3D Scanning Technology - A Comparative Analysis

Part of the MCAA's Construction Technology Research Series

Performed by

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Committee Chairman's Note

As contractors, we are facing a challenge when it comes to technology. The pace of technology is moving so fast that it is becoming more and more difficult to keep up. You could say that the basics of heating and plumbing haven't significantly changed in a century. However, the tools and the processes we use to build have evolved exponentially in just the last few years. The MCAA Board of Directors has identified construction technology as being an imperative opportunity and threat for our members in the immediate future.

Last year, the MCAA Board took the critical step of establishing a permanent initiative on construction technology and formed the Construction Technology Committee to guide its activities. This committee was established to help our members not only keep pace with technology, but to also thrive in these uncertain times. This report is the first research project that this committee has produced in what will be a multi-part research series.

The research series this year will focus on construction technology and center on building information modeling (BIM) as the core technology explored. Why BIM? BIM has become a revolutionary technology that we predict will become fundamental to our operations in the next decade. While BIM is a tough bull to tame, it provides the opportunity to drive incredible productivity increases through fabrication, total stations, estimating, pricing and scheduling. It also provides the ability to embed advanced information into the model to benefit building operations.

The MCAA Construction Technology Committee partnered with JBK Labs to conduct this independent research. For the results to be credible and of value, they needed to be developed by professional, technology-fluent researchers who represent an independent third party. We also wanted the research to be comparative and detailed so that the results would explain differences in products or software.

3D Scanning

The committee chose to begin our research project by evaluating 3D scanning technology. It might seem strange because MCAA contractors have not heavily adopted 3D scanning technology, but sequentially, we wanted to look at the first step of the process and focus on how to build data into the model. 3D scanning is not the only way to begin building a model, but it is an optional start point that can be beneficial, depending on the project.

Forecasts also point to increased 3D scanning use. With the higher rate of adoption of BIM, contractors will begin looking for ways to maximize the productivity in building the models and leveraging the data. 3D scanning offers contractors the ability to precisely measure an existing site, component or assembly and bring that information into a BIM model. It can save tremendous time in measuring, taking notes, designing, documenting conditions and rebuilding a BIM model. It also allows you to take an “as-built” condition after a project to document completion.

I hope you enjoy this report and please feel free to contact me if you have any questions or comments.

Brian Helm, President, Mechanical Inc., Freeport, Illinois
Chairman, MCAA Construction Technology Committee

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What is this report about?

MCAA's Construction Technology Research Series

Members of the MCAA stand to greatly benefit from the rapidly evolving technologies in the space of construction and maintenance that can expedite work, increase precision, and prevent mistakes. The MCAA's Construction Technology Research Series explores scanning, tracking, layout, design, and fabrication technologies using BIM and other tools to explore their potential value to the MCAA.

Report abstract

This section of the research project is a canvas of *3d scanning technology*. Included is an assessment of various laser, non-laser scanning and photogrammetric hardware and software tools in the context of mechanical contractors.

Who made this report?

This report was written by JBKLabs, the research and development team of JBKnowledge, Inc.

Focus on readily-available technology

This study focuses on technology that is available for practical use at the time of writing. Any technology that was deemed too bleeding-edge for practical use is included in the **What's next?** section at the end of this report.

How this research was conducted

The research in this study was conducted through a combination of hands-on analysis of tools
and interviews with industry experts. We focused on sharing industry expert knowledge to make sure our tool analyses were accurate.

What is BIM?

BIM is Building Information Modeling. BIM models are databases that represent the physical and functional characteristics of a place. BIM can be thought of in a number of dimensions:

- **1-3D BIM**: the 3-dimensional characteristics of a space (the 3D model)
- **4D BIM**: time is introduced, so the 3-dimensional representation of the space can be observed through time
- **5D BIM**: cost is introduced, so cost of materials can be observed through time
- **6D BIM**: as-built is introduced, so the state of the space after construction is completed is represented, including maintenance, operation, specifications, photos, warranty data, etc

BIM adoption

BIM has already become a critical component of construction process. Between layout, QAQC, and as-builting, BIM expedites project completion and significantly cuts costs. In 2014, three quarters of construction firms reported a positive ROI on their BIM program investments, and a majority reported a reduction in errors and omissions on work done[1]. With an expectation that contractors' BIM-related work will increase by 25% a year, the time to seriously adopt BIM is now[2].

[1] Bernstein, *The Business Value of BIM for Construction in Major Global Markets*, 1.
[2] Ibim.

What is scanning?

Scanning is the process of capturing *reality data*, that is, the exact 3D state of a space in time. Traditionally, *reality data* is captured using a measuring tape and a pen and paper to make measurements and construct a two-dimensional drawing of a scene. With scanning, that process can be automated. Introducing automation to capturing *reality data* serves two purposes:

1. To limit or remove human error in measurements that requires repeat visits
2. To expedite the time spent capturing measurements, and all processes that follow

Scanners are devices which use one or more of several types of capture technology to automate measurements. Once these measurements are captured in a set of *reality data*, that reality data can be transformed into readily-consumable data, such as a 2D CAD drawing, or a 3D BIM model.

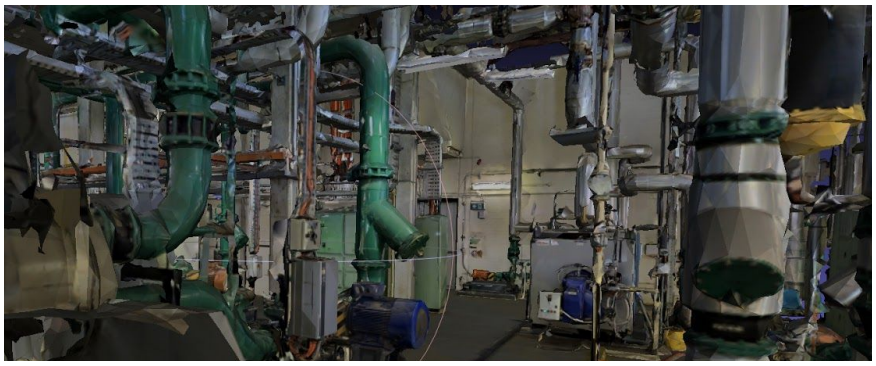
What is *reality data*?

Reality data is a dataset that represents a place. Some common examples of *reality data* formats:

- Point cloud: a cloud of points, each point representing a point of measurement from a scan of a space

The points are so densely packed that they appear to be a real space, but individual points can be seen along the boundaries of the scan where density decreases.

- Mesh: a mesh is a 3D model constructed from a scan that uses geometry to represent a space



A mesh of a captured space. Notice the blocky geometry -- the angles of the real space are estimated in geometric form.

The scanning workflow

The basic scanning workflow is as such:

1. Walk through your scanning environment and plan your scan locations or path to provide ample overlap for registration (30%) and line-of-sight to all important areas
2. Place reference spheres or placards around your scanning environment (optional but recommended for better registration)
3. Create and configure a project on your scanner
4. Begin your scan
5. Move the scanner through your scan locations or path and capture *reality data*
6. Transfer the scans from your scanner to your point cloud **processing** software
7. Use the spheres, placards, edges, automatic registration to register your scans together into one conglomerate point cloud
8. Trim excess points from the point cloud and reduce the point cloud to a manageable number of points
9. Use the point cloud directly for measurement (in a software like ReCap), or **post process** the point cloud to generate BIM models (in a software like Revit or AutoCAD)
10. CAD or BIM models can be used for generating as-builts, for QAQC, and for performing layout

Scanning spheres and placards

Reference spheres and placards are visual indicators that are used as common reference points for registering point clouds from multiple scans together. They are only necessary for registering when more than one scan is taken.

