EuroSDR BUILDING EXTRACTION COMPARISON

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ABSTRACT:

The paper focuses on comparing accuracies obtained with photogrammetry and laser scanning in building extraction. The objective of the EuroSDR Building Extraction comparison was to evaluate the quality, accuracy, feasibility and economical aspects of semi-automatic building extraction based on photogrammetric techniques with the emphasis on commercial and/or operative systems, semi-automatic and automatic building extraction techniques based on high density laser scanner data and semi-automatic and automatic building extraction techniques based on integration of laser scanner data and aerial images. The project consists of three test sites by the Finnish Geodetic Institute (FGI), namely Senaatti, Hermanni and Espoonlahti, and one test site by the Institut Geographique National (IGN), namely Amiens. For each test site following data was provided to the partners: aerial images, camera calibration and image orientation information, ground control point coordinates and jpg images of point locations (not for Amiens), laser scanner data and cadastral map vectors of selected buildings. Participants were requested to create vectors of 3D city models. 3D-models were obtained from 11 participants. The paper confirms with experiments that laser scanning is superior in deriving building heights, extracting planar roof faces and ridges of the roof, whereas photogrammetry and aerial images are superior in building outline and length determination.

1. INTRODUCTION

Three-dimensional geographical information systems suitable for various applications such as urban planning, visualization, environmental studies and simulation (pollution, noise), tourism, facility management, telecommunication network planning, 3D cadastre and vehicle/pedestrian navigation are of increasing importance in urban areas. Semi-automatic and automatic methods for 3D city models using photogrammetric and laser scanning techniques are aimed in order to reduce the costs of providing this data with reasonable level of detail. Due to the complexity of the full automation with photogrammetry, majority of development work has focussed on semi-automatic systems, in which e.g. recognition and interpretation tasks are performed by the human operator, whereas modelling and precise measurement is supported by automation. In addition to photogrammetric techniques relying on aerial images, the generation of 3D building models from laser scanning-derived point clouds are becoming an attractive alternative. This development has been triggered by the sensor technology allowing dense point clouds. Also, the integration of laser point clouds as well as photogrammetric processes with aerial photos provides new technological solutions. Short summary of the state of art dealing with building extraction methods can be obtained from Baltsavias (2004), Brenner (2001), Grün (1997), Gülch (2000), Mayer (1999), Maas and Vosselman (1999) and Paparoditis et al. (1998).

Due to the fast development of sensors and methods during the last 5-6 years, it was accepted that under the EuroSDR Commission III “Production Systems and Processes”, a joint test was undertaken in order to compare various methods. The objective of the *Building Extraction* project was to evaluate the quality, accuracy, feasibility and economical aspects of

1. Semi-automatic building extraction based on photogrammetric techniques with the emphasis on commercial and/or operative systems.
2. Semi-automatic and automatic building extraction techniques based on high density laser scanner data.

3. Semi-automatic and automatic building extraction techniques based on integration of laser scanner data and aerial images.

This paper reports the results obtained in the study for the first time. The paper focuses on comparing accuracies obtained with photogrammetry and laser scanning in building extraction.

2. MATERIAL

2.1 Test sites

The project consists of three test sites by the Finnish Geodetic Institute (FGI), namely Senaatti, Hermanni and Espoonlahti, and one test site by the Institut Geographique National (IGN), namely Amiens. Senaatti includes the area around the Senate Square in Helsinki main city centre, three to six storey houses and Lutheran Cathedral built mainly in the 19^{th} century. Hermanni is a residential area with few trees about 3 km of the main city centre with four to six storey houses built mainly in the 1950's. A third test site, Espoonlahti, is located in Espoo, about 15 km west of Helsinki with high-rise buildings, large number of trees and terraced houses. Test site Amiens is located in the city of Amiens in Northern France in a residential area. Amiens consists of small houses with small height variation and closely packed to each other.

2.2. Aerial images and laser scanner data

For each test site following data was provided to the partners:

- aerial images
- camera calibration and image orientation information
- ground control point coordinates and jpg images of point locations (not for Amiens)
- laser scanner data
- cadastral map vectors of selected buildings

	Espoonlahti	**Hermanni**	**Senaatti**
Photos	Stereo pair	Stereo pair	Stereo pair
Date	26^{th} of June 2003	4^{th} of May 2001	24^{th} of April 2002
Camera	RC-30	RC-30	RC-30
Lens	15/4 UAG-S, no 13355	15/4 UAG-S, no 13260	15/4 UAG-S, no 13260
Calibr. date	22^{nd} of November 2002	18^{th} of January 2000	14^{th} of April 2002
Flying height, scale	860 m, 1:5300	670 m, 1:4000	660 m, 1:4000
Pixel size	14 microns	15 microns	14 microns

Table 1. Applied aerial images.

