Terrestrial LiDAR Capabilities for 3D Data Acquisition (Indoor and Outdoor) in the Context of Cadastral Modelling: A Comparative Analysis for Apartment Units

Jacynthe POULIOT and Marc VASSEUR, Canada

Key words: LiDAR (Laser Scanner), Laser Rangefinder, 3D Cadastre Models, 3D Data Survey, Apartment Units Modeling, Comparative Analysis

SUMMARY

The paper presents a comparison of terrestrial LiDAR and Distancemeter for surveying 3D spatial data of property units (indoor and outdoor) and producing cadastral representations (2D and 3D). Two study sites representing apartment buildings (co-ownership units) were surveyed with both instruments and six criteria related to data acquisition steps (survey time, number of measures, number of operators) and data modeling steps (preprocessing time, time for modelling the geometry of the objects, completeness) are used to enable the comparison.
To produce 2D maps LiDAR technology ended with performance in term of survey and modeling time a little lower compare to Distancemeter. To produce 3D models LiDAR technology shows better results compare to Distancemeter. The number of objects to model and the geometric complexity of these objects are important criteria to take into consideration to determine the advantages of LiDAR technology compared to traditional instruments. For instance, LiDAR point cloud offers the possibility of producing more detailed 3D model (i.e. containing not only cadastral limits).

RÉSUMÉ

Ce manuscrit présente les résultats de la comparaison entre un LiDAR terrestre et un instrument d’arpentage classique (le distancemètre) pour des fins d’acquisition et de modélisation (2D et 3D) de données servant à représenter l’intérieur et l’extérieur d’une unité de condominium. Deux sites d’étude correspondant à des condominiums de deux étages ont servi aux expérimentations. Ces sites ont été relevés avec les deux instruments et comparés sur la base de six critères dont des critères pour l’acquisition des données (temps de levé terrain, nombre de mesures, nombre d’opérateurs) et pour la modélisation (prétraitement, temps pour construire les représentations spatiales, et la complétude). Les résultats montrent que la technologie LiDAR performe moins bien du point de vue des temps d’acquisition et de modélisation que le Distancemetre. Par contre, la technologie LiDAR propose une meilleure performance pour la production des modèles 3D. Deux importants critères sont à prendre en compte pour déterminer les avantages de la technologie LiDAR soit le nombre d’objets à relever et la complexité géométrique de ces objets. Par exemple, le nuage de points LiDAR permet la production de modèles 3D plus détaillés (i.e. qui ne contiennent pas uniquement les limites cadastrales).

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1. INTRODUCTION

3D cadastre models are recognized as valuable solutions to provide enriched spatial representation for overlapping properties, above-ground and subsurface infrastructures, mining rights, etc. (Paulsson and Paasch, 2013; Pouliot et al., 2011; Stoter et al., 2013). Cadastral plans and 3D models provide help for a variety of users and tasks depending on the country (van Oosterom et al., 2011). Mainly, they are used to support property identification and registration, and to provide spatial foundations for the security of real estate transactions. One prerequisite for producing 3D cadastral models is having access to 3D spatial data (indoor and outdoor) of the property unit (Jazayeri et al., 2014). For cadastral purposes related to apartments with co-ownership units, the third dimension of spatial data may be expressed as vertical elevation (orthometric or ellipsoidal altitude) or Z coordinates of the boundary unit, height of the building level, or volume of the legal 3D units. Various land survey instruments are currently used to acquire such 3D spatial data, including GNSS/GPS, total station, stereo-photography, distancemeter (laser rangefinder), and terrestrial LiDAR (laser scanner). A recent questionnaire sent to members of the professional association of land surveyors in the province of Quebec reveals that the field instruments currently used to survey vertical data for apartments with co-ownership units are distancemeter, ribbon, total station and GPS. Photogrammetry and terrestrial LiDAR are less popular instruments. When the same land surveyors were asked what they anticipated practices in 10 years to be, LiDAR is foreseen as one of the best instruments to survey vertical cadastral information of apartments with co-ownership units.

