OXFORD BROOKES UNIVERSITY

OISD Technology

Oxford Institute for Sustainable Development

Modern methods of construction and prefabrication
Sustainable building design
Construction and life cycle costing
Steel, concrete, timber, masonry and glass construction
Construction design guidance and regulation
Building physics including: thermal, acoustic, structural and airtightness testing and analysis

Building envelope systems
Product and systems development
CAD and computer modeling

Contact:
Prof. Ray Ogden

Report 11/2008 SCI

Survey of Buildings: accuracy achievable using laser scanning for design and fit of over-cladding solutions

Client

Steel Construction Institute

Oxford
February 2008

Author

N Walliman

OISD Technology
Department of Architecture, School of the Built Environment, Oxford Brookes University, Gipsy Lane Campus Oxford OX3 0BP
Phone: +44 (0) 1865 483208, Fax +44 (0) 1865 483298, Email oisdtech@brookes.ac.uk
http://www.brookes.ac.uk/schools/be/oisd/act/technology/index.html!

Survey of Buildings: accuracy achievable using laser scanning for design and fit of over-cladding solutions

Version 2: February 2008
Produced by N Walliman, OBU for ROBUST

1. Introduction

Overcladding solutions for upgrading the thermal and weathering performance of existing buildings using prefabricated steel components requires highly accurate survey data of the external walls of the buildings in order to ensure that the components will fit without having to make onsite-alterations. Current steel overcladding systems allow for a tolerance to the fixing points of about 5 mm in all directions. The accuracy of the data gained from the survey of the existing surfaces to be overclad must therefore fall within this limit. Steel cladding presents a precise, smooth finish where any uneaveness or irregularity of spacing of panels will be very obvious to the observer.

This is in contrast to competing overcladding solutions that consist of fixing a layer of foam insulation board directly to the existing façade and rendering this with a specially formulated reinforced coloured render coat. The insulation board can be easily cut on site to adjust to the shapes on the facade, any uneaveness of the existing surfaces can be smoothed out. The rendered finish is usually textured and without joints, making any imperfection of finish less obvious.

The types of buildings that are upgraded by overcladding are often very tall and the facades are difficult to access for manual survey techniques without being fully scaffolded or served by lifting systems. Laser survey methods are increasingly being used to make accurate surveys of buildings during and after construction, as well as of other types of engineering constructions and topographical surveys of land forms, natural and artificial. Laser surveying allows three dimensional measurements to be made from a distance and, if sufficiently accurate, could be an essential tool for preparing the necessary data on which prefabricated steel overcladding of large buildings could be designed and fabricated.

This paper investigates the issues that govern the accuracy of laser scanning based on literature by Geoff Jacobs published in the Professional Surveyor Magazine and summarises a recent report by Boeler and Marbs on tests they carried out on a variety of laser scanners, in order to examine whether laser scanning provides sufficiently high definition and accurate survey data for designing and fabricating prefabricated steel overcladding solutions.

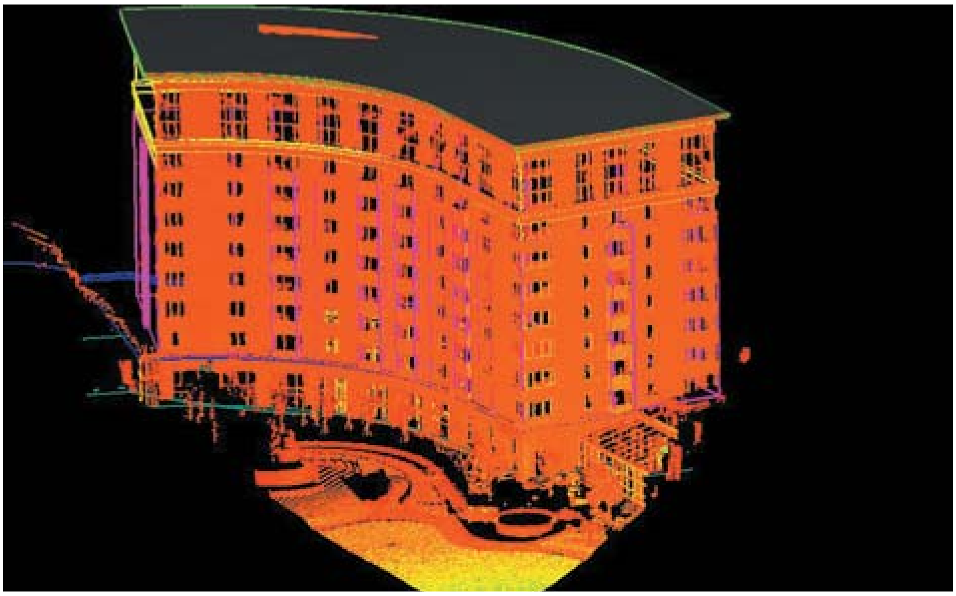


Figure 1. High-definition survey of 10-story building met high-accuracy requirement. Image courtesy: Cullinan Engineering

2. Principles of laser scanning

Laser scanning can provide a high-accuracy, high-confidence, reflectorless total station. Just as reflectorless total stations are used for capturing single points, a laser scanner can perform an analogous task, by a slightly different, yet very powerful and enabling path.

