THE USE OF LASER SCANNER DATA FOR THE EXTRACTION OF BUILDING ROOF DETAIL USING STANDARD ELEVATION DERIVED PARAMETERS

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ABSTRACT

3D city modelling is a rapidly growing research area in the field of feature extraction. As the demand for 3D data increases, so does the necessity for higher detail building models. The use of aerial imagery and photogrammetric processing has been dominant in the field of feature extraction for several decades. Recently this dominance has been challenged by laser scanning techniques which offer direct 3D data capture at high resolutions. This paper investigates the use of laser scanning data for roof detail extraction. This has already been considered by Maas and Vosselman (1999) who used data with a sample spacing of more than five points per m^2. The data set in this paper was created using an Optech Airborne Laser Terrain Mapper 1020 LIDAR sensor with 2.5m point spacing which was interpolated onto a 2m regular grid. The aim of this paper is to explore the extent to which useful roof detail can be extracted using this relatively low resolution LIDAR data. A 2D building outline database was used to define the roof boundaries.

The ability of the LIDAR data to extract roof detail was tested using algorithms based on LIDAR elevation and derived slope and aspect parameters. An industrial area and a residential area were selected as test sites. Results show that the LIDAR aspect parameter was the most successful at reconstructing building roofs. Using LIDAR aspect data, the results show a percentage correspondence of derived roof ridges to actual ridges of around 33% for the residential area (86% for the industrial area). The amount of roof detail extracted is greater for the industrial study area due to the simpler, larger roof structures. The report concludes that relatively low resolution laser scanning data can be used to extract roof detail, but that results are only significant for large, simple roof buildings.

1 INTRODUCTION

In recent years there has been an increasing interest in the availability of 3D descriptions of real world scenes, especially within urban areas. These 3D city models are being sought after for use in a wide range of applications including urban planning and virtual reality applications (Newton, 1996). As the technology behind 3D modelling matures, there is an increasing requirement for greater building detail. This paper looks at a possible data source for one aspect of building description, that of roof detail.

The field of feature extraction has been dominated for several decades by the use of aerial photography and photogrammetric processing. Building recognition is one research area within this field which focuses mainly on the extraction of building outlines using edge detection techniques (Frère et al., 1997). Attempts have been made using aerial imagery to extract 3D roof detail supplementary to the ground plan information. Grüen and Dan (1997) attempted to match extracted roof and building line segments derived from aerial imagery to an *a priori* building classification. A semi-automated approach was tested by Lang and Förstner (1996) by creating building models based on building examples from the actual study area. It is likely that this procedure would be more time consuming than the method adopted by Grüen and Dan (1997), but may end up being more accurate due to the site specific nature of the building models.

Photogrammetry for 3D modelling has limitations. Braun et al. (1995) state that aerial imagery contains too much information in addition to the building information that would enable easy extraction of building outlines and roof information. 3D information is imposed onto a 2D image format making 3D reconstruction harder. Lengthy stereo-matching procedures are required to extract height information using user defined sampling methodologies. Low contrast edges and poor image perspectives make building extraction more complex still.

Laser scanning is a relatively new technology that is challenging the dominance of photogrammetry in the field of feature extraction, especially for 3D city modelling. Laser scanning offers direct 3D data capture at high resolutions and the possibility to extract roof detail. Hug (1997), Maas and Vosselmann (1999) and Weidner (1997) have looked at the extraction of buildings using laser scanner data. Maas and Vosselmann (1999) have looked in particular at the extraction of roof detail. They use raw laser scanner point data which for their study has a density of over five points per square metre. Triangulation of the point data and other processing stages were required to produce high detail roof structures. Authors such as Jaafar et al. (1999) and Haala and Brenner (1999), however, have used the more common form of laser scanner data which is a regular grid interpolated from the point data. Problems such as mixed pixel effects caused by the grid interpolation can reduce the amount of information that can be extracted from the data (Axelsson, 1999).

This paper uses a 2m resolution gridded laser scanner data set which represents the terrain, vegetation and buildings as a Digital Surface Model. The grid was produced by interpolation of the raw point data which was created by an Optech Airborne Laser Terrain Mapper (ALTM) 1020 LIght Detection And Ranging (LIDAR) sensor. The sensor scans the surface with a 2.5m point spacing. The point spacing and resolution is much lower than that used by Maas and Vosselmann (1999), and is more representative of the majority of LIDAR data sets which can have point densities of up to one point per $10m^2$. If roof detail can be extracted from the 2m resolution data, it suggests that the majority of laser scanner systems with relatively low resolution data sets may be able to satisfy the demand for roof detail for 3D city models. This would benefit laser scanner users who cannot afford or find high resolution laser scanner data for their applications.