Based on this input, the issue of identifying the capabilities of terrestrial LiDAR instruments to survey 3D lots for apartments with co-ownership units appears important and relevant. Terrestrial LiDAR is used for a wide variety of applications such as city modelling, robotics, archaeology, agriculture, or in the mining industry, (Shan and Toth 2008). However, as far as we know, no specifications and few experiments exist for acquiring LiDAR data adapted to cadastral modeling of indoor and outdoor property units (Jamali et al., 2013; Hao, 2011; Souza and Amorim, 2012). This new field of application of the LiDAR instrument is a motivating factor; it may represent a lucrative market for land surveyors and resellers. Is the requirement the same for cadastral application and city building modelling? This study will try to answer this question by examining the capabilities in comparing traditional survey instrument with terrestrial LiDAR for acquiring 3D spatial data required for the production of cadastral representation (2D plans and 3D models).

2. STUDY CASES AND METHODOLOGY

The methodology consisted of using a terrestrial LiDAR (laser scanner) to survey two apartment buildings (co-ownership units) and comparing its capabilities with current survey instruments to produce 2D cadastral plans and 3D models. The features of interest are the boundaries of the 3D units, which are not visible (*fiat* objects) and consequently deduced from human opinion, and the presence of physical objects (*bona fide*); in the case of an apartment such physical objects may correspond to walls, ceilings, floors, stairs, etc. The study cases are located in the province of Quebec, Canada, and correspond to a simple apartment structure composed of two levels with two co-owners (private and common parts). Table 1 shows some technical information for the LiDAR used. For the traditional survey, both sites were measured with a distancemeter instrument (a portable laser rangefinder with a precision of 5 mm for a distance of 50 m). Callidus and Faro LiDAR instruments were selected mainly because they were available in our laboratory. The focus of the study is not to compare one LiDAR technology to another, but the fitness for use of LiDAR acquisition approach (scanning instruments) compare to traditional survey instrument. The survey and relative comparison were performed in a way to limit the impact of using two distinctive LiDAR instruments.

Table 1. Characteristics of the LiDAR used during the survey

	Site A	**Site B**
Instruments	Callidus CP3200	FARO Focus 3D[1]
Year of commercialisation	1997 to 2006	2010 to now
Spec Field of view (H:V)	360:140	360:305
Spec Distance range	0.6 to 120 m	0 to 32 m
Spec Precision (distance of 50 m.)	5 mm	2 mm
Survey resolution	2 to 20 cm between each points	2 to 20 cm between each points
Number of survey point cloud	562 544	24 350 000

Figure 1 presents a picture of the two apartment buildings. Both sites were survey by distance meter and LiDAR instruments. Figure 2 shows for each site the 2D plans produced from LiDAR data (plans of site B were built by Groupe VSRB, http://www.groupevrsb.com/, a private firm collaborating with us). For site A, 10 indoor stations and 5 outdoor stations are scanned by the LiDAR while for site B 15 indoor stations and 3 outdoor stations were required. Objects to be scanned are walls, ceilings and floors. In total, site A needs 16 walls to be recorded while site B require 49 walls. To this, we collected and recorded the measure of the height of the ceilings and the altitude of the floors. Finally, figure 3 presents the 3D models produced from the LiDAR points (Trimble RealWorks for scan assembling and Bentley suite for map designing were used).