In addition to the variation in construction type, DTM and canopy differences, the test sites have also been flown with different laser scanners (TopEye, TopoSys-I, TopoSys-Falcon) and with different pulse densities (from 1.6 to about 20 pulses per m^2)(Table 2).

Amiens data was delivered by IGN. Eleven airborne images from a digital acquisition on June 23^{rd} 2001 with IGN's own digital camera were used. The ground pixel size is approx. 25 cm. The characteristic of these acquisitions was the large overlap rate (around 80%) between the different images. Laser scanning data from Amiens consists of 4 strips covered with Toposys. Point density was 4 points per m^2. Given data included a digitised cadastral map with a 2D description of buildings in DXF-format.

	Espoonlahti	**Hermanni**	**Senaatti**
Acquisition	14^{th} of May 2003	End of June 2002	14^{th} of June 2000
Scanner	TopoSys Falcon	TopEye	TopoSys-1
Flight altitude	400 m	200 m	800 m
PRF	83 000 Hz	7 000 Hz	83 000 Hz
Scanning angle	± 7.15º	± 20º	± 7.1º
Point density	10-20 per m^2	7-9 per m^2	1.6 per m^2
Swath width	100 m	Ab. 130 m	Ab. 200m
Mode	First pulse	2 pulses	First Pulse

Table 2. Applied laser scanner data.

2.3 Requested task

Participants were requested to create the vectors of the 3D city models using the given material. Participants were allowed to use any method and data combination. 3D models were asked to consist of permanent structures of the test area: buildings modelled as detailed as possible (this mainly concerns roof structures) and terrain so that it is possible to measure building heights using the model. In addition, the participants were requested to describe their process, economical aspects and time spent for the process.

2.4 Reference data

Reference data was collected in November and December 2003 using a Trimble 5602 DR200+ tacheometer. Measured targets include corners of walls, roofs, chimneys and equivalent constructions as well as ground points next to building corners. Altogether about 980 points were measured in Espoonlahti, 400 in Hermanni and 200 in Senaatti.

Known points were used to orientate the tacheometer to test site's coordinate system.

In Espoonlahti, points by Espoo City Survey Division were used. The coordinates were transformed from Espoo coordinate system to Finnish National Grid using transformation parameters of the National Land Survey of Finland. After the transformation, one known point was used to determine a small systematic shift to correct the error in transformation; same point was used as reference point in laser data and aerial image acquisition. All used known points in Espoonlahti were also measured using RTK-GPS equipment to ensure that there are no gross errors. In Hermanni, points by Helsinki City Survey Division were used. In Senaatti, tacheometer was orientated to the rectangular coordinate system of Helsinki by measuring corners of buildings (coordinates were obtained from cadastral map) and height was obtained by measuring a known height point in the area.

On all three test sites, FGI repeated observations to same targets from different station set-ups to control the uniformity and accuracy of reference measurements. The differences in these repeated measurements were on the average 4.7 cm in plane (max 8.3 cm) and 1.2 cm in height (max 3.5 cm) on altogether 19 control observations. An empirical fact is that a distance measurement directly to the surface of e.g. a building wall is affected by the angle between the wall and the measuring beam, especially on long distances as the laser footprint expands. This effect can also be seen in these control measurements, where measured distances are somewhat longer than usual, thus giving a slightly more pessimistic value of the total accuracy than expected.

Reference data for test site Amiens included 32 roof points measured manually from aerial images. The given accuracy (standard deviation) of these points is 25 cm for X, Y and Z. The reference data was measured and delivered by IGN.

3. METHODOLOGY

3.1 Methods used by the participants

3D-models were obtained from 11 participants (Table 3). Participants were allowed to use the delivered data (aerial images, laser data and selected ground plans) as they wished. Table 3 summarizes the used data and the degree of automation for building extraction.

Participant	Used data			Level of automation
	Laser data	Aerial images	Ground plan	
Cybercity		100		low
Hamburg		100		low
Stuttgart		100		low-high
IGN	50	50		medium
ICC laser+aerial	80	20		low
ICC laser	100			low
Nebel+Partner	90	10		high
FOI	100			high
FOI outlines	100		X	high
C+B Technik	100		X	high
Delft	100		X	medium
Aalborg	100		X	high
Dresden	100		X	high

Table 3. Summary of used data and level of automation for building extraction.