If a surveyor wants to, for example, capture a corner point for a structure that was well out of reach, he/she has basically three options: either find a way to get (up) there to put a reflector on the corner or use some means of remote sensing, such as a reflectorless total station or to survey a point that's within reach and then estimate an offset to the point that's out of reach. Laser scanners are another means of remote sensing, but rather than take a single shot of the corner point, they can spray the corner area with a fine array of points, commonly referred to as a cloud. From this fine array of point data, the scanner can then accurately extract the corner point.

Jacobs (2005) maintains that high-definition surveys have proven over time to sport three advantages over traditional methods that can provide valuable risk reduction benefits for cost- and schedule-conscious project managers. These construction risk-reducing advantages are:

- Higher level of completeness
- Better accuracy
- Quicker availability of as-built data

3D Laser Imaging can provide cost-effective construction QA services. 3D point clouds allow easily modelling and depiction of ornate building overhangs, cornices, and facades. After the initial scan is complete, 3D Laser Imaging can import the proposed design directly into the laser scan data and give the contractor a real time, as-built referenced to design.

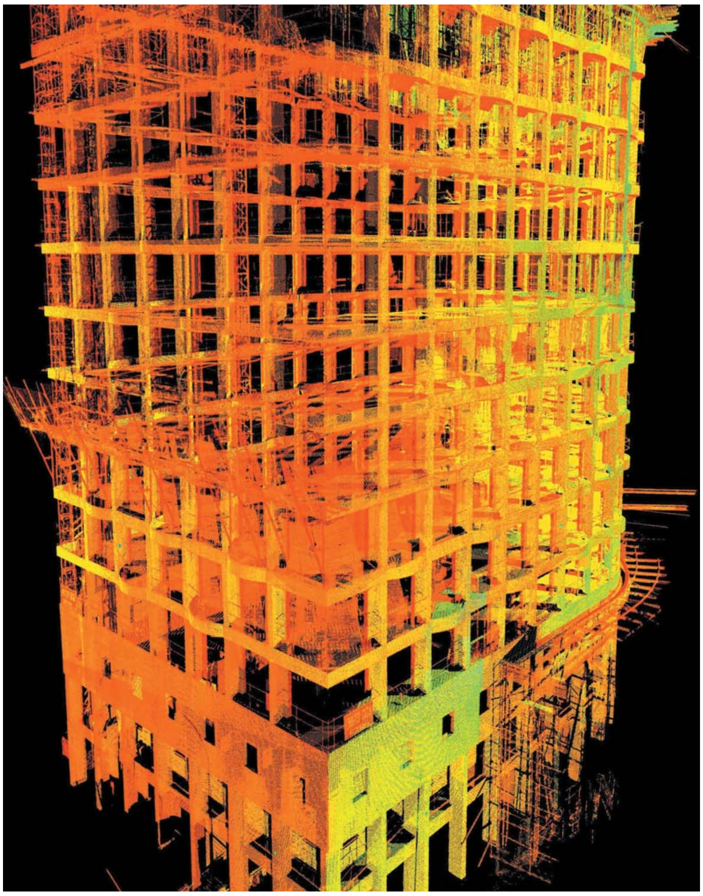


Figure 2. Scans of 22-story building were used for construction QA and window frame as-builts. Image courtesy: Mabat

Other service providers equipped with suitable high-accuracy scanners have also used them extensively in the Construction Stage of projects that involve building claddings. In this application, scanning is used to accurately extract the location of tie-point clips that have been installed on new steel. The clip locations are then used to accurately fabricate framework for the external cladding to ensure smooth installation.

Building claddings, such as glass outer walls or pre-fabricated concrete facades, are often attached to inner structural members via special clips or other specific attachment points. Sub-structures connect a modern building's structure with its outer cladding structure. These substructures are often fabricated after the building's steel structure is erected, attachment clips have been installed, and the 3D locations of the attachment clips have been measured precisely.

Over-cladding solutions in building refurbishment also rely on accurate measurement of building features such as openings, corners and junctions. This measurement task has historically been done with traditional survey equipment and man-lifts. Over the last few years, however, laser scanning has started to replace these traditional methods.

Figure 3. Scanning is used for surveying cladding substructure attachment points. Image courtesy: Mabat

3. Factors that influence accuracy

Several features of a laser scanner contribute to the level of definition it is capable of achieving in a high-definition survey. Several features of a scanner contribute to the level of definition or resolution that can be achieved via the data it collects. Since the greatest differentiating technical feature of a laser scanner, compared to traditional survey tools, is the detail it can collect, it helps to clearly understand these key contributing features:

- Scan density and spot size (or beam diameter)
- Scan noise
- Edge effects
- Resolution
- Range accuracy
- Angular accuracy
- Surface reflectivity
- Environmental conditions

3.1 Scan density and spot size

Generally, the higher the scan density, the less noisy the data, the higher the accuracy of each measurement, and the smaller the spot size, then the higher the definition of the survey. Smaller spot size, especially combined with higher density, provides advantages because captured points will be less susceptible to edge effects, surface curvature effects, abrupt changes in surface reflectivity, and oblique angle effects. Another advantage of small spot size is that a smaller beam has a better chance of “sneaking through” tight clearances, such as through foliage or services, to the structure located behind.