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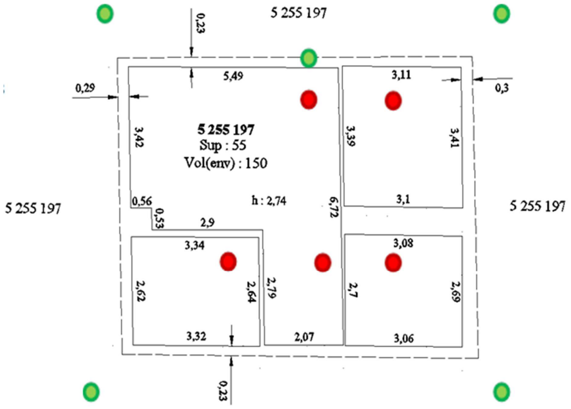
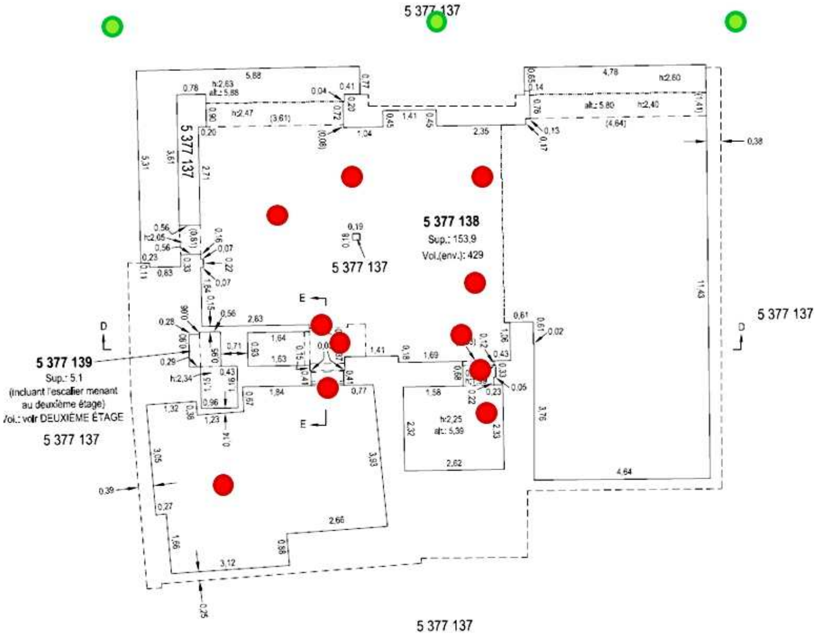
[1] FARO Laser Scanner Laser Focus 3D is now traded by Trimble under the name Trimble TX5.

Site A Site B

Figure 1. Two apartment buildings surveyed by the terrestrial LiDAR

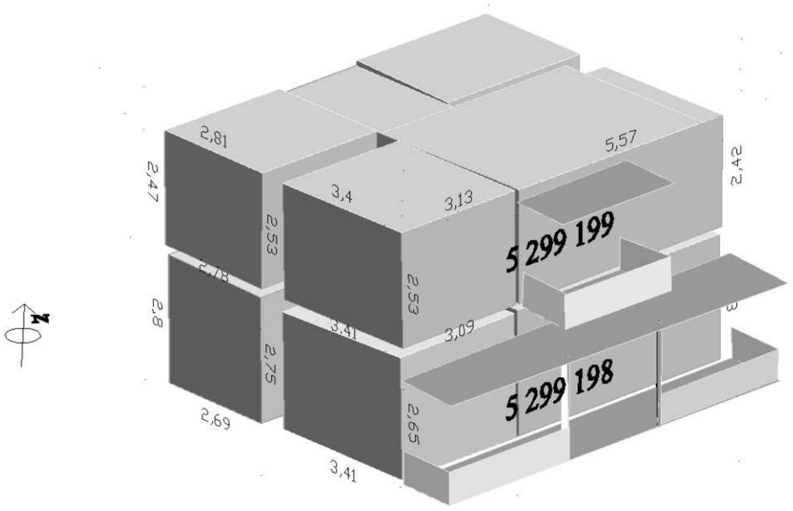


Site A (1st Floor)

