Accuracy assessment of building extraction using LiDAR data for urban planning/transportation applications

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ABSTRACT

Urban and transportation planning require land-use inventory (2D and 3D city models) to support the visualization and analysis of land-use patterns in the context of existing and future situations. These patterns impact travel behaviour, resulting in traffic volume and travel mode alteration. Thereby, identifying different land uses is crucial to transportation/urban planning studies. In particular, buildings as the “containers” of socio-economic activities are among the most important objects as they are constantly subjected to construction and destruction. On the other hand, providing precise building information such as floor space data is a vital input for integrated land-use transportation models (ILUTM). Moreover, a more cost-effective building information collection method is required to replace traditional ground survey techniques or estimation methods practiced in transportation related studies. Airborne laser scanning commonly referred to as LiDAR is an established technology which can collect the location and elevation of the reflecting surfaces of large areas. Building extraction from LiDAR data is a delicate process only available in high-end extraction solution software. By utilizing a normal LiDAR analysis program, this paper attempts to compare the accuracy of building information (e.g. building footprints and height) extracted from LiDAR data with the ground truth information at several zonal levels, e.g., Census block or tract, from the south side of the City of Fredericton. The accuracy of building information extracted from LiDAR data is quantified, and its applicability for land use and transportation is verified. Study results show that LiDAR technology is a timely and cost-effective approach for extracting building/land use information, and it can be considered as a valuable tool for sustainable urban/transportation planning.

Keywords: LiDAR, Remote Sensing, Land-use, Transportation, Urban planning, floorspace, Buildings

INTRODUCTION

Urban and transportation planning require land-use inventory (2D and 3D city models) to support the visualization and analysis of land-use patterns in the context of existing and future situations. These patterns impact travel behaviour, resulting in traffic volume and travel mode alteration. Thereby, identifying different land uses is crucial to transportation/urban planning studies (1). In particular, buildings as the “containers” of socio-economic activities, are among most prominent objects as they are constantly subjected to construction and destruction; leading to rapid changes of activity locations and travel patterns in urban areas. Therefore, an effective building information collection method is required to replace traditional ground survey techniques. Airborne laser scanning commonly referred to as LiDAR is an established technology which can collect the location and elevation of the reflecting surfaces of large areas. LiDAR point cloud data requires classification prior to building extraction, a delicate process only available in high-end extraction solution software.

In this project, we evaluate the accuracy of LiDAR extracted building information in urban planning/transporation studies. By utilizing a freeware LiDAR analysis software, this project attempts to compare the accuracy of building information (e.g. building footprints and height) extracted from LiDAR data with the ground truth information at several zonal levels, e.g., Census block or tract, from the south side of the City of Fredericton. The accuracy of building information extracted from LiDAR data is quantified, and its applicability for land use and transportation studies is verified. Study results show that LiDAR technology is a timely and cost efficient approach for extracting building/land use information, and it can be considered as a valuable tool for sustainable urban/transportation planning.

The remainder of this paper is organized as follows. In the subsequent section, the basics of LiDAR data collection process is explained due to its importance for understanding the feature extraction process. Followed by that the importance and application of LiDAR returns are explained while the “Related work”section looks into the background of this study. We also outline the building extraction procedure and methodology. Extraction results and accuracy assessment methods are also introduced and detailed in this section. In the final section, the approach is evaluated by an accuracy assessment. Last but not least, we conclude the paper by discussing the obtained results with details on future improvements of the approach.

LiDAR TECHNOLOGY

Light Detection and Ranging (LiDAR) technology is an effective way of producing digital elevation models (DEMs). LiDAR products can provide cost effective, horizontal and vertically accurate elevation data sets. These data sets have many applications, such as natural and man-made elements detection followed by 3D modelling of the identified objects. The LiDAR system, consists of three technologies: lasers, GPS, and inertial navigation system. The combination of these three tools allows recovering the returning points of the laser with high accuracy. The travel time of the laser pulse is recorded and using the three tools previously mentioned, accurate x, y and z coordinates are gained. The reflection of the laser beam striking one or more objects is termed as “*return*”. LiDAR return operate in three modes (2):

- First-return which measures the range of the first object encountered.
- Last-return which measures the range of the last object, usually contacting the ground surface under the vegetation.
- Intermediate returns, which measures the, range of mid way objects. They are ideal for determining vegetation structures.

