Chapter

New Metrics for Spatial and Temporal 3D Urban Form Sustainability Assessment Using Time Series Lidar Point Clouds and Advanced GIS Techniques

Sara Shirowzhan, John Trinder and Paul Osmond

Abstract

Monitoring sustainability of urban form as a 3D phenomenon over time is crucial in the era of smart cities for better planning of the future, and for such a monitoring system, appropriate tools, metrics, methodologies and time series 3D data are required. While accurate time series 3D data are becoming available, a lack of 3D sustainable urban form (3D SUF) metrics, appropriate methodologies and technical problems of processing time series 3D data has resulted in few studies on the assessment of 3D SUF over time. In this chapter, we review volumetric building metrics currently under development and demonstrate the technical problems associated with their validation based on time series airborne lidar data. We propose new metrics for application in spatial and temporal 3D SUF assessment. We also suggest a new approach in processing time series airborne lidar to detect three-dimensional changes of urban form. Using this approach and the developed metrics, we detected a decreased volume of vegetation and new areas prepared for the construction of taller buildings. These 3D changes and the proposed metrics can be used to numerically measure and compare urban areas in terms of trends against or in favor of sustainability goals for caring for the environment.

Keywords: point cloud, voxel, time series lidar, 3D spatiotemporal changes, urban remote sensing, machine learning, 3D urban form, support vector machine (SVM) 3D change detection, smart cities

1. Introduction: 3D sustainable urban form

Urban form is defined as a composite of the patterns of land use, transportation network and urban design [1]. It is also defined as the spatial pattern of the "large, inert and permanent physical objects" ([2], p. 47). Anderson et al. [3] defined urban form as the "spatial pattern of human activities". Aggregation of repetitive elements determines a form and urban form is a result of urban patterns [4]. Indeed, these urban patterns are the results of the repetition and combination of undifferentiated elements [4]. Considering the scale of analysis, Tsai [5] classified the levels of urban form analysis into neighborhood, city and metropolitan area together with three variables of density, diversity and spatial structure. These variables for different scales of analysis may carry different meanings. Therefore, firstly, the scale of analysis needs to be determined, and then the meaning of the variable for that scale needs to be found. While plot and urban block are the terms implying local scale, urban form is used for a range of scales from local to regional (i.e. neighborhood, city and metropolitan area).

Sustainability of urban form is a crucial topic that needs to be carefully considered for future cities.[1] The need of sustainable cities was recognized by the United Nations (UN) in setting up the UN Sustainable Development Goals [6], in which the 11th goal aims to "Make cities and human settlements inclusive, safe, resilient and sustainable". According to the UN, city populations are growing with about 54% of the global population,or about 3.9 billion people, now living in cities [6]. One of the issues facing future cities centers around climate change. Land use has been known as one of the major factors affecting the level of heat in urban areas at a large scale. If we think about cities in three dimensions, we see that the height and bulk of buildings are also important factors in local climate phenomena, in particular the urban heat island (UHI) effect defined by the temperature difference between urban areas and their surrounding rural areas. Building height and geometry affect the distribution patterns of shade, wind speed and wind direction. Urban canyon geometry (orientation plus aspect ratio, the ratio of average building height to street width) affects street ventilation and the dispersion of air pollution. In turn, these factors interact with the urban heat islands effect to create a unique urban microclimate.

Knowledge of three-dimensional (3D) urban growth including changes in human formed and natural objects requires accurate monitoring systems that are able to identify areas with greater changes that are unsustainable and therefore can be prioritized areas for greater attention for intervention policies and activities. In this way, the monitoring system helps to build a more resilient urban form that should maintain adequate levels of the natural environment in built-up areas.

In addition, urban vegetation cover has positive effects on microclimate since it helps to reduce carbon emissions though absorbing CO_2 as well as mitigating other gaseous and particulate air pollution. Additionally, it helps to minimize soil erosion, retain soil moisture and reduce the generation of dust.

Current urban change studies focus on land use change detection occurring in decades or annually at large scales and ignore short-term changes of vegetation within built-up areas. Also, detected urban changes are generally two-dimensional; for example, rarely changes within an area of lawn or area of trees have been noticed. The differential effects of trees and grass areas on microclimate can be easily understood in terms of shading and evapotranspiration. Also in Shanahan et al. [7], the benefits of tree cover in a city in the UK one in Australia, were estimated by 'Nature Relatedness', in which tree cover varied from less than 10% to more than 60%. The Natural Relatedness scale correlates well with attitudes toward nature and distinguishes between those who are enthusiastic about nature and those who are not. The chapter demonstrates the benefits of tree cover including reduced stress and asthma and 'psychological restoration'. 'Nature dose intensity' in the form of trees taller than 2 m was assessed using airborne lidar and NDVI from Landsat 8 images [8].

This raises a critical question about how vegetation cover changes compared to 3D changes in built form in urban areas. Through exploring fine resolution 3D

[1] In this chapter more or less 'sustainable' refers to the dynamic relationship between vegetation and built form in the city

changes within a built up area and to answer the above research question, this work reviews and discusses existing 3D metrics for defining sustainable urban form (3D SUF), proposes some new 3D metrics and develops a new approach to processing time series airborne lidar for monitoring 3D SUF, to support decision-making in favor of a more resilient and sustainable urban form for future generations.

The rapid growth of high-rise urban development has created an urgent need for new methods for characterizing the trends and patterns of these developments, including changes in time series 3D data sets. Repeated airborne lidar data coverage can provide accurate 3D data revealing changes of building heights over time. Integration of information derived from remote sensing acquisition systems with new digital technologies, such as GIS-based applications, provides a unique opportunity to the users for interactive accessibility to the magnitude of change.

In this research, we use the advanced remote sensing technology of Light Detection and Ranging (lidar) to acquire time series airborne data to detect 3D morphological changes in inner city locations and visualize the outcomes in a GIS-based application in which the end-user can readily access information about these changes.

2. Developing conceptual approaches of urban growth modeling toward 3D

There are two major conceptual approaches at metropolitan scale for the analysis of spatial and temporal urban patterns, namely, traditional and modern perspectives. These approaches are illustrated in **Figure 1** adapted from Herold [9]. Herold explains that processes produce structures in the traditional top-down view (i.e. from process to structure), whereas two-dimensional spatial arrangements of urban elements such as open and public spaces (i.e. structures) are representative of socioeconomic activities or policies and strategic plans to achieve a certain type of urban pattern (i.e. process) in the modern bottom-up view (i.e. from structure to process). Demand for land, master plans and economic forces are major drivers

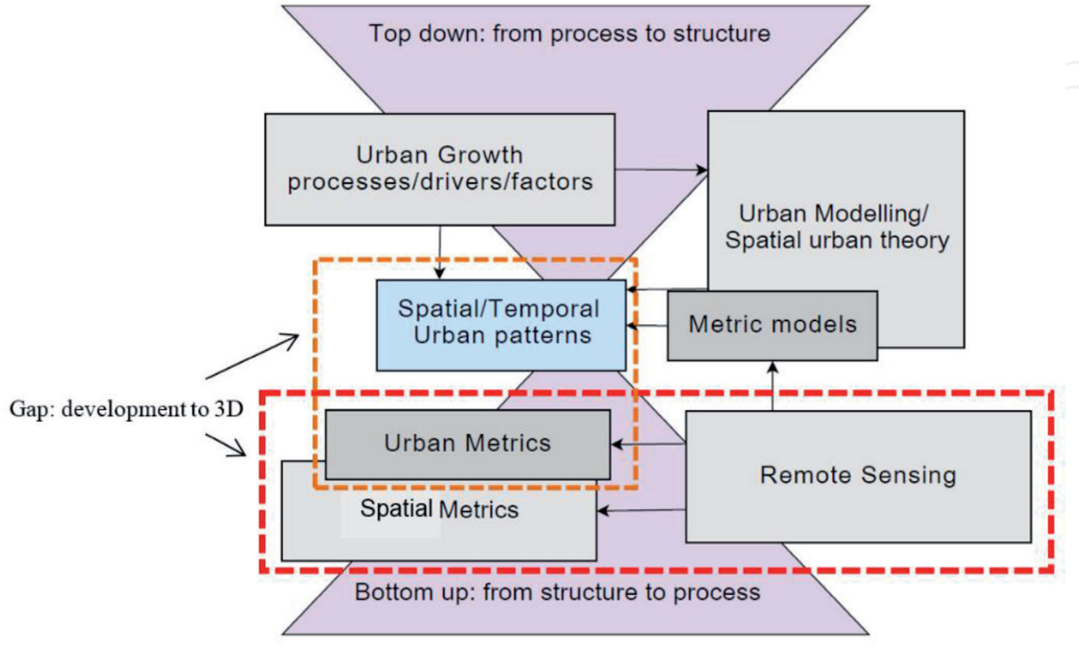

Figure 1.
Developing conceptual approaches for studying 3D urban dynamics (adapted from Herold et al. (2005)).

and factors that affect urban change over time. Indeed, the question is how a type of pattern for change in urban structures results from these processes. As shown in **Figure 1**, urban metrics are applied to remote sensing data to derive spatial and temporal patterns of urban structure and development in the bottom-up view known as modern perspective. Then the derived structure becomes the subject for analysis and investigation of the underlying processes. In contrast, it can be argued that the processes are the major drivers of the existing patterns of urban form and structure [9] in the traditional perspective.

While two-dimensional information on urban development patterns is typically derived from the modern approaches, they have not been applied to investigate 3D knowledge of urban patterns. This gap is noted in **Figure 1**, and the aim of this research is to fill the gap of vertical urban development pattern analysis by proposing new 3D metrics and employing 3D remote sensing data (i.e. airborne lidar).

The motivation for proposing new 3D compactness metrics in this study is the current lack of appropriate metrics. Two commonly used metrics in urban planning are building coverage ratio (BCR) and floor area ratio (FAR). BCR is defined as the building coverage area divided by the area of the land lot (plot). This metric is also known as the building–to-land ratio (BTL). FAR refers to the ratio of the combined area of building floors to the total area of the land lot. As seen, BCR and FAR are 2D and 3D, respectively. While FAR has been calculated using remote sensing data such as airborne lidar, it suffers from the problem of uncertainty, because FAR is calculated based on assumptions about each floor height. This metric is subject to uncertainty because floor height is definitely higher for a retail land use in a large shopping center than for low-density residential land use (Yu et al. [10]). Also, the threshold of floor height differs from city to city.

Past and current practices in urban form studies focus on themes such as the two-dimensional growth of urban form or horizontal development in space and time [11, 12] as shown by the following:

- growth of built up areas as a 2D phenomenon [13];
- using 2D landscape metrics for analysis of sustainable development of urban form over time [14];
- using temporal remote sensing data for assessment of urban form and morphology changes over time for considering sustainability [15];
- claiming to address sustainability aspects, but the study only focuses on 2D urban form study over time [16];
- analysis of 2D expansion of cities using remote sensing data [17], considering compactness as a sustainable urban form and other relevant studies [18];
- sustainable 2D brownfield development [19];
- change of 2D land use considering compact the urban form paradigm as a claimed sustainable urban form [20, 21].

There are also studies on the effect of urban form on energy consumption for a sustainable city [22].

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3. Problems of 3D urban development studies in literature

Nowadays the use of 3D building models focuses on visualization, which also have high "potential for supporting the 'smart city' concept" [23]. 3D city models are often managed by using CityGML that is an information model for storing, representing and exchanging of virtual 3D city models. While there are methods in CityGML that demonstrate the 3D changes to buildings [24] in urban areas, there are some problems with these methods that are listed below:

- Studying time series 3D models is a very time-consuming task.
- Such studies usually only consider cities as places of buildings, whereas cities consist of buildings, infrastructure, trees and other vegetation cover established on terrain with various topographical characteristics across different locations.
- This kind of change detection using existing 3D city models is not appropriate for applications of disaster monitoring, as the 3D models are not representative of real situations and as well they require a lot of time to produce.

Indeed, the as-built city models derived from airborne lidar data are closer to reality than those 3D models created from cadastral layers and building height information which usually ignores detailed height information of the different parts of a building. Also, advanced remote sensing airborne lidar data captured over urban areas is an accurate source of 3D data from which to derive 3D city models. Change detection from time series airborne lidar data is a preferred approach as it does not include the above-mentioned problems. As well, advanced data collection methods such as using remote piloted aerial system (RPAS) can be used for collection of data immediately after rapid changes consequent on disaster events such as floods or earthquakes. There are several algorithms for detection of these changes from time series airborne lidar data. One of the major problems in urban change detection studies of airborne lidar data is that the pixel-based algorithms that are more appropriate for calculation of volumetric changes suffer from either lack of height change information or a high level of noise.

There are other problems relevant to 3D metrics for assessment of the sustainability of urban form. While there are 3D metrics for comparison of different urban forms or to characterize 3D cities, there is a lack of appropriate metrics for application into the assessment of the sustainability of urban form over time, as defined in the Introduction. Koziatek and Dragicevic (2019) proposed 3D indices for spatial and temporal urban analysis of 3D urban expansion, but one of the major problems of their studies is that they do not use time series 3D remote sensing data for exploration of the real changes of the buildings over time. There is a problem of uncertainty in their 3D models because various sources of building height data are used to create time series 3D city models. For example, the number of floors is one source of building height data, but as discussed before, heights between floors for buildings with different functionalities vary; therefore, estimation of building heights for an urban area with various building uses based on number of floors is very inaccurate.

All in all, a thorough review of the urban form literature and metrics [25] shows that even though urban form analysis has a long history in the literature, there are deficiencies in metrics development including (a) a lack of 3D studies using remote sensing for sustainability assessment of urban form and (b) a lack of studies on 3D urban growth assessment for sustainability.

Considering current rapid urbanization and the above-mentioned lack of studies on sustainable 3D urban development, there is an urgent need to numerically characterize how 3D urban development affect the sustainability goals of caring for the environment, including maintaining (and ideally, enhancing) vegetation.

4. Proposing novel methodology and 3D metrics for sustainable urban form assessment over time

4.1 Airborne lidar and technical methods

Light detection and ranging (lidar) measures ranges from an airborne scanner which scans at right angles to the flight direction, to the terrain surface using a pulsed laser and generates rich 3D point clouds about the terrain surface and objects on the surface. The round trip time of the laser pulses from aircraft to the ground allows the determination of the distance from the laser scanner to the terrain or objects. Together with known positions and attitude of the scanner derived from a global navigation satellite system (GNSS) receiver for the determination of instantaneous positions of the aircraft and an inertial measuring unit (IMU) for the determination of instantaneous velocities and orientations of the aircraft this also enables determination of accurate 3D coordinates of points representing the terrain or any visible objects on the terrain. After pre-processing, the data can be used for a wide range of applications such as urban growth monitoring, biomass estimation and object measurements. **Figure 2** illustrates the summary of the entire process of data acquisition and applications.

A digital surface model (DSM) is generated from airborne lidar data elevation values projected on a raster data format.

Figure 3 represents a flowchart of our tested time series airborne lidar data processing and the method for application of the proposed 3D metrics. Ground, vegetation and building classes can be extracted from temporal airborne lidar data sets which are Digital Surface Models (DSM). The difference between the ground elevation and elevations of buildings and vegetation, provides the height of these objects above ground. Also, voxelization of the buildings and vegetation classes would be advantageous to overcome the problem of different point density and sampling of the time series airborne lidar data. Comparison of the buildings and vegetation changes over time from either approaches (i.e. the approach of

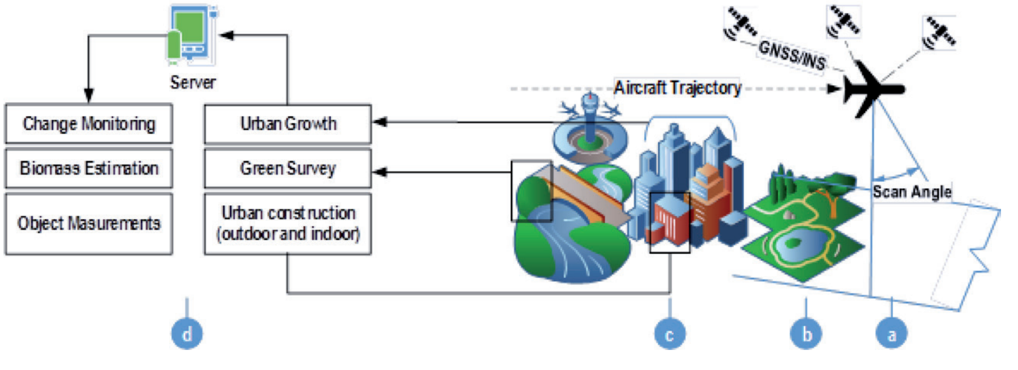

Figure 2.
Generating big data for urban growth and construction change analysis, (a) airborne lidar; (b) biomass survey; (c) dimensions of buildings; (d) data collection and processes.

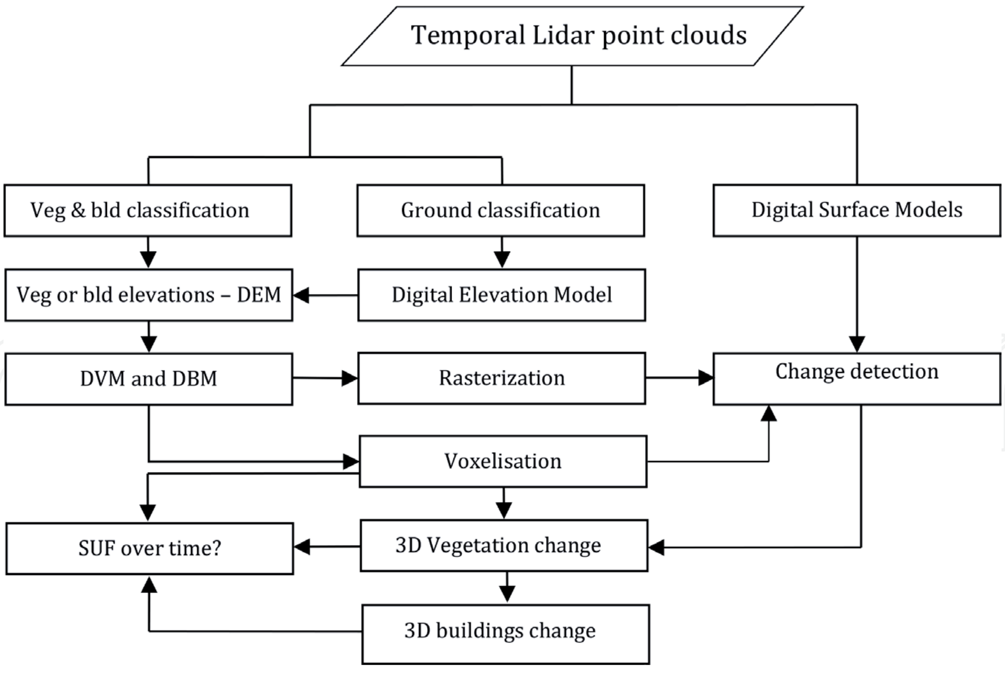

Figure 3.
The flowchart of the proposed procedure of airborne lidar data processing for the calculation of 3D metrics of sustainable urban form. Note: UFS: Urban form sustainability; DBM: Digital building model; DVM: Digital vegetation model; bld: Building; veg: Vegetation.

classification then detecting changes or the approach of change detection) can be used in a SUF study so as to see how the volumes of buildings change compared to the volume of vegetation, as one indicator of sustainability.

One of the challenges regarding various change detection algorithms is that, especially for time series airborne lidar, the performances of these algorithms are not evaluated for large data sets covering vast urban areas. In addition, the results of these algorithms are not compared to identify the most appropriate one for determining three-dimensional changes of urban developments. Matikainen et al. [26] have also confirmed that there have been limited studies on change detection over large urban areas.

A lack of criteria on which to base comparisons of change detection methods for characterizing vertical urban development is also another problem. In this study, two criteria for the evaluation of change detection algorithms have been developed; namely, determination of the range of height changes; and differentiation between new or increased heights, as against demolished or decreased heights in the building class.

4.1.1 Study extents

Time series airborne lidar data for the University of New South Wales are considered as spatiotemporal 3D test data to quantify 3D changes of buildings compared with vegetation. **Figure 4a–c** illustrates these data sets, and areas of 3D changes can be seen by comparing them. Details of these data sets are summarized in **Table 1**.

4.2 Building and vegetation metrics

As discussed before, there is a lack of metrics for assessment of sustainability of urban form as a 3D phenomenon over time. We propose the following metrics to be added for this purpose.

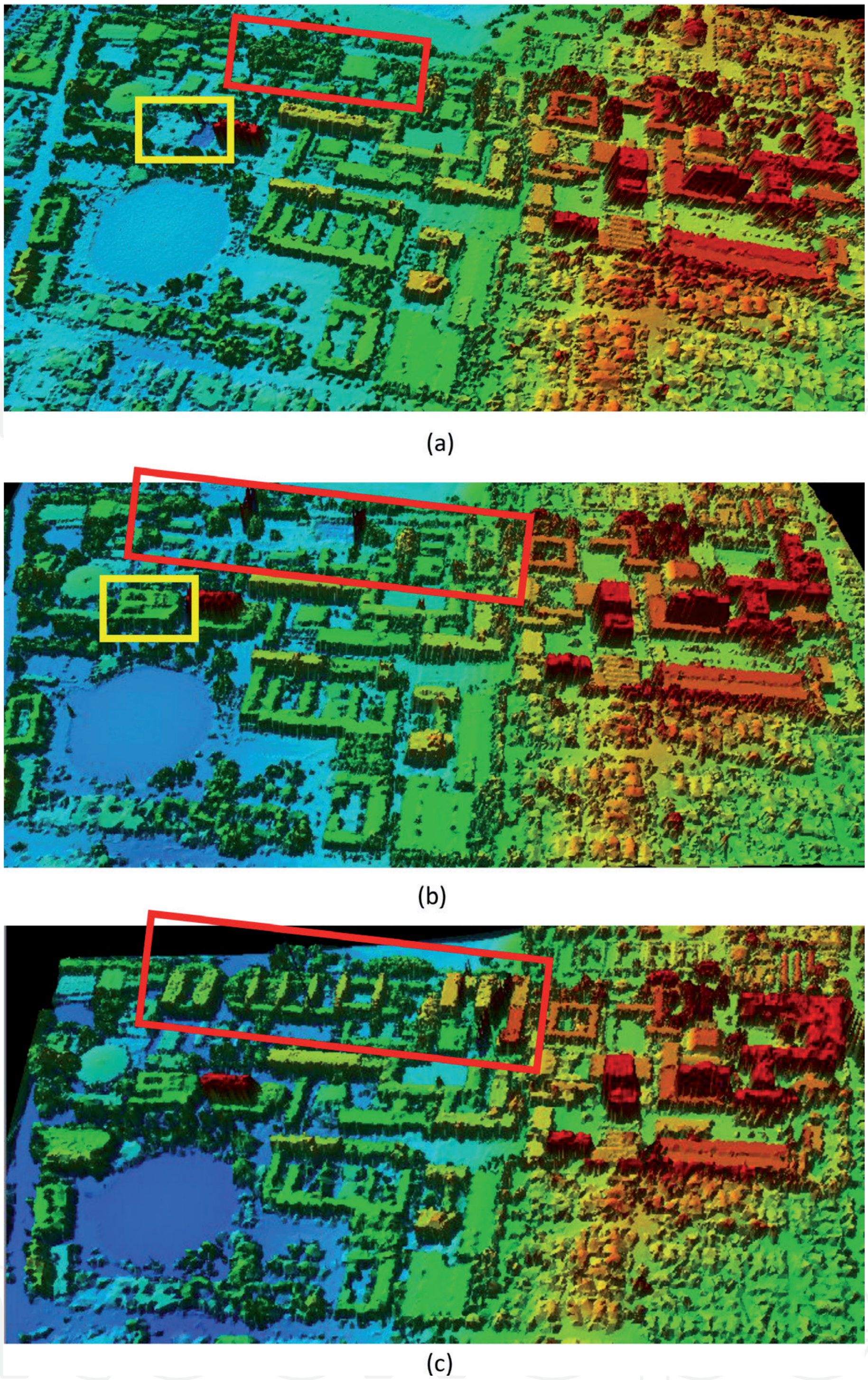

Figure 4.
Time series airborne lidar data over the selected area of Sydney, Australia and demonstrated areas of changes in yellow and red rectangles: (a) lidar data collected in 2005; (b) lidar data collected in 2008 and (c) lidar data collected in 2013.

	2005 UNSW	2008 UNSW	2013 UNSW
	Optech ALTM 1225	**Optech ALTM 3100, Optech ALTM 3025**	**Leica ALS50-II**
Vertical accuracy (m)	0.10	0.15	0.3
Horizontal accuracy (m)	0.5	0.5	0.8
Density (points/m^2)	1	1.3	1.57

Table 1.
Detailed information of airborne lidar data sets used in this study.

4.2.1 Ratio of volume change (R_{VC})

For comparison of the changes of new and demolished buildings, a volumetric descriptor of ratio of volume change ($\boldsymbol{R_{VC}}$) is proposed in (1):

$$R_{VC} = \frac{\sum_{i=1}^{k} n \times h_{in}}{\sum_{i=1}^{l} d \times h_{id}} \quad (1)$$

where $\boldsymbol{n}$ demonstrates the area of a pixel on detected new buildings and $\boldsymbol{h_{in}}$ demonstrates the height of that pixel above ground, $\boldsymbol{d}$ represents the area of a pixel in demolished buildings and $\boldsymbol{h_{id}}$ is its corresponding height value. This ratio can be calculated using the results of image differencing.

One of the limitations of DSM differencing method is the selection of the appropriate thresholds for the unchanged class. Lu et al. [27] proposed thresholds to be $[m - \gamma\sigma, m + \gamma\sigma]$ in the histogram of the resultant difference image (i.e. DSM_d), where m is the mean of the distribution and σ represents the standard deviation. Shirowzhan [28] tested different values between 2 and 4 for the thresholds of γ in this study area and found that $\boldsymbol{\gamma} = 3$ is an appropriate value.

The next step for this 3D metric is a careful visual inspection to determine whether the areas of change belong to buildings because the result of image differencing includes both buildings and vegetation changes. If this ratio is more than 1, it means that the volume of new buildings is greater than the volume of demolished buildings. However, this metric cannot show whether the development is of vertical form. Therefore, complementary descriptors are necessary to recognize whether the urban form change is vertical growth. For example, if this ratio is greater than 1 and the new buildings are higher than the demolished ones, it can be concluded that an infill vertical development is occurring in a study area.

4.2.2 Mass and space index

Other volumetric descriptors for spatial and temporal 3D urban growth can be proposed which use improved concepts of 3D mass and space in urban planning. Examples of a 3D mass index and a 3D space index are defined in (2) and (3) as the ratio of the volume of buildings (or vacant space if applicable) to the total volume of an assumed cube, whose footprint is the ground surface area including all buildings, and its height equals the tallest building height in the study extent. For a study extent, after calculation of the volume of new and demolished buildings, an increase in the 3D mass index will represent a trend toward more compact 3D urban form. The assumption for the cube is that it only contains buildings.

$$3D\ MassIndex = \frac{Vb}{Vc} = \frac{\sum_{i=1}^{n} b \times h_b}{Vc} \quad (2)$$

$$3D\ Space\ Index = \frac{Vs}{Vc} = \frac{Vc - \sum_{i=1}^{n} b \times h_b}{Vc} \quad (3)$$

where V_b is the volume of buildings, V_c is the volume of the containing cube and V_s represents the volume of vacant space. In a pixel-based method, b is the area of a pixel representing built form and h_b is the corresponding height of the pixel.

5. Results

Temporal point clouds of the selected case study were analyzed based on the developed procedure (refer to **Figure 3**). The purpose of the analysis was vegetation and building classification, ground classification and creating a DSM. Each of these objectives is presented in the following sections:

5.1 Building and vegetation classification from airborne lidar

For classification of buildings using ERDAS Imagine software, various thresholds are tested for the parameters of minimum slope, minimum area, plane offset, minimum height, maximum height and roughness and we came up with the optimum values to be 30, 100, 1, 2.5, 10,000 and 0.3 for each of the parameters, respectively (see **Figures 5** and **6**). The results show misclassifications between ground and buildings, building boundaries and vegetation. In addition, some of the buildings with multi-level attachments to the rooftops are classified as vegetation. These misclassifications can be overcome through postprocessing by careful manual adjustment.

5.2 Change detection and calculation of the 3D metrics

The results of change detection using an integrated approach of SVM and together with DSM differencing are presented in **Figure 7**. **Figure 8** also shows the profile views of an excavated site in 2005 that was changed to a tall building in 2008. As seen in **Figures 6** and 7, the level of noise is very low for the integrated approach compared with when DSM differencing only is used and the magnitude

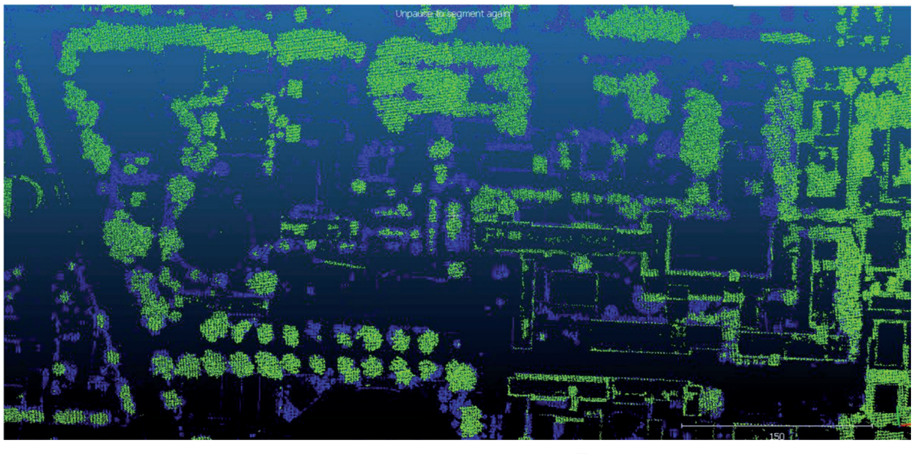

Figure 5.
Vegetation classification.

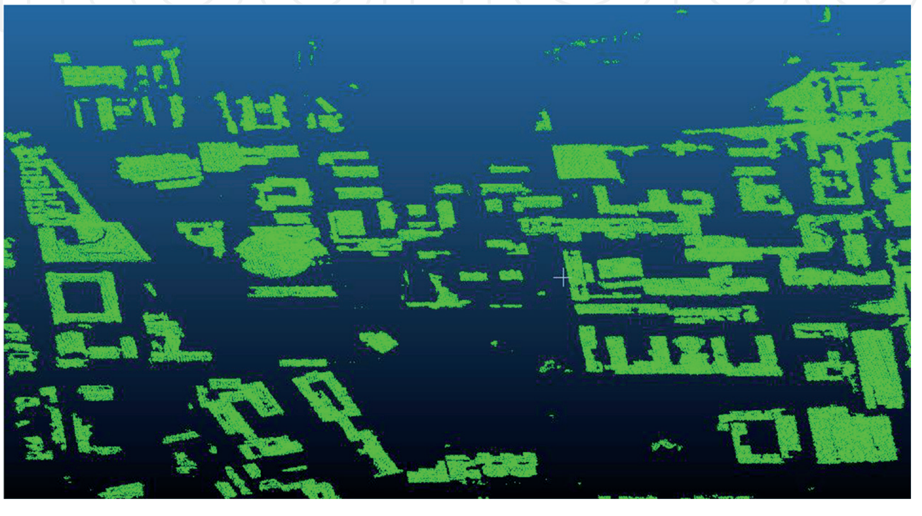

Figure 6.
Building classification.

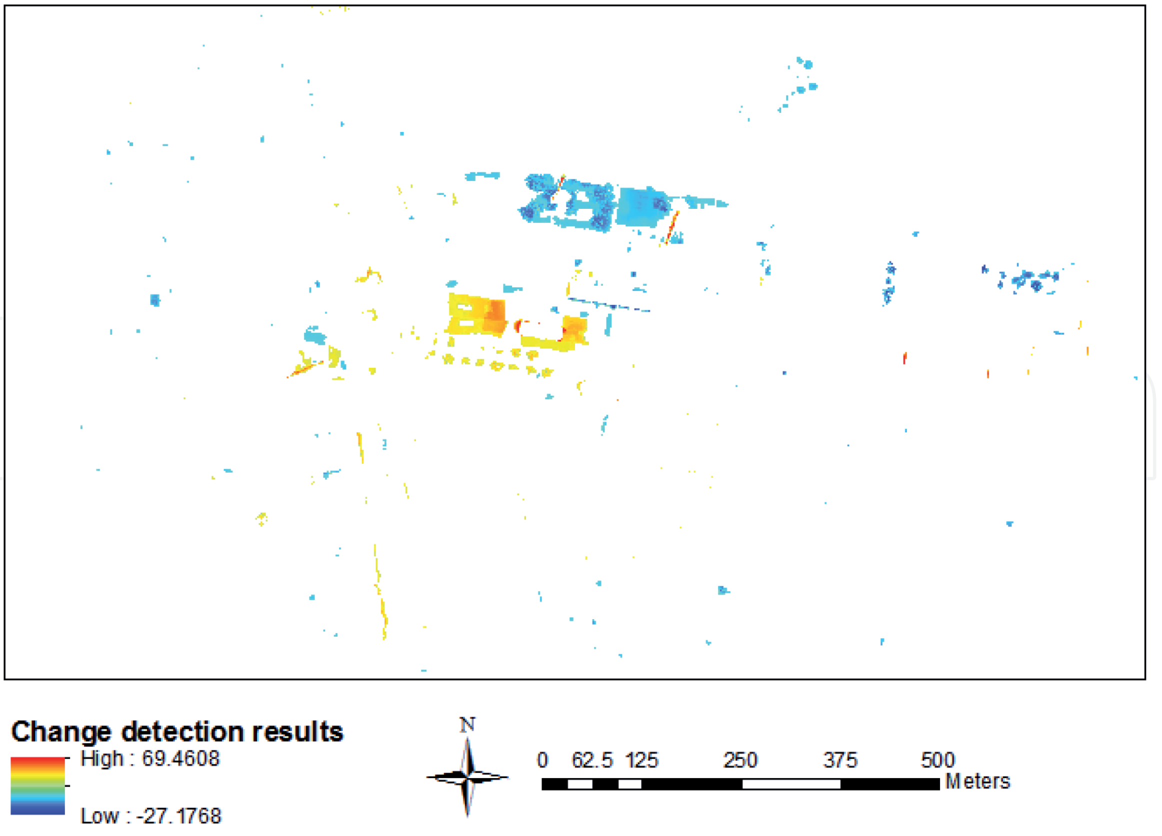

Figure 7.
Results of 3D change detection between 2005 and 2008 from the integration of DSM differencing and SVM.

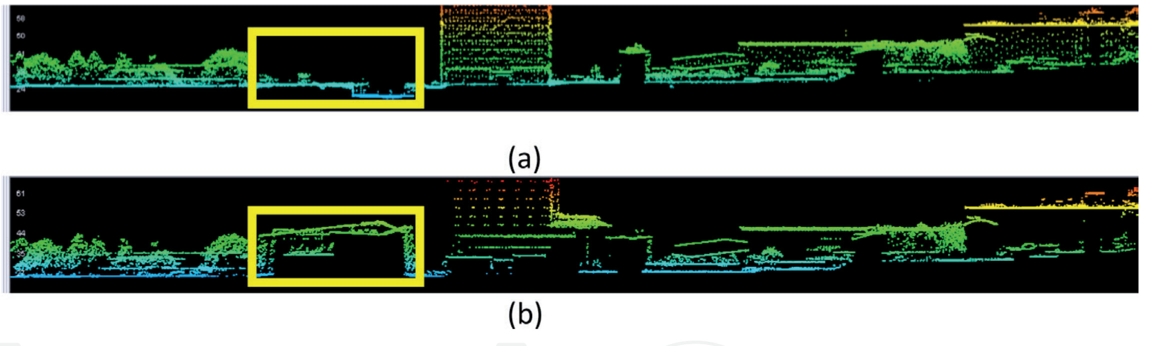

Figure 8.
Changes of profiles views for an excavation site to a new tall building from 2005 to 2008.(a) excavated site, (b) the new tall building.

of change can be accessed for each pixel. Having these values for each pixel gives a major advantage for the calculation of 3D metrics as proposed in Section 4.2. While this method is recommended in this research, there are other problems which need to be resolved before developing it further. One problem is to differentiate between buildings and trees in the changed results. For the problem of occlusions among trees and building points, it seems that separation of these two classes of objects in the change detection result is very challenging. The approach of classifying buildings first and then determining change detection second, is also challenging as the differences of lidar point densities impact the results [29].

6. Discussion

The analysis of the changes of urban form including buildings and trees in 3D space is important because contributions of changes in tree canopy cover compared with changes in grass cover have significantly different effects related to the reduction of air pollution and also evapotranspiration levels that affect the microclimate conditions. This information will result in better data driven decision making for smart solutions for future 3D developments of cities, as well as demonstrate 3D green spaces in cities if land conversion from tree cover to built-up areas occurs. Having the changes of height data, urban planners can make better decisions for smart changes of urban form for future developments, considering the negative impacts of buildings on the natural environment of the cities. Smart changes of urban form refer to data driven decision making on the areas within cities with higher potential of change.

This research introduced a robust method for exploring 3D changes of cities to see whether these changes can be considered as being toward or away from a more sustainable 3D urban form, based on the relationship between built up and vegetated areas, in particular tree canopy. Future work will focus on the speed of change in different urban areas for the vegetation and building classes.

Similar metrics can be proposed for vegetation or a combination of vegetation and buildings. However, current technical problems of data collection and also extraction of individual trees using airborne lidar need to be resolved. The data collection problem here refers to the separation of tree canopy from vegetation, as well as the loss of many lidar points in tree structures below canopy level, that affects the extraction of the complete shape of a tree crown. The incompleteness of tree shape reconstruction necessarily affects the results of the calculation of the volume of trees. In addition, the pixel-based approach in tree volume calculation may be affected by the lidar sampling density and distribution, since a tree sampled by multi-temporal airborne lidar will be represented by totally different sets of points in each epoch. As well, depending on the scattering characteristics of the lidar laser, we could see differences in the heights of pixels representing the trees in each epoch.

In the previous work, the authors found that for monitoring of 3D building changes over time, a change detection approach is preferred compared to a process of building classification of time series lidar data [29]. In this study, we found that change detection is not sufficiently accurate for vegetation classes, therefore, we recommend voxelization of the classified vegetation for future studies.

These sampling problems impact on the voxelization of the tree points. In addition, a further problem for the voxelization of lidar point clouds is that tree trunks may not be sampled leading to gaps between tree crowns and the ground which are not registered in the rasterization process.

So far, we have found that for the calculation of volumetrics of vegetation, the change detection approach is not sufficiently reliable as unchanged trees are sometimes detected as changed trees (cut trees or new trees) from the sampling of airborne lidar data. To alleviate this problem and to overcome the problem of inconsistency of classified time series lidar data, we have tested voxelization of classified buildings and vegetation. In addition, change detection of vegetation to identify growth is not sufficiently accurate. Therefore, future work should focus on development of methods for detection of vegetation growth as another class of change in urban areas. This should be possible as future lidar systems will provide much higher densities of sampling, which together with multispectral lidar systems will enable more accurate height measurement of trees.

Vegetation cover as a valuable component of a healthy built environment within cities motivates us to ask a critical question for future studies. Indeed, the question is whether 3D vegetation cover change could be a more influential factor in changing the local climate and affecting health and wellbeing than grassed areas. So far, we know that the observation of the trees in providing shade and the mechanism of photosynthesis in absorbing CO_2 confirm that preserving trees within built-up areas is crucial for caring for the environment leading toward more sustainable urban forms for future generations.

Our work is intended to provide fundamental information for "wise management of natural resources" ([30], p.6) in which we provide information on the location of changes in the natural and human-made resources within cities.

From an urban planning and design perspective, this work provides a pathway to the development of rapid assessment protocols for estimating the directions in which our precincts and cities are trending in terms of sustainable development. Such an approach would take the increase (or decrease) of vegetation, in particular tree canopy, as a proxy for a rising or falling level of sustainability in an urban location. Of course, sustainability, particularly in the urban context, is far more complex than this, including such factors as climate change mitigation and adaptation, consumption of renewable and non-renewable resources, biodiversity protection and so on. But an increase or decline in urban vegetation over time represents a fundamental trend, which can indicate a great deal about other aspects of urban sustainability.

7. Conclusions

The lack of appropriate metrics and methodologies for the assessment of the sustainability of urban form over time motivated us to conduct this research. In this chapter, we proposed novel 3D metrics and potentially appropriate methodologies and tested these methods. Our tests results show that while airborne lidar data is a very accurate and promising source of data for detection of changes of the volume of buildings, there are areas requiring improvement in 3D reconstruction of trees and vegetation from airborne lidar, to enable its use in an urban change detection studies. We found integration of SVM and DSM differencing appropriate for the building change detection and proposed a voxelization approach for vegetation change detection in future research.

We observed a trend of decreasing volume of vegetation and increasing the volume of buildings using three of epochs airborne lidar data from 2005 to 2013 in a developing urban area in Sydney, Australia. This implies a trend against sustainability goals and suggests a need for intervention policies for preserving the natural objects such as trees in a built environment.

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