The more advanced model (of two methods used) of the **University of Aalborg** applied the adjustment to all the points within the building outline and use the weighting of each point to separate the points not belonging to a roof plane. When one roof plane is found, all the points belonging to this roof plane are removed from the point cloud and the process continues interatively. This procedure continues until the method cannot find any more roof planes. The advantage of the method is that it finds all the roof planes and in the same procedure it calculates the parameters of the roof planes.

CyberCity (see e.g. Grün and Wang, 1999) used their own software and methods to extract buildings using aerial images, camera calibration and exterior orientation information. Used software included Visual Star, which is a digital photogrammetric workstation with various features (e.g. measurement and updating of 3D objects and generation of digital surfaces), and CyberCity-Modeler™ (CC-Modeler™) including CCModeler for topological structuring and CCEdit for improving the geometry of the building model (CAD system for 3D city models) and to export the data into the DXF format.

C+B Technik used an in-house developed software (by Dr. Wild). The primary goal of the software is to automatically derive the main shape of buildings. First a triangle net is created from the laser scanner data, which builds the basic data structure for the modelling process. The basic computation method selects the laser scanner points within a building polygon. Triangles are combined to surfaces and triangle sides are classified as edge lines. The resulting surfaces, edges and corners are analysed and edited to achieve the typical building objects, which are for example inner vertical walls, horizontal or tilted roof planes and horizontal ridges. The surfaces are also adapted to the building polygon, so that for example an edge line and a house corner fits together. The extraction of buildings from laser scanner data is split into an automatic computation phase and into an interactive check and editing phase.

TU Delft used their own software and methods to extract buildings using laser data and ground plans (see Vosselman and Dijkman, 2001, Vosselman and Süveg, 2001). If building outlines were not available, they were manually drawn in a display of the laser points with colour-coded heights. In test site Hermanni only buildings with given ground plan were modelled. If the point cloud within a building polygon could be represented by a simple roof shape (flat, shed, gable, hip, gambrel, spherical, or cylindrical roof) the model of this roof was fitted to the points with a robust least squares estimation. Often building models can be decomposed interactively such that all parts correspond to the above mentioned shape primitives. If the point cloud was such that all roof planes could be detected automatically, an automatic reconstruction was attempted based on intersection of detected neighbouring roof faces and the detection of height jump edges between roof faces. If the two above situations did not apply, the building polygon was split into two or more parts until each part fulfils one of the two above conditions. Optionally, point clouds were edited to remove outlier points that would disable an automatic roof reconstruction.

TU Dresden method (Hofmann, 2004) used point clouds obtained by a pre-segmentation of airborne laser scanner data. It is a plane-based approach that presumes that buildings are characterized by planes. It utilizes a TIN-structure that is calculated into the point cloud. The method only uses point clouds of the ALS data that contain one building. In order to get such point clouds polygons coarsely framing the building can be used to extract the points (e.g. in ArcGIS). The polygons can be created manually or map or ground plan information can be used. The parameters of every TIN-mesh, which define its position in space uniquely, are mapped into a 3D triangle-mesh parameter space. As all triangles of a roof face have similar parameters, they form clusters in the parameter space. Those clusters that represent roof faces are detected with a cluster analysis technique. By analyzing the clusters, significant roof planes are derived from the 3D triangle parameter space while taking common knowledge of roofs into account. However, no prior knowledge of the roof as e.g. the number of roof faces is required. The obtained roof planes are intersected in accordance to their position in space. By analyzing the intersected roof faces, the roof outlines are determined and the ground plan is derived.

FOI used their own software and methods to extract buildings using laser data with or without given ground plan. Without outlines the three pre-processing steps of the building extraction algorithm were: grid the data to obtain digital surface models (DSMzmax and DSMzmin), estimate the ground surface (DTM), and classify the data above the ground surface (vegetation / buildings). Each group of connected pixels classified as buildings are used as ground plan for the building extraction algorithm. With outlines, instead of classifying the data (step 3 above), the outlines have been used to create a classification image with buildings. The classification image is used to specify the ground plans of the buildings. The outlines have not been used when estimating the roof polygons along the contour of the building. The building extraction algorithm has been used as it is. The applied building extraction algorithm is a product of an ongoing work, the objective is to develop a fully automatic method general enough to handle most buildings, for example buildings having curved or non-parallel walls. For each ground plan detected in the classification, elevation data is used to extract planar roof faces. By following the outlines of roof faces, intersection lines and height jump sections between adjacent faces are determined. Finally, polygons are estimated for each roof face. This is done by estimating lines along the outlines of the faces. Having defined the polygons of the roof faces, a 3D model of the building is constructed.