Each LiDAR point obtained in the sweeping process is categorized as one of the groups mentioned above.

LiDAR returns and classification

LiDAR points are classified based on their return type. First returns can be used to create digital surface models that include features above the ground surface, such as buildings, bridges, and tree canopy. Intermediate returns are valuable in separating plants and trees from other objects among the above ground features. Last returns are a first approximation of the bare ground surface (3).

In addition to recording the time of a return pulse, most LiDAR systems record the intensity, or the magnitude, of the return pulse. In other words, they not only consider the fact that there is a return pulse, but they also measure the strength of the return. Objects with high reflectivity, such as snow or a metal roof, show a higher intensity return than dark objects, such as asphalt roadways (4).

LIDAR data can be classified according to the returns and intensity of the laser pulse reflections. LiDAR systems have the ability to record multiple returns for the same pulse. A laser beam originating from the aeroplane, may impact leaves at the top of a tree canopy, by traveling further, striking more leaves or branches and then touching the ground surface at the end. Due to the fact that the laser beam does not only contain one return from the same laser pulse; thus the point will be assigned as having a multiple return. This feature is crucial in distinguishing between buildings and trees in highly vegetated areas. On account of this, if a return is single, it can be inferred that a building or ground surface has been struck, and if it's a multiple return, then the points are probably related to vegetation. The last return of the beam, processing multiple returns, can be classified as ground surface.

Overall LiDAR provides the following functionalities (3):

- Active Sensing System.
- Measures range distances.
- Records time between emission, reflection and receive time.
- Provides direct terrain measurements, unlike in the photogrammetry technique which uses infrared technology.
- Day or night operation except when coupled with digital camera.
- LiDAR provides a point cloud with X.Y, Z positions.

BACKGROUND

There has been many geomatic studies to evaluate LiDAR data accuracy, for example, a study at the American Environmental Agency (5). The research brought out by this Agency is more concerned with accuracy assessment of DEMs in natural surfaces and places with difficult access. All result show that LiDAR is very accurate in generating DEMs in natural surfaces according to their environmental criteria. On the other hand, geomatic research on LiDAR has been largely devoted to enhancing details of a building perimeter using the point cloud data. It is resulted that by integrating photogrammetric data with LiDAR data, cleaner boundaries are obtained (6).

In 2001, NASA initiated an R&D program for the accuracy assessment of LiDAR for building extraction purposes (7). Their research was mainly focused on comparing the automatically extracted buildings with reference data, which contained building outlines and roof type information. The feasibility of creating 3D views of building footprints within the vegetative context of the image scene was examined. In another part of the study, an accuracy assessment was conducted against ground truth information. However, height information did not exist in the reference data and the vertical accuracy assessment was not possible (7).

A large amount of research has been done for improving LiDAR classification algorithms with more emphasize from remote sensing (8). Moreover, the Author discusses current extraction algorithms that are mainly applied and again new methods and algorithms to enhance building boundary conditions. Not much information exists on assessing the application of this new technology in transportation/urban planning related studies. However, this does not decline the importance of such remote sensing provided data in these areas.

Integrated land use-transportation models are in need of a variety of data in order to properly allocate and predict activities and interactions between different land use types. Moreover, the database developed for this purpose is integrated of parcel related and employment information (9). This may seem straightforward; however, most agencies lack employment density information mainly due to the absence of building floor space data (10). This clearly indicates the importance of building and floorspace data highly essential in planning applications which is not readily available.

STUDY DATA & METHODOLOGY

As previously explained, the objective of this study is to evaluate the accuracy of LiDAR extracted building information at zonal level (which is the most practiced level of aggregation in transportation modelling). Prior to conducting an accuracy assessment analysis, for more convenience different layers must be overlayed using ArcMap. The First phase is to extract buildings from the available LiDAR data; developing a shapefile of the city's buildings. The second phase is to overlay the ground truth layer containing building boundaries obtained from ground surveys and stereo photography with the buildings obtained from LiDAR data. This layer will act as our reference layer. The Final phase is to conduct a comparison analysis between the two layers of information in a few sample zones and evaluate the accuracy.

