3D Data Sourcing for Land and Property Information: A Geometric and Semantic Perspective

Ida Jazayeri, Abbas Rajabifard, Mohsen Kalantari

Centre for Spatial Data Infrastructures and Land Administration, Department of Infrastructure Engineering, University of Melbourne
(jazayeri, abbas.r, saeidks@unimelb.edu.au)

Abstract

Population growth has prompted land administrators to re-evaluate the current land development cycle, incorporating the third dimension to enable a more complete and effective property registration system. This research, which centres on the 3D data sourcing methods, has suggested a set of data sourcing requirements. It is envisaged that the culmination of legal entities together with the geometric and semantic components of our cities in a 3D environment will enable a more complete and effective land and property information registration system that will in turn ultimately help decision-making processes in our governing bodies to better manage economic development and build sustainable communities. Focussing on two of these requirements (geometric and semantic) an investigation on data acquisition techniques is discussed. Implementation of UAV data is suggested as an effective data sourcing method, particularly for developing countries and poverty stricken areas, where low cost is critical.

Keywords: 3D data acquisition, land administration, building reconstruction, 3D cadastre, 3D visualisation, UAV

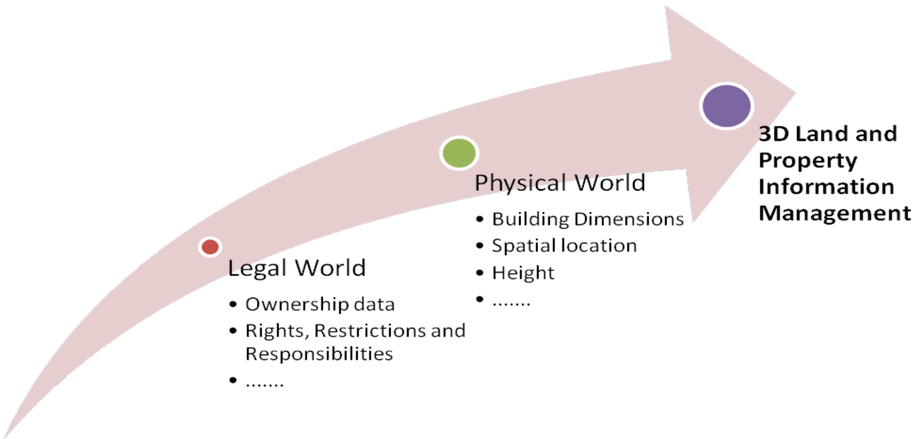
1 INTRODUCTION

Managing the growth of our existing communities and optimising the design of our future cities is critical in both developing countries and modern societies. A key aspect of this is the effective management and maintenance of land and property information.

Traditionally land and property information, which includes geometric, visual and legal data for each property unit, has been two-dimensional (2D) based on 2D land parcels. Surveyors, planners, developers and architects have used paper drawings and plans to document the land registration process. While functional, this system is inefficient and costly, without a clear and effective description or visualisation of the third dimension or legal entities. And current 2D survey plans are no longer able to represent the reality of inter-related titles and land uses with their complexities. Multiple page 2D plans cannot be easily understood or visualised outside the domain of highly specialised professional surveyors. And finally, 3D architectural drawings do not deliver legal authority in land and property registration.

The significant developments in 3D data acquisition techniques, visualisation, image processing algorithms and computer power, as well as trends such as Volunteered Geographic Information and BIM, have facilitated the creation of 3D models of buildings and cities around the globe. While some of these solutions only offer visually pleasing results, the addition of semantic information with greater richness in data will mean that virtual 3D city models can be more widely implemented around the world by organisational bodies such as governments, city planners and emergency services. Such organisations require highly detailed 3D models that reflect the complexity of building objects and the interrelations (Stadler & Kolbe, 2007). In addition, including the geometry of a 3D model, (i.e. dimensions, building height, indoor plans) will allow for high-level analysis and management. Incorporating the legal information which comprises of ownership data, as well as the rights, restrictions and responsibilities associated with land and property units, will complete the 3D model.