Hamburg University of Applied Sciences used a digital photogrammetric workstation DPW770 using SocetSet from BAE Systems / Leica Geosystems to extract buildings using aerial images, camera calibration and exterior orientation information. After the import of the digital aerial images on the digital station using the given camera calibration and exterior orientation data, the automatic interior orientation of each image was performed in order to achieve the necessary transformation parameters from pixel into image coordinates. The quality of the exterior orientation of each stereo pair was checked for existing y-parallaxes and by comparing the measured and given control points. If the exterior orientation was accepted, the measurements of the roof points were performed using the software module Feature Extraction of the SocetSet. In Feature Extraction the operator can select three different roof types (flat, peaked or gabled) and measure roof points at a predetermined sequence including one point for ground elevation. Based on these measurements the building is modelled. Complex features were broken down into simpler components, which were later combined in AutoCAD. Finally, the measured data was transferred to AutoCAD 2000 for the correction of some measurements and for modelling of the complex buildings.

ICC used TerraScan, TerraPhoto and TerraModeler software by Terrasolid to extract buildings using laser scanner data with and without aerial images.

IGN used calibrated aerial images in multi-view context in test site Amiens and calibrated aerial images and laser DSM in test sites Espoonlahti, Hermanni and Senaatti. For each test site IGN created a pseudo-cadastral map manually using aerial images. Workflow was divided to preparation (fully automatic procedures such as DSM and true ortho processing), cadastral map edition and pruning, 3D reconstruction of buildings and quality control. Materials and methods varied between test sites. In Amiens test site, first a DSM and the true ortho associated were processed by correlation using the multi-view context. For prismatic models the 2D shape was edited and the median height on DSM was measured. For other models the skeleton of the central ridge was edited manually in one image and the system automatically reconstructs the 3D shape. Finally, the quality was controlled with difference image of 3D polygons and DSM. In Espoonlahti test site, pseudo-cadastral maps were edited on single image with height adjustment using the roll-button of the mouse. For each 2D polygon median height was measured on laser DSM. Finally, the quality was controlled with difference image of 3D polygons and DSM. In Hermanni test site, pseudo-cadastral maps were edited on single image with height adjustment using the roll-button of the mouse. The reconstruction was fully automatic using these 2D polygons and laser DSM. In Senaatti test site, several modules were used. Sometimes pseudo-cadastral maps were edited on single image with height adjustment using the roll-button of the mouse. After this, reconstruction was carried out using a model driven approach (Flamanc et al. 2003). Moreover, fully manual tools have been used for complex buildings. Finally, special tools as dome edition mode were used to extract specific structures.

Nebel + Partner used TerraScan software by Terrasolid to extract buildings using laser scanner data. Aerial images were not used for any measurements, only image crops were used as superimposed images for a better visual interpretation of the laser point clouds during the measurement of the roofs. Before the manual measurements in the point clouds each laser data set was automatically classified as buildings, ground elevation, and high, medium and low vegetation by TerraScan. In TerraScan software Construct Building tool was applied, which automatically finds roofs based on laser hits on planar surfaces of the roofs resulting in vectorized planes of each roof. Roof boundaries could also be created or modified manually.

Stuttgart University of Applied Sciences used inJECT1.9 (pre-release) software to semi-automatically extract buildings using aerial images, camera calibration and exterior orientation information. For a description of the used automated tools see (Gülch and Müller, 2001). The general workflow was: derivation of image pyramids with MATCH-B software, import of given exterior orientation data into OrthoMaster, automatic interior orientation in OrthoMaster1.4, automatic derivation of MATCH-AT project file, direct import in inJECT1.9, measurement of buildings without stereo-viewing. Parametric or polyhedral 3D building models were used with one common ground height for a building part or for a building composite. Partly the building models were measured as CSG structure forming composite buildings. Snapping function, rectangular enforcement for polygonal measurements, automatic enforcement of planarity were used. Basically all ground height measurements were done by image matching. The rooftop height and some shape features of saddleback and hip-roof buildings have been measured by area based and feature based image matching.

3.2 Analysis using reference points

Reference points were used to analyse the accuracy of the location, length, height and roof inclination of the modelled buildings. Location accuracy was analysed separately for plane and for height.