It is rare for a laser scanner vendor to provide information in their specs about how they define their “spot size” or “beam diameter”. What exactly does a spot size of

"6mm" or "15mm" or "50mm" mean? Is it the maximum diameter - fuzzy edge and all - or just the main, centre part of the beam?

There are currently two popular, yet different, definitions of spot size in industry. The first is based upon on a model of a Gaussian distribution of the beam's intensity, or irradiance, across its diameter. Basically, the Gaussian model of a laser beam characterizes the beam's maximum intensity as being at the centre of the beam, with intensity falling off in a Gaussian profile as you go outward (seeFigure 4. Gaussian Irradiance Profile). Many laser beams conform to this profile.

Based on a Gaussian diameter definition, a "6 mm diameter beam" means that at a beam diameter of 6 mm, the intensity of the beam is 13.5 percent of the maximum intensity at its centre. The full beam actually extends beyond this diameter, but the vast majority of the beam's energy is within this diameter. In a sense, using a scientific, Gaussian diameter definition of beam diameter for laser scanner specification purposes is very conservative.

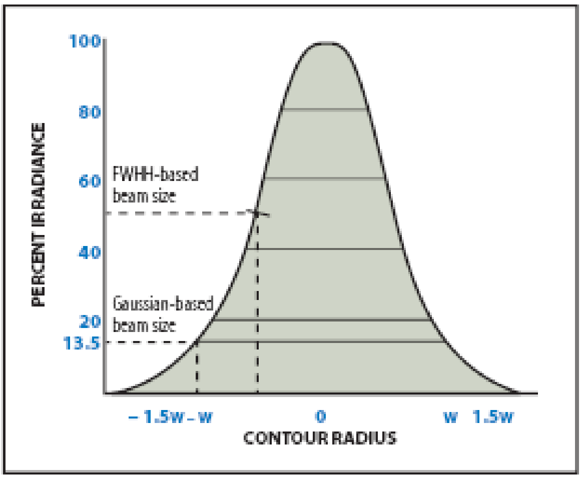


Figure 4. Gaussian Irradiance Profile

The second popular definition is the width of the beam at the half-intensity points. This is a more general definition that can be applied to any beam intensity profile, not just Gaussian profiles. This definition asks the question, "At what diameter of the beam is the intensity of the beam equal to 50 percent of its maximum, centre intensity?" Clearly, this definition results in a smaller beam diameter value than that based on the Gaussian diameter.

Unless a vendor is clear about how they define their spot size, there is no way to know if the spot sizes being compared are based on the same definition. There are currently no standards in the survey industry that cover this aspect, so vendors are free to define spot size however they like.

Another factor that complicates things is the fact that a beam's diameter varies as a function of its distance from the scanner. Unmodified, the diameter of a laser beam will naturally tend to increase with distance (see Figure 4).

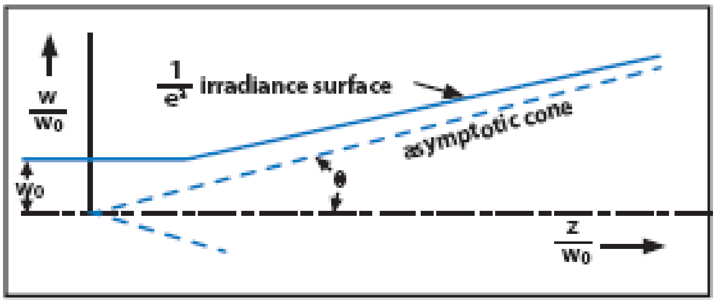


Figure 4. If left unmodified, the beam waist radius, W0, tends to increase with range, Z

So all other factors being equal, the definition of a scan will be less clear further away from the scanner (decreasing scan density as a function of increasing distance compounds this effect). The beam diameter from such scanners can easily grow to 10X or even more over the specified range of the scanner!

To calculate or estimate how large the beam will grow, vendors of these types of scanners usually specify the diameter of the beam at the exit of the scanner and then provide a divergence value. Typically stated in milliradians, or mrad, this reflects how fast the size of the beam grows as a function of distance. For example, a beam with a starting diameter of 10mm and a divergence value of 3 mrad will have a beam diameter of 160mm at a range of 50m from the scanner.