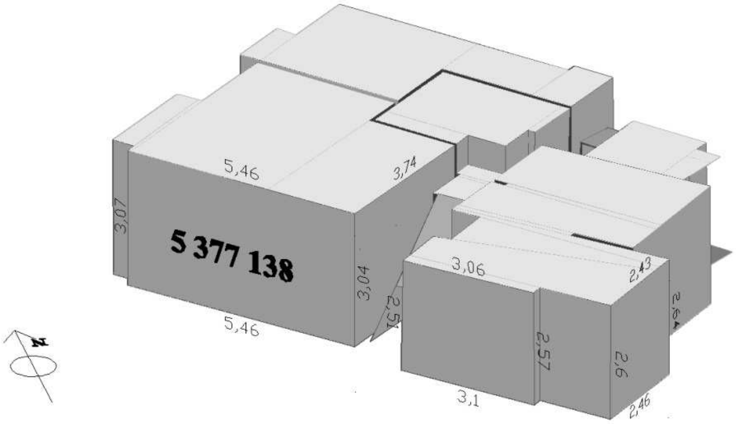


Site B (1st Floor)

Figure 2. Examples of 2D maps produced from the LiDAR survey for the sites A and B (red dots =indoor stations, green dots=outdoor stations)



Site A (1st and 2nd floors)



Site B (1st floor)

Figure 3. 3D models produced from terrestrial LiDAR for sites A and B

3. COMPARISON

To enable the comparison, a list of criteria was first established, some are related to the acquisition phase and others to the modelling steps. This list was verified with the land surveyor firm. 2D plans and 3D cadastral models were produced from traditional spatial data collected by laser rangefinder (distancemeter) and laser point cloud (LiDAR). Regular cartographic production and 3D modelling techniques and software were used. The 2D cadastral plans created from the distancemeter were produced by a land surveyor firm (Groupe VRSB), and they respect the specifications of the Quebec Department of natural resources which is responsible for maintenance of the cadastral system. The graphic tolerance for the plans is 21 cm at a scale of 1000. The rest including the 3D models were produced by the authors, respecting the same specifications. Tables 2 and 3 present a subset of the results of the comparison made.

Table 2. Overall comparison between Distancemeter and terrestrial LiDAR for cadastral data acquisition

	Distancemeter	**LiDAR (Faro; Callidus)**
Survey duration	4h	4h ; 5.5h
Number of measures or scans	50	18 ; 10
Number of operators	1	1 ; 2

Table 3. Overall comparison between Distancemeter and terrestrial LiDAR for cadastral data modelling

	2D plan production		**3D model production**	
	Distancemeter	**Faro; Callidus**	**Distancemeter**	**Faro; Callidus**
Preprocessing time (Scan assembling)	1h	1h; 7.5h	1h	1h; 19h
Geometric modelling of all objects	4h	7h; 7h	5h	1.5h; 15h
Completeness (number of objects collected/required)	100% (49/49, 16/16)	100% (49/49); 160% (26/16)	125% (20/16)	150% (76/49) ; 400% (64/16)

4. DISCUSSION AND CONCLUSION

Some facts may be outlined from the comparison between the distancemeter and LiDAR survey instruments. The survey duration of the LiDAR instrument is slightly longer than the distancemeter. This result is dependent on scan speed, the number of scans and the view angle per scan. The number of field measures is obviously much lower for the distancemeter compared to LiDAR. The number of operators is also important to consider. For the distancemeter, only one operator was required, while for the Callidus two operators were necessary and one operator for the Faro. If we try to estimate the survey cost, including depreciation (5 years), the survey duration and the number of operators, LiDAR varies from 15% (Faro) to 200% (Callidus) higher compare to distancemeter. Recent technology like the Faro instrument obviously shows better results compare to older system like the Callidus. As well, data acquisition strategy may also be setup for LiDAR technology in order to reduce the survey duration and cost. For instance, not scanning the entire space but only specific objects related to the boundary of the 3D units was perceived has a valuable approach but not experiment in the current tests. In overall, the acquisition phase is quite comparable between both instruments.