The statistics for the LiDAR data under study is listed in Table 1.

Table 1: Point cloud statistics

Return	**Number of points**	**Percentage(%)**
1st return	18,949,603	77.14
2nd return	4,656,206	18.96
3rd return	929,792	3.79
4th return	28,066	0.11
Total	24,563,667	100

Building extraction process using LAStools

LAStools (11) is a software utility consisting of many tools for LiDAR data processing. This includes the ability to extract building information out of LiDAR point clouds. However, to achieve this, a set of tools is used and each one must be applied in its correct phase, in the classification and extraction procedure. Many of the tools require execution from the command line and are initially less user friendly since they lack a graphical user interface(GUI).

The LiDAR data provided for this project was available in 13 separate files. Each file was one sweep of the aircraft across the City of Fredericton (South side). The first phase is to merge the LiDAR data into one file to make the analysis easier. This is done by using the Lasmerge tool. The second phase is the classification stage which assigns each point as either building, ground or vegetation. Lasclassify is the tool that provides the ability to classify buildings and vegetation of LiDAR points. However, this tool requires that the bare earth points and point heights (using lasheight) be identified prior to classification. This stage is performed using the Lasground tool. Lasclassify tries to find neighboring points that are at least 2 meters above the ground. According to what was explained in the LiDAR technology section, by detecting the first and multiple returns, buildings can be distinguished from tall trees that are also 2 meters above ground level. After conducting classification using Lasground and Lasheight, the buildings are ready to be identified.

Most algorithms available for feature extraction purposes are based on the height level of the LiDAR cloud points. However, this is not the only criteria that extraction is based upon. Before ground features can be extracted from the laser points, their height must be computed first. Extraction algorithms identify features mainly based on their height (12). For example, if a set of points positioned closely next to each other have approximately the same height (e.g. More than 2 meters from the ground) they'll be assumed a building. Nevertheless, if the rooftop is slightly declined there will be a higher chance of the laser reflection to come back as a "*single return*". This will help the algorithm to classify those points as a building roof (and not a tree), due to the multiple return nature of trees.

EXTRACTION RESULTS

Figures 1 and 2 display the lidar points after classification using the Lasview tool. Each point is colored according to its classification.