A second approach that some vendors use is to collimate the laser beam. A simple, non-moving beam expander (i.e. lens) is inserted which acts like a reverse telescope such that the beam stays relatively small over much of the scanner's useful range. In this case, a beam may exit the scanner at 6mm, for example, narrow down to 3 or 4mm at 25m range, and then increase back to 6mm at 50m range. Past 50m, the beam diameter will increase at a slightly higher rate than if the beam had not been collimated. The benefit is that the beam diameter will be <6mm from its exit point all the way out to 50m, and it will still be smaller well beyond 50m than if the beam had not been collimated. With this approach, all surfaces in the <50m range are captured with a spot size <6mm.

Specifying the accuracy of such systems is also a challenge, as accuracy specs have to state the extent to which a beam is being focused for a particular measurement accuracy claim.

3.2 Scan noise

Noise is the accidental errors of range measurements that result in arbitrary range deviations. This can be caused by inaccuracies in the instrument and moving objects such as people, vehicles or wind blown vegetation or wires, or obstructions in the line of vision.

3.3 Edge Effects

Even when well focused, the laser spot on the object will have a certain size. When the spot hits an object edge, only a part of it will be reflected there. The rest may be reflected from the adjacent surface, a different surface behind the edge, or not at all (when no further object is present within the possible range of the scanner). Both, ranging scanners and triangulation scanners produce a variety of wrong points in the vicinity of edges. The wrong points (artifacts, phantom points) are usually to be found on the ray from the laser deflection point in the instrument through the edge point, behind the edges (when looking from the scanner). The range error may vary from just a fraction of a millimetre to values of several centimetres. In addition, the object representation in the point cloud is larger than reality since the point will be recorded at the angular position of the centre of the ray even if the object is hit only with the edge of the ray. Obviously, wrong points are inevitable since the laser “spot” cannot be focused to point size. It can be assumed that well focused lasers will show better results.

3.4 Resolution

The term “resolution” is used in different contexts when the performance of laser scanners is discussed. From a user’s point of view, resolution describes the ability to detect small objects or object features in the point cloud. Technically, two different laser scanner specifications contribute to this ability, the smallest possible increment of the angle between two successive points and the size of the laser spot itself on the object. Most scanners allow manual settings of the increment by the user.

3.5 Range Accuracy

The range at which targets can be placed and the accuracy at which their centres can be extracted at that range is not currently part of vendor specifications, but it is nevertheless an important practical aspect for planning and executing accurate high-definition surveys.

In the case of ranging scanners, range is computed using the time of flight or a phase comparison between the outgoing and the returning signal. Ranging scanners for distances up to 100 m show about the same range accuracy for any range. Triangulation scanners solve the range determination in a triangle formed by the instrument’s laser signal deflector, the reflection point on the object’s surface and the projection centre of a camera, mounted at a certain distance from the deflector. The camera is used to determine the direction of the returning signal. In contrast to the ranging scanners, the accuracy of ranges acquired with triangulation scanners diminishes with the square of the distance between scanner and object (Boehler and Marbs, 2002). Ranging errors can be observed when known distances in range direction are measured with the scanner.

A laser scanner’s specification sheet may include a “Maximum range of X meters.” This means simply that the scanner can obtain an acceptable return at X meter range from a surface with a specified diffuse surface reflectivity (ρ) value, e.g., 5%, 40%, 80%, etc. (An 80% value would be a white dull paint, 40% a grey dull paint, and 5% a black dull paint.) However, it is very dangerous to interpret this to mean that the given scanner can be used to conduct a high-definition survey at a range up to X meters and still achieve the desired accuracy of the final deliverables. The reason for this is that unlike total station surveys, which rely on single point measurements, high-definition surveys rely on dense scan data from which deliverables, including elements such as lines and surfaces, are extracted.

While a scanner may be able to receive returns to a maximum range of X meters, the range at which targets can be placed for high-accuracy targeting may be shorter than this. A “useful range” is the range at which targets can be scanned for accurate extraction of features. Localized fine scans are increasingly used for accurately extracting single points for a feature of interest (e.g., bolt head, mounting clip, building corner, window edge, flange face, etc.).

3.6 Angular accuracy

The laser pulse is deflected by a small rotating device (mirror, prism) and sent from there to the object. The second angle, perpendicular to the first, may be changed using a mechanical axis or another rotating optical device. The readings for these angles are used for the computation of the 3D point coordinates. Any errors caused by the axes/bearings or angular reading devices will result in errors perpendicular to the propagation path.

Range error may or may not be range-dependent, but angular errors are directly range-dependent. In practice, higher single point accuracy, smaller spot sizes, and higher scan densities enable deliverables to be extracted from scan data with higher accuracy.

3.7 Surface reflectivity

Laser scanners have to rely on a signal reflected back from the object surface to the receiving unit in case of ranging scanners and to the camera in case of triangulation scanners. In either case, the strength of the returning signal is influenced (among other facts such as distance, atmospheric conditions, incidence angle) by the reflective abilities of the surface. White surfaces will yield strong reflections whereas reflection is weak from black surfaces. The effects of coloured surfaces depend on the spectral characteristics of the laser (green, red, near infrared). Shiny surfaces usually are not easy to record. It has been observed that surfaces of different reflectivity result in systematic errors in range. For some materials these errors may reach amounts several times larger than the standard deviation of a single range measurement. Some scanners which provide some type of aperture adjustment show errors in the first points after the laser spot has reached an area of a reflectivity differing considerably from the previous area, and it can be observed that the correct range is achieved only after a few points have been measured. For objects consisting of different materials or differently painted or coated surfaces, one has always to expect serious errors. These can only be avoided if the object is temporarily coated with a unique material which, of course, is not applicable in most cases.

