Constructing Auckland: 2013 Building Outlines Update in the Urban Core and its Periphery

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RIMU Research and Evaluation Unit

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Constructing Auckland series

Executive summary

The Buildings data set currently in use at Auckland Council is essentially a decade old. The original building outlines (or footprints) date to 2008. A second 2010 Buildings data set was produced, which mostly appended missing North Shore City data without further update or correction.

This project undertook the first comprehensive update of the building outlines for the urban core and its periphery, expanding by almost 50% the area of mapped footprints. Rather than manual digitisation of aerial photography used in the previous efforts, it did so via a semiautomatic method using council's 2013 LiDAR data. In total, 596,076 building structures were mapped in Auckland's urban core and periphery (corresponding to the extent of the 2013 LiDAR capture), including 14,611 new buildings (since 2010). This new construction totalled 3.4 million square metres (3.4km^2 or 344ha), a 3.3% gross increase from 2010. (The net effect for the entire area is unknown, however, since this is the first mapping of the urban periphery.) In addition, a total of 5607 existing buildings not previously recorded were detected and mapped within the urban core.

The creation of the 2013 Building outlines data set also facilitated the first change detection analysis of Auckland's building dynamics. Between 2010 and 2013, new construction in the previously mapped urban core covered a total of 3.3 million square metres (3.3km^2 or 334ha), a net increase of 2.2 million square metres (2.2km^2 or 217ha), or a 2.2% increase in footprint area. The net increase in building numbers was 1774. These figures do not directly translate to specific dynamics such as new dwelling construction. More specific follow-on studies of building topology and land use will explore these dynamics. Among the recommendations from this study are to recognise building outlines as a dynamic component of the urban matrix that needs regular updating. Many modern and emerging data and analytical methods are available to facilitate the construction of a buildings trajectory for Auckland.

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1.0 Introduction

Cities are places of constant change: creation and re-creation. Some areas across the region are newly developed, whereas established areas are in ongoing states of flux with alterations and redevelopments. Given this dynamism of the built environment, updating spatial data of the built environment and analysing its change are important (e.g., Du et al., 2016, Huang et al., 2014).

Building outlines (or footprints) comprise a fundamental spatial data set for local government. Building outlines provide important information about the landscape of the built environment, which can be used to inform city planning and emergency management, as well as to understand social dynamics and land-use change. Building outlines are used for multiple purposes across Auckland Council (AC), including as data for consents and planning; contours for floodplain mapping; and input to modelling efforts, such as the Capacity for Growth and capacity economic feasibility models (Balderston and Fredrickson, 2014, Fredrickson and Balderston, 2013). Various Auckland Council units currently use building outline data and have expressed interest in updated data, including Healthy Waters, Plans and Places, and the Research and Evaluation Unit (RIMU).

Auckland itself is a growing city. The population grew by more than 250,000 people (an 18% increase) in the decade to 2017 (Statistics New Zealand: Population Statistics, 2017). Combining this population growth with concern over housing affordability, there is much public and political focus on residential construction activity but still a lack of up-to-date reliable data, with monitoring and analyses usually relying on proxy data sets such as building consents. Tracking actual construction is therefore necessary, yet not done.

Currently, there are approximately 550,000 properties (defined as rateable units) in Auckland (Miller, 2017, Hu, 2018). Rating units and structures are not analogous, though, as rating units may host no buildings, a single building, or multiple ones; and some structures may be built across more than one rating unit.

For its part, the “Buildings” data set currently in use for Auckland (dating back to 2010) numbers 648,000 separate structures: more than one building can exist on a property, such as separate garages, outbuildings, or multiple dwellings on residential properties or multiple buildings on commercial properties. Yet, against the backdrop of a growing city, and its resulting increased pressures, the Buildings data set has remained static for the last eight to ten years.

1.1 Objectives

The Constructing Auckland programme emerged from the impetus to update and extend Auckland Council's Buildings data set in order to improve understanding about the growth and change of the city. The programme seeks to compile a time series of building outlines to explore both change in the built environment and opportunities to keep this dynamic data current through methodological advancement. This requires methodological and analytical research to create and analyse a comprehensive time series of building outlines for the Auckland region, extending from 2008 to the present.

This 2013 Buildings project serves as an update in and of itself as well as a pilot project and proof of concept to understand buildings as a dynamic component of the region's physical landscape, undertaking the first buildings change detection analysis in Auckland. In this first phase of the programme, the specific objective was to update Auckland's building footprints with three key components:

1) Update and extend the buildings data via more recent source data;
2) Explore data sources and methods to modernise the capture of building outlines beyond manual digitisation of aerial photos; and
3) Understand Auckland's building activity and development transformation through a change detection of buildings.

This technical report presents an update of Auckland Council's "Buildings" data set using 2013 LiDAR data (addressing points 1 and 2 above), as well as a general, regional change detection between the 2010 and 2013 building outline data sets (addressing point 3). A more detailed analysis of building patterns and dynamics will be released in a separate study. Through a planned continuation of the Constructing Auckland programme, it is hoped that changes in Auckland's built environment over a decade (2008-2018) can be investigated in order to better understand the intensification and expansion of this growing metropolis.

2.0 Background

Building outlines have been a sought-after piece of information for multiple stakeholders (governments, private companies, citizens), with interest only increasing as the importance of the information to a wide range of sectors is recognised.

2.1 Methodological approaches

Producing building outline layers for cities and regions has been a resource-intensive process, requiring manual labour (Du et al., 2016). The human interpretation of aerial photography and manual digitisation of building outlines is a long-standing method, serving as the bridge between traditional hand-drawn mapping techniques and modern automated detection made possible by remote-sensing data (aerial photography and, later, satellite imagery). It is well-recognised that aerial photographs offer an accurate source for building outlines (Hu et al., 2003, Shan and Lee, 2005). Yet, due to the complexity and volume of data, manual approaches are difficult, time consuming, and costly.

With the proliferation of remotely-sensed data, including fine-scale multispectral satellite imagery and LiDAR[1] point clouds, an array of processing algorithms have been developed with the goal of making the process automatic or semi-automatic (Shan and Lee, 2005, Awrangjeb et al., 2010, Hu et al., 2003, Huang et al., 2014, Zhu et al., 2008). The method used depends on the data and their information content, including spectral and textural characteristics. (Indeed, human interpretation is based on both of these.) There are well-established techniques, such as image classification, edge detection/orientation, and object-oriented feature extraction, that facilitate automating building detection to a degree.

LiDAR feature extraction uses spatial characteristics of the point cloud as well as each point's location (x,y,z), intensity, and return number attributes (Emison, 2009, Tomljenovic et al., 2015) to identify specific types of objects on the ground, such as trees or buildings. The process produces not only a building footprint, but also roofline polygons, roof segmentation (flat, pitched, or gabled), and polygonal vector generation wire frame models. According to Hu et al. (2003), "Airborne LiDAR's accurate 3D information for structure roofs and most opaque surfaces greatly simplifies large-scale urban modelling", and can be manual, semiautomatic, or fully automatic. Buildings can be detected via their height and texture insofar as "High

[1] LiDAR stands for Light Detection and Ranging, a remote sensing method in which a laser is used to measure distances to the Earth's surface.

objects with low roughness correspond to building areas" (Dorninger and Pfeifer, 2008).

In the end, many of the most promising techniques make use of the strengths of both imagery and LiDAR through data fusion techniques (Du et al., 2016). In a multi-method comparison, the best building extraction was achieved with LiDAR data, which was further improved by merging with imagery (Demir et al., 2008). Thus, the building detection methods have moved from manual mapping and digitisation of aerial photography to computer algorithms used for image interpretation, LiDAR data extraction, or a fusion of the two (Awrangjeb et al., 2010).

2.2 Comprehensive building outline compilations

Many cities and other localities have produced building outline data sets, and the initiatives are broadening (e.g., PSMA Australia, 2017, Wallace et al., 2018). Australia has undertaken a comprehensive buildings mapping project at the national, and therefore continental, scale (www.geoscape.com.au, PSMA Australia, 2016). Using satellite data and copious ancillary data, the project used a semiautomatic detection process to outline buildings and other features, such as trees and swimming pools, through using Digital Globe imagery "with machine learning algorithms to automatically extract built environment attributes" (Wallace, 2017). They also relied on a large staff of 50 using a "proprietary editing platform" (*Bill Singleton (ecopia)*, *personal communication, 4 December 2017*). The mapping company behind the project has indicated regular updates will be part of the programme (*B. Singleton*, *personal communication, 4 December 2017*).