The aim of this paper is to investigate whether or not any meaningful roof detail can be extracted from the test LIDAR data set.

The roof detail will be extracted from the LIDAR data by processing elevation and derived slope and aspect parameters using ARC/INFO GIS software. Algorithms will be developed within ARC/INFO that will manipulate the parameters to extract the maximum amount of roof detail. Each parameter will be assessed for its performance alongside the other parameters. Ordnance Survey 2D vector building outlines will be used to isolate the LIDAR building data so that the methodology can concentrate on roof detail extraction rather than building recognition. The extraction results will be compared with the actual roof structures observed in the field.

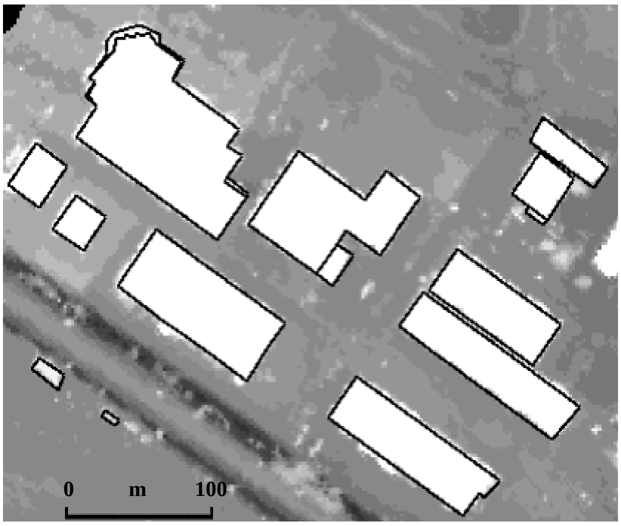


Figure 1 LIDAR representation of industrial area with vector building boundaries (boundaries reproduced from Ordnance Survey mapping with the permission of The Controller of Her Majesty's Stationery Office, Crown Copyright. ED 273554).

2 STUDY AREA

Two study areas were chosen that represented alternative building scenarios. An industrial area was chosen because of its high number of large, simple roofed buildings. If the LIDAR data is to derive accurate roof detail for buildings then it will most likely be from these. Figure 1 shows the industrial area as the LIDAR sensor captured it with building outlines added for extra clarity. An example photograph of the industrial area is given in Figure 2. It shows the dominant roof structure for this area which is a two segment roof split by a central ridge running parallel to the building's long axis.

A residential area was chosen to represent a more challenging task for the LIDAR data. The buildings in this area (Figure 3) are smaller with more complex roof structures than the industrial area buildings. There is also non-building noise from objects such as trees, cars and hedges (Figure 4).

3 METHODOLOGY

To assess the performance of the LIDAR data parameters for extracting roof detail, a field survey was undertaken to create a control data set of all roof structures. These were then compared qualitatively to the LIDAR algorithm results using various comparative statistics.

3.1 Error Assessment

Before the algorithms were tested, an error assessment of the LIDAR and vector buildings was carried out. This was to ensure that any results were put into context with any inherent inaccuracies in the data sets.

Figure 2 Example of industrial area buildings.

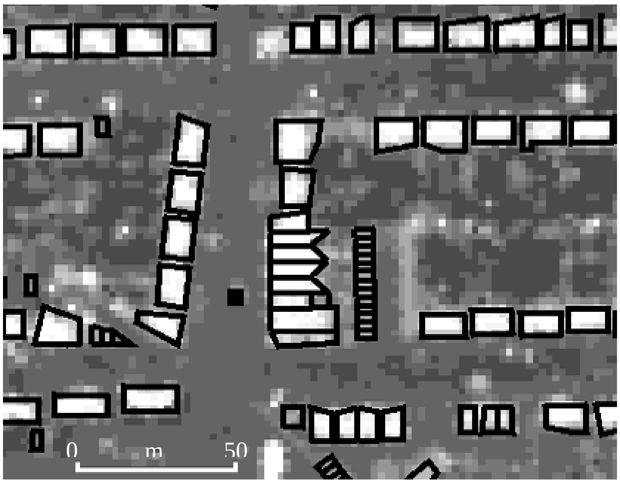


Figure 3 LIDAR representation of residential area with vector building boundaries (boundaries reproduced from Ordnance Survey mapping with the permission of The Controller of Her Majesty's Stationery Office, Crown Copyright. ED 273554).