- Reference spheres: spheres to be placed on a tripod or magnet that can be used as reference points for registering point clouds

(image by Laser Scanning America)

- Placards: checkerboards that can be placed on walls, floors, or ceiling to provide a visual reference point for registering point clouds. Placards are effective up to 30 degrees of angle

(image by Laser Scanning Europe)

Registration

Registration is the process of “stitching” several point clouds together to form a single point cloud. This is necessary when a large area must be scanned, because a tripod scanner will not have line-of-sight to the entire area. There are many tools to expedite the registration process, but it can be difficult to perform and ensure a sub-millimeter accuracy is maintained. Tools like placards and spheres can be used to provide common points of reference. Some tools provide automatic registration of scans, but manual registration can also be performed by a skilled operator.

More on scanning

Difference between a total station and a laser scanner

A total station accurately measures the distance from itself to a point in space or a prism, one measurement at a time. A scanner, on the other hand, will rotate and capture 360 degrees of measurements. After scanning, the scanner will have collected a "point cloud", which is a 3D map of all the points where the laser hit. This point cloud can be used to create CAD drawings or BIM models. Leica has a great video series describing the laser scanning process.

Low cost scanners

As alternatives to expensive laser scanning solutions emerge, the barrier to entry for affordable in-house scanning is quickly abating. Solutions like IR scanners, stereoscopic scanners, and photogrammetry are enabling low cost scanning for projects where sub-millimeter total station or laser scanner measurements are not required.

"First pass" scanning

A great use of low cost scanning solutions is "first pass" scanning. A contractor can purchase an inexpensive low-accuracy scanner to make a "first pass" scan of a room or building to gauge an approximation of the space, and come back later to make a full scan. While not useful for QAQC or as-builting, "first pass" scanning can provide a good starting point for layout and help to determine which spaces need a more precise scan.

Scanning vs. processing

Scanning, while it does require some training, is often the easier portion of the scanning process. Processing (stitching, or registering) scans into completely accurate point clouds and further into usable CAD drawings, point clouds, or BIM models is a significantly more difficult endeavor. It's not unusual to invest $150,000 to $200,000 in an expert scanning technician and $10,000 per seat of software[3]. In house scanning requires frequent scanning to make a positive ROI.

Scanning as a service

As far as precise laser and total station scanning are concerned, scanning services are available to lessen the financial investment of in-house scanning. Expensive scanning

[3] Ryan Hacker, *True Point Scanning Solutions*.

hardware is typically a fraction of the total cost. Scanning services can provide on site-scanning as a service to cut the expenses required in performing scanning in-house.

Processing as a service

Some contractors who need to spend time on-site already may wish to perform the scans themselves and use a processing service to build CAD drawings or BIM models from their scans. Some scanning service providers will work with contractors to help them purchase scanning hardware, train on it's use, and then provide the processing as a service.

Free station scanning vs. traverse scanning

In free station scanning, the station is moved from point to point on the site with respect to the controls. Because the station is free to be moved, it requires the operator to stitch the scans together relative to the control points (this is called *registration*). This can introduce some inaccuracy. On the contrary, traverse scanning automates the stitching by providing survey measurements each time the scanner is moved. Traverse scanning scanners are often significantly more expensive, but they can eliminate the chance for small human error in manual registration.

To buy or to rent?

The decision to purchase a scanner depends on the type of scanner purchased, and the frequency by which scanning will be performed.

Purchasing an optical scanner or a drone for photogrammetric scanner is generally a good idea. These types of scanners are generally lower cost and transport well. On the contrary, laser scanners are generally very expensive and most scanners (excluding FARO) are difficult to transport. Laser scanners are often more financially economical to rent from a rental service.

Purchasing a laser scanner (and all the other required resources: training, computer, software) requires extremely frequent scanning for a positive ROI. Often laser scanners will be outdated and expected replaced within five years, so enough scans to match a several hundred thousand dollar investment will be required. On that note, we were surprised to learn even scanning service providers are renting laser scanners. Despite their primary business being laser scanning sites for their customers (so they surely scan at a very high frequency), they still prefered to rent laser scanners due to the fast pace of technology driving fast-obsolescence.

Evaluations of MEP-focused scanners

Laser scanners

Traditional laser scanners use Class 1 lasers (safe to the human eyes) to scan and produce point clouds. These scanners are very expensive but can produce extremely accurate point clouds. Typically laser scanners are easy to operate with some training.

Leica ScanStation C10

The Leica ScanStation C10 (image by Leica Geosystems).

Scanner type	Laser scanner
Handheld or tripod based	Tripod
Cost	< $50,000 used
Accuracy & Range	● Effective range up to to 300 m ● 6mm accuracy at 50 m
Compatibility	● Exports to Leica Cyclone ○ Can export to ReCap then to Autodesk products
Pros	High precision. Traverse scanning is used to prevent any

	operator inaccuracies introduced in the registration process. The scanner's time of flight technology is more accurate on rounded shapes, such as plumbing and conduit. The scanner is durable (IP54) and can be used in adverse weather or high dust environments.
Cons	Older and very slow compared to newer models, but a dependable model. Bulky -- hard to transport (cannot fit in overhead storage of a plane). Still very expensive.
Conclusion	The Leica C10 can be found used for about the same price as a new FARO scanner. The C10 sacrifices FARO's simpler user experience with more precise scanning.

Leica ScanStation P16

The Leica ScanStation P16 (image by Leica Geosystems).

Scanner type	Laser scanner
Handheld or tripod based	Tripod
Cost	< $150,000 (contact Leica)
Accuracy & Range	● Accurate to 40 m ● 0.5 mm noise at 40 m
Compatibility	● Exports to Leica Cyclone ○ Can export to ReCap then to Autodesk products
Pros	Extremely high precision. Traverse scanning is used to prevent any operator inaccuracies introduced in the registration process. The scanner's time of flight technology is more accurate on rounded shapes, such as plumbing and conduit. The scanner is durable (IP54) and can be used in adverse weather or high dust environments.
Cons	Very expensive. Operation of the scanner is more complex that most competition, due to its dated interface and dependence on traverse scanning for ultimate accuracy. Bulky -- hard to transport (cannot fit in overhead storage of a

	plane like a FARO can).
Conclusion	The Leica ScanStation P16 is the most accurate short distance laser scanner that we reviewed. While it comes at a cost, for scanning complex geometry, the P16 offers high precision.

Trimble TX5

The Trimble TX5 (image by DigChip).

Scanner type	Laser scanner
Handheld or tripod based	Tripod
Cost	< $35,000 used
Accuracy & Range	● Accurate to 120 m ● 0.6 mm noise at 40 m
Compatibility	● Imports into FARO's SCENE software
Pros	The TX5 scanner can be found used for a low price with many of the features of a FARO scanner. Its small form factor makes it easy to transport.
Cons	The TX5 scanner uses phase-based scanning which trades some accuracy for speed. Scans will (particularly around round objects like pipes) create some artifact points that can obscure the final point cloud and cause some imprecision when building the BIM model over the scans. Not ideal for adverse weather or very dusty environments.
Conclusion	The Trimble TX5 is actually a Trimble-branded FARO Focus laser scanner. Because the TX5 is an older model, it can be

	found for a lower price. It also is fully SCENE compatible.

Trimble TX8

The Trimble TX8 (image by Trimble).

The Trimble TX8's scan parameter menu (image by Trimble).