Differences between values derived from 3D-models and reference data were computed. Minimum, maximum, medium, mean, standard deviation, RMSE and interquartile range (IQR) values were calculated. Interquartile range (IQR) values represent the range between the 25^{th} and 75^{th} quartiles. IQR was mainly used in this paper as a quality measure of the models. Significantly deviating measurements were detected using threshold levels: lower bound at the 25^{th} quartile minus 1.5*IQR and upper bound at the 75^{th} quartile plus 1.5*IQR.

4. RESULTS

When comparing the results it must be stated that not only do the analysed methods differ but also the level of experience of operators and completeness of used procedures differ between participants. Laser scanning methods in universities are merely technology demonstrators rather than products.

4.1 Accuracy of building outlines and length determination

In general, photogrammetric methods were more accurate in determining building outlines, Figure 1. Taking into account all test sites the IQR value of photogrammetric methods ranged from 14 to 36 cm (average 21 cm, median 22 cm and std 7.2 cm of IQR values). The corresponding values for aerial image assisted laser scanning ranged from 20 to 76 cm (mean 44 cm, median 46 cm, std 18.5 cm). Laser scanning based building outline errors ranged from 20 to 150 cm (mean 66 cm, median 60 cm, std 33.2 cm).

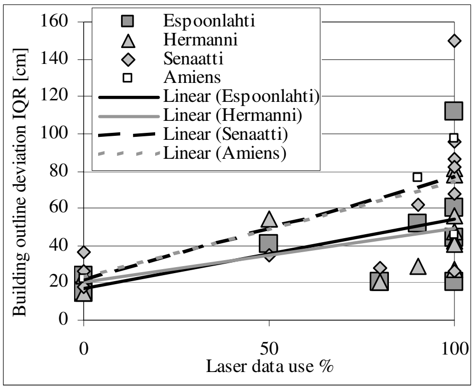

Figure 1. Building outline deviation.

Point density, shadowing of trees and complexity of the structure were the major reasons for site wise variation of the laser scanner based results. The lowest accuracy was obtained with the lowest pulse density (Senaatti). Also in Amiens, the complexity deteriorated the performance. It was almost impossible to reveal the transition from one house to another using DSM data in Amiens. The small number of trees, simple building structure and relatively high pulse density resulted in the highest accuracy in Hermanni test site.

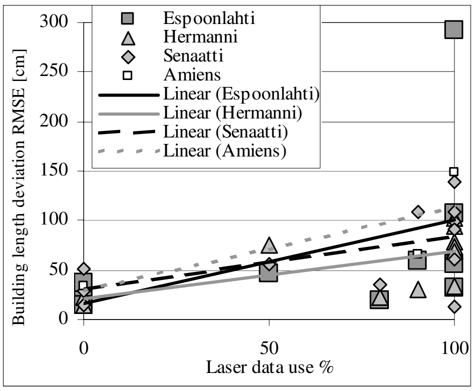

Figure 2. Building length deviation.

In building length determination (Figure 2), laser based methods were not as accurate as photogrammetric methods, as could be expected from the above. The photogrammetrically derived lengths varied from 14 to 51 cm (RMSE, mean 26 cm, median 22 cm, std 12.6 cm). Lengths obtained with aerial image assisted laser scanning varied from 19 to 108 cm (mean 59.4 cm, median 57 cm, std 31.2 cm). The laser scanning based lengths varied from 13 to 292 cm (mean 93 cm, median 84.5 cm, std 60.9 cm). With laser scanning the complexity of the buildings was the major cause for site wise variation rather than the point density.

4.2 Elevation and roof inclination accuracy

Laser scanning is at its best in deriving building heights (Figure 3), extracting planar roof faces and ridges of the roof. The IQR value for the laser scanning height determination ranged from 4 to 153 cm (mean 32 cm, median 22 cm, std 31.5 cm). One fully automatic method caused high errors modifying the mean value. Laser scanning assisted by aerial images resulted in IQR values between 9 and 34 cm (mean 18 cm, median 16.5 cm, std 8.5 cm). Photogrammetric height determination ranged from 14 to 54 cm (mean 33 cm, median 35 cm, std 18 cm). Height determination accuracy followed exactly the laser scanning point density. With high-density data in Espoonlahti, all participants could provide average height with better accuracy than 20 cm IQR value.