Figure 4 Example of residential area buildings.

A quantitative assessment of LIDAR vertical accuracy was made by comparing LIDAR heights against Ordnance Survey spot heights from a 1:1250 map. Root Mean Square Error (RMSE) was derived from the comparison as a measure of vertical error (Jaafar and Priestnall, 1998). The planimetric accuracy of the LIDAR data was determined qualitatively using the author’s own observations as well as available literature.

The planimetric accuracy of the vector building data was extracted from the dataset's metadata.

3.2 Survey Methodology

The survey data set is a plan description of the roof structure for every building in the LIDAR data set. A visual assessment of each building was made in the field, and all roof edges including dormers and other small extensions were drawn onto a 1:1250 building map.

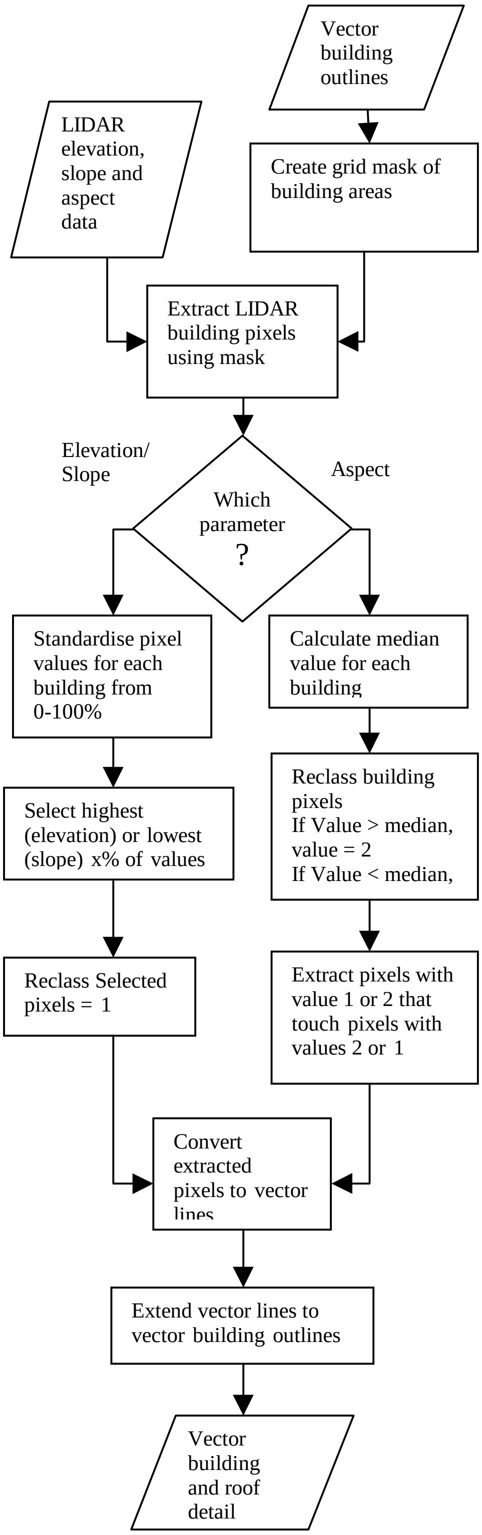


Figure 5 Flowchart of algorithm development process.

3.3 Algorithm Development

LIDAR elevation and derived slope and aspect parameters were used in the algorithm development. Each parameter was taken in turn and manipulated by the algorithms to extract the maximum amount of information from it. Figure 5 is the standard algorithm used for all three parameters. To save processing time the vector building data was used to isolate LIDAR building pixels only. Each LIDAR building was then queried in an attempt to derive roof ridge features from the pixels. These features were then vectorised and edited. Small error lines were removed and where possible ridge lines were extended and attached to the original building outlines.

The algorithms were tested on buildings whose roof structure was dominated by a main central ridge running parallel to either of the key planimetric axes of the building (e.g. building on left side of Figure 2). The assumption was that if the LIDAR data could not extract the main ridge then it would not be able to extract the finer elements of the roof structure. Some of the industrial buildings were composed of multiple main ridges and attempts were made to extract all these features.