Figure 1: 3D land and property information dimensions



This research, which centres on 3D data sourcing, focuses upon the geometric and semantic initiatives taking place that can be applied for the creation and application of accurate, 3D modelling solutions, used to enhance and improve land and property information management. As illustrated in Figure 1, the culmination of legal entities together with the physical components of our cities in a 3D environment will enable a more complete and effective land and property information registration system that will in turn ultimately help decision-making processes in our governing bodies to better manage economic development and build sustainable communities.

2 CURRENT PRACTICE

At present, most land and property registration processes are paper-based systems in 2D with little or no 3D visualisation or analysis capabilities. The z-coordinate describing the height dimension of each building is captured in current systems but illustrated only in 2D using complicated survey plans mainly derived from architectural plans. These plans usually involve many pages of 2D figures and text describing both the geometric and legal aspects of each property. The complicated nature of these documents affect the communication of information and result in ineffective and slow data creation with limited access to critical information.

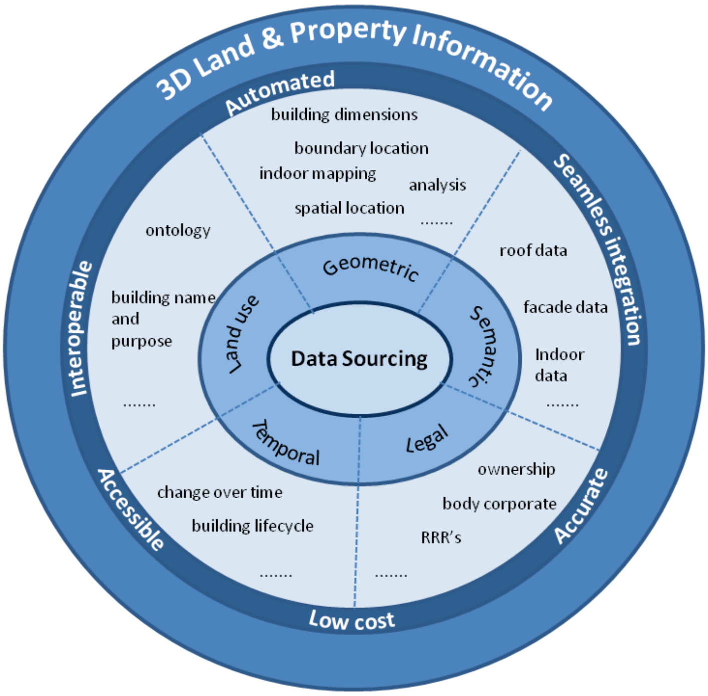
Although this process varies within different institutions around the globe, the 2D and 3D information collected generally comes from the architects and from the field using traditional survey equipment, including theodolites and GNSS receivers on the ground. The instrumentation and processes are designed in such a way to facilitate the derivation of accurate distance measurement optimal for surveying tasks and developing subdivision plans.

3 REQUIREMENTS FOR SOURCING DATA IN 3D

Data sourcing for 3D land and property information registration needs to deliver intelligent information that is not only visually explicatory but extended to include architectural and survey information, ownership data as well as rich semantic and geometric information that change over time. The requirements for 3D data sourcing have been gathered from the 2nd International Workshop on 3D Cadastres, held in Delft, The Netherlands, and from discussions at a collaborative research workshop on ‘Land and Property Information Management in 3D’ held at the University of Melbourne, Australia.

It is suggested that the requirements for data sourcing be classified into 5 dimensions, as illustrated in Figure 3: (1) Geometric, the geometry and shape of a land parcel and building including accurate survey information, indoor floor plans, dimensions, bearings, distances, height as well as the spatial position of the objects & coordinates; (2) Semantic, the physical attributes of the land and building, including facade data, roof data, materials, surrounding environment; (3) Legal, information relating to ownership, rights, restrictions and responsibilities, boundary data, easements and body corporate; (4) Land Use, the information relating to the meaning of land and property including a description of what it is and what it is used for; (5) Temporal, a description of how the land and property changes over time during its lifecycle.