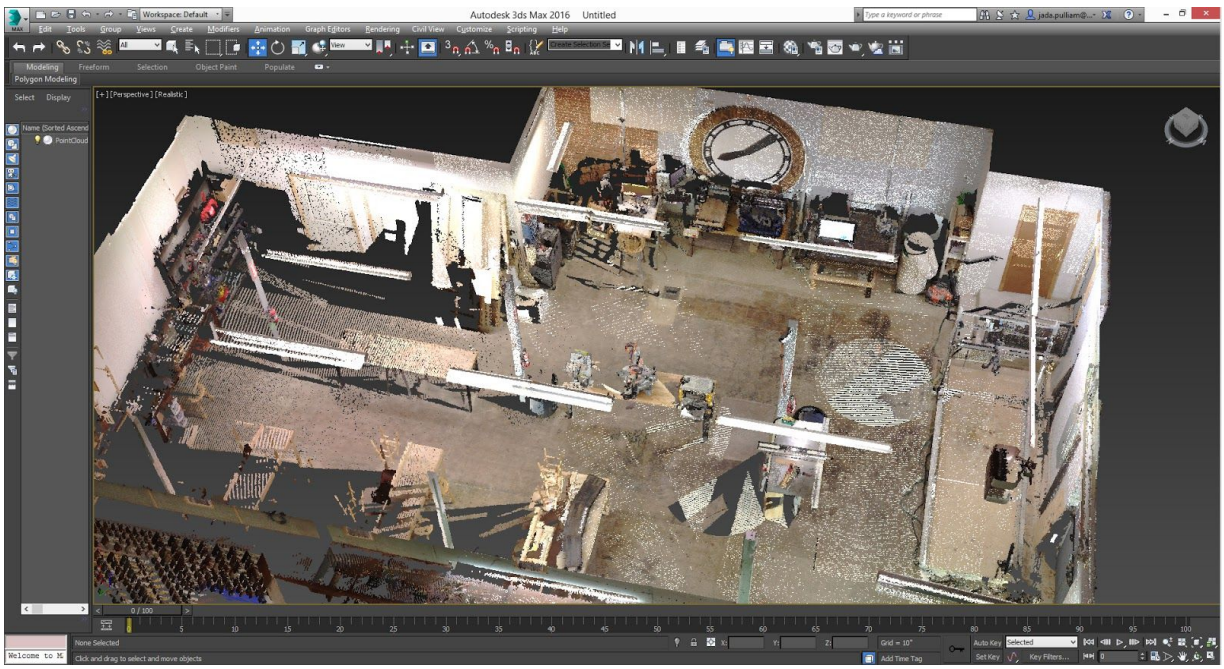
Scanner type	Laser scanner
Handheld or tripod based	Tripod

Cost	< $60,000 (contact Trimble)
Accuracy & Range	● Accurate to 340 m ● < 2 mm at 100 m
Compatibility	● Exports directly into Trimble RealWorks.
Pros	The TX8 scanner is a fast time of flight scanner. The scanner is fast at a 3 minute high quality scan.
Cons	The TX8 is new and expensive. The TX8 also does not include a camera, so it only creates uncolored point clouds. Not the highest quality scanner.
Conclusion	The Trimble TX8 is a departure from the more affordable FARO-based TX5. While not a huge improvement in scan capability, the IP54 durability rating is an improvement.

FARO Focus3D X Series

The FARO X330 scanner on its tripod.

The FARO X330 scanner's simple interface, where scans can be configured and run.



A section of the point cloud captured by FARO X330 scanner.

Scanner type	Laser
Handheld or tripod based	Tripod
Cost	● X30: ~ $35,000 (contact FARO) ● X130: ~ $50,000 (contact FARO) ● X330: ~ $65,000 (contact FARO)
Accuracy & Range	● X30: 0.6 m to 30 m (black and white) ● X130: 0.6 m to 130 m ● X330: 0.6 m to 330 m Accuracy: +/- 2 mm
Compatibility	● Exports FARO FLS file ● Imports into FARO's SCENE software
Pros	FARO's X series scanners are on the less expensive side of the laser scanning market. FARO has put significant effort into

	improving the ease of the scanning process. The user interface makes it extremely easy to set up and run a project. A competent employee with FARO's complementary training is more than capable of operating the scanning portion of the process with a FARO scanner. The X series scans very quickly. The package comes with FARO training and a seat of the SCENE software. Its small form factor makes it easy to transport, and better suited for capturing tight plant environments. The FARO scanners can also be mounted upside down. We expected some inaccuracy from phase-based scanning, but were pleasantly surprised that the point cloud was very accurate. We noticed no issues around rounded geometry or reflective surfaces.
Cons	The FARO X series scanners use phase-based scanning which trades some accuracy for speed. Not ideal for adverse weather or very dusty environments.
Conclusion	The FARO X series scanners are excellent quality, small form factor, budget-friendly laser scanners. The X30 is a short-range scanner that is excellent for capturing small spaces.

FARO Freestyle

The FARO Freestyle handheld scanner.

The SCENE Capture app running on a Microsoft Surface Pro tablet powers the FARO Freestyle and processes the scan as it is captured by the sensor.

A quick capture of some shelving performed by the FARO Freestyle.

Scanner type	Laser
Handheld or tripod based	Handheld (walk while scanning)
Cost	< $20,000 (contact FARO)
Accuracy & Range	● Freestyle: < 1.5 mm ● Freestyle X: < 1.0 mm Effective volume: 8 m^3 -- not intended to be a stand-alone scanner, but a complement to a tripod based scanner
Compatibility	● Scanning is powered by the SCENE Capture app on a Microsoft Surface Pro tablet ● Point clouds can be brought into SCENE to register
Pros	Excellent companion to a larger scanner for filling in tight, crowded spaces where line-of-sight on a tripod scanner fails. Lightweight. Its small form factor makes it easy to transport.

Cons	Not great for overly bright or dark environments. USB flash can be a battery drain[4]. The SCENE Capture app, while optimized for Microsoft Surface Pro tablets, can bog down under many projects and run slow.
Conclusion	The Freestyle is meant to be a complementary device to a full laser scanner. The handheld scanner would be great for manually registering in a detailed large boiler or pump skid to a bigger scan by a tripod scanner.

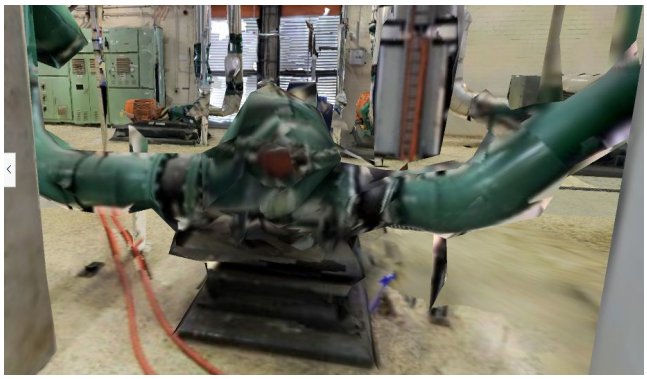
[4] "Review of Handheld Scanners from FARO, DotProduct, and More", Eugene Liscio, P. Eng., http://www.sparpointgroup.com/guest-blogs/vol13no4-review-of-handheld-scanners

Non-laser scanners

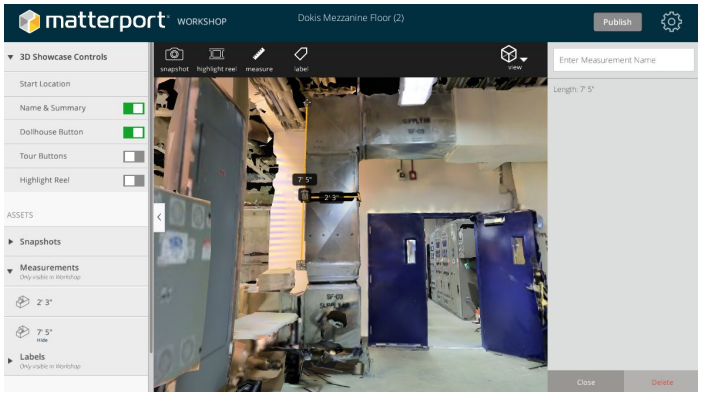
Non laser scanners typically use a combination of IR and optical sensors to produce measurements like a traditional laser scanner at a lower price point (and at the cost of some accuracy and range).

Matterport

The Matterport scanner (image by CNET).



This Matterport scan shows the blocky mesh generated by Matterport's scanner.