3.3.1 Elevation. For each building the assumption made was that the main ridge was the highest region of the building. The higher the pixel value, the more likely that pixel holds ridge information. The algorithm looked at the top 5-15% of roof pixel values in an attempt to extract a continuous linear pixel grouping of elevation values that represent the main ridge.

3.3.2 Slope. Around the main ridge, slope values change abruptly, being close to zero at the ridge itself. The lowest 15-30% of slope values were tested for their ridge extraction performance.

3.3.3 Aspect. All buildings were assumed to be comprised of two sloping roof segments joined by the main ridge. Aspect values were split into two groups each representing one of the two roof segments. The median aspect value was taken as the threshold pixel value that separated the two groups. Values below the threshold were classified as one and values above as two. This created a border between the one and two pixels that was extracted through vectorisation as the roof ridge.

4 RESULTS AND DISCUSSION

Statistics were produced from the assessment of the LIDAR data set for roof ridge extraction. One statistic compared the algorithm derived roof ridges with those collected in the field. If a derived ridge was near parallel and close to the actual building ridge then this was marked as a successful ridge derivation. The decision as to whether a derived ridge matched an actual ridge was made qualitatively from a visual assessment. A percentage score was calculated for the number of derived ridges that matched the actual ridges (Table 1).

A statistic was also produced that split the successfully derived ridges into two groups. Those that exactly matched the actual ridge in orientation and location were separated from those classed as near matches. Table 2 shows the absolute number and percentage of exactly matching derived ridges.

4.1 Algorithm Comparison

The aspect parameter derived from the gridded LIDAR data is the most successful at roof ridge extraction (Table 1). It performs better at both the residential and industrial sites.

	Derived/ Actual Ridges		**Percentage Derived/ Actual Ridges**	
Parameter	**Residential**	**Industrial**	**Residential**	**Industrial**
Aspect	68/204	36/42	33.33	85.71
Slope	50/204	22/42	24.51	52.38
Elevation	27/204	18/42	13.24	42.86

Table 1 Comparison of algorithm derived ridges for each parameter to actual ridges.

	Exact Match Derived Ridges/Total Number of Derived Ridges		**Percentage of Derived Ridges that Exactly Match Actual Ridges**	
Parameter	**Residential**	**Industrial**	**Residential**	**Industrial**
Aspect	35/68	28/36	51.47	77.78
Slope	47/51	22/22	92.16	100
Elevation	27/27	18/19	100.00	94.74

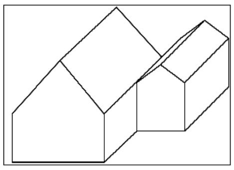
Table 2 Comparison of exactly matched derived ridges to total number of derived ridges.

Slope is the next most effective parameter at ridge extraction followed by elevation. The lowest 25% of slope values and top 10% of elevation values were found to be the most effective in representing roof ridges. Figures 6a-e illustrate how each parameter responds to an example building from the LIDAR data set. Figure 6a is a 3D visualisation of a large, simple roofed industrial building. It has two main roof sections, one high and one low. Both sections are made up of two roof segments that converge to a central ridge.

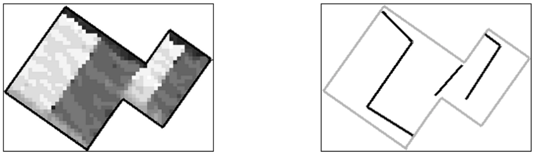
The performance of aspect is shown in Figure 6b. The two roof segments can be clearly seen with a definite grey scale break that defines the main ridge (Figure 6b.i). Both segments do have some noisy pixels, but these are removed during the execution of the aspect algorithm which groups all pixels together for a particular roof segment. The extracted lines based on the aspect values are shown in Figure 6b.ii. The main ridge is successfully extracted on both levels of the building. So too is the inverse ridge that marks the boundary between the two roof sections. Several error lines can also be seen. These are mainly due to the LIDAR sensor picking up the vertical building sides and representing them as sloping roof segments producing error ridges. This effect can be partly attributed to the low scan angle of the LIDAR sensor distorting the building shape.

For the slope and elevation algorithms, a certain range of percentage values were extracted for each building to represent the main ridge. This differs from the aspect algorithm which focuses on homogenising the roof segments before the ridge was extracted. The slope parameter manages to avoid the noisy building edges because the slope values are high in those areas and only the low slope values were queried in the algorithm. This produces a cleaner representation of both main ridges.