Figure 3: 3D data sourcing requirements classification



There are numerous papers with describe methods for sourcing and reconstructing geometric properties of a building ((Haala & Kada, 2010)) and visualising the results (e.g.(Xie et al, 2012)) and examples of integrating visualisation with semantically enriched models (e.g. (Méstral et al., 2012) however there are less examples focusing on sourcing legal boundaries and the only examples which analyse the life cycle of a property over time are found in Building Information Modelling. It is envisaged that the culmination of these five dimensions will help to deliver a complete model required for effective registration that is both accurate from a technical sense, while also facilitating accessible and coherent transfer of information for improved communication of land and property related data. In developing countries which deal with poverty, a major factor in the requirements classification is low cost. The data sourcing methods must be lost cost, efficient and effective.

4 3D DATA SOURCING METHODS

This paper focuses on the geometric and semantic requirements for 3D data sourcing.

4.1 Geometric and semantic components

Data sourcing for acquiring information relating to the geometric and semantic dimensions of a land and property registration system is fundamentally 3D modelling for geometric object reconstruction. There are many different available methodologies that have been proposed and developed for the acquisition of 3D models, including photogrammetry, computer vision, computer graphics and laser scanning. The method of creation and technology implemented depends largely on the requirements and application of the resulting 3D model. For application in developing countries, the technology implemented must be cost-effective.

3D modelling can be classified into range-based modelling via active sensors, which includes terrestrial laser scanning, LiDAR and mobile mapping, or image-based modelling via passive sensors (using imagery) specifically architectural plans, terrestrial photogrammetry, high-resolution satellite imagery, aerial imagery and more recently Unmanned Aerial Vehicles (UAV).

4.1.1 Range-based modelling

During the last decade, laser scanning, both airborne and terrestrial has been one of the most significant advancements in acquiring 3D data. Also referred to as LiDAR, it has emerged as a standard technology for 3D data acquisition and can be classified as (i) Terrestrial Laser Scanning (TLS), where the scanner is ground-based on fixed camera stations; (ii) Airborne Laser Scanning (ALS), where the scanner is mounted on aircraft and; (iii) Mobile Laser Scanning (MLS), a more recent development where the scanner is mounted on a moving vehicle on the ground.

There have been a number of studies e.g. (Grussenmeyer & Landes, 2008; Fowler & Kadatskiy, 2011; Sahin et al., 2012) that have compared the different types of laser scanning in order to determine point positioning accuracies and provide advantages and disadvantages for the various methodologies. A comparison study by (Fowler & Kadatskiy, 2011) showed that terrestrial laser scanning results in superior point positioning accuracies to aerial laser scanning or mobile laser scanning systems.

TLS is now widely applied in field survey. And one of the most important and widest utilisation areas of laser scanners is recording and modelling buildings for 3D urban models (Voegtle et al., 2008).

Nowadays, ALS, which is costly and data intensive, is used to obtain surface models, and roof information for the reconstruction of buildings. The TLS and MLS systems are used in applications that require details of building facades in the production of photo-realistic 3D city modelling.

Recently, MLS campaigns have been conducted, providing data on urban environments in much higher detail. MLS has been used to acquire a massive collection of detailed data for 3D city modelling, building facade construction and capture of vegetation and road features for inventories. But their application is still limited due to their cost and high amount of data that they capture ((Sahin et al, 2012). In their study, (Sahin et al, 2012) suggest that MLS should be used for larger scale application areas and can be integrated with other data acquisition techniques for a more complete model.

4.1.2 Image-based modelling

Advancements in digital photogrammetry have also meant that image-matching algorithms can be used to produce 3D models fit to compete with laser scanning with respect to accuracy. Image based modelling is defined by (Remondino & El-Hakim, 2006) as a complete process that starts with image acquisition and ends with an interactive 3D virtual model. While the 3D reconstruction from images is an area active research, the focus has moved from improving quality and completeness to improving automation and efficiency. There are a number of papers which describe algorithmic developments to automate object reconstruction (e.g. (Parys & Schilling, 2012)).

Advantages of imaging methods are the level of details, economic aspects, portability, handling in spatial limited environments and short data collection time; the disadvantages remain in the post-processing when the texture of the object is poor (Sahin et al., 2012).