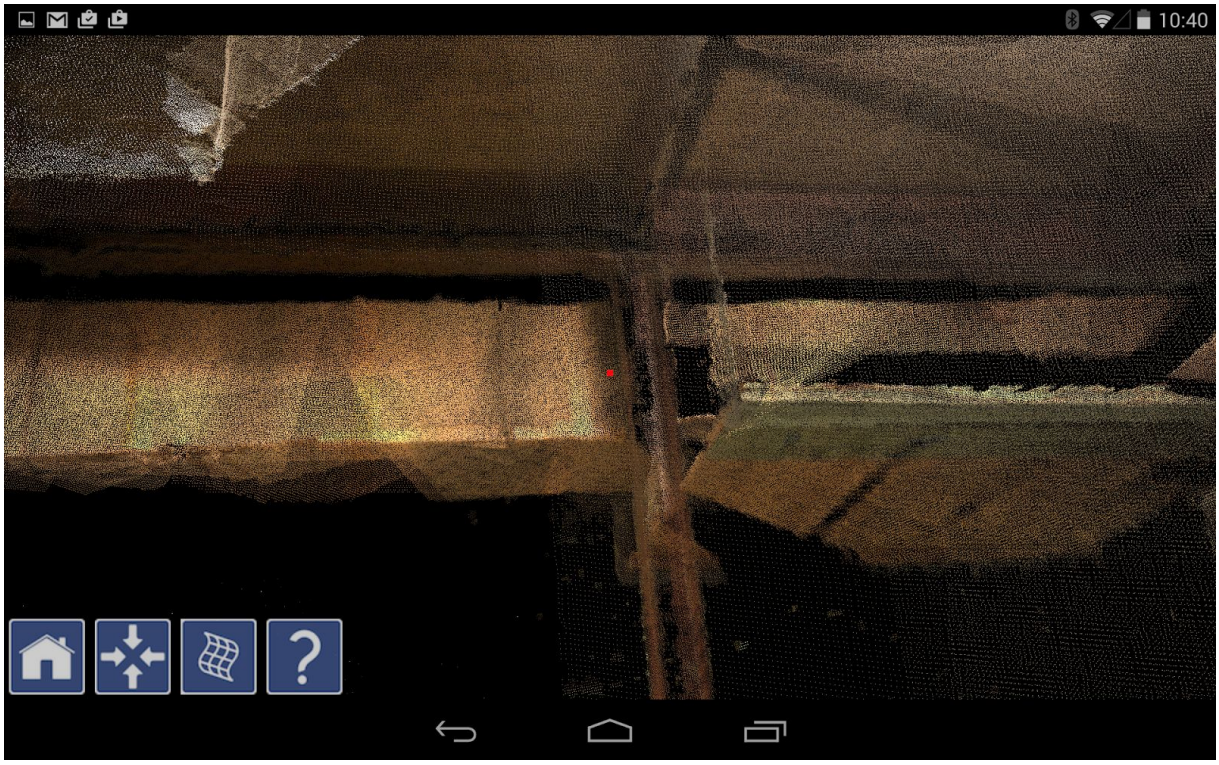
Measuring in Matterport Workshop.

Scanner type	Optical and infrared
Handheld or tripod based	Tripod
Cost	$4,500
Accuracy & Range	1% inaccuracy of distance measured (30' → 0.3' inaccuracy)
Compatibility	● Exports a textured OBJ ● Matterport Workshop can be used to inspect, measure, do basic labeling, and distribute scans (similar to Autodesk ReCap)
Pros	Easy to use, a significant ease of use improvement over traditional scanners.
Cons	Captured photo spheres are high quality, but the underlying models captured are low quality so ineffective for reliable measurement (but useful for first-pass scanning). Tagging is only available in a top-down view of the model.
Conclusion	Matterport, while the cheapest solution, is certainly more geared for real estate than AEC. It's cheap and useful for first-pass scanning and as-built photos of wet and dry before ceiling and drywall, but not effective beyond that for MEP. It may be interesting to see how the product improves if Matterport focuses on AEC.

More reading	Matterport

Trimble (DotProduct) DPI-8

The DPI-8 is a handheld scanner attached to an Android tablet (image by DotProduct). The yellow / green areas on the display show reality data captured in real time.

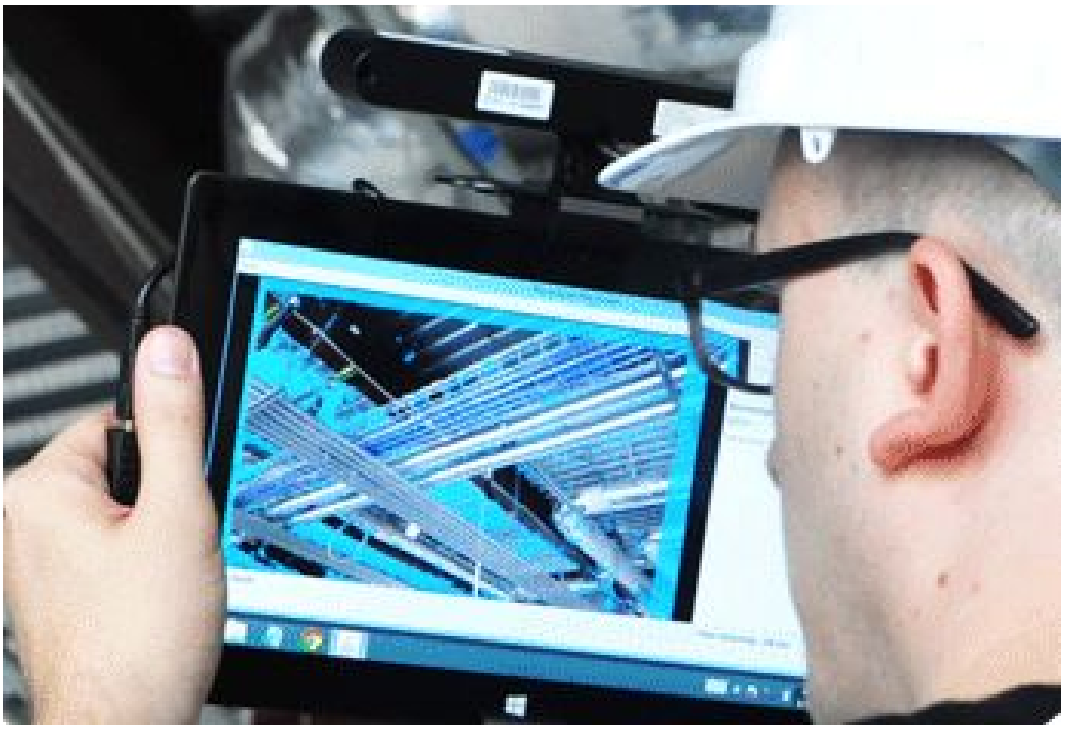


A screenshot of the Phi.3D software used by the DPI-8 device. This screenshot shows a point cloud generated on device.