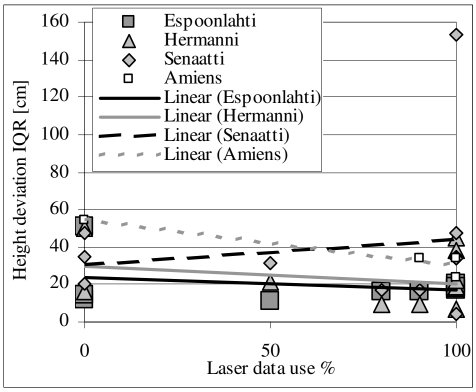

Figure 3. Target height deviation.

Roof inclination determination was more accurate when using laser data than photogrammetry, but there exists large variation in quality due to methods and test sites (i.e. complex buildings). The RMSE using laser scanning for roof inclination varied from 0.3 to 9 degrees (mean 2.7 degrees, median 0.85 degrees, std 4.4 degrees). The corresponding values for aerial image assisted laser scanning ranged from 0.6 and 2.3 degrees (mean 1.3 degrees, median 1.1 degrees, std 0.6 degrees) and for photogrammetry ranged from 1.0 to 17.9 degrees (mean 5.2 degrees, median 3.2 degrees, std 6.3 degrees). In Senaatti and Amiens, the roof inclinations are steep and roofs short, so even small errors in target height determination lead to large errors in inclination angle. Test site Hermanni is relatively easy for both methods, in Hermanni the accuracy of roof inclination determination was about 2.5 degrees for photogrammetric methods and about 1 degrees (RMSE) for laser based methods.

4.3 Time use, degree of automation and elaborateness

The degree of automation varied significantly among the participants of this test. In general, the laser data allows higher automation in the creating models. Editing of the complex building models are needed slowing down the process. Even though some laser-based processes are relatively automatic, the processes are still under development. In general the plane target accuracy is affected by the degree of automation (and method, Figure 4); while the accuracy on low automation methods is about 20-30 cm, on high automation methods it is about 60-100 cm (IQR). The target height accuracy seems to be almost independent of the degree of automation (Figure 5).

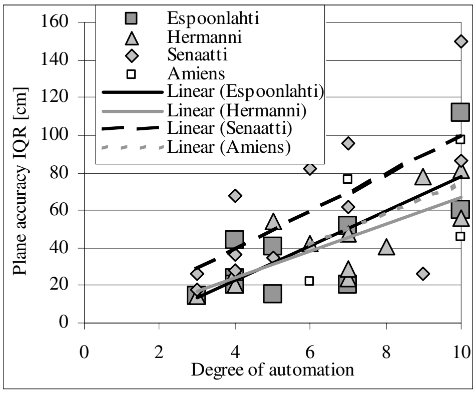

Figure 4. Obtained planimetric accuracy as a function of automation.

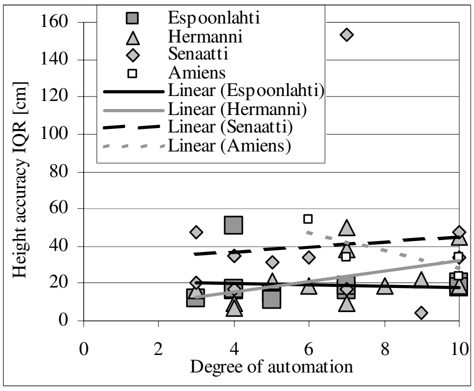

Figure 5. Obtained height accuracy as a function of automation.

In general the methods using aerial images and interactive processes are capable of producing more details in building models, but only some providers modelled more detailed structures such as chimneys and ventilation equipment on roofs.

5. CONCLUSIONS

The paper compared the performance of photogrammetric, aerial image assisted laser scanning and laser scanning based methods in building extraction, especially in the determination of building outlines, lengths, height and roof inclination. Paper confirms with experiments that laser scanning is superior in deriving building heights, extracting planar roof faces and ridges of the roof, whereas photogrammetry and aerial images are superior in building outline and length determination. In building outline determination, point density, shadowing of trees and complexity of the structure were the major reasons for site wise variations of the laser scanner based results. In building length determination with laser scanning, the complexity of the buildings was the major cause for site wise variation rather than the point density. Height determination accuracy followed exactly the laser scanning point density. Using the high-density data in Espoonlahti, all participants could provide an average height with better accuracy than 20 cm IQR value. Roof inclination determination was more accurate when using laser data than photogrammetry, but there exists large variation in quality due to used methods and test sites (i.e. complex buildings). In general, the target plane accuracy is affected by the degree of automation, while the target height accuracy seems to be almost independent of the degree of automation. More research is needed to further study the accuracy obtained with each method in order to be able to develop new, better algorithms, especially for laser scanning.

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