Nowadays, the increase in resolution for aerial cameras as well as the introduction of low-cost unmanned aerial vehicles is transforming the traditional methods in place for airborne data and presents an opportunity for new methods of 3D data acquisition. High-resolution satellite images have been widely used for building reconstruction (e.g. (Kocaman et al., 2006),(Fraser et al,, 2002), (Lafarge et al. 2006)). Cross-track stereo images acquired by systems like SPOT-1,2 and 3, IRS-IC/ID and High-Resolution-Geometry (HRG) sensors SPOT-5, IKONOS, OrbView-3 and Quickbird provide multiple-view terrain coverage that allows for a multi-image matching approach for surface reconstruction. The launch of GeoEye-2 in early 2013, which has a resolution of 0.25m, may initiate research that demonstrate the use of satellite imagery for more detailed and higher accuracy modelling that is low cost.

For large ground coverage with better image resolution and greater accuracy, aerial photogrammetry generally provides good radiometric quality and high redundancy due to large image overlap. There are many examples of building reconstruction methods using aerial imagery alone (e.g. (Mayer, 1999), (Baillard & Maıtre, 1999)) however over the past decade, research in this area has focussed on the integration of aerial imagery fused with other data sources such as ground plans and LiDAR discussed in more detail in the following section.

While aerial photogrammetry can provide texture information, the imagery cannot provide high level detail or even recognisable features due to significantly oblique viewing angles resulting in poorly reconstructed facades that contain information often required for land and property information management, such as boundary information. With the exception of roof data, detailed information about a building has traditionally been captured best from the ground (Akbarzadeh et al., 2006).

Rather than taking individual imagery from buildings in a city, the recent advent of mobile mapping solutions allows for the possibility of fully automatically generated, texture-mapped, ground-level 3D models. Further examples of 3D data captured from video includes (Gool & Zisserman, 1997), (Akbarzadeh et al., 2006) and (Tian, 2011).

Roof data should be acquired from ortho-rectified images which have traditionally be obtained from aerial imagery or high resolution satellite imagery. However in complex building structures, the resolution obtained from ortho-images decrease and the authors suggest that this may be better captured via new methodologies such as Unmanned Aerial Vehicles.

Figure 4: A UAV: Octocopter

An Unmanned Aerial Vehicle (UAV) is an aircraft flown either controlled autonomously, semi-autonomously or under the remote control of a pilot on the ground or in another vehicle (See Figure 4). UAVs address the limitations of the traditional airborne-based mapping systems, including the high flight altitude which results in low resolution, inadequate for land and property information management and high cost. UAV based mapping provides the required accuracy with respect to cadastral laws and policies and is competitive to other measurement technologies in terms of economic aspects (Eisenbeiss, 2011).

Recently, there have been a number of studies reporting on the use of UAVs in cadastral applications for the generation of elevation models and 3D objects. An example of this is in (Manyoky et al., 2011) who assessed the feasibility of using a UAV to gather cadastral information in Switzerland. In this study aerial images were taken over a calculated flight plan and the camera was tilted to navigate around complex building structures acquiring images from the facades of the buildings. The achieved accuracy here was about 2.0cm horizontal, and 5.0cm vertical which is below the required accuracy of 3.5cm horizontal and 7cm vertical accuracy required in the Swiss cadastral system.

One of the major advantages of UAVs compared to manned systems are that UAVs can fly in inaccessible places such as areas affected by natural disasters (earthquakes, volcanic, flood plains) and areas with difficult terrain such as mountains and deserts. Another major benefit of UAVs is the cost factor, as UAVs are less expensive and have lower operating costs than manned aircrafts. As a result, UAVs have been tested in remote areas, where many homes have been built without the luxury of property surveys to accurately define boundaries (e.g. Cunningham et al., 2011)).