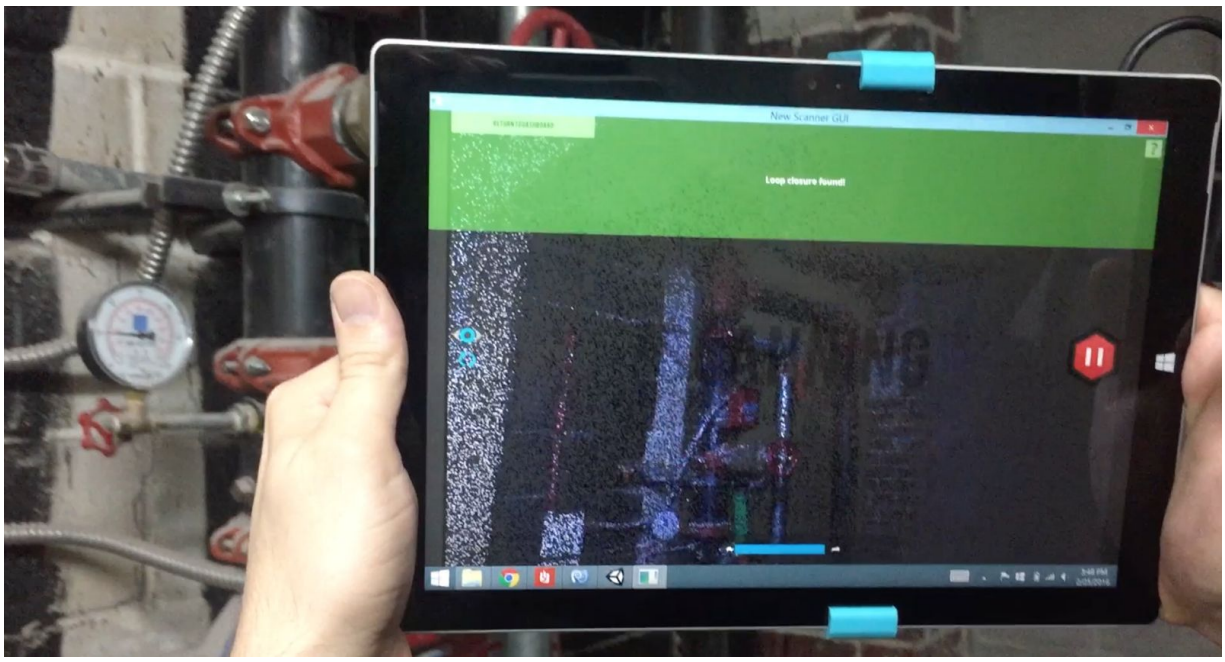
Scanner type	Optical and infrared
Handheld or tripod based	Handheld (walk while scanning)
Cost	$5,150
Accuracy & Range	● Effective scan volume of 15’ x 30’ x 12’ ○ Targets can be used for registration of larger spaces ● +/- 2% accuracy in effective scan volume
Compatibility	Exports PTS, PTX, PLY, PTG, Cyclone, and E57 formats. DotProduct’s proprietary .dp format has a plugin for ReCap that highly compresses scans to about 10% of a comparable PLY format, great real time verification of field scans back in

	the office.
Pros	Easy to use, lightweight scanner for small areas. Point clouds are fully processed on device, so no laptop is needed for the capture and processing steps. Because point clouds are processed on device, the user can see the full point cloud without importing to a laptop. Verification that a scan is complete can be done in the field so that areas are not missed.
Cons	Scans are lower accuracy than that of a more expensive scanner. The scanner operates of tablet battery, so battery life will be short.
Conclusion	The DotProduct DPI-8 scanner is an excellent companion to a tripod laser scanner. For small areas where a tripod scanner cannot have line of sight, the DPI-8 can produce good quality scans for a low cost.

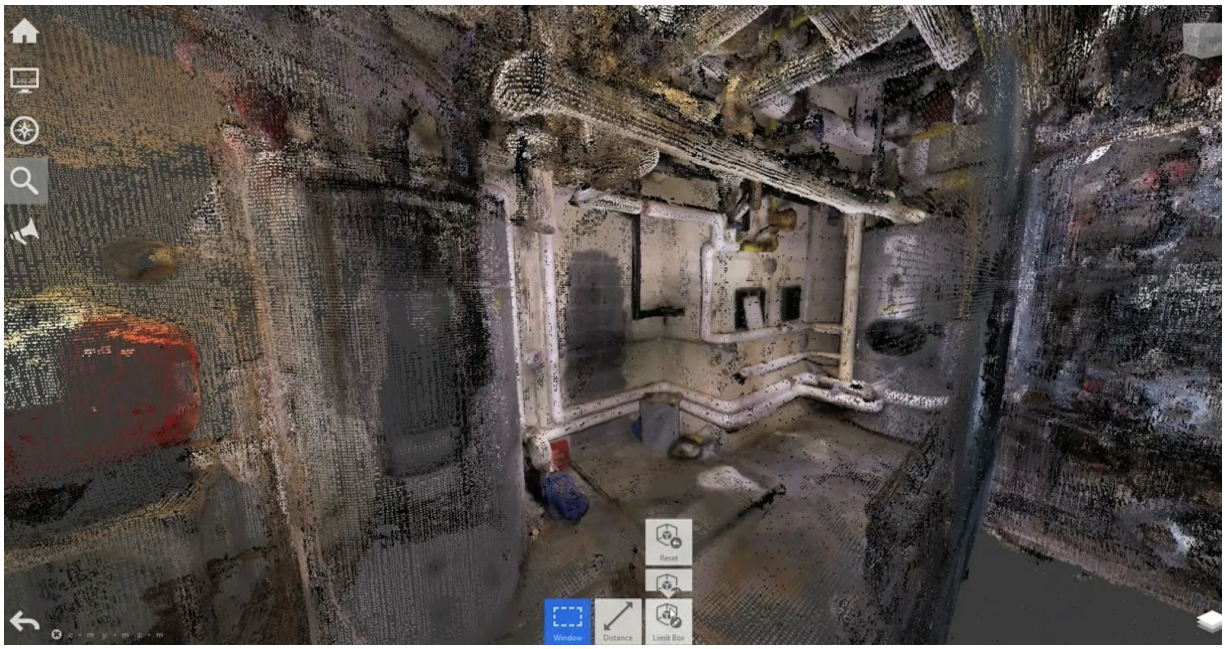
Paracosm



The Paracosm scanner attaches to a Microsoft Surface Pro tablet (image by Paracosm).



A scan in progress using the Paracosm software. The software will automatically notify the user when loop closure takes place during the scan.



A point cloud captured by the Paracosm software shown in ReCap.	
Scanner type	Optical and infrared
Handheld or tripod based	Handheld (walk while scanning)
Cost	● $400 / mo for 20 scans / mo ● $800 / mo for 60 scans / mo ● $1200 / mo for 200 scans / mo Plus the cost of a Microsoft Surface Pro tablet.
Accuracy & Range	● 12’ - 15’ effective range ● Short range: < 2 cm accuracy ● Wall to wall range: 2 - 3 cm accuracy ● > 5000 sqft range: 2% inaccuracy ● Can automatically register a scan of an area < 8000 sqft
Compatibility	● Exports ReCap, textured OBJ, and LAZ or E57 point cloud ● Darkroom software provides distribution, but just has a basic web viewing tool. Users will need to download the export to measure or tag
Pros	Easy to use, a significant ease of use improvement over traditional scanners. The ability to walk while scanning is extremely effective for capturing tight spaces that a tripod scanner could not reach. Uses a high quality PrimeSense sensor built by an Apple-owned company.
Cons	Models are not as high quality as with a laser scanner but higher quality than Matterport. Tagging and measuring should be done in ReCap or other software.
Conclusion	Although more expensive than Matterport, the quality of scans and the fact that the scanner is not restricted to a tripod makes the Paracosm solution a good first-pass solution for MEP scanning.

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Point cloud processing software

Point cloud processing software is used to take one more raw scan files from a scanner, clean excess points, register (stitch) the scans together into one, and prepare the point cloud data for post processing. Typically scanning is fairly easy, but processing point clouds can be difficult to do and requires substantial training to ensure no accuracy loss is made by human error.