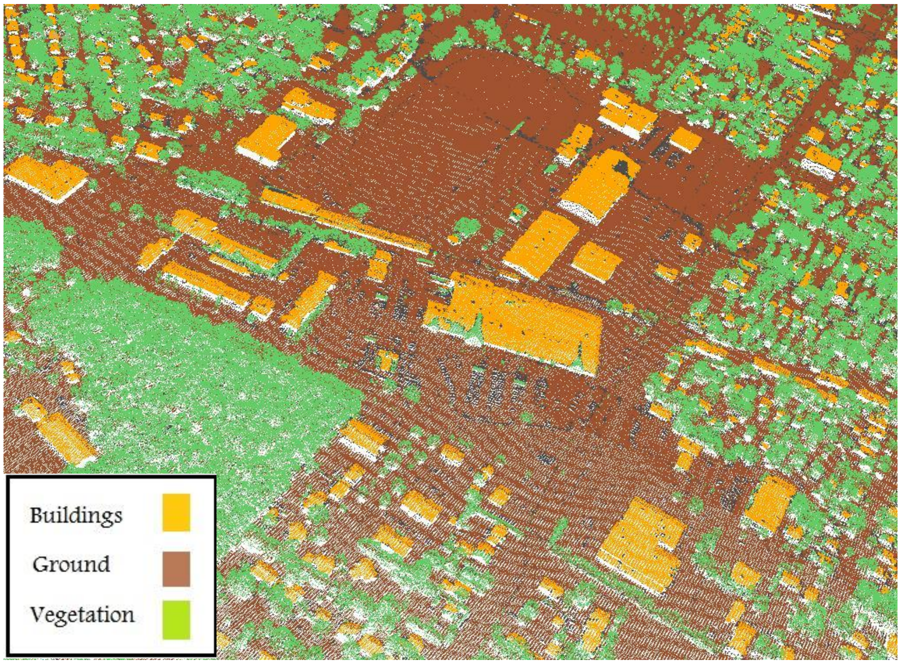

Figure 1) Classified LiDAR points in 3D view

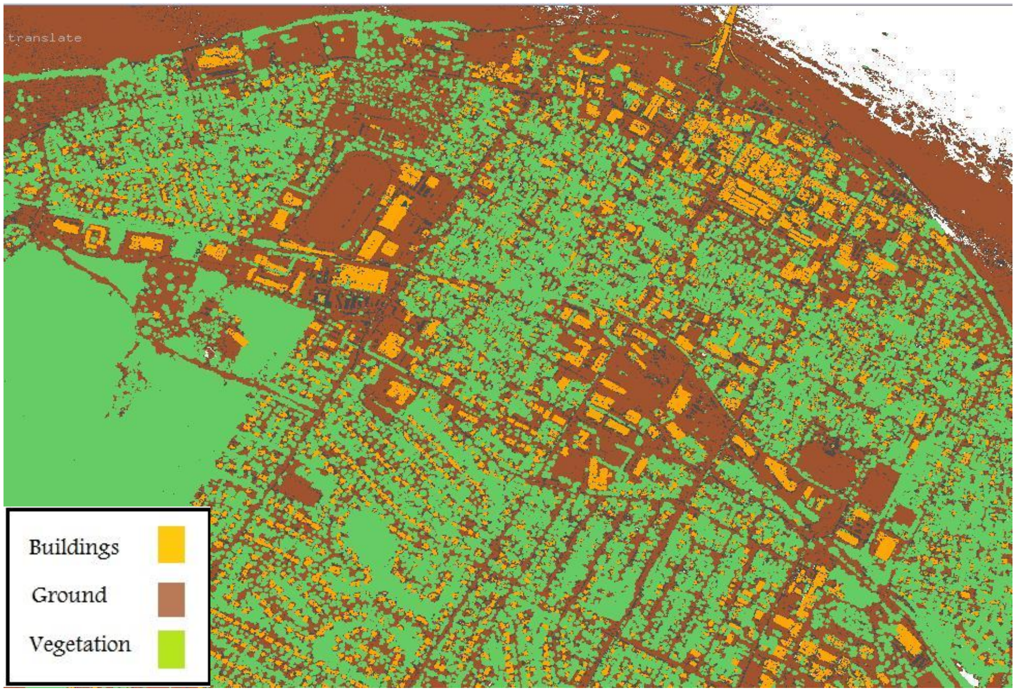

Figure 2) LiDAR classified points, 2D view from above

By eliminating vegetation, only ground surface and building objects are obtained. Figure 3 is a view of the buildings extracted, illustrated using FUGRO viewer.