Regarding the modelling phase, the results show mixed conclusions. The production of 2D plans by distancemeter clearly presents better results compared to LiDAR technology while, it performs better for the production of 3D models compares to 2D plans. The main issue for LiDAR data processing is to determine the geometry of the object extracted from the numerous point clouds, while with distancemeter, the geometry of the object is already established in the field (by the operator). This situation is easily explained by the distinctive mode of data acquisition of each instrument. LiDAR systems scan everything in the space while with the distancemeter, the operator has to decide in the field what objects are to be surveyed. If the operator forgets to survey some objects, another survey will be required. The production of the 3D models tooks a longer time with the distancemeter than with Faro data but was faster compared to Callidus data. This situation is explained by the fact that no targets were used on the site for the Callidus survey. Scan assembling and the modelling of the objects were thus more complex and time consuming when keeping the same production specifications. If we compare the completeness of the 3D models, it appears that the number of objects in the final product is higher for the point cloud compared to distancemeter. Obviously, this situation is explained by the mode of data acquisition of LiDAR technology that collects all objects in the field of view, no matter if they are of interest. This aspect may be foreseen as an advantage of using LiDAR technology, more specially when multi-usage of the 3D spatial data are planned (e.g., for urban planning or architectural projects).

Based on our experiment, it is currently difficult to draw conclusions about the distinctiveness of these results between surveying and modelling cadastral data compared to other kind of objects like city buildings. It is clear that for physical objects like walls and ceilings, the challenges are quite similar (scan resolution, scan assembling, obstruction, object reflectance). Determination of the boundary of the 3D units (*fiat* objects) still remains the results of the opinion of an expert. For traditional surveying, this opinion is somehow integrated with the field survey, while for LiDAR technology, this opinion may be estimated during data processing. This situation may have important impact depending on who is doing the survey and the modeling phases. The number of objects to model and the geometric complexity of these objects are certainly some of the main criteria to take into consideration to determine the advantages of LiDAR technology compared to traditional instruments. For instance, LiDAR point cloud offers the possibility of producing more detailed 3D model (i.e. containing not only cadastral limits).

In conclusion, we can state that LiDAR technology offers interesting performance for surveying apartments and producing cadastral data. However our experiment has many limitations. For instance, two apartment buildings are not sufficient to generate robust recommendations about better practices for LiDAR data acquisition and modelling. The selected apartment buildings were structurally quite simple (two levels) and did not allow us to fully address the complexity factor (geometric complexity of the object), which is probably one significant and distinctive criterion between both instruments. One of our future hypotheses to test would be: Higher is the geometric complexity of the building, better performs the LiDAR. Regarding the surveying of common or private parts, no attention was paid to this end. We treated them as the same category of object. Further tests may integrate those decision elements.

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BIOGRAPHICAL NOTES

Jacynthe Pouliot is a full professor at the Department of Geomatics Sciences (www.scg.ulaval.ca) at Université Laval, Quebec, Canada and currently the head of the Unit. She is an active researcher at the Center for research in Geomatics (www.crg.ulaval.ca) and owns a personal discovery grant from the Natural Sciences and Engineering Research Council of Canada. Her main interests are the development of GIS systems, the application of 3D modeling techniques and the integration of spatial information and technologies. Since 1988, she is a member of the Professional association of the Quebec land surveyors. She is also involved in the committee of the 3D Ethics Charter (www.3dok.org) and member of the FIG working group on 3D Cadastres.

Marc Vasseur is ending a master degree in Geomatics Sciences at Université Laval, Québec, Canada. He is also graduated in engineering (topography) from the Institut National des Sciences Appliquées (INSA) of Strasbourg, France.

CONTACTS

Jacynthe Pouliot
Department of Geomatics Sciences
Université Laval
1055 avenue du Seminaire,
Quebec City
CANADA, G1V 0A6
Tel.: +1 (418) 656-2131, poste 8125
Fax: +1 (418) 656-7411
E-mail: jacynthe.pouliot@scg.ulaval.ca

Marc Vasseur
Department of Geomatics Sciences, Université Laval
1055 avenue du Seminaire,
Quebec City
CANADA, G1V 0A6
Tel.: +33 (0)6 79 59 47 89
E-mail: marc.vasseur.01@gmail.com