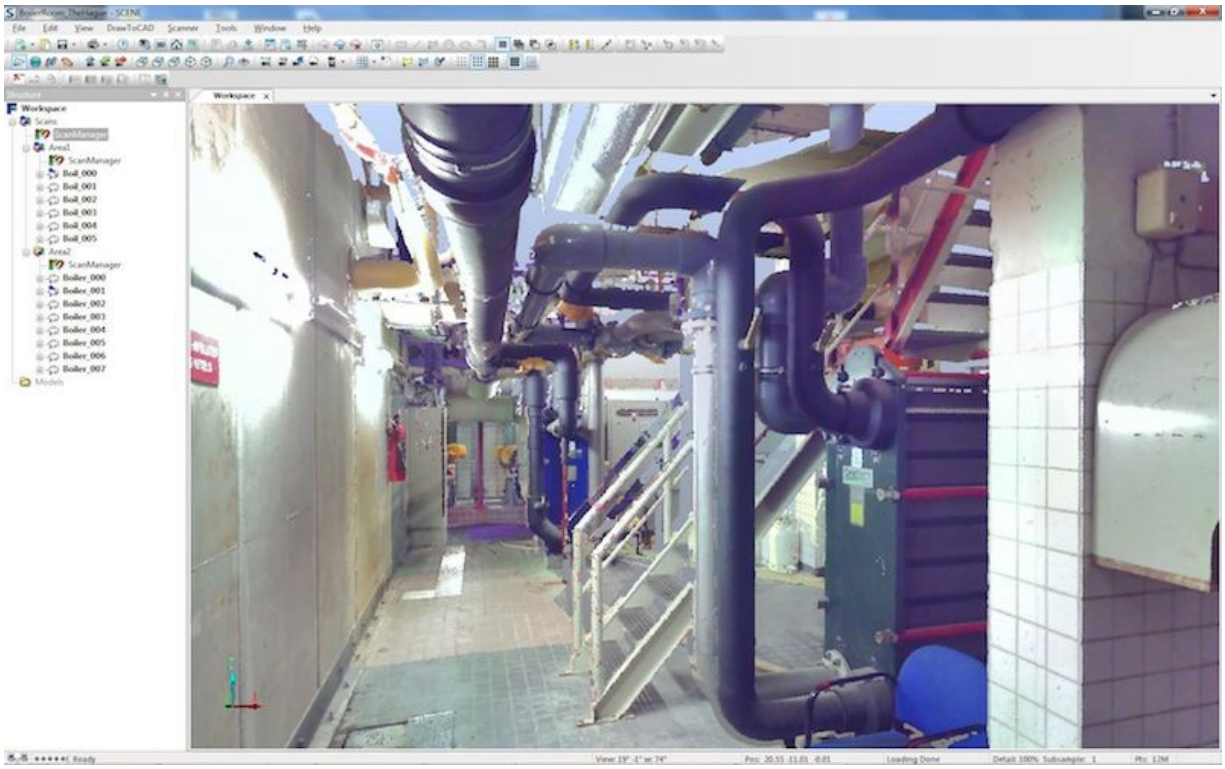
Autodesk ReCap

We imported a quick point cloud of some structural steel and duct work into ReCap 360 Ultimate.

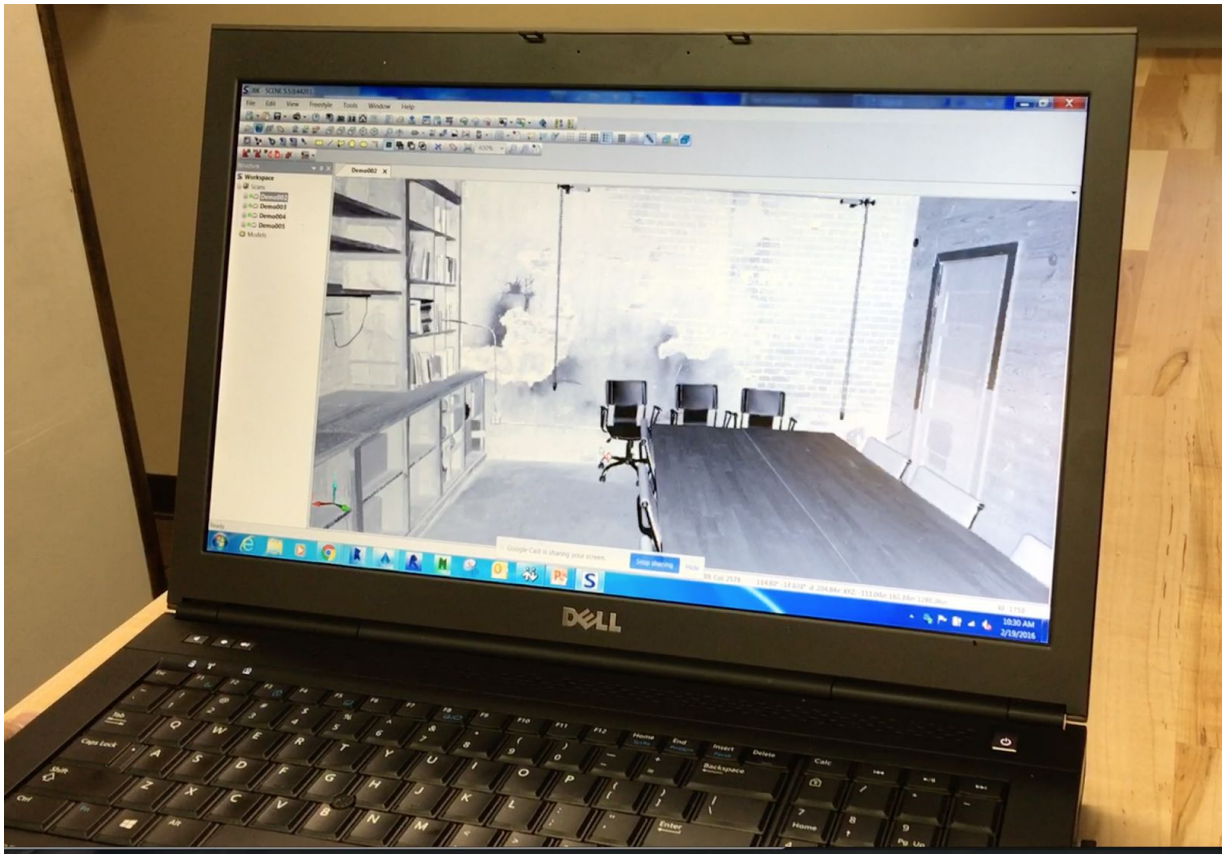
Description	ReCap's free edition can process laser scans into laser point clouds and panoramas that can be viewed in the ReCap viewer. ReCap 360 and ReCap 360 Ultimate can additionally import digital camera photos into estimated point clouds and meshes.
Cost	● ReCap: free ● ReCap 360: $500 / yr / user ● ReCap 360 Ultimate: $2,000 / yr / user

Compatibility	Compatibility with most all laser scanners and Autodesk modeling programs.
Pros	Attractive price point. Simple to use. Compatible with the majority of scanners and Autodesk software. Features cloud to cloud registration for laser scans.
Cons	Cloud to cloud registration only. Point cloud export is tuned for Autodesk programs, it may be hard to use out of an Autodesk workflow.
Conclusion	ReCap is a great tool if you stay within the Autodesk product suite.

FARO SCENE



FARO Scene showing a scan. The photosphere is shown in the navigator, and measurements can be made by clicking any two points (image by SPAR Point Group).