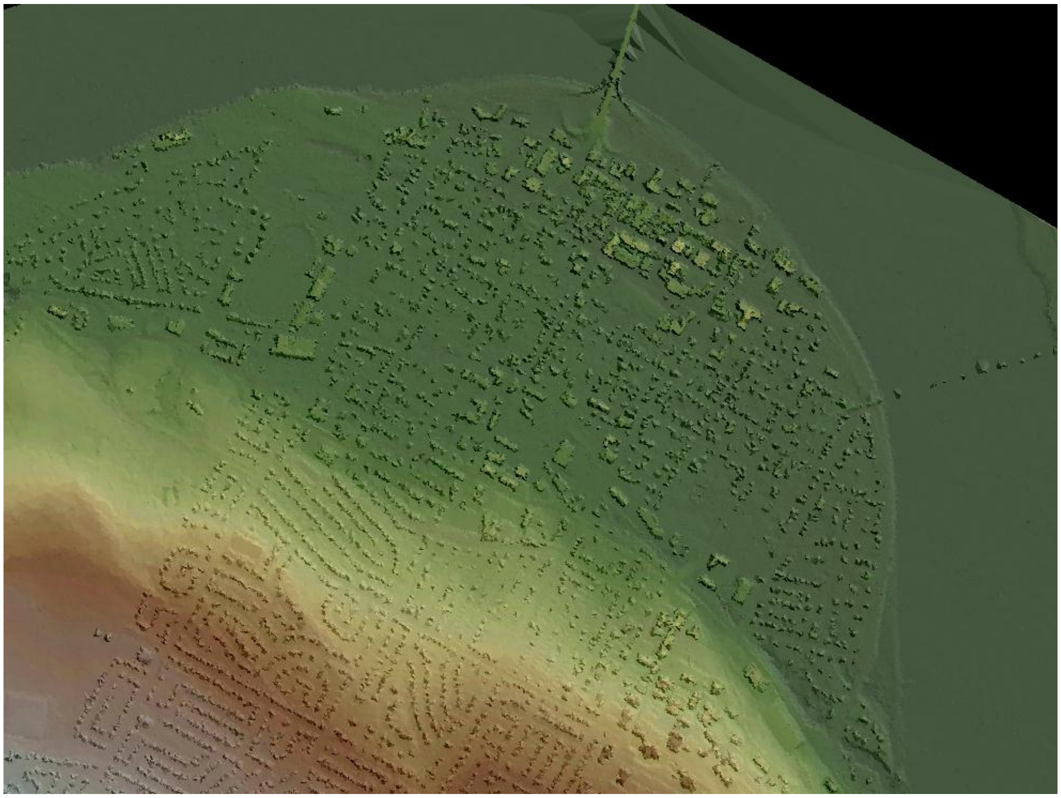

Figure 3: City of Fredericton- view from above after eliminating vegetation

The last phase of building information acquisition from LiDAR point cloud is determining the building boundaries. This is possible by using a tool named Lasboundary. This tool reads classified LIDAR data (which we previously classified) and computes a polygon boundary for the points. The computed building boundaries are then obtained as a shape file layer, ready to be inputted into ArcMap as shown in Figure 4.

Figure 4: Building footprints extracted using LiDAR point clouds

Overlaying shapefiles

The extracted building layer and the reference layers are now ready to be overlayed in ArcMap. To compare the datasets in ArcMap, both layers must be entered into a single data frame. Using a single data frame has the benefit of both datasets being in the same coordinate system. The ground truth layer has the NAD 1983 CSRS New Brunswick Stereographic coordinate system.

The coordinate system of the shapefile obtained from LiDAR data is UTM 19. In order to correctly overlay this layer with the ground truth, the coordinate system of the extracted layer is first defined using the "*define tool*" in ArcMap (13). Second, by means of the define projection tool this layer is projected to the ground truth layer coordinate system. The layers are now accurately overlayed.

Accuraccy assessment

Now that all three layers are placed correctly over each other in ArcMap. We are able to calculate the total building area and height of the extracted buildings and compare them to the ones of the ground truth in each zone. As shown in Figure 5, in the area of Fredericton under study, 8 sample zones are considered for accuracy evaluation purpose. The zones are carefully chosen to have a realistic representation of different types of buildings in a city. The building layer obtained from LiDAR data primarily lacks attributes related to each polygon's area and height. By using ArcMap's "*calculate geometry*" tool, the area, maximum, and minimum heights are obtained and assigned to each polygon that are recorded in the layer's attribute table. Buildings attributes in each zone are then copied and pasted into Microsoft Excel cells. The total amount of building areas and building heights are calculated in every zone, and the percentage of accuracy is computed using Equation 1.

$$Accuraccy = \frac{Total\ area\ or\ height\ of\ LiDAR\ extracted\ buildings\ in\ zone}{Total\ area\ or\ height\ of\ ground\ truth\ buildings\ in\ zone} \quad (1)$$

Figure 5: City of Fredericton sample zones for study

RESULTS

The results of this study are summarized in Table 2. By taking a closer look at the detailed information related to each zone separately, it is seen that in almost all of zones the number of building polygons do not match in the two layers under consideration. This does not mean that the applied extraction process has been unable to identify a considerable number of buildings. The case is that usually buildings (specially large ones) are a compound of a number of buildings settled next to each other. The base layer has distinguished between these buildings by drawing a line between them and identifying them as a separate polygon. Moreover, the extracted building layer from LiDAR hasn’t differentiated between buildings in such a case. That is why the LiDAR layer has less number of polygons but, it doesn’t mean that the extraction procedure hasn’t been able to identifying many buildings.