3.8 Environmental Conditions

Temperature: Any scanner will only function properly when used in a certain temperature range. Even within this range, deviations may be observed, however, especially in the distance measurement. It should be noted that the temperature inside the scanner may be far above the temperature of the surrounding atmosphere due to internal heating or heating resulting from external radiation (sun). Obviously, temperature effects may show systematic changes over time.

Atmosphere: As in any optical distance measurement, the change of the propagation speed of light due to temperature and pressure variations affects the results. For short ranges this is often neglected. Also, many users report that measurements in surroundings where dust or steam is present lead to effects similar to the edge effects described above.

Interfering radiation: Lasers operate in a very limited frequency band. Therefore filters can be applied in the receiving unit allowing only this frequency to reach the receiver resp. the camera. If the radiation of the illumination source (sunlight, lamps) is strong as compared to the signal, enough of this ambient radiation will pass the filter and influence the accuracy or prevent any measurements at all.

4. Equipment and software

The laser scanner consists of hardware and software components. The hardware includes the main scanner unit, a notebook computer to drive the scanner unit and to store the scanned data temporarily at field, and a desktop PC in office for processing the scanned data.

Typical software includes the Cyclone, Microstation with COE (Cyclone Object Exchange) and the Cloudworx for Microstation. Cyclone is used to drive the scanning unit at field with the notebook and process the scanned data with the desktop PC in the office. The Microstation with COE is a plug-in application for exchange data between Cyclone and Microstation. Whereas, the Cloudworx for Microstation is another plug-in application module to enable the viewing of point clouds under Microstation environment.

5. Tests on a range of scanners

Researchers at Germany’s FH Mainz Institute for Spatial Information and Surveying Technology developed a test apparatus to assess the accuracy of various laser scanners (Boehler and Marbs, 2004). Tests using different scanners (each with its unique scan density, spot size, and single point position accuracy) to capture the exact same object, show that scan results can vary widely.

Scanners tested at i3mainz were the following:

Callidus Precision Systems (2 instruments)
Leica HDS2500 (2 instruments)
Leica HDS3000 (2 instruments)
Mensi S25
Mensi GS100
Mensi GS200
Riegl LMS-Z210
Riegl LMS-Z420i
Riegl LPM-25HA 2004/2004 1
Zoller+Froehlich Imager 5003

5.1. Noise

A very fast and easy check for the noise of range measurements can be achieved when a plane target perpendicular to the observation direction is scanned and the standard deviation of the range differences of the points from an intermediate plane through the point cloud is computed. As an additional result, this test also detects if range is internally only provided with a certain resolution (e.g. 1 cm) which is the case for some instruments (Kern, 2003). Three different surfaces are used: white, grey and black with reflectivities of about 80, 40 and 8 %. For accurate scans a low deviation figure is required.