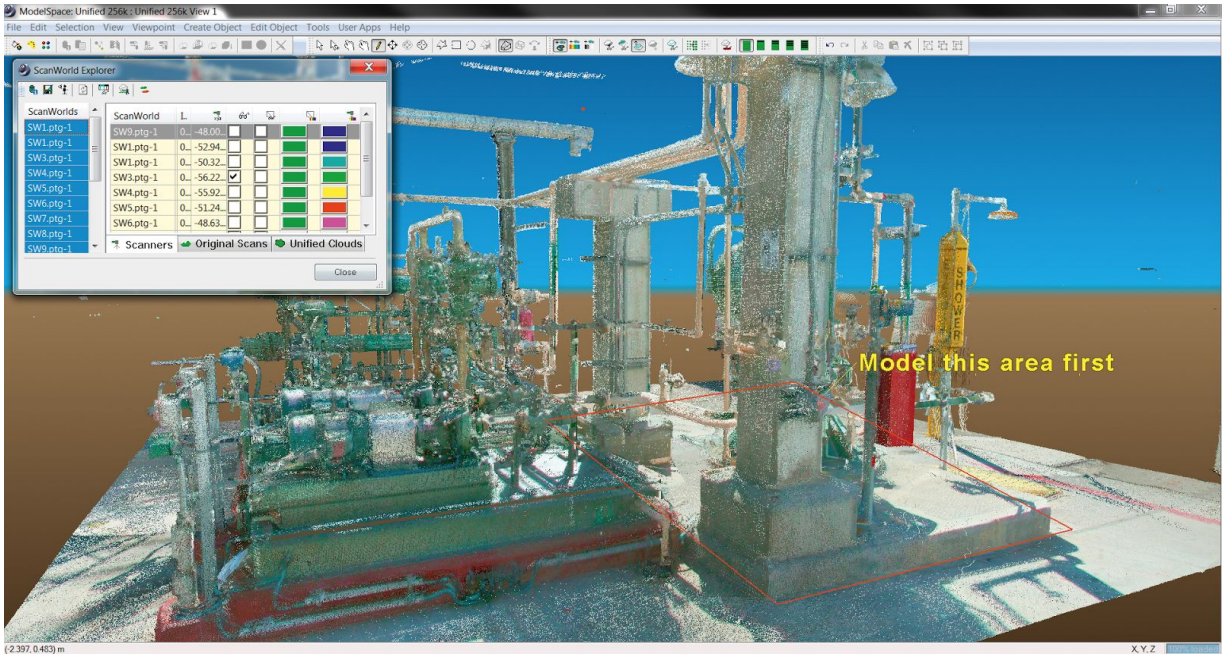


FARO SCENE showing a grayscale photosphere generated by scanning a conference room.

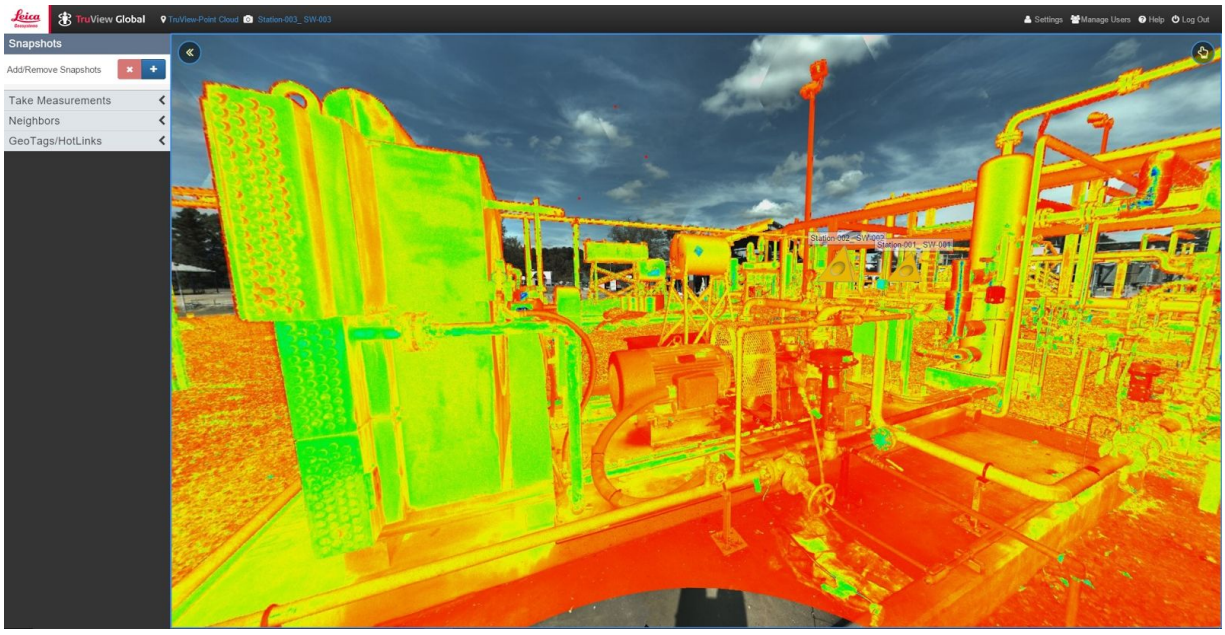
Description	FARO SCENE is a point cloud editing software that FARO packages with its scanners. The software is easy to use, effective for many scans, and features great tools for registration and editing.
Cost	$10,000 / seat (free with purchase of FARO scanner)
Compatibility	FARO SCENE is compatible with FARO Focus scanners; additionally, SCENE can import the E57 format that most scanners export for a wide range of compatibility.
Pros	SCENE supports cloud to cloud recognition, so scans can be automatically registered by common points rather than having to manually register using spheres and placards (however it is

	still good practice to use spheres and placards in case the cloud to cloud fails, so a repeat trip is not required).
Cons	SCENE supports FARO exports best, and can sometimes have issues with “full compatibility” of other scanners. Some exports from Leica scanners in E57 format have failed to import properly.
Conclusion	SCENE is an easy to use, leading software for processing scans. It is an excellent choice for use with a FARO scanner, particularly since it comes free with the purchase of a scanner.

Leica Cyclone

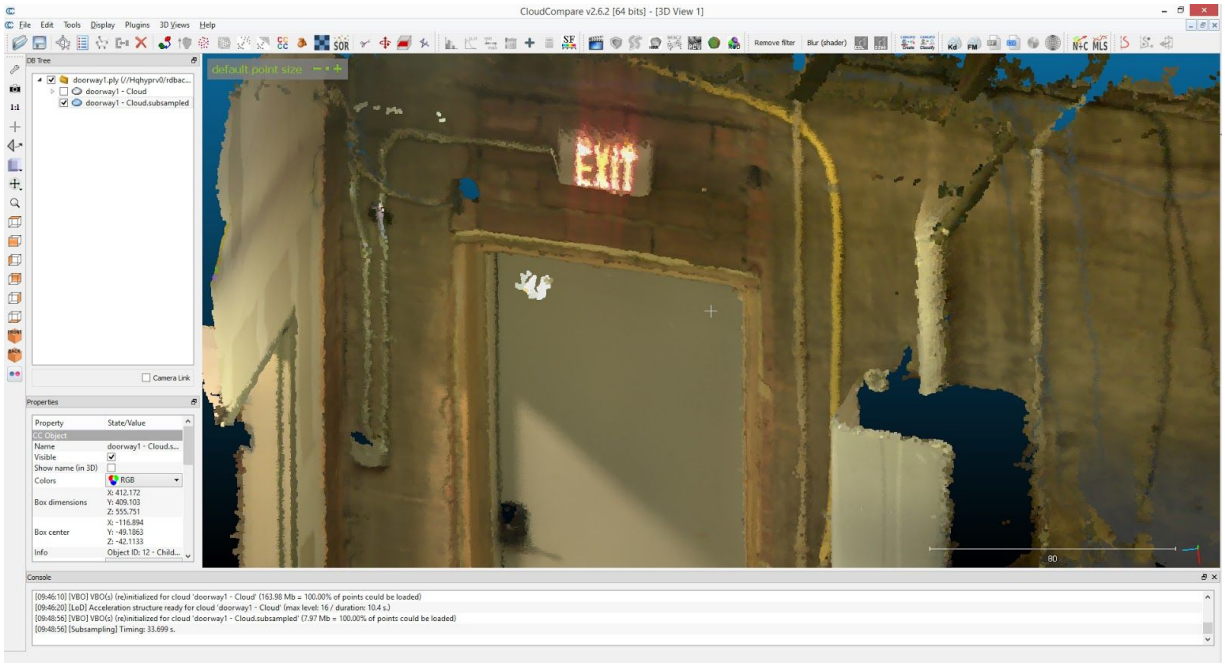


Leica Cyclone's ModelSpace is used to view the BIM model database (image by Leica).