Table 2: Accuracy assessment results

	1	2	3	4	5	6
ZONE	**Total Area**	**Total Height**	**Total Area Extracted**	**Total Height**	**Area Accuracy(%)**	**Height Accuracy(%)**
1	13869.11 m^2	189.80	m^2 14014.33	174.07	98.96	91.71
2	7320.90	157.60	6270.88	214.36	85.66	73.52
3	15611.91	47.70	14733.47	76.70	94.37	73.11
4	25176.67	177.90	23076.03	135.81	91.66	76.34
5	3578.23	35.40	3169.31	31.70	88.57	89.55
6	15638.66	106.77	15718.40	127.20	99.49	83.94
7	8361.41	90.10	8737.14	127.75	95.70	70.53
8	58757.77	240.60	57520.75	275.4	97.89	87.36
Average	-	-	-	-	94.04	80.76

RESULTS DISCUSSION

LiDAR has the advantage of picking up vertical geometry of ground features. This can be used for calculating building heights. However, a building's roof is not a flat surface having a specific height. Worth mentioning, other features on rooftops like chimneys in residential buildings or central antennas on rooftops mostly visible in large buildings make the process of assigning a certain height to a building more difficult. The polygons extracted from LiDAR data have z value for each point of the building area but, it is crucial to wisely choose one or a combination of points heights that can most accurately represent the building's height. The first method to achieve this is to find the maximum and minimum height of each building and consider the building's height as the mean of these two measures. The results of accuracy assessment using this method are shown in the sixth column of Table 2. This has lead to an average amount of roughly 81% accuracy. However, some issues still exist that have to be clarified to obtain more truthful results related to building heights. The first issue is that, all of the extracted information are compared to the ground truth, but it is unknown to the writer, the building height measuring criteria of the ground truth layer. It is necessary to know if they have considered the highest point of the building as the building elevation or maybe assumed the starting point of the roof top as the building height. Not knowing this criteria has made it quite difficult to decide what method to use for height calculations.

Another technique is to convert each polygon's vertices into points and find the average height of the building perimeter. The following 4 steps have been followed in ArcMap to achieve this:

1. Running the Feature Vertices To Points tool with the ALL option.
2. Running the Add XY Coordinate tool on the points. This would add X, Y and Z coordinate fields to the point feature class.
3. Running the Summary Statistics tool to calculate the average or maximum values of the POINT_Z field, using the ORIG_FID as the Case Field.
4. Running Join Field tool to link the statistic table with the building polygons through the ORIG_FID and polygon ObjectID fields. Now a field of average Z is assigned to the building polygons.

By following these steps, the average height of each building along its perimeter is acquired. However, not much difference was observed between the previous maximum, medium mean, and the average Z obtained in the four step procedure mentioned.

Regarding the results brought up in Table 2, it can be concluded that an average of 94% accuracy is achieved in extracting building footprints from LiDAR laser points. This shows that obtaining building areas from LiDAR point clouds is remarkably accurate and reliable and the information can be applied in land use and transportation studies. However, the building heights obtained seem to be less accurate than the building footprints, having an average accuracy of nearly 81% compared to the ground truth information. According to the previous explanations on calculating building heights, it is believed that by clarifying the aforementioned concerns, a more precise method could be applied to find the building's elevations and to increase the average height accuracy. Another problem that causes uncertainty is that surprisingly ground truth information on building heights (obtained from stereo images by a consulting company) does not seem to be correct. Some of the large buildings in zone 8 are recorded to have heights as low as 3 meters. As verified through Google Maps Street View, this information cannot be true and consequently be used as a reliable base for comparison. However, another approach for accuracy assessment is also pursued to further clarify this issue.

The procedure used to evaluate height extraction accuracy is first: to find the total heights of buildings in a certain zone. However, by adding up all of the building heights regardless of the space that the building is occupying means that every building has the same amount of effect on the overall results. In land use and transportation studies since buildings are assumed containers of socio-economic activities, larger buildings should be weighted more than smaller ones. This is the reason that instead of solely depending on building height it is more beneficial to calculate and assess the accuracy of average volumes that buildings occupy in each zone. This approach is applied by multiplying the average height of each building by its area. The results are presented in Table 3.