4.1.3 An integrated approach

Over the past 10 years, there have been a number of systems developed that integrate LiDAR, CCD cameras and GPS/INS for the derivation of highly detailed 3D spatial data (e.g. (Nagai et al., 2004; Nagai et al., 2008). And there are a number of researchers who have developed methods to combine data for building modelling, e.g. LiDAR and optical imagery ((Chen et al., 2004), LiDAR and high-resolution satellite imagery ((Sohn & Dowman, 2007), (Guo, 2003), LiDAR and aerial imagery (Kwak, 2013). Multiple data fusion, from a number of sources such as panchromatic images, terrain models, laser scanning data or cadastral map often enhances the reliability of the data acquisition process (Suveg & Vosselman, 2004). And in most cases, a combination of laser scanning and image based modelling maybe the best solution (Grussenmeyer & Landes, 2008). The benefits from metric information acquired from point clouds and descriptive information obtained from images combined can be thought of as an important step to an optimal three dimensional measurement tool (Abdelhafiz, 2009). A review of a number of approaches to acquire, process and visualise 3D information from the integration of terrestrial images and point cloud data have been described in (Remondino & El-Hakim, 2006).

By combining laser scanning data with digital imagery, it is now possible to create photorealistic 3D models of buildings and of the terrain with high accuracy. Fully

automated generation of dense 3D point clouds which can be converted to wireframe and texture are becoming more readily available and boast high-accuracy results.
An example of an integration of TLS and terrestrial photogrammetry is in (Sahin et al., 2012). Their study focuses on a proof of concept to create a 3D city model by combining photogrammetric and laser scanner data.

MLS has been combined with cadastral maps in (Hao et al., 2011). In their study, (Hao et al., 2011) assess the applicability of introducing the MLS data and processed building facade maps for 3D physical building and apartment units modelling in the cadastral registration in Istanbul. Another example is in (Hammoudi et al., 2010) where georeferenced terrestrial laser data was collected at street level, filtered and segmented into a cloud of dominant facade walls. The facade cloud is extracted using an adapted Progressive Probabilisitc Hough Transform (PPHT). An increase in availability of mobile mapping services such as Google StreetView, Microsoft StreetSide and Earthmine has promoted research to find new applications for this information rich data. (Taneja et al., 2012) discuss the applicability and benefits of combining cadastral information with spherical panoramic images acquired from mobile mapping for city planning and tracking changes in the urban environment. Their study illustrates that the dense spatial sampling offered by these panoramic systems can be used together with 3D information to produce powerful geospatial datasets.

An example of a 3D surface model, extracted photogrammetrically from satellite imagery, based on the geometric building information embodied in existing 2D ground plans includes (Tack et al., 2012). The advantage of this kind of method is large coverage, an entire township or city can be imaged with only two stereo image pairs. The disadvantage is a lack of level of detail as a result of the low resolution imagery, as well as the 3D point cloud density to reconstruct a complex building roof shape. Digital surface models have also been widely used to classify and model city data in 3D, through the integration of LiDAR or stereo-imagery with remote sensing images e.g. (Chen et al., 2009; Wurm et al., 2011).

4.1.3 Evaluation

A summary of these technologies and their capabilities to capture the required data for the geometric and semantic components of a 3D land and property information system are illustrated in Table 1 and Table 2. The evaluation shows that of the available technologies, UAVs may provide a new approach to sourcing the geometric and semantic dimensions based on their low cost and effectiveness in gathering required information for an effective 3D land and property information system.

Table 1: Evaluation of sourcing semantic requirements

		Semantic		
		Facade	Roof	Indoor
Range-based	Terrestrial Laser Scanning	+ Yes, with detail − costly	− No, not visible	+ Yes − costly
	LiDAR/Aerial Laser Scanning	+ Yes − limited	+ Yes − costly	− No, not possible
	Mobile Laser Scanning	+ Yes	− No	− No, not possible
Image-based	Terrestrial photogrammetry	+ Yes, with detailed texture	− No, not visible	+ Yes − requires field work
	Aerial photogrammetry	+ Yes − limited	+ Yes − costly	− No, not possible
	High-res satellite imagery	− No	+ Yes	− No, not possible
	Unmanned Aerial Vehicle (UAV)	+ Yes, with detail	+ Yes, with detail	− No, not possible
	Cadastral plan	− complex to interpret	− complex to interpret	− complex to interpret
An integrated approach	LiDAR & photogrammetry	+ Yes, with detailed texture − costly	+ Yes, with detail − costly	+ Yes − costly − requires field work
	LiDAR & high-res satellite	+ Yes − costly	+ Yes	− No, not possible
	LiDAR & aerial photogrammetry	+ Yes − costly	+ Yes − costly	− No,not possible
	Terrestrial Laser Scanning & Terrestrial photogrammetry	+ Yes, with detail − costly	− No, not visible	+ Yes − requires field work
	Mobile Laser Scanning & cadastral plans	+ Yes, with detail	− No, not visible	+ Yes, from plans
	High-res satellite & cadastral	− No	+ Yes	+ Yes, from plans