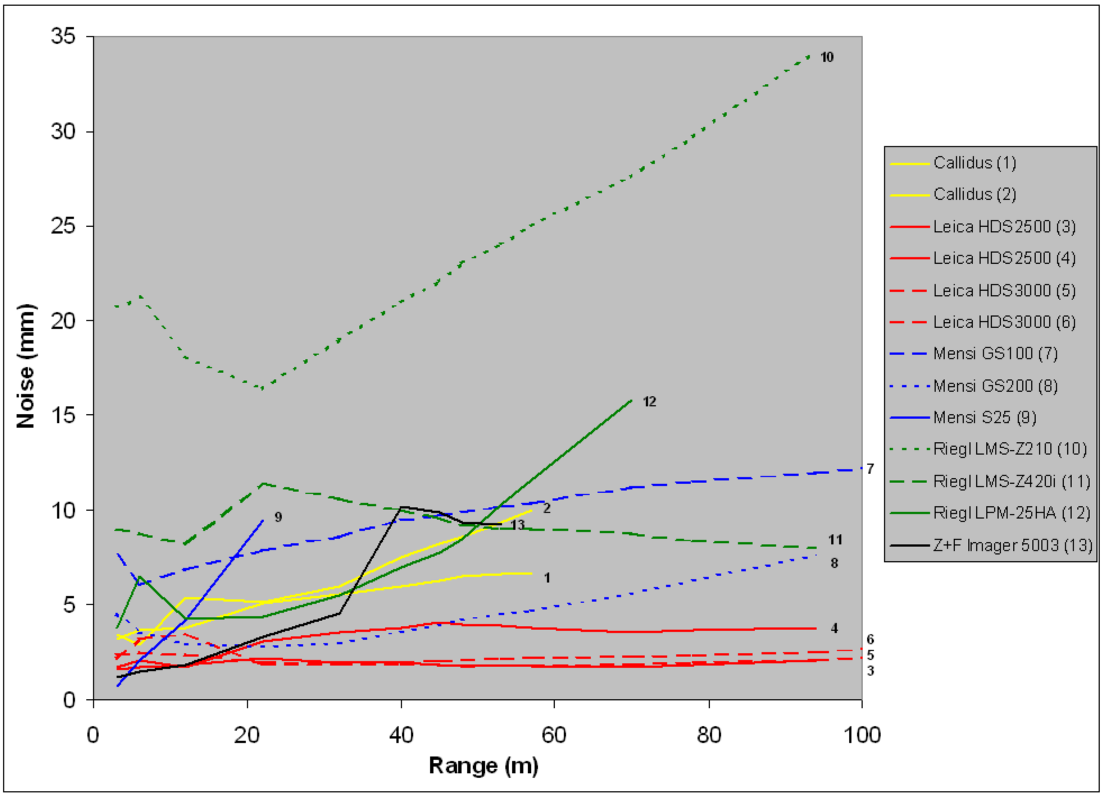


Figure 5. Measuring noise in range direction (standard deviation for a single point) for different scanners on a grey surface (40% reflectivity).

As seen in Figure 5, there are several instruments that record low noise figures of less than 5 mm deviations at ranges up to 50 m. The Leica models and Mensi G5200 fall within this category.

5.2. Distances at right angles to range

These are distances between points at the same range distance. Most of these distances are relatively short. Several scanning ranges from 15 to 50 m were tested. When differences between the true values and the values derived from scanning occur, they can be related to inaccurate measurements of angles in the scanner. In the results below, the spatial distances are those between the centres of two spheres which have been modelled from a large number of scanned points on the spheres' surfaces. The modelling can be considered as a low pass filtering process. The deviations of single scanned points may be considerably larger. Although it could be expected that distance errors caused by angles grow with range, this could not be observed in most cases. Therefore distance errors are shown as results (Table 2) instead of angular errors.

	Vertical distances (std. deviation in mm)	Horizontal distances (std. deviation in mm)	Maximal absolute difference in mm
Callidus Precision Systems (1)	5.6a	4.3 a	12.2 a
Callidus Precision Systems (2)	9.9 a	2.5 a	18.3 a
Leica HDS2500 (1)	0.8	0.8	1.6
Leica HDS2500 (2)	0.5	0.5	1.1
Leica HDS3000 (1)	1.3	1.1	2.9
Leica HDS3000 (2)	1.1	1.8	2.8
Mensi S25	3.8 b	3.4 b	9.2 b
Mensi GS100	1.9	2.3	3.3
Mensi GS200	4.7	2.2	8.3
Riegl LMS-Z210	10.2 a	16.8 a	27.1 a
Riegl LMS-Z420i	1.7	2.1	4.1
Riegl LPM-25HA	2.5	3.9	6.5
Zoller+Froehlich Imager 5003	2..9	7.5	11.1

Table 1. Differences between known and scanned distances between two spheres orthogonal to range.

Table 1. Difshows the standard deviations (mm) based on 12 independent vertical and 12 independent horizontal spatial distances. The letters refer to the notes below:

a. Because of limited angular increment tested for short ranges only.
b. Influenced by low range accuracy due to triangulation principle at far range; much better for close ranges (e.g. 0.8 mm vertical. and 0.2 mm horizontal. at 4 m range)

It can be seen that the standard deviations for different instruments vary considerably. Even at close range some scanners (marked with “a” in Table 1) have problems to resolve the spheres due to large laser spots and coarse angular increments. This results in poor “angular” performance although the angular positioning of the centre of the laser beam itself may be much more accurate. Note also that some instruments have different accuracies in vertical and horizontal directions. It can be seen that for both vertical and horizontal measurements the Leica models, Mensi models and Riegl models all achieve the <5 mm accuracy according to the standard deviation, though only the Leica models, Mensi GS100 and Reigl LMS-Z420i fall within this tolerance with the maximal absolute difference.

5.2 Distances in range direction

The same type of spheres were used to measure the performance of the scanners in measuring the distance between them placed at different distances almost in line with the scanning beam. Because of the filtering effect, deviations of single points may be considerably larger.

	Close range < 10 m (std. dev. in mm)	Far range 10 – 50 m (std. dev. in mm)	Maximal absolute difference
Callidus Precision Systems (1)	1.5	–a	2.6
Callidus Precision Systems (2)	2.8	- a	5.9
Leica HDS2500 (1)	0.6	1.1	2.3
Leica HDS2500 (2)	0.4	0.5	0.9
Leica HDS3000 (1)	0.8	1.0	2.0
Leica HDS3000 (2)	1.2	0.7	2.3
Mensi S25	1.4 b	4.6 c	7.7 c
Mensi GS100	2.6	2.0	8.2
Mensi GS200	1.1	1.1	2.7
Riegl LMS-Z210	19.7	- a	40.4
Riegl LMS-Z420i	2.6	2.7 d	5.9
Riegl LPM-25HA	3.5	5.7 e	6.4
Zoller+Froehlich Imager 5003	1.6	0.7 f	12.3

Table 2. Differences between known and scanned spatial distances between two spheres in range direction.