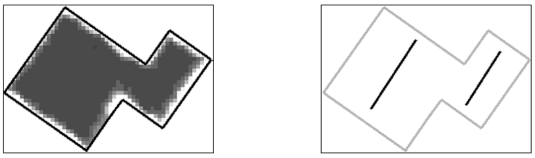
The elevation parameter also avoids the noisy building edge (Figure 6d). However, it is even less useful than the slope algorithm as it only manages to identify one of the two main ridges present on the roof. This is because the ridge to the right hand side is lower than the left hand one. The elevation algorithm extracts higher elevation values to represent the roof ridge, and therefore any lower ridges are omitted. This is not necessarily a problem in the residential areas where it is common for only one main ridge to be present, but in industrial areas multiple ridge buildings are much more widespread.



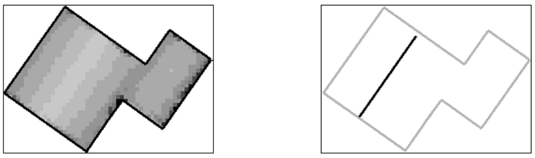
a. 3D Building Visualisation



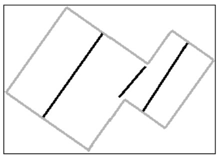
b.i. Aspect values b.ii. Aspect results



c.i. Slope values c.ii. Slope results



d.i. Elevation values d.ii. Elevation results



e. Edited Aspect results

Figure 6 Roof ridge extraction results for an industrial building.

Figure 6e is the aspect parameter results after the final processing stage, with the extracted ridges having been removed manually if erroneous, and the correctly defined ridges extended where possible to the original building structure. Error ridges could be removed automatically by using the slope parameter to eliminate the steep wall pixels that seem to cause the error ridge problem.

Although the aspect parameter recognises the highest number of roof ridges compared to slope and elevation, the number of exact matches is lower than the other two parameters which have near perfect records (Table 2). This is probably due to the greater exploratory nature of the aspect algorithm. A trade off is made between the tidier slope and elevation parameters that are more likely to define a ridge in its exact position compared to the aspect parameter that produces more error ridges, but provides a more comprehensive absolute coverage of main building ridges. The aspect parameter should still be preferred regardless of the accuracy with which roof ridges are represented because of its higher performance at ridge recognition.

4.2 Site Comparison

The algorithm comparison provided an insight into which derived parameters from the LIDAR data could be used to extract roof detail. A comparison of the industrial and residential area results in Table 1 and Table 2 highlight properties of the LIDAR data that may affect the effectiveness of the elevation, slope and aspect parameters at roof ridge extraction.

The percentage values for derived ridges to actual ridges are much higher in the industrial area compared to the residential area (Table 1). The large buildings and simple roof structures are largely responsible for this high rate of extraction success. The LIDAR data set used in this paper has a grid resolution of 2m. For residential buildings this can cause problems, because the pixel size is too large to adequately represent the complicated variations in roof structure that residential buildings generally display. Dormers, chimneys, television aerials and other roof objects can all contribute to the scrambling of roof ridge information held by the pixels. Chimneys and other extrusions were also present on some of the industrial building roofs but are small in comparison to the roof size. They did not therefore affect the roof ridge extraction to the same extent as in the residential area.

Another key difference between the two areas was the amount of noise from objects surrounding the buildings. In the residential area, neighbouring houses, trees, cars, hedges and fences are often positioned close to a building. Information from these features can mix with the building data as a result of the interpolation of the LIDAR point data to a grid. This makes the extraction of roof detail much harder. Mixed pixel effects are not as prolific in the industrial area especially since neighbouring buildings are positioned some distance from each other, and most other objects are small in comparison to the building itself.

Ground information can contribute to mixed pixel effects and is a common problem for both areas. This results in building edge information being smoothed. For small buildings ground information can penetrate all the way into the central building pixels and affect the extraction of roof ridges.

4.3 Other Influences on Results

Mention has already been made of the effect of the LIDAR data’s grid resolution and mixed pixel effects on the results. Other factors have also influenced the results in Table 1 and Table 2. For this paper, the vertical accuracy of the LIDAR data was found to have an RMSE value of about +/-0.3m. This is fairly similar to the decimetre accuracy values quoted by authors such as Lohr (1998).