Leica's TruView (included in Cyclone PUBLISHER) is useful for publishing point clouds for other users to use for measuring and marking up (image by Leica).	
Description	Cyclone is Leica's suite for point cloud management. The suite provides for registration of Leica point clouds, processing into CAD or BIM models, and survey measurement extraction. Cyclone can also import point clouds generated from other scanners. Publishing, collaboration, and import toolkits exist to streamline workflow.
Cost	< $10,000 (contact Leica)
Compatibility	Leica Cyclone can import scans from Leica and FARO scanners.
Pros	Provides the highest performance environment for laser scanning projects. Makes it easy for users to manage data efficiently in databases. The Publisher component allows for easy distribution of BIM models for measurement, tagging, and review by other users. Cyclone also includes a piping model which allows for insertion of flanges, valves, reducers, etc that can be linked to specs.
Cons	Limitations when modelling complicated point clouds that comprise a number of irregular shapes. Training documentation is difficult to find.
Conclusion	Cyclone is the highest performance toolset for processing laser scanning projects, but also complex and difficult to use.

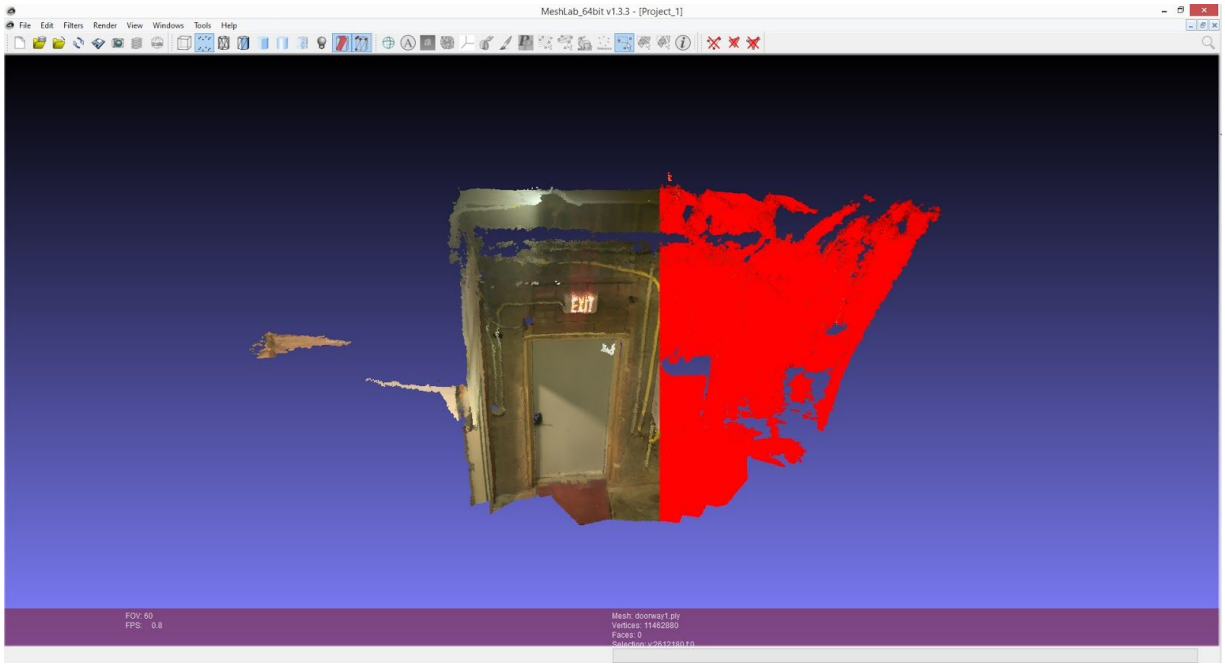
CloudCompare



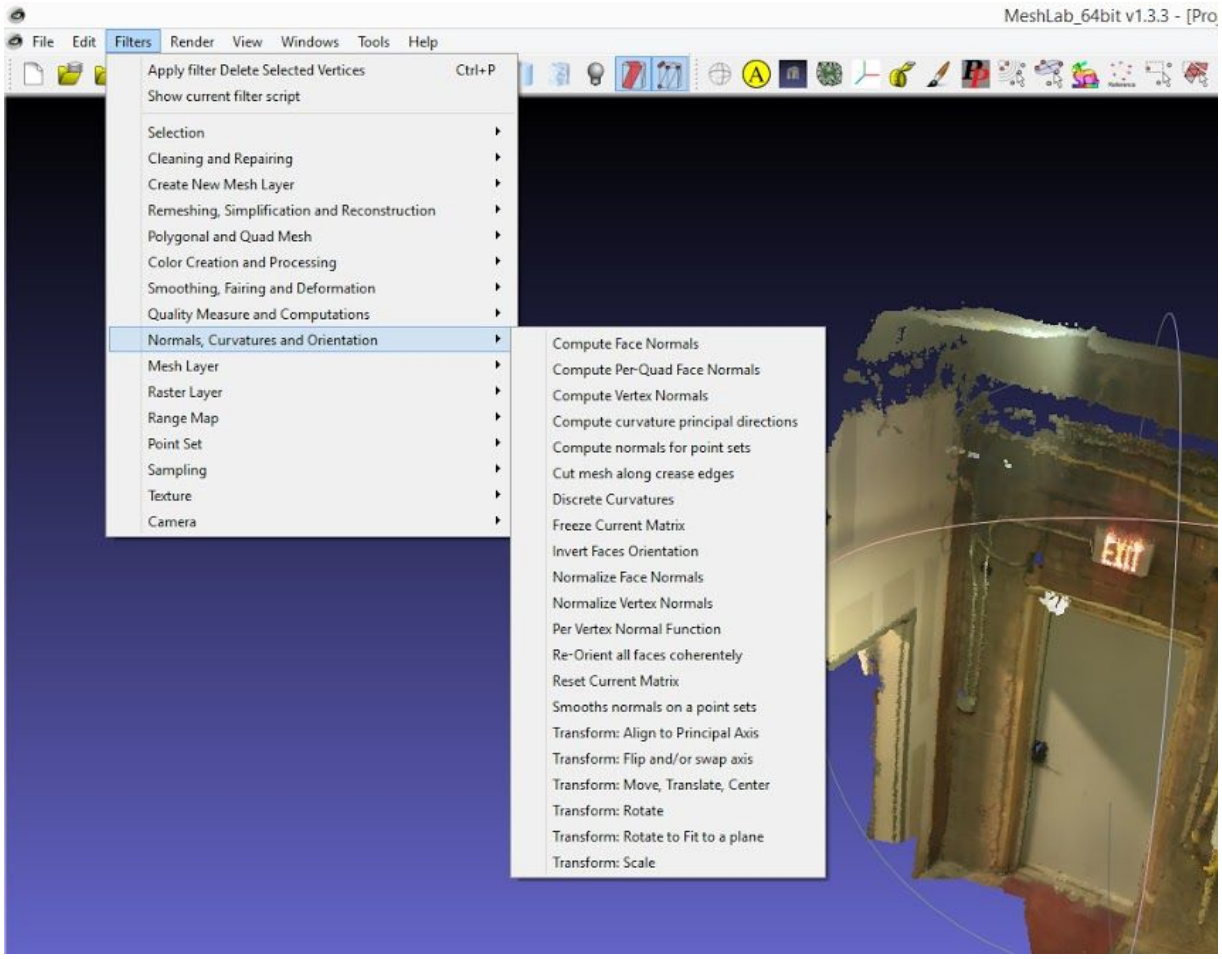
Inspecting a point cloud of a wall and door in CloudCompare.

Description	CloudCompare is a free tool for processing point cloud data collected from scans.
Cost	Free
Compatibility	CloudCompare supports a wide variety of imports, from PTX, PTY, OBJ, E57, PCD, and DP.
Pros	CloudCompare is very stable compared to Meshlab. CloudCompare's compatibility is very good.
Cons	CloudCompare doesn't have as many filters or tools as Meshlab.
Conclusion	CloudCompare is more stable and a great solution for a catch all import of point cloud data.

Meshlab



Trimming part of a point cloud in Meshlab.