Table 3: Zonal comparisons of building volumes

Zone	Ground Truth Total Building Volume(m^3)	Lidar Extracted Total Building Volume(m^3)	Accuracy Percentage
1	75405.26	111317.41	67.74
2	32591.50	40124.20	81.23
3	79697.42	98658.74	80.78
4	175028.20	215143.74	81.35
5	20013.95	21945.14	91.20
6	101050.22	126724.43	79.74
7	44446.10	54852.84	81.03
8	385156.64	673140.42	57.22
Average	-	-	77.54

Results in Table 3 show that by taking such an approach, the average accuracy percentage decreases slightly. However, the accuracy levels are expected to be higher than this amount, but due to further unknown issues existing in the ground truth information the accuracy has declined. The results in Table 3 clearly state that accuracy decreases in zones having larger buildings, (specially in zone 8 with 57%) and it is strongly suspected that flaws exist within the height information provided by the ground truth layer.

CONCLUSIONS AND FURTHER RESEARCH

As previously explained, we found out that the information regarding the building heights, which was the base of our comparison, is imperfect. However, by conducting a ground survey in person building heights from LiDAR data roughly matched their number of floors. Moreover, the results completely show that the "truth layer" definitely contains flawed building heights but, extracted heights from LiDAR are very close to the estimations based on common sense.

The main purpose of this study is to introduce LiDAR remote sensing technology as a precious tool to identify and quantify important urban features such as buildings and innovatively apply it to urban/transportation planning studies and applications. Due to lack of floorspace information from traditional data source such as Census, this measure has been either completely neglected or in many circumstances, very inaccurately estimated where required such as ILUTM inputs. At an aggregate level, floorspace information obtained from LiDAR can be seen as a reliable input for land-use transportation models such as PECAS or for application in microsimulation based models; considering agents at an individual level. Other applications include improving bus route efficiencies by insuring the highest amount of population coverage from LiDAR instead of inaccurate density data at large zone levels. LiDAR can also be of use in improving road safety by digitizing constructed roads features providing the opportunity to match design blueprints with the real outcome.

REFERENCES

1. **O'Connor, Jennifer.** *Land Use Planning and Transportation.* s.l. : PAG.

2. The University of Texas at Austin School of Architecture. [Online] Community and Regional Planning Program. http://soa.utexas.edu/crp/gis/arcgis_tips/coordinate_system_set.html.

3. *LIDAR Principles and Applications.* **Burtch, Robert.** s.l. : Surveying Engineering Department, Ferris State University.

4. *PENNSTATE College of Earth Sciences.* [Online] https://www.e-education.psu.edu/lidar/l1_p6.html.

5. **Keil Schmid, Kirk Waters, Lindy Dingerson, BrianHadley, Rebecca Mataosky, Jamie Carter, and Jennifer.** *An Introduction to Lidar Technology,Data, and Applications.* Charleston : National Oceanic and Atmospheric Administration (NOAA), 2008.

6. **Habib, Ayman F.** *Integration of Photogrammetric and LiDAR Data for Accurate Reconstruction & Realistic Visualization of Urban Environments.*

7. **Director), Mr. Tim Haithcoat (GRC Program.** Building Extraction - LIDAR Project report. [Online] http://www.icrest.missouri.edu/Projects/NASA/FeatureExtraction-Buildings/REPYear2-build-extraction.pdf.

8. *Building Boundary Extraction Based On LIDAR Point Cloud Data.* **Wei, SHEN.** Shanghai : ISPRS, 2009.

9. Transportation and land managment agency. [Online] [Cited: Febuary 5, 2012.] http://www.rctlma.org/genplan/content/appendix/appendixe.html.

10. **Pflum, Erin Kapena.** *EMPLOYMENT DENSITY IN THE PUGET SOUND REGION.* Washington D.C : University of Washington, 2004.

11. **Isenburg, Martin.** [Online] http://www.cs.unc.edu/~isenburg/lastools/.

12. *Automatic Building Extraction From Airborne Laser Scanning Data.* **Michel Morgon, Klaus Tempfli.** Ohio State University, USA : ISPRS Commission III, Symposium, 2002, Vol. Volume XXXIV Part 3 A+B.

13. ESRI-Forum. [Online] esri/forum.com.