One of the main error sources for planimetric accuracy was the planimetric shift observed between the LIDAR data and the 2D vector building outlines. In some cases the occurrence of roof edge pixels did not coincide with the building boundary and was often up to one pixel width outside that of the boundary. As Huising and Gomes Pereira (1998) admit this shift may be due to local factors such as planimetric building errors. The vector data used is claimed to have a planimetric accuracy of anything up to +/-1m. Systematic error may also cause a shift in building information. Shadowing resulting from low LIDAR scan angles (+/-19 degrees for this study) can be seen predominantly in the industrial area due to the high building sides hiding other building sections from the LIDAR sensor. A comprehensive guide of other error sources from laser scanner systems can be found in Huising and Gomes Pereira (1998).

4.4 LIDAR and Roof Detail Extraction - Next Steps

The use of relatively low resolution LIDAR data for roof detail extraction is restricted by the generalisation of roof structure information into grid cells. Mixed pixel effects created by the interpolation of the raw point data into a regular grid have contributed to increasing the difficulty with which roof detail can be extracted. One solution may be to use the raw data itself as demonstrated successfully by Maas and Vosselmann (1999). The processing of point data, however, tends to be a harder task compared to the simpler algorithms that are needed to manipulate grid data. Another solution could be to use a data set with a higher grid resolution derived from a higher point spacing. Increases in the level of roof detail may be possible with this higher resolution data, but the increases may not be sufficient enough to justify the higher cost of the data.

Having discussed alternatives to the LIDAR data used in this study is not to say that it did not produce interesting results. The results derived from using the aspect parameter from the LIDAR data showed promising signs of being used as a useful indicator of the dominant ridges and segments of a building roof. There is the possibility that aspect could be used to define sub-ridges by splitting the roof aspect values into more than two groups. Some initial testing using four groups showed however that this produced poor results with the aspect groups imposing their own structure on the roof.

Instead of trying to increase the amount of detail that can be extracted using this resolution data, a task which is unlikely to be successful, attention should be concentrated on using the available results for applications that require general roof detail. Applications such as virtual reality and the visualisation aspects of planning applications (Newton, 1996) which may require more than the basic rectangular block structure of a single height building, could use this level of roof detail. Higher detail 3D city models may be necessary to satisfy the public's inquisitiveness into the finer details of particular building construction schemes for example.

After roof segmentation it is possible to extract height information for each new segment which could be used to update current 2D spatial databases with quantitative 3D information. A degree of semi-automation may be necessary for this process with the derived roof ridges acting as guidelines for the user's own interpretation of the roof structure.

5 SUMMARY AND CONCLUSIONS

This paper has assessed the use of relatively low resolution LIDAR data for the extraction of roof detail from buildings, primarily for 3D city modelling. A 2D spatial database of vector building outlines was used to locate the roof extents. Two study areas were used to test the LIDAR data, an industrial area with large simple roofed buildings, and a residential area with smaller buildings and more complex roof structures. Through the use of LIDAR elevation, aspect and slope parameters, attempts were made to extract the main roof ridge of a building. Results suggest that it is possible to extract general roof detail using this data, especially for large buildings with simple roof structures. The aspect parameter performed best, extracting the largest majority of ridges from the buildings. Of these extracted ridges using aspect, just over half can be considered to be exact matches. In the residential areas, the smaller buildings and more complex roof structures made it much harder for the LIDAR data to produce meaningful roof detail.

Other LIDAR data sets with similar or lower resolutions will most likely suffer the same problems experienced in this assessment. The vertical and planimetric accuracy levels of the LIDAR data are not conducive to the extraction of accurately positioned and located roof detail. The problems with the LIDAR data were substantial even though the buildings used in the study were chosen for their relatively simplistic structures.

Despite these limitations, the level of roof detail extracted in this study is suited to several applications such as visualisation and spatial database updating. A semi-automated approach to roof detail extraction may need to be employed for these applications. The extracted ridges can be used as a guide for the user to better define the extent and nature of the ridges. To increase the amount of roof detail that can be extracted from this LIDAR data, the resolution, or rather the original point spacing of the LIDAR sensor, should be made more dense. This will, however, increase the cost of the data and make it less affordable to most laser scanner users. LIDAR data accuracy levels need to be improved further, as well as the relative accuracy levels between LIDAR data and any assisting data sets such as the 2D vector data set used in this paper. Until the use of higher density laser scanner instruments becomes more widespread and the cost of the technology decreases, relatively low resolution laser scanner data can be used to extract general roof detail from buildings.

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