	Mobile Laser Scanning/TLS & UAV	+ Yes, with detail − costly	+ Yes, with detail	+ Yes − costly
	UAV & cadastral plans	+ Yes, with detail	+ Yes, with detail	+ Yes, from plans

Table 2: Evaluation of sourcing geometric requirements

		Geometric				
	(for acronyms see Table 1)	Building dimensions	Boundary location	Spatial location	Indoor mapping	Analy-sis
Range-based	TLS	+ Yes, with high accuracy − costly − facades only in dense areas	− No	− Relative	+ Yes, possible − costly	+ Yes
	LiDAR/ALS	+ Yes, with accuracy − costly	+ Yes − costly	+ Yes, via on-board GNSS − costly	− No	+ Yes
	MLS	− building facades only	− No	+ Yes, via car GNSS	− No	+ Yes
Image-based	TP	+ Yes − less accurate high-rise>100m	− No	− Relative	+ Yes, possible	+ Yes
	AP	+ Yes, with high accuracy − costly	+ Yes, − costly	+ Yes, via on-board GNSS − costly	− No	+ Yes
	High-res Sat	− Only building shape	+ Yes	− requires control points	− No	+ Yes
	UAV	+ Yes, with high accuracy − subject to environ. cond.	+ Yes	+ Yes, via on-board GNSS	− No	+ Yes
	Cadastral plan	+ Yes − Difficult to interpret	+ Yes − Difficult interpret	− Relative	− too complex	− No

An integrated approach	LiDAR & P	+ Yes, with high accuracy − costly	+ Yes − costly	+ Yes − costly	+ Yes, possible − costly	+ Yes
	LiDAR & high-res sat	+ Yes, with high accuracy − costly	+ Yes − costly	+ Yes, via on-board GNSS − costly	− No	+ Yes
	LiDAR & aerial	+ Yes, with high accuracy − costly	+ Yes − costly	+ Yes, via on-board GNSS − costly	− No	+ Yes
	TLS & TP	+ Yes, with high accuracy − costly and limited to facades only in dense areas	− No	− Relative, requires control points	+ Yes, possible − costly	+ Yes
	MLS & cadastral	+ Yes, from plans − costly	+ Yes	+ Yes, via car GNSS	− No	+ Yes
	High-res & cadastral	+ Yes, from plans	+ Yes	− Relative	− No	+ Yes
	MLS/TLS & UAV	+ Yes, with high accuracy − costly	+ Yes	+ Yes, via car and on-board GNSS	+ Yes, possible − costly	+ Yes
	UAV & cadastral	+ Yes, with high accuracy	+ Yes	+ Yes, via on-board GNSS	+ Yes, possible	+ Yes

5 CONCLUSIONS

Following an overview of the current practice in land and property information management, this research has suggested a set of data sourcing requirements, based on the 2nd International Workshop on 3D Cadastres, held in Delft, The Netherlands, and from discussions at a collaborative research workshop on ‘Land and Property Information Management in 3D’ held at the University of Melbourne, Australia. Focussing on two of these requirements, the geometric and semantic dimensions, this research has investigated both image-based and range-based methods for data acquisition that can be applied in developing countries to help governing bodies manage our growing communities.

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Author/s:
JAZAYERI, IDA; RAJABIFARD, ABBAS; Kalantari, Mohsen

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3D data sourcing for land and property information: a geometric and semantic perspective