Table 1. Difshows the standard deviations (mm) based on at least 12 independent short distances in close range and 14 independent distances in far range. The letters refer to the notes below:

a. Modelling of spheres not possible for far ranges due to limited angular increment.
b. But 0.2 mm at 4 m range and 0.5 mm at 6 m range.
c. At 22m range.
d. Only 4 measurements at far range.
e. Only 3 measurements at far range.
f. Only 2 measurements at far range.

It can be seen that not all of the instruments achieve the <5 mm accuracy that is being looked for. For far range standard deviation of measurements of between 10 to 50 m, again, the Leica models all achieve this, as well as the Mensi models and the Riegl LMS-Z420i and the Zoller+Froelich Imagaer 5003. Taking the maximal absolute differences, one of the Callidus Precision Systems instruments, as well as all the Leica, and the Mensi GS200 are sufficiently precise.

As the special location of points rely on range as well as on angles, the results of Table 1 and Table 2 should be considered in combination for a complete assessment of special accuracy. When this is done, only the Leica models will reliably return sufficiently accurate data to achieve the required standard.

5.3 Resolution

Small objects need to be identified in a survey so a good resolution is required in order to pick these up accurately. In order to test the instruments, a target as shown in

Figure 6 was scanned from two different ranges, 6 m and 22 m. The resultant point clouds of the longer range test are shown in Figure 7. Small grid increments of 1 mm where used where possible. Ideally, points should be recorded on the front star shaped panel as well as the rear panel to show the star shaped outline.

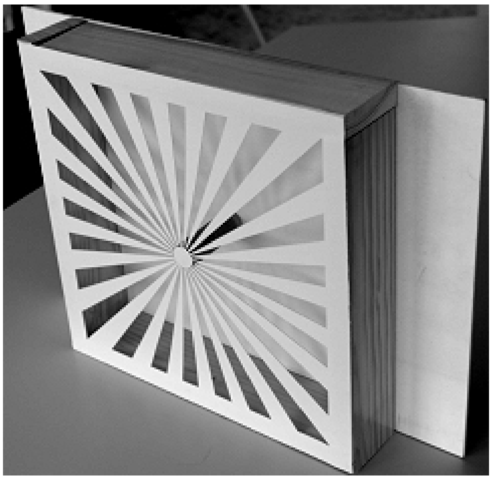


Figure 6. Target with slots of varying widths for resolution tests

Three typical results as shown in Figure 7 have been selected to demonstrate the variations in both levels of resolution an edge quality.

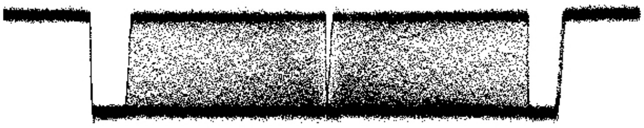
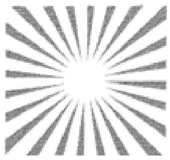
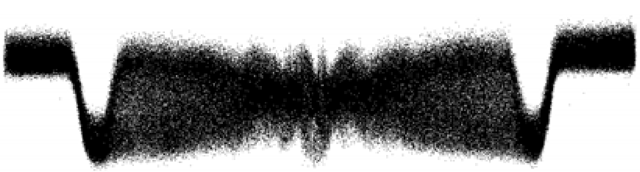
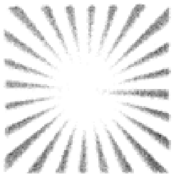
Quality	Cross section of point cloud	Points on back plane of target
High		
Medium		
Low		

Figure 7. Typical Results of the resolution and edge effect test using the target shown in Error! Reference source not found.**. Scanned at 22 m range.**

The results of the tests on the instruments are shown in Table 3.

Scanner	**Level of resolution**	**Edge quality**
Callidus	*point density too low to resolve the object at this range*	Low
Leica HDS 3500	High	Average
Leica HDS 3000	High	Average
Mensi S25	Low	Average
Mensi GS100	Medium	Average
Mensi GS200	Medium	Average
Riegl LMS-Z210	*point density too low to resolve the object at this range*	Low
Riegl LMS-Z420i	Low	Average
Riegl LPM-25HA	Low	Average
Z+F Imager 5003	Low	Low

Table 3. Resolution and edge effect performance of different scanners

5.4 Influence of surface reflectivity

Although scanning results are consistent when measuring most surfaces, some types of surfaces can result in systematic errors. Tests were carried out on shades of white to black, metal paint, aluminium foil, blue foil and orange (such as used on traffic cones). Very white surfaces (i.e. 80% and greater) recorded consistently accurate results.