Microsoft released a data set for all US building footprints (Lin et al., 2017, Microsoft, 2018). They used a process of semantic segmentation to recognise building pixels on aerial imagery, followed by a polygonisation routine to convert building pixel "blobs" to polygons (Microsoft, 2018).

For its part, Land Information New Zealand (LINZ) undertook a pilot project to produce building polygons in a few regions (LINZ Data Service, 2016). Due to its popularity, it expanded into a nationwide effort (LINZ Data Service, 2018). For the most part, the building polygons have been produced from image classification and object extraction of aerial photos acquired by regional councils. The coverage for Auckland has been completed in two phases, released after the initiation of this 2013 LiDAR update project. During the pilot project, 2012 aerial photos produced by Waikato Regional Council filled in some of the southern areas of the Auckland region, and 2015 aerial photos commissioned by Northland Regional Council resulted in building outlines across the northern part of the region. A recent release has resulted in other gaps being filled with 2017 aerial photos from Auckland.

Such analytical approaches are reaching mainstream audiences, for whom the virtues of “machine learning to extract building footprints, count cars, and monitor construction projects to determine changes and progress over time”, are extolled, especially in the context of the value of data that can be derived from such image analytics (Andrews, 2017). The expectation for comprehensive, detailed spatial data are only increasing as both the imagery and derived data products reach more audiences.

3.0 Methods

3.1 Study area and data

The Auckland region is the second-most northern region in New Zealand, after Northland, covering both land and sea. The terrestrial portion of the region covers 4896 km^2, as defined by the mean high water spring (MHWS) land/sea boundary. This encompasses the land it occupies on the North Island as well as islands in the Hauraki Gulf, including the populated Great Barrier and Waiheke Islands among others (Figure 1).

Politically and administratively amalgamated in 2010 into one "super city", the Auckland region includes both urban and rural areas. The city of Auckland is New Zealand's largest in terms of both population and economic activity. Many other cities and towns adjoin this urban isthmus to create a wider metropolitan area that extends along a north-south corridor between west and east coasts. The Auckland region comprises approximately one-third of both the national population and economy.

In recent years, during a time of population of growth, Auckland has undergone both intensification of the built environment and extensification of the urban boundaries. Building topologies are changing where alterations and redevelopments occur in commercial and residential districts. In traditionally suburban areas, "kiwi quarter-acre" sections with single houses have either been subdivided for the purposes of adding single family houses onto vacant land or cleared to redevelop, often into denser housing topologies such as terraced housing, apartment blocks, or multiple separate dwellings. Lifestyle blocks, or large residential homes on large landholdings, dot the countryside at the edge of the urban extent.

3.1.1 Existing buildings data

Auckland Council has not had a complete buildings data set that covers its entire jurisdiction. That stems in part from the fact that no thorough building outlines project has been undertaken since individual councils were amalgamated into the current unitary authority. Two previous building outline data sets in 2008 and 2010 have been produced (Table 1) with partial coverage of the region (Figure 2).

Table 1 Auckland Council Building Outlines data sets

Data Set (version)	Source Date	Production Date	Extent (km^2)	Source Data type	Method
2008 Buildings	2007/09*	2008/09	1138	Aerial photography	Manual digitisation
2010 Buildings	2010/11	2012	1471	Aerial photography	Manual digitisation
2013 Buildings	2013	2017/18	1897	LiDAR point clouds	Object extraction

* 2007/08 AKL urban ortho imagery; supplemented by 2008/09 AKL urban orthoimagery; 2006 imagery as a last resort if no other suitable imagery existed for a particular area

Figure 1: Auckland region

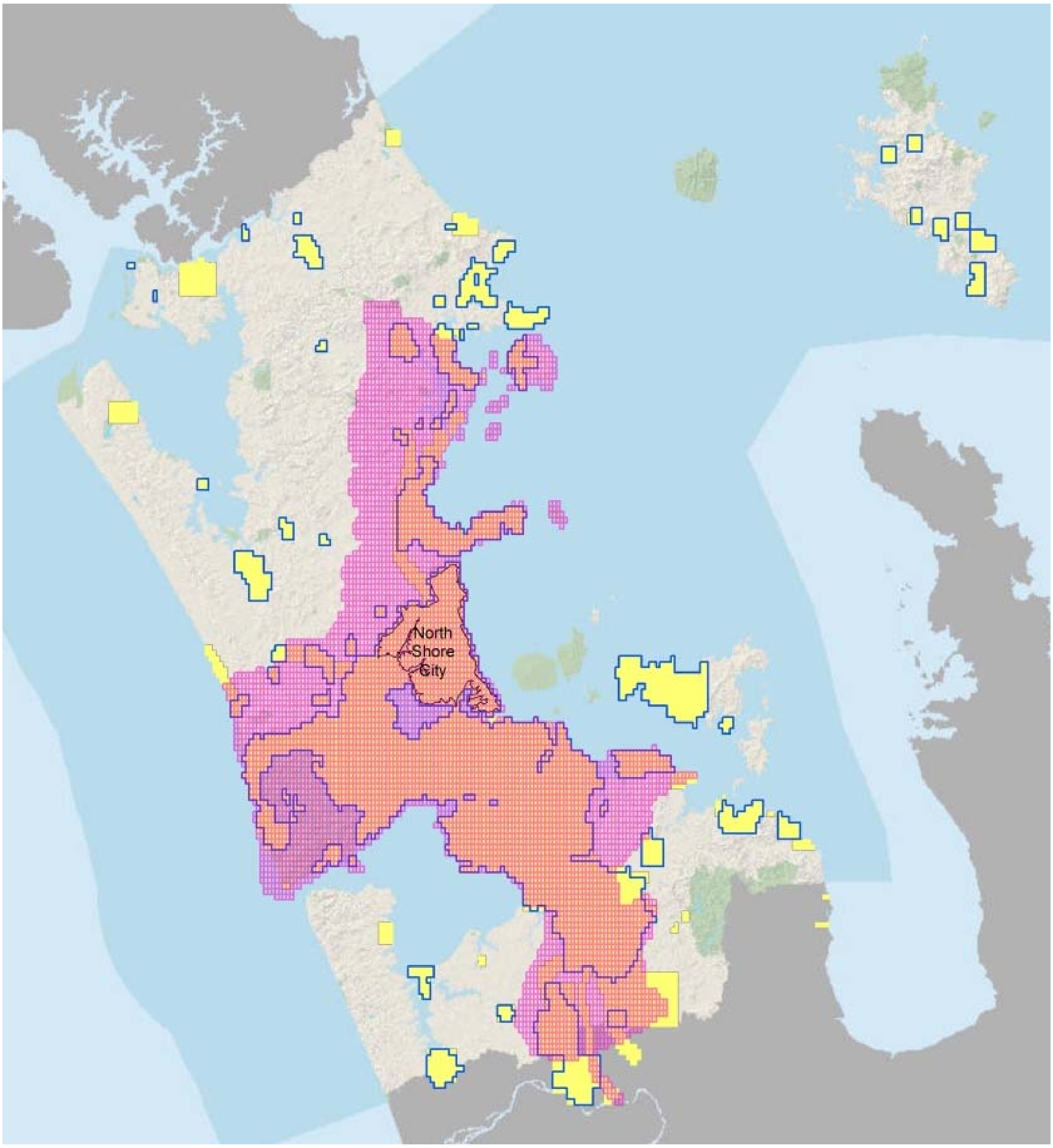
Auckland Council's predecessors first developed a building outlines feature class data set in 2009 by manually digitising 2007/2008[2] Auckland Urban Orthophotography, supplemented with 2008/2009 imagery and 2006 imagery, as needed (Table 1). Outsourced to India, specific instructions were provided about building topologies, and the minimum mapping unit was 1 m^2 (Terralink, 2008). Hereafter referred to as the 2008 Buildings, the source imagery covered a land area of 1268 km^2 within the region; the building footprints did not correspond to this entire area since North Shore City Council (130 km^2), a separate government entity at the time, did not participate in this pan-council project. Other than that, the 2008 Buildings covered most of the urban core, as well as outlying settlements in the rural north and south (Figure 2).

Although not labelled with a date or version number, the current "Buildings" feature class in use at Auckland Council, hereafter referred to as the 2010 Buildings, consists of an update of the 2008 Buildings, which was produced by Auckland Council's Geospatial department in 2012 by digitising 2010/2011 aerial photos (Table 1). The project incorporated the former North Shore City Council's building outlines for the first time, as well as digitised any detected changes in buildings via reviewing aerial photos acquired during the 2010/11 season; overall, the focus remained on the former and attention to latter was considered *ad hoc* (Suruj Prasad, *personal communication, 30 June 2017*). No project documentation for the creation of the 2010 Buildings data set exists beyond Terralink's (2008) original project specification for the 2008 Buildings (S. Prasad, *personal communication, 30 June 2017*). The 2010 Buildings cover 1471 km^2, corresponding to the 2010 aerial imagery collection, encompassing most of Auckland's urban core from Whangaparaoa in the north through the central isthmus to Pukekohe and Waiuku in the south (Figure 2). Additional areas included outlying rural settlements, especially in the north of the region, as well as Waiheke and Great Barrier islands.

While the 2008 Buildings data set is considered to be relatively accurate and comprehensive, the 2010 Buildings data set is not, with particular gaps in digitisation and only additions of missing areas but no deletions of removed structures or additions of new buildings in established areas (S. Prasad, *personal communication, 30 June 2017*). In the 2010 Buildings data set, 107 footprints are tagged as historic.

[2] Imagery collection are labelled by the season of collection, denoting that the austral summer crosses two calendar years. (Thus aerial imagery collected during a summer field season will begin in 2007 and end in 2008.)

Figure 2: The extent of source data for each building outlines data set:
2008 aerial photo coverage (blue outlines); 2010 aerial photo coverage (solid yellow); and 2013 LiDAR extent (pink tile grid outline).The overlap of the 2010 and 2013 extents defines the urban core for the purposes of the change detection. The urban periphery corresponds to areas only with LiDAR data (pink tiles).



In sum, the currently available Buildings data available for Auckland is eight years old; in some cases, it is a decade old where edits were not made to the 2008 Buildings data set in the course of editing for the 2010 update.

3.1.2 Source data for building footprints update

At the time of project initiation in 2017, Auckland Council's 2013 LiDAR data offered the best resource for both the spatial extent of the data capture and the resolution of the data. Already acquired by AC, it comprised an underutilised data set that could be mined for more information at no additional data acquisition cost. The 2013/14 LiDAR campaign (NZ Aerial Mapping and Aerial Surveys Limited, 2015) covered 2250 km^2 in total, of which 1897 km^2 was over land. This aligned with 80% (1171 km^2) of the 2010 Buildings data set – all of the urban core but not the outlying rural settlements, including Helensville and Waiuku, or islands in the Hauraki Gulf (Figure 2). The 2013 LiDAR data cover an additional 726 km^2 in the urban periphery not previously mapped, expanding the coverage of mapped buildings by 49% in comparison to the 2010 urban core.

3.2 Delineating 2013 building footprints

Building features were extracted from the entire 2013 LiDAR data using ENVI version 5.3 (Exelis Visual Information Solutions; Boulder, Colorado, USA). The full LiDAR point cloud data were processed in the ENVI LiDAR module to extract building vectors (objects). The minimum area for a building was defined as $10m^2$. The near ground filter width was set to 300 cm to avoid detecting other objects, such as vehicles.

The 2013 LiDAR data consist of 6511 tiles aligned with the NZTopo50 grid at 1;1000 scale. All 6177 LiDAR tiles overlaying land were processed; those containing only open water were not. Due to computer processor limitations, the LiDAR data were batch processed on 22 subgroups of the tiles. The subgroups were re-assembled into a complete building outline polygon coverage after all object extractions were completed.

3.3 Quality assessment and trajectory annotation

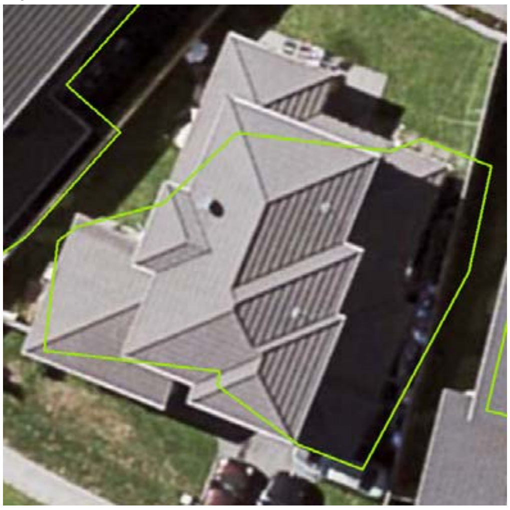
The building objects extracted from LiDAR were inspected for quality (Figure 3); they ranged from accurate, complete outlines of building rooftops to partial footprints ("blobs"), whose geometries required correcting. In addition to these incomplete building outlines were a prevalence of false positives, especially patches of vegetation ("tree houses"). In order to correct the results of the object extraction

Figure 3 Accuracy of building outlines automatically delineated via featured extraction: a) accurate, b) realistic with missed details (e.g., internal corners), and c) "blobs".

a)

b)

c)



algorithm, ENVI's iterative process of object identification refinement and re-processing was investigated, but found to be inadequate, neither producing effective refinement in building geometries nor altering the detection of false positives or false negatives.

Given the varied quality of the polygon shapes of the LiDAR-derived building footprints, we decided to update the 2010 Buildings data set with the 2013 LiDAR-derived buildings, rather than remap the entire region with the latter. This approach took full advantage of the existing data set (perceived to be generally tidy building outlines from two iterations of manually digitised buildings from high resolution aerial photos), using it as a baseline for both updating and expanding the coverage. The two data sets were combined by using all footprint polygons greater than 10 m^2 in the 2010 Buildings as the baseline coverage and adding all polygons from the 2013 LiDAR extraction that did not intersect (overlap) with a 2010 polygon. This resulted in adding any new (or previously unidentified) buildings, but did not identify changed structures *in situ*.

A quality assurance workflow was developed in ArcGIS v. 10.2 (Environmental Systems Research Institute (ESRI); Redlands, California, USA) to address three issues: edit incomplete or inaccurate LiDAR-derived building polygons, identify false positives (e.g., “tree houses” or other objects), and correct false negatives (buildings not detected in either the 2010 data set or via the object extraction of 2013 LiDAR).

Analysts methodically checked assigned geographic areas for these three issues. Building polygons were annotated for trajectory information, including:

- Building status (Current, Under Construction, Former, or Error)
- Modification reason (New, Alterations, Resited, or Correction), and
- Error type (e.g., Vegetation, Other Object, or Landform).

Polygon shapes were corrected as necessary, and false negatives were manually digitised.

The building definition set out in the original 2008 buildings digitisation project was followed in order to decide which structures constituted a “building”: identifiable as permanent and enterable, with a roof or covering and walls (Terralink, 2008). Other structures, such as carports, in the merged data set (whether sourced from the 2010 Buildings or the 2013 LiDAR extraction) were recorded as “Other Object”. This process resulted in both cleaning the data set and collating a change detection trajectory data set through the annotations.

The updated, merged data set (consisting of the 2010 Buildings and 2013 LiDAR object extractions) was checked in a customised ArcMap editing session using ancillary data, including the source data for both data sets: the 2010 aerial photos and the Intensity layer and digital surface model (DSM) from the 2013 LiDAR to show the point cloud density. Both the 2010 Buildings and 2013 LiDAR extractions were loaded separately into the session for comparison, where needed. An imagery time series was also used to support verification of building status, type, and change, including the 2006 and 2008 imagery that underpinned the original 2008 Buildings data set and earlier work, as well as the 2015 aerial photos (the current imagery set at the time of the project). Contemporaneous 2013 imagery was needed to ground truth dynamic or recent changes detected by the 2013 LiDAR extraction, especially in rural areas where Auckland Council had not collected imagery in 2010, but it was not possible to acquire access to this through Auckland Council during the QA process. To fill this gap, contemporaneous imagery was searched in Google Earth Pro v 7.1.5.1557 (Google; Mountain View, California, USA) for cross-referencing and verification.

Once completed, the QA was reviewed by a separate researcher. All possible trajectories combinations of Building status, Modification reason, Error type, and Source were reviewed and checked for sensibility and accuracy. A quantified accuracy assessment of the data has yet to be completed, but would be conducted upon completion of the regional compilation (see Discussion).

4.0 Results

4.1 2013 Buildings update

The following results encompass all building types across all land uses, such as dwellings, outbuildings, and commercial premises for footprints with a minimum area of 10 m^2. The 2013 LiDAR update of the 2010 buildings feature class comprises a total of 595,471 existing footprints (Table 2) in the expanded urban area[3] (Figure 2), 97.5% of which existed in 2010. Of these, 2316 instances of alterations were noted, wherein an existing building had been remodelled, resulting in a new footprint. Another 82 were resited into a new position on a property. In addition to the existing buildings, 14,611 new (since 2010) buildings were detected, including both greenfield development and infill construction (e.g., redevelopment of a site). A further 596 buildings were under construction (UC) in both infill and greenfield settings, and three alterations were under construction. Across the entire extent of the 2013 update, including the urban core and its periphery, new construction totalled 3.4 million square metres (3.4 km^2 or 344 ha), a 3.3% gross increase from 2010 (Table 2). (The net increase cannot be calculated due to a lack of removal data in the urban periphery.)

Table 2: Buildings as of 2013 in Auckland's urban core and periphery*

		Area (m^2)				
2013 Building status	**Count**	**Minimum**	**Maximum**	**Mean**	**STD**	**Sum**
Existing	580,860	10	82,553	177	580	103,087,547
Alterations	2,316	12	80,879	517	2,471	1,196,458
Resited	82	12	323	126	51	10,342
New	14,611	10	35,276	235	728	3,440,069
Total current buildings	**595,471**	**10**	**82,553**	**179**	**584**	**106,527,617**
Under construction (UC)	596	14	30,663	344	1,393	205,171
UC-alterations	3	161	195	180	17	539
Total UC buildings	**599**	**14**	**30,663**	**343**	**1,389**	**205,710**

*corresponding to the 2013 LiDAR capture area

Of these total figures for the 2013 LiDAR update area, 14,893 footprints were delineated for the first time in the periphery of the urban core, courtesy of the expanded capture area of the 2013 LiDAR mission (Figure 2). (Across this periphery,

[3] Comprised of the previously mapped urban core and the newly mapped urban periphery (i.e., the 2013 LiDAR extent). Note this does not include the 2010 Buildings footprints outside the LiDAR capture extent.

109 buildings were delineated in the 2010 Buildings data set, but they are scattered across the area, indicating a random capture and not part of a broader 2010 extent.) With fewer imagery dates available in these rural areas, building trajectories from 2010 were not always possible to verify (i.e. determining whether a building mapped for the first time had been there in 2010 or was newly constructed since 2010). Of those that could be compared to the 2010 landscape, 410 were new construction and eight were under construction. Nine buildings had been altered between 2010 and 2013. These dynamics may be underestimated due to the lack of verification imagery for 2010.

4.2 2010 Buildings quality assessment

In order to conduct a change detection between 2010 and 2013 for the urban core, the 2010 Buildings data set was cleaned. The quality assessment (QA) of the 2013 LiDAR update resulted in a QA of the 2010 Buildings in the urban core.

The 2010 Buildings data contained a number of errors, including footprint delineation, false positives, and false negatives. Inaccurate footprint shapes consisted of unchanged, existing buildings (as distinct from alterations) for which the footprint had not been recorded accurately, whether in the 2010 or 2008 digitisation efforts. In total, 3259 footprints were corrected for outline shape.

Unexpectedly, 1986 of the footprints $\geq 10m^2$ recorded in the 2010 Buildings data set were false positives: not buildings, but other objects such as carports, pergolas, and shipping containers. In at least 82 cases, these other objects were not present in the 2010 imagery, having already been removed from the site after first detection in 2006 or 2008 but not deleted from the 2010 buildings data set. In five cases, the false positives were vegetation.

False negatives were also detected, identifying buildings for the first time that were present since at least 2010. The LiDAR object extraction detected 4471 existing buildings not previously recorded within the mapped urban core. A further 1136 existing buildings were digitised manually for the first time during the QA process.

The false positives and false negatives verified the notion that the 2010 Buildings comprised only a limited update of the 2008 Buildings: adding missing data from the North Shore, but not capturing much change in the built environment, whether deletions or additions. An improved version of the 2010 Buildings was thus defined from the 2013 Buildings update informed by the trajectory annotations made during the QA. It comprises all existing buildings present as of 2010 within the urban core (Figure 2) from all sources, capturing both unchanged 2010 buildings and those corrected for shape, as well as existing buildings detected for the first time by either

2013 LiDAR object extraction or manual digitisation during QA (the false negatives). All detected non-building objects (false positives) were removed. For the building outlines ≥10m^2 in the urban core, this corrected version of the 2010 Buildings comprises 578,695 footprints, in contrast to the 575,151 footprints according to the 2010 Buildings data set currently in use by Auckland Council.

4.3 Building change detection 2010-2013

After data cleansing, the dynamics of change between 2010 and 2013 were examined for the urban core (Figure 2), for which data existed in both time periods (Table 3). Between 2010 and 2013, 12,427 building structures were removed and 14,201 new buildings were constructed. These trajectories point to a net increase in building numbers of 1774 between 2010 and 2013, but do not directly translate to specific dynamics such as new dwelling construction. Many removals were small structures such as garden sheds, but there were also many instances of house removals, usually for the purposes of site redevelopment. New buildings included new houses as well as outbuildings and commercial premises. The mean area of new buildings was larger than that of removed ones. The net gain in building footprint area was 2,173,888 m^2, almost double the footprint area removed (Table 3). An additional 203,667 m^2 of building footprint area was under construction in 2013. These details must be further examined in order to understand functional net gains and losses; size area distributions and building topologies will be examined in conjunction with these statistics in follow-on studies.

Table 3: Building dynamics between 2010 and 2013 in Auckland's urban core

		Area (m^2)				
Building status	**Count**	**Minimum**	**Maximum**	**Mean**	**STD**	**Sum**
Existing in 2010	578,695	10	82,553	175	566	101,090,768
New buildings	+14,201	10	35,276	235	737	3,340,917
Removed buildings	-12,427	10	24,490	94	403	1,167,029
Existing in 2013	**580,469**	**10**	**82,553**	**178**	**573**	**103,264,656**
Under construction*	588	14	30,663	345	1,402	203,128
UC-alterations	3	161	195	180	17	539
Total UC in 2013	**591**	**14**	**30,663**	**345**	**1,398**	**203,667**

*UC

Of the new construction detected in this 2013 LiDAR update (Table 2), 97% was built in the urban core, again with the caveat that new builds in the urban periphery may be under-detected (Table 3).

5.0 Discussion

5.1 Urban dynamics

This first-ever change detection of Auckland's buildings demonstrates the dynamics of the built environment. In a short three-year period, 14,201 new structures were built in the previously mapped urban area (dubbed the "urban core" here), a 2.5% addition to the number of buildings compared to 2010. This was balanced by a 2.1% loss of building stock through removals. Nevertheless, a net increase of 2.2% in developed area occurred, taking account new buildings and changes to footprints through alterations: the total area of building footprints in the urban core increased by almost 2.2 million square metres (2.2 km^2 or 217 ha) between 2010 and 2013. If the 588 buildings under construction area are included, the net increase was 2.4%.

This level of activity is of similar magnitude to other locations, though the Auckland figures still need to be examined more closely for building topology and land use. For example, across Germany's federal states, the number of residential main buildings increased 0.7% to 2.5% between 2012 and 2014; the number of industrial/ commercial buildings changed -1.3 to 12.2% (Hartmann et al., 2016).

In general, new buildings are larger than existing ones (Table 3). The 2013 mean building outline area (178 m^2 ± 573 m^2) increased over the 2010 one (175 m^2 ± 566 m^2). This is conservatively skewed (i.e. the size gap between new and existing buildings is likely to be greater than the means indicate) in that the maximum building size is larger in the existing 2010 buildings, including large alteration projects, which were bigger than any of the new construction projects. At the same time, the existing buildings include more small outbuildings than do the new or under construction categories. An increase in building size can be noted in the mean areas of new construction (235 m^2 ± 737 m^2) and those under construction (345 m^2 ± 1402 m^2). The types of buildings, land uses, and construction projects – and thus building topology – matter greatly in such comparisons and will be further examined in future work.

5.2 Method assessment

5.2.1 New method: the LiDAR extraction

The goal of undertaking an automated building detection method is both to detect buildings and to delineate robust building outlines. This is not only to update a spatial buildings data set, but also to facilitate a trajectory analysis of the built environment (Zhu et al., 2008, Du et al., 2016).

There is a distinction to be made between change detection and precise building outlines: each represents its own methodological challenges, with most studies concentrating on one or the other. In a study that pursued both, Du et al. (2016) were able to detect change in buildings, but not to delineate precise building outlines. Others found challenges in building detection. One study noted the approach produced “wonderful results for buildings extraction and acceptable results for change detection” (Zhu et al., 2008). Each methodological development makes its own definitions and distinctions, with ongoing challenges in precisely defining building outlines and automatically detecting change (Pang et al., 2018). Moreover, most method development studies are conducted on small study areas, such as a few city blocks or square kilometres (Tomljenovic et al., 2015, Du et al., 2016, Pang et al., 2018, Pope and Prasad, 2015). The production of building outlines at regional or continental scale concentrate more on volume production than fine-scale accuracy (PSMA Australia, 2017, Wallace et al., 2018) and still rely on large teams of human operators to address the latter when conducted.

Maintaining the sizeable ambition of this (pilot) project to deliver both a regional-scale data set – mapping buildings across almost 1900 square kilometres rather than a city block – as well as a change detection of the built environment, we landed on a hybrid approach. First, the automatic object extraction identified and delineated buildings. Due to the mixed quality of these building outlines (largely due to the quality and density of the point cloud data, exacerbated by challenging mix of terrain and scene composition), the manual verification and correction workflow was developed in order to facilitate correct delineation of building outlines and labelling of trajectories. In the end, this 2013 update can be characterised as a semiautomatic feature extraction and change detection, of which the two key components were object detection and footprint quality.

5.2.1.1 LiDAR detection ability

The object feature extraction of buildings from the LiDAR data used an automated approach; it did not rely on a human operator for detection. The strength of the automated building detection via LiDAR object extraction is demonstrated in the detection of new construction as well as existing buildings never previously captured. In the 2013 Buildings update, more than 14,000 new structures were detected within the urban core, and almost 15,000 structures were mapped for the first time in the urban periphery. Moreover, the object extraction approach improved the buildings data set by “discovering” more than 4000 existing buildings, previously missed in manual digitisation efforts.

The object extraction from the data captured most of the buildings. Of the additional buildings detected for this update, 79% were detected via the LiDAR object extraction, with the remaining 21% manually digitised by an operator during the QA process. Of the existing buildings captured for this first time in this update, 77% were via LiDAR extraction, with the remainder via manual digitisation.

Of the newly constructed buildings, 85% were detected by object extraction from the LiDAR and 15% were manual captures. However, only 18% of those buildings under construction at the time of the LiDAR flight were delineated via object extraction; the absence of a full structure and complete roof does not result in a point return that indicates a building. Note, this is not necessarily a problem of false negative in that the building does not technically exist while still under construction; it could be argued to omit these footprints from the project altogether. We chose to include them, however, with an eye towards capturing known buildings for a comprehensive building footprint data set and understanding how the built environment is changing.

The LiDAR outlines also indicated errors in the existing building footprints, where an extracted 2013 footprint differed from the 2010 one, providing the opportunity to improve the data set.

In contrast to these positive detections, false negatives required more direct involvement from operators. The absence of a LiDAR-derived polygon was not a straightforward indication of a building removal: sometimes it did signal the removal of a structure, whereas other times it was simply due to a lack of data (sparse point clouds or point misclassification) and therefore no building extraction, requiring manual digitisation.

5.2.1.2 Quality of building footprints

Few studies consider the quality of building extractions (Shan and Lee, 2005). In a developmental paper establishing work flows for building model outline creation, the “portion of completely properly modelled buildings is about 75%” (Dorninger and Pfeifer, 2008). In that study, researchers found they were not able to accept results as calculated, but rather had to further refine the selection of building regions interactively.

The quality of the building footprints extracted from the 2013 LiDAR data was mixed, falling into one of three categories (Figure 3). First were accurate footprints. In many cases, the LiDAR-derived object aligned with the actual building as previously mapped or as checked against 2013 or 2015 imagery (Figure 3a). This occurred most frequently for simple building shapes: rectangles or other rectilinear shapes and those with few corners. The second category comprised those that were realistic except for small, technical errors – usually drawing a diagonal between two roof corners rather than following an interior right angle (Figure 3b). A particular subset of this category was the inclusion of objects adjacent to the roof in the building outline, such as a tree canopy or patio umbrella. These were corrected manually. The third category of objects were unrealistic building outlines or, in some cases, what could be best characterised as “blobs”: amorphous polygons (of circular or diagonal nature) that served to detect the presence of a structure but not provide an accurate enough footprint (Figure 3c). These were corrected manually as well. Complex roof contours (but not necessarily building shapes), were more likely to fall into this third category.

The second and third categories were annotated as “inaccurate shape”, indicating that the LiDAR polygon required manual editing to produce an accurate building footprint; 36% of the LiDAR building footprints were thus labelled. On one hand, this indicates the level of post-processing in this project (a result of both the quality of the point cloud acquired and the building extraction algorithm used) and that there was only a 64% clean acceptance rate, similar to other studies (Dorninger and Pfeifer, 2008). On the other hand, it may be too conservative a statistic, given that it includes both mostly accurate footprints with “technical errors” (e.g., fixing an interior corner or courtyard) and those that did not capture a realistic footprint. Here lies the distinction between detection and footprint delineation.

One other anomaly in the footprint data set were duplicate polygons for the same data set. For example, among new construction in the Millwater subdivision, overlapping and mostly complete building outlines were delineated on a subset of houses. More common, though, were the case of “blob” polygons covering portions of roofs. This usually occurred on larger buildings (though not always) or those with complex shapes, i.e., two or more polygons were delineated for separate (sometimes overlapping) portions of a single buildings. These were annotated as duplicate polygons: 336 were labelled as such (though this may undercount their occurrence due to inconsistency among editors).

5.2.1.3 Errors (LiDAR false positives)

Just as there were some instances of false negatives in the LiDAR data set (i.e., non-detection of existing buildings or those under construction), there were also false positives (i.e., non-building polygons). The LiDAR object extraction contained three main types of errors: other objects, landform, and vegetation. “Other objects” (n=10,700) comprised ground components not considered buildings, such as carports, petrol station forecourt canopies, and water tanks. This is not an error of detection so much as definition: the object existed on the ground but was distinguished as something other than a building. Landform errors (n=541) occurred where a change in topography, and thus elevation, resulted in a mis-interpretation as a building.

Vegetation errors (n=36,075) were by far the most prevalent error in the LiDAR object extraction. These are a common problem with LiDAR extraction (Du et al., 2016) and a focus of methodological research for their detection and removal from building outlines (Demir et al., 2008, Awrangjeb et al., 2012).

Overall, LiDAR data continue to attract interest for their practical and potential usage in buildings detection. The implementation remains mixed, especially at scale, as noted by Agius and Brealey (2014):

> it is quick and easy to produce building footprints from LiDAR point cloud data…. However this (sic) data cannot be used as a simple replacement to updating building features captured at large-scale. This is because the shape, detail and positional accuracy are not enough to satisfy the specifications of topographic mapping.

While we were able to successfully delineate building footprints at finer scales across a regional extent, the challenge remains consistency across the large study area as well as detecting the full range of building change trajectories.

5.2.2 Previous method: manual digitisation

In the previous two building editions, manual digitisation produced precise building outlines as well as errors deriving from mistakes in human judgement about building objects and shapes. These issues were particularly true for the 2008 Buildings. While this also affected the 2010 Buildings, the larger number of errors for this version involved the lack of updating the built environment for both new construction and removals.

In total, 8981 errors were detected in the 2010 Buildings during the QA process, 64% of which were less than 10 m^2. These small polygons were non-building objects, such as tanks and umbrellas, captured in the original manual digitisation of the 2008 building outlines, in part facilitated by the 1 m^2 minimum mapping unit set for the project (Terralink, 2008). A number of the small object errors were data errors: slivers or other artefacts of polygon creation. Across all size classes, 7676 "other object" errors were identified, most of which carried over from the 2008 Buildings. In theory, other object errors should be less prevalent in a manually digitised data set than in an automatically-generated one since the higher-level process of judgement can be used to determine whether an object fits the building definition by the analyst in real-time during capture.

A second type of error deriving from the 2008 Buildings digitising project was the inclusion of extraneous objects such as deck umbrellas and tanks in building footprints, where adjacent to a building roofline. These were not corrected in the 2010 buildings footprints update. During the 2013 Buildings QA process, 3229 of these building footprints were corrected for shape.

Neither building removals nor new construction were attended to in the 2010 Buildings update. Buildings removed between 2008 and 2010 were not deleted from the 2010 building footprint data set. The detection and deletion of building removals (i.e. the absence of a previously mapped building) can be a particular challenge. Neither was new construction added to the established areas of the urban matrix, especially infill development in residential neighbourhoods. Further, a subset of these two categories were alterations to building structures (whether increases or decreases in size) that occurred since the previous time period. Both additions and removals can be more difficult situation for human operators, who have to notice a visual change in a complex matrix, than for object extraction algorithms, where a new detection or lack of data indicate change. The latter, though, is perhaps the most problematic situation, as the lack of data can indicate either a building absence or a data error.

5.2.2.1 Overestimating the number of buildings

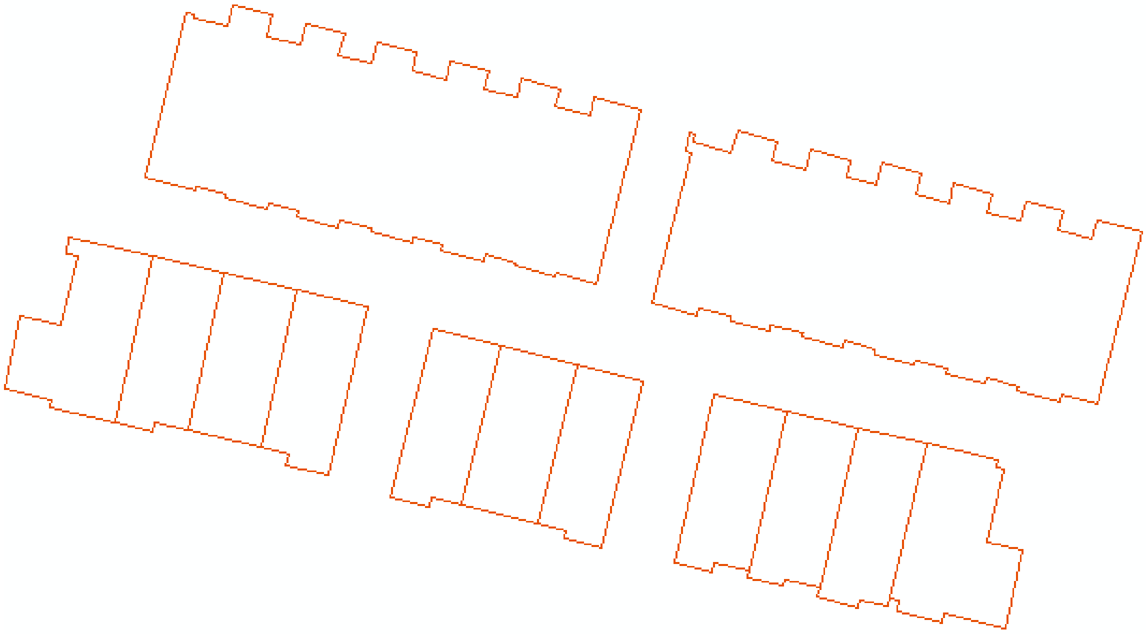
The 2010 Buildings data set also overestimates the actual number of buildings due to a confounded definition of buildings instituted in the 2008 Buildings project (

Figure 4). The overall guidance instructed using the roof outlines to capture the building shape, but to distinguish buildings that touch: “Semi-detached houses that are clearly two (or more) dwellings should be digitised as different building outlines” (Terralink, 2008). This is a problematic definition, and directive, insofar as buildings and dwellings are not the same thing. A building is a structure that can contain one or more dwellings—or functional units if for commercial purposes, though a similar direction was explicitly *not* given for commercial purposes; but rather: “Capture the total outline of conjoined commercial buildings as one building when they touch each other and have the same use” (Terralink, 2008).

The distinct units of any building cannot be accurately judged from an aerial perspective consistently for the entire building stock. While It may be possible to distinguish probable unit boundaries from roof outlines for units within one structure (e.g., adjoined terraces, townhouses, or row houses), especially with distinct architecture, assumptions can lead to errors.

Moreover, these types of dwellings may be distinguished, but not all dwellings would thus be, e.g. large apartment blocks would be captured as one building, not multiple ones. Nor would internal flats of main houses be captured. Thus, the distinction must be made between physical structures and functional units. Whereas the former can

Figure 4 Buildings as structures vs. units: single representation of building, e.g., delineating functional subunits of an overall structure (bottom row) and group representation of building, e.g., capturing the physical structure itself (top row). These exist as shown in the 2010 Building footprints, demonstrating two different interpretations of buildings are adjacent in the data set.



be detected through remotely-sensed data (whether imagery or LiDAR), the latter require ancillary data such as addresses. They are two separate data sets: either "single building representation" or "building region representation" (Hartmann et al., 2016). The remote sensing of buildings through image processing produces building region representation – outlining the total structure, which may comprise a single building or a group of "buildings"/dwellings contained by one structure. The specific sites, dwellings, or functional units within those structures or building groups are "single building" designations, often requiring address information.

It is important to employ a consistent approach to building mapping. The 2010 Buildings data set contains the mixed definition of buildings, which have been inherited by the 2013 Buildings update: these types of errors were not fully corrected (where there were no changes to existing 2010 buildings). So, all three Auckland Council building outline data sets overestimate the number of structures and underestimate the number of dwellings for their respective mapped extents.

5.2.3 Resource requirements

The manual digitising of the 2008 Buildings was outsourced to India, involving almost 40 people. The New Zealand project team, not including council staff, consisted of six roles: project manager, technical lead, and four QA operators. The production contractor comprised 33 people: project manager, production manager, technical lead, and 30 operators (Terralink, 2008).

In contrast, this 2013 LiDAR update was conducted entirely in house with one project lead, two staff (contributing part-time hours), and two interns hired to work on the project for a period of five months. In terms of materials, the project used existing data owned by Council to perform the LiDAR object extraction. It was a relatively efficient process: with the available computing power, the object extraction itself was completed over the course of a few weeks, requiring minimal personnel involvement. The QA required the most personnel hours and took six months to complete given staff availability.

5.3 Reflections on automation

Auckland Council has long relied on visual interpretation and manual digitisation of aerial photography for a variety of data and mapping needs – a traditional method, which is time consuming and expensive (Zhou and Austin, 2008) and, perhaps, not altogether accurate. This project forges into new territory for Council, eschewing manual digitising in favour of applying analytical computing power to extract new information from existing data.

Still, the implementation of this first phase of the programme relied on hands-on involvement from data checkers and editors. In part, this stemmed from council's standard reliance on digitising and manual editing rather than investing more time in new method development for automating aspects of the QA. At the same time, humans remain the gold standard for image interpretation due to their cognitive ability to synthesize a variety of information for decision making. Some would assert that human editing is the most accurate, though this can be debated for the errors introduced (Section 5.2.2). As noted in 2003, "semiautomatic systems are more mature and practical than automatic systems. The use of knowledge and machine-learning method, continues to improve automatic building extraction" (Hu et al., 2003).

While generic, full automation remains the aim for deriving information from remotely-sensed data, it is still difficult for many reasons: "Automation is always a substantial objective in developing computer technologies. However, automation is not practically valuable if the automated technology does not reliably deliver demanded results" (Tseng and Wang, 2003). The criteria for usage is that the "algorithm should be fast, accurate and robust". That is, the automation should be faster than manual mark-up with a high probability of detection and low false alarm rate (Pope and Prasad, 2015).

As noted more than a decade ago, "most complex model construction is semiautomatic, requiring a fair amount of operator intervention and resulting in painfully slow evolution of wide area models" and semiautomatic systems "are likely to remain the most practical systems for large-scale urban modelling in the near future" but that developing automatic methods is a clear trend (Hu et al., 2003). The respective strengths of computers and humans leads to a logical semiautomatic workflow, which is both practical and valuable. Computers can do low-level tasks faster than humans (e.g. model fitting and extraction), and humans can perform high-level tasks more reliably (e.g., deciding which building model should be used) (Tseng and Wang, 2003). Thus, it is possible to advocate for a "a semi-automatic procedure to combine the human ability of image understanding with the number-crunching capacity of computers" (Tseng and Wang, 2003).

5.3.1 Auckland Council's implementation of semi-automation

Thus, there is a division of labour in the semiautomatic conceptual framework, which was reflected in the implementation strategy of the 2013 Buildings update. The low-level task of automatic detection of building outlines across the entire LiDAR data capture extent (Figure 2) was completed quickly and efficiently in the ENVI LiDAR module, requiring a few weeks of computer processing time with only minimal time required of a researcher for organising and supervising the processing. High-level task requirements emerged due to both the extraction quality and the change detection analytical needs. The former included the mixed quality of the building outlines (Figure 3) as well as false positives (errors) and false negatives (omissions). The latter involved interpretation of changes to buildings on site between time periods. All of these could be further automated by creating work flows to shift some of the decision making into low level tasks by both using multiple imagery sources and developing analytical tools.

This was not possible in the current project due to the lack of contemporaneous imagery and a proclivity to rely on manual checking in favour of exploring algorithms with unknown outcomes. It was not possible to secure resources to acquire 2013 imagery, which would have served as ground truth information (as well as allowed complete mapping across the region for the area not covered by the LiDAR extent). The lack of 2013 imagery resulted in a requirement for more hands-on staff time and a longer project timeframe.

We still accessed the “ground truth” information by referencing 2013 imagery available in Google Earth, but it slowed the QA process considerably. If the 2013 imagery could have been imported into the editing session, the validation and editing of footprints would have sped up considerably via immediate validation of building detection and shape at any location for purposes of ground truthing. Instead, analysts had to use bracketed time periods (2010 and 2015 aerial imagery) to interpret the 2013 landscape within the ArcGIS QA workspace; if further confirmation was required for 2013 due to either potential change in that period or lack of imagery at 2010 and 2015, then the analyst had to cross-reference the location in a separate Google Earth window. This was a significant problem in some areas of the urban periphery where council has not previously prioritised imagery acquisition. This in turn, cost more in terms of staff time spent on QA. It also affected accuracy where imagery resources were lacking.

More importantly, the lack of imagery also prohibited algorithm development for designing further workflows to detect and remove false positives, false negatives, and change trajectories. In the dynamic urban landscape, it is important to use contemporaneous ancillary data, as the constant state of flux changes ground components. To develop algorithms requires consistency in the landscape by using data (imagery) from the same time period. And, careful validation against ground components is necessary, of course; “without ground-truth measurements, quantitatively evaluating modelling results is difficult” (Hu et al., 2003).

Appropriate contemporaneous imagery would have facilitated the ability to automate some of the QA (e.g., Pope and Prasad, 2015). For instance, most of the vegetation errors could have been tagged and removed from the buildings data set by cross referencing a vegetation index from the 2013 imagery. The automatic detection and removal of most false positives (errors of vegetation, landform, and even some small, other objects), is the next step of development for projects such as these, requiring an investment into appropriate ancillary data and time to develop algorithms before diving in to manual checks and digitisation.

Likewise, contemporaneous imagery could assist the detection of false negatives and change detection through spectral and textural comparisons of imagery to LiDAR data as well as other time periods.

6.0 Summary

This project set out to update Auckland Council's building footprints and, in the course of doing so, pieced together the history of the organisation's building footprint detection. Until now, the data set in use has been labelled simply as "Buildings", without any indication of time period. Through the pursuit of this project, we ascertained Auckland Council's Buildings feature class dates to 2010, when the North Shore City data were merged into the original 2008 Buildings, without a comprehensive update of change in the built environment. For the most part, then, council's Building data set is a decade old.

This project conducted the first comprehensive update and change detection of Auckland Council's building footprints. It updates the previously mapped urban core and expands its coverage by 50%. This version of the 2013 update is still not a regional coverage due to data limitations insofar as it relied on the 2013 LiDAR data acquisition, which was not flown for the entire region.

Although this update dates back five years to 2013, it has value and was, indeed, done purposefully. The idea for this project was conceived in 2016 (with initiation in 2017), and at the time, the LiDAR data were the best resource held by Council. In addition, the decision to use the existing LiDAR data set was a decision to explore methodological advancements for deriving building footprints and to extend council's technical capabilities. The strength of the approach is in the successful and efficient delineation of building outlines, especially the detection of buildings the human eye does not necessarily notice, such as new infill buildings within an urban matrix or those largely obscured by a tree canopy.

The 2013 Buildings update was implemented as a pilot project with the intention to build an ongoing programme in order to track changes in the built environment through time. This project has delivered Auckland's first building outlines update, providing a trajectory with two time periods. Although the 2013 Buildings data set is essentially a five year update on the 2008 Buildings, the change detection was calculated from 2010 due to the correspondence of capture areas. In this three year period, new construction and alterations in the previously mapped urban core comprised a net increase of 2.2 million square metres (2.2km^2 or 217 ha), or a 2.2% increase in area.

This project provides a thorough and expanded update of Auckland's Building footprints (with the exception of outlying areas due to data limitations). Particular attention has been paid to quality assurance using best available (public) imagery. The project still relied heavily on manual interpretation in the QA process, which at times led to editing errors. These are areas for future work, along with incorporating further updates (such as possibly the 2016-18 LINZ building outlines for Auckland) into an ongoing change detection in order to understand Auckland’s dynamic built environment.

7.0 Recommendations

This first thorough update of Auckland's building outlines has exposed limitations in council's approach to dynamic spatial data sets, with potential areas for improvement:

1) Recognise buildings, and the built environment, are dynamic not static

Regular updating of building outlines is essential, just as it is for other environmental data sets. Rather than maintain a static data set for a dynamic entity, a shift in approach is needed towards creating regular updates, perhaps every three to five years.

2) Understand the importance and validity of trajectories

Auckland Council has not previously labelled the Buildings data with a time period. Nor has it kept available historical versions in active working directories, but rather only "current" versions of data sets. When this project first started, we had to request the 2008 Buildings version be pulled from archives.

Current data alone is not sufficient to understand the dynamics of a changing built environment; trajectories are important. Change detection is a vital part of city planning, management, agenda setting. A shift in thinking and approach to data are needed to understand the trajectories of the dynamics of a city. Data sets should be labelled with the time period of data capture so that these trajectories may be understood.

3) Consider the entire region

Auckland's history of capturing remotely-sensed data (aerial photography and LiDAR) has distinguished the region's urban portions from its rural areas. Data have been acquired more often at finer scales in so-called urban zones. The 2008 and 2010 Buildings data sets were only produced for these built-up areas (which is inseparable from the data availability). But, it is important to consider the region as a whole. Data collection and data production need to be wall to wall, border to border. It is important to collect spatial information across the entire region, via remotely-sensed data, in order to understand the interconnections of the region. Moreover, in this growing metropolis, the urban region is extending into the rural areas apace: the lack of regional data precludes the possibility of understanding current growth as well as trajectories due to a lack of baseline data. The lack of data only reinforces conventional wisdom or pre-conceived notions about the actual built environment (specifically) and land use (generally) in rural areas – a significant gap in environmental and natural resource management for Auckland.

4) Further develop Auckland’s buildings trajectory

This first thorough buildings update and change detection is just the beginning. This data set can be extended in time a space to meet copious council data needs and improve work streams.

This 2013 Buildings update is a partial coverage of the region (a version 1). A complete regional 2013 Buildings coverage (a version 2) could be produced by making use of other remotely-sensed data sources, pending prioritisation and resourcing of such a project.

Another time step can be added to the trajectory, courtesy of the LINZ national buildings outline project. The LINZ building outlines for Auckland currently is a compilation across time periods (from 2012 to 2017) and has not undergone quality assurance or an accuracy assessment. It can thus be considered a starting point from which to produce another time step, once aligned to a specific time period (year) and assessed for quality and accuracy. As region-wide data become more available, whether through optical imagery or LiDAR, a regular programme of work can be developed to keep the building footprints up to date, with ongoing change detections.

5) Embrace methodological and technological advancements for detection

An embrace of innovation, such as using new data sources and analytical techniques for buildings detection, could result in efficiency gains and new information for the organisation. For example, there is much opportunity to produce regular updates of Auckland’s building outlines. This would be facilitated via further development of semi-automated approaches and techniques to better produce building outlines at scale.

The four main areas of work for method improvement would be 1) to improve the quality of generated outlines through the object extraction method; 2) to develop automated workflows to attend to most false positives; 3) to develop image processing routines to detect false negatives; and 4) to improve the data merging process in order to detect areas of building replacement (in contrast to new builds) in the case when an existing data set is updated by new building footprints rather than a total remap. The first will likely be aided by the improved quality of new LiDAR data sets; the increased point cloud density facilitates the detection and delineation of building outlines.

In addition, 3-D building data are increasingly of interest to governments world-wide and are becoming more feasible all the time. With Auckland Council’s continued interest and efforts in LiDAR data collection, there is much scope to develop a three-dimensional view of the region to complement the work done here.

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9.0 References

Agius, C. ad Brearley, J. 2014. Can Building Footprint Extraction from LiDAR be Used Productively in a Topographic Mapping Context? *Future Preparedness: Th ematic and Spatial Issues for the Environment and Sustainability.*

Andrews, J. 2017. More Than A Pretty Picture: What Businesses Should Know About Satellite Imagery. *Forbes.*

Awrangjeb, M., Ravanbakhsh, M. and Fraser, C. 2010. Automatic detection of residential buildings using LIDAR data and multispectral imagery. *ISPRS Journal of Photogrammetry and Remote Sensing,* 65**,** 457-467.

Awrangjeb, M., Zhang, C. and Fraser, C. 2012. Building detection in complex scenes through effective separation of buildings from trees. *Photgrammetric Engineering & Remote Sensing,* 78**,** 729-745.

Balderston, K. and Fredrickson, C. 2014. Capacity for Growth Study 2013 (Proposed Auckland Unitary Plan): Results. Auckland Council technical report, TR2014/010.

Demir, N., Poli, D. and Baltsavias, E. Extraction of buildings and trees using images and LIDAR data. The International Archives of Photogrammetry, Remote Sensing, and Spatial Information Sciences, 2008 Beijing. 313-318.

Dorninger, P. and Pfeifer, N. 2008. A Comprehensive Automated 3D Approach for Building Extraction, Reconstruction, and Regularization from Airborne Laser Scanning Point Clouds. *Sensors,* 8**,** 7323-7343.

Du, S., Zhang, Y., Qin, R., Yang, Z., Zhou, Z., Tang, Y. and Fan, C. 2016. Building Change Detection Using Old Aerial Images and New LiDAR Data. *Remote Sensing,* 8.

Emison, B. 2009. LiDAR Feature Extraction Methodologies. *2009 Civil Commercial Imagery Evaluation Workshop.*

Fredrickson, C. and Balderston, K. 2013. Capacity for Growth Study 2012: Methodology and Assumptions. Auckland: Council technical report, TR2013/009.

Hartmann, A., Meinel, G., Hecht, R. and Behnisch, M. 2016. A workflow for automatic quantification of structure and dynamic of the German building stock using official spatial data. *International Journal of Geo-Information,* 5.

Hu, C. 2018. Rates Assessment Extract. *In:* (RIMU), R. A. E. U. (ed.). Auckland: RIMU.

Hu, J., You, S. and Neumann, U. 2003. Approaches to large-scale urban modeling. *IEEE Computer Graphics and Applications***,** 62-69.

Huang, X., Zhang, L. and Zhu, T. 2014. Building Change Detection From Multitemporal High-Resolution Remotely Sensed Images Based on a Morphological Building Index. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 7**,** 105-115.

Lin, G., Milan, A., Shen, C. and Reid, I. RefineNet: Multi-Path Refinement Networks for High-Resolution Semantic Segmentation. 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), July 2017. 1925-1934.

Linz Data Service 2016. NZ building outlines (Pilot). *In:* Land Information New Zealand (Ed.).

Linz Data Service 2018. Building Outlines Data. *In:* Land Information New Zealand (ed.).

Microsoft 2018. USBuildingFootprints. Microsoft.

Miller, C. 2017. Auckland's new hotspots revealed: Find your property's value. *New Zealand Herald*, 20 November.
NZ Aerial Mapping and Aerial Surveys Limited 2015. LiDAR Flyover 2013/14 Project Final Report. Auckland: for Auckland Council.
Pang, S., Hu, X., Cai, Z., Gong, J. and Zhang, M. 2018. Building Change Detection from Bi-Temporal Dense-Matching Point Clouds and Aerial Images. *Sensors,* 18.
Pope, P. and Prasad, L. 2015. Building Detection using EO, Lidar and GEOBIA. Los Alamos, NM (United States): Los Alamos National Laboratory.
PSMA Australia 2016. Geoscape Evaluation Dataset - Data Release Report. Canberra, Australia: PSMA Australia Limited.
PSMA Australia. 5 December 2017 2017. PSMA inspires new 2D building footprints product. [Accessed 5 December 2017 2018].
Shan, J. and Lee, S. 2005. Quality of building extraction from IKONOS imagery. *Journal of Surveying Engineering,* February**,** 27-32.
Statistics New Zealand: Population Statistics 2017. Subnational estimates (TA, AU)), by age and sex, at 30 June 1996, 2001, 2006-17 (2017 boundaries). *In:* ZEALAND, S. N. (ed.). Wellington: Statistics New Zealand.
TERRALINK 2008. Quality Plan ALGGi Topographical Data Capture 2008. Auckland: Terralink.
Tomljenovic, I., Hofle, B., Tiede, D. and Blaschke, T. 2015. Building Extraction from Airborne Laser Scanning Data: An Analysis of the State of the Art. *Remote Sensing,* 7**,** 3826-3862.
Tseng, Y.-H. and Wang, S. 2003. Semiautomated Building Extraction Based on CSG Model-Image Fitting. *Photogrammetric Engineering & Remote Sensing,* 69**,** 171-180.
Wallace, A. 2017. How many buildings are in Australia? Geoscape is counting. *Spatial Source.* https://www.spatialsource.com.au/.
Wallace, T., Watkins, D. and Schwartz, J. 2018. A map of every building in America. *The New York Times*, 12 October 2018.
Zhou, W. and Austin, T. 2008. An object-oriented approach for analysing and characterizing urban landscape at the parcel level. *International Journal of Remote Sensing,* 29**,** 3119-3135.
Zhu, L., Shimamura, H., Tachinbana, K., Li, Y. and Gong, P. 2008. Building Change Detection Based On Object Extraction In Dense Urban Areas. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XXXVII.

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