and non-ground points and further classified into buildings and vegetation using the built in software commands. The proximity of the features in this settlement made it difficult to extract the positional data and discern individual building features from the LiDAR. Ground points and non-ground points are shown in Figures 7 and 8 respectively overlaid on the orthophotos.

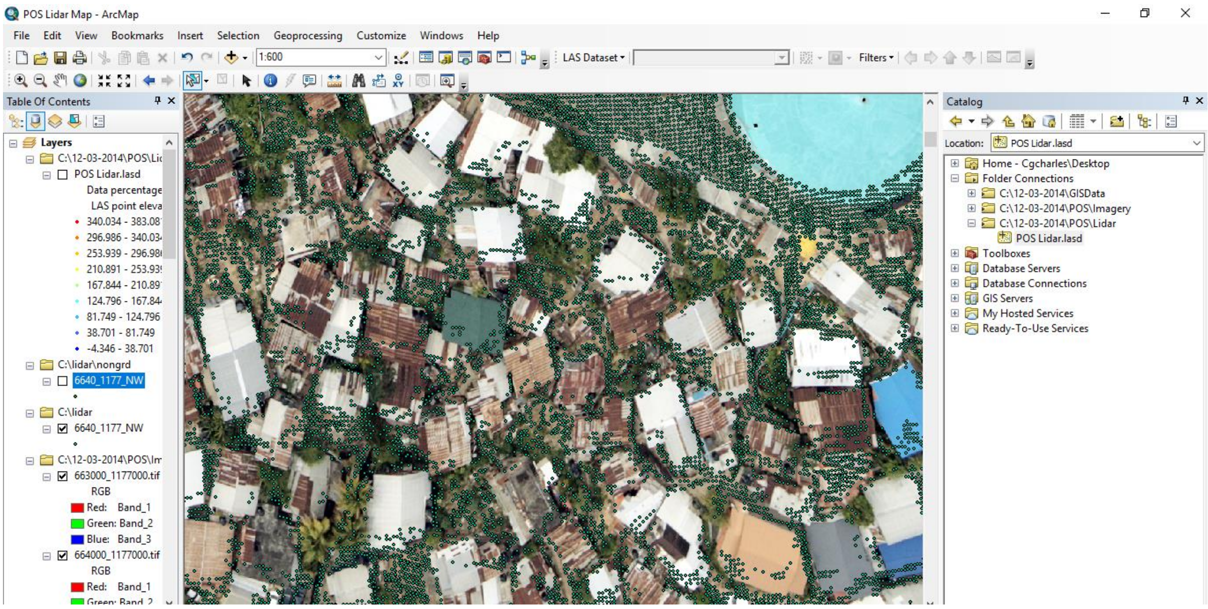

Figure 7. Dense ground point cloud from LiDAR data

First returns from the LiDAR point cloud were used to visualise the close mass of buildings as shown in Figure 9. The profile of the hill all the way up to the large water tanks at the top of the hill is also shown in Figure 9. The local Naparima datum for both horizontal and vertical coordinates was used. Overlapping rooftops can be seen in the profile along a longitudinal line from the top to the bottom of the hill.

It was recognised that features on the ground were not possible to be seen in most instances, except where clear areas existed such as on the roadway or in the area close to the water tanks. This meant that there would be difficulty in planning of infrastructure corridors on the ground.

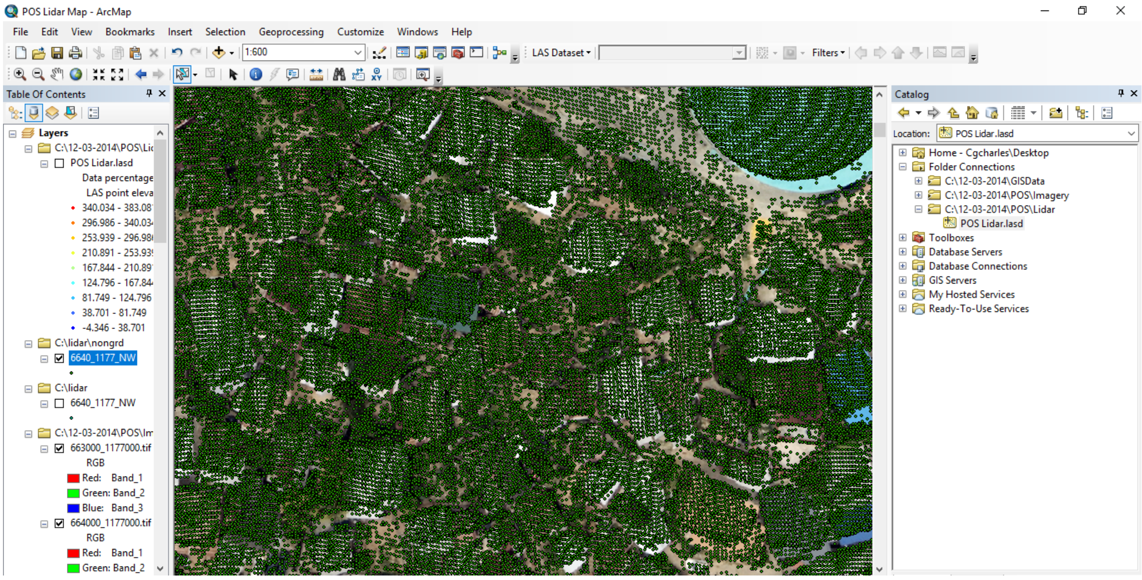

Figure 8. Dense non-ground point cloud of LiDAR data

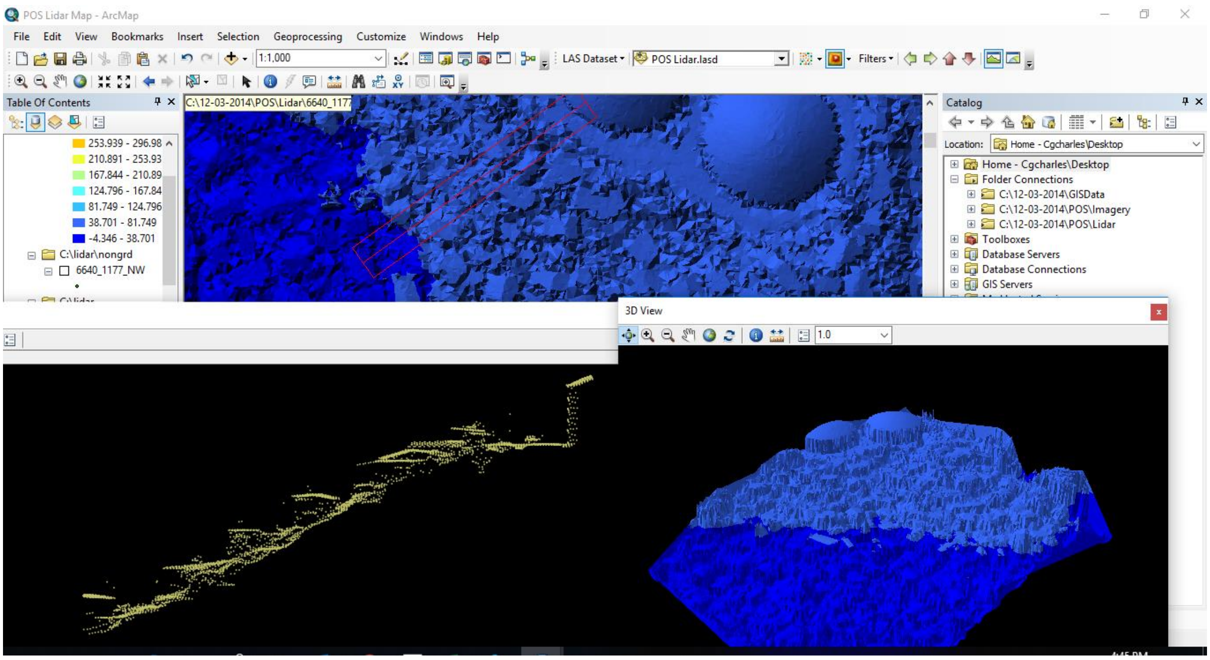

Figure 9. Composite showing profile and 3D view of a section of the hill

The digital elevation model was subtracted from the LiDAR non-ground first return points, so that the heights displayed for all points were computed from a constant (flat) surface to provide the distance above the datum of Mean Sea Level. Figures 10 and 11 show the result.

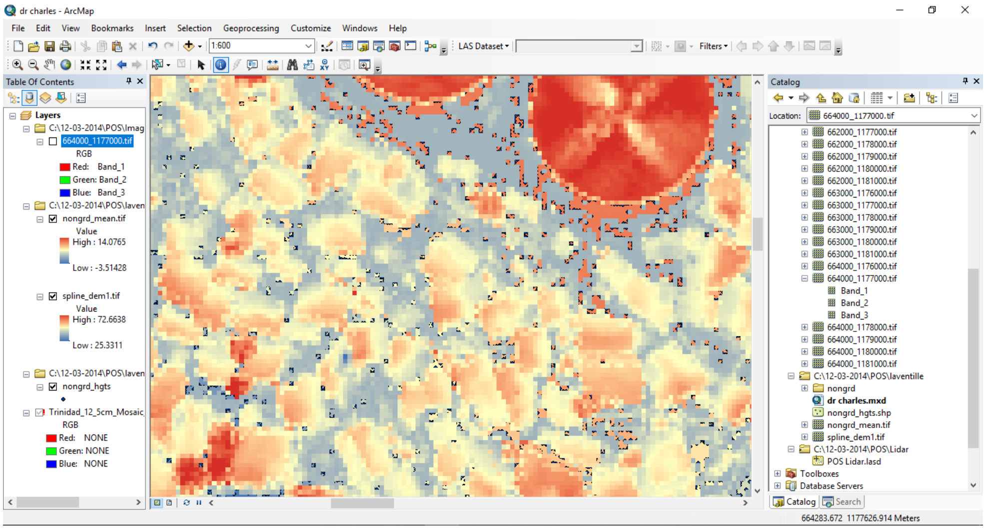

Figure 10. Automatic identification of buildings

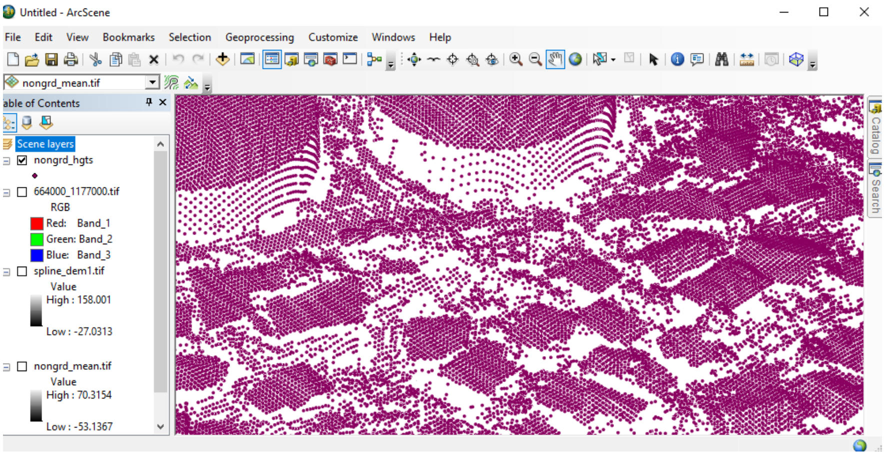

Figure 11. Buildings identified in ArcScene

At this point the individual property units were manually digitised. Individual roofs were manually defined with the assistance of the orthophotos. The complete land units were also defined via recourse to examination of the difference between the ground points and the roofs as established by first returns from the LiDAR. Differentiation was made between the physical features visible in the LiDAR and the legal location of the boundaries with priority placed on the boundary locations and not necessarily the physical extents of the land units. For example, even though hipped roofs could have been defined and visualised as such, a flat surface at the mean height of the highest and lowest points of the roof was deemed to be adequate for defining the upper limit of the parcel. Since insufficient information can be seen from the physical features, assumptions were made regarding the legal extents of rights. Figure 12 shows a small sample of complete identified 3D land units where the extent of the rights was taken to be the vertical face from the roof edges intersecting with the ground and not the walls of the house. The heights of the roofs are averaged from the height points of the corners and apices of the roof. The height differences between the ground and non-ground or first returns were averaged for each building roof.

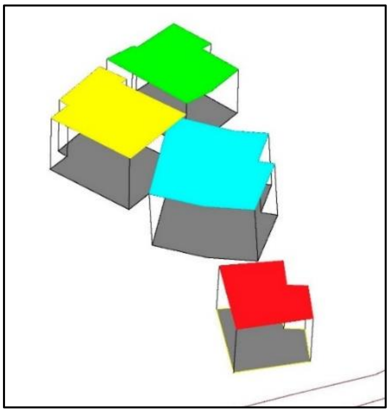

Figure 12. Identified land units showing overlaps and intersections

5. ANALYSIS

The cadastral boundaries of the occupied rights are assumed initially to follow the physical extent of the house and also include all that volume covered by the eaves of the roof and extending to the ground surface as defined by the LiDAR ground points. As a result of the density of the overlapping areas covered by the roofs, it is difficult to determine what activities are being performed on the ground that may also be establishing ownership rights. The actual use of buildings, including sheds, and outhouses, and the ownership of any fruit trees may also be evidence as to rights. It is therefore apparent that some level of ground investigation still needs to be performed to collect additional boundary information. It is acknowledged that, for any cadastre, some type of rights adjudication needs to be performed on the ground prior to recording or formalising the tenure. No ground truthing or further evidence gathering was done for the purposes of this work. The 3D land units derived from the LiDAR point clouds, however, while time consuming to define, go a long way towards developing a preliminary 3D cadastre graphic component for the area and can also be of assistance for areas similar to Laventille.

6. CONCLUSION AND FUTURE WORK

The main objective of determining a method to extract as precise as possible topographic data related to tenure boundaries, given limited data, was achieved. It was determined that while the LiDAR offers many benefits for the creation of a 3D cadastre for densely populated low-income areas of the urban environment where owner-funded data is not available, there was difficulty in the digital acquisition of individual faces of the land units. The research currently being done on automated extraction of features and feature components can help to improve the process. However, owing to the relatively small size of the typical informal settlement in Trinidad and Tobago, it may not be essential for completely automatic processes to be used and manual assistance is nevertheless required to ensure that the boundaries are logical. Many obscured features in the shadow of buildings may be described by the point cloud but may not be visible on the orthophoto and would still need ground verification. The findings from this investigation are therefore that automated extraction of buildings in densely occupied informally tenured and informally planned areas is difficult using automated processes inbuilt in mapping software and data captured with less than maximum precision specifications. Manual assistance is required for the extraction. Details on the ground were also obscured by the buildings and trees, obviating the possibility of obtaining sufficient information for planning of infrastructure. Further work should include additional data gathering on the ground and the use of UAV systems for obtaining more precise LiDAR data. .

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