Surface material	**Measured too short** Number of instruments out of 13 tested (range of inaccuracy)	**Measured too long.** Number of instruments out of 13 tested (range of inaccuracy)	**No points recorded**
White 90%	0	0	0
White 80%	0	0	0
Grey 40%	3 (4-13 mm)	0	0
Black 8%	4 (3-8 mm)	0	0
Metal paint	0	2 (10-100 mm)	0
Alumin. foil	3 (10-30 mm)	3 (15-250 mm)	0
Blue foil	6 (3-22 mm)	2 (6-18mm)	2
Orange (cone)	0	10 (7-100 mm)	0

Table 4. Distance correction in mm due to different surface materials

6. Conclusions

Using laser survey techniques, it is likely that the survey data of building facades will be gathered from the ground or adjacent buildings from a distance of up to 50 m. In order for the measurements to be of sufficient accuracy for designing and fabricating prefabricated steel overcladding solutions, an accuracy of measurements within 5 mm in all directions must be achieved.

It is obvious from the results of tests described above that laser survey techniques can provide this level of accuracy as long as the correct instrument is used, the right techniques and software are adopted and environmental conditions and reflective surfaces are suitable.

Because this level of accuracy at this kind of distance is near the limit of the capabilities of this technique, only the most accurate laser scanners and rigorous field procedures allow laser scanning to be successfully used in this application. Very fine scanning capability (e.g., 1.5 mm grid spacing) and small spot size (~ 5 mm) at this kind of range are essential.

The laboratory tests demonstrate the variability of the performance of different makes and models of laser scanner. Of the ten models tested, it appears from the tests that only the Leica models are sufficiently accurate for use topical surveys for prefabricated overcladding systems.

Boeler and Marbs also suggest that apart from accuracy, other factors such as specification and selling price are important. It should also be noted that support and warranty conditions are all different. Consider also how often the instrument has to be calibrated and what time, services and outlay are required over time. Do not forget that suitable scanning and modelling software is also required and whether this should be purchased separately from other suppliers apart from the instrument manufacturer.

7. Trying it out

Regardless of how vendors specify their scanners with respect to spot size (or any other feature), some vendors are more conservative in their specifications than others. So two scanners specified with the same spot size, and all other factors being equal, can still show differences in the level of definition achieved. A scan beam that has a small diameter over a long, useful range can provide users with significant benefits in both the level of definition achieved and field productivity. Those evaluating laser scanning should be careful to understand the basis of vendors' specs for this key feature and how a given scanner's spot size changes with distance from any given scanner. Testing scanners and talking with peers who have used different types of scanners can also help in assessing this factor

Users gain experience over time as to what they can achieve regarding useful range and the accuracy of the resulting deliverables. Specifications regarding maximum laser scanner range can be misleading for those accustomed to interpreting total station specifications. In order to better assess a scanner's useful range it's best to try a system out for yourself or talk to the rapidly growing number of others who own or use such systems.

Alternatively, it is possible to buy the services of surveying companies who are expert in the techniques of laser surveys. A very precise specification of what is required will be necessary to ensure comparative competitive costing of the service, sufficiently accurate and reliable survey detail, and guarantees of the standard of the work carried out.

8. References

The main source of detailed expertise relating to laser surveying in provided by a principal manufacturer of laser surveying equipment – Leica Geosystems, HDS, Inc. Some other manufacturers of laser surveying equipment are Callidus Precision Systems, Mensi, Riegl and Zoller+Froehlich.

This report largely compiled from information written by Geoff Jacobs published in as series of articles for the Professional Surveyor Magazine (www.profsurv.com). Geoff Jacobs has been employed by Leica Geosystems, HDS, Inc. since 1998. He currently acts as Senior Vice President, Strategic Marketing.

Jacobs, J. (2004) 'Extracting Points, Lines, Surfaces, Features Models from Point Clouds' *Professional Surveyor Magazine* Vol. 24 No. 9
Jacobs J. (2004) 'High Definition Surveying-3D Laser Scanning: Understanding the "Useful Range" of Laser Scanners' *Professional Surveyor Magazine* Vol. 24 No. 11
Jacobs J. (2005) 'High Definition Surveying—3D Laser Scanning: Uses in Building and Architectural Surveys' *Professional Surveyor Magazine* Vol. 25 No. 6
Jacobs J. (2005) 'High Definition Scanning - Laser Scanning: Big Advantages, Even for Small Projects' *Professional Surveyor Magazine* Vol. 25 No. 9
Jacobs J. (2006) 'High Definition Scanning: Uses of Scanning in Construction and Fabrication' *Professional Surveyor Magazine* Vol. 26 No. 2
Jacobs J. (2006) '3D Scanning: Understanding Spot Size for Laser Scanning' *Professional Surveyor Magazine* Vol. 26 No. 6

Information on the tests referred to in this report taken from the following text:

Boeler, W., Marbs, A. (2004) *Investigating Laser Scanner Accuracy.* i3mainz, Institute for Spatial Information and Surveying Technology, FH Mainz: University of Applied Sciences. http://www.leica-geosystems.com/hds/en/lgs_29445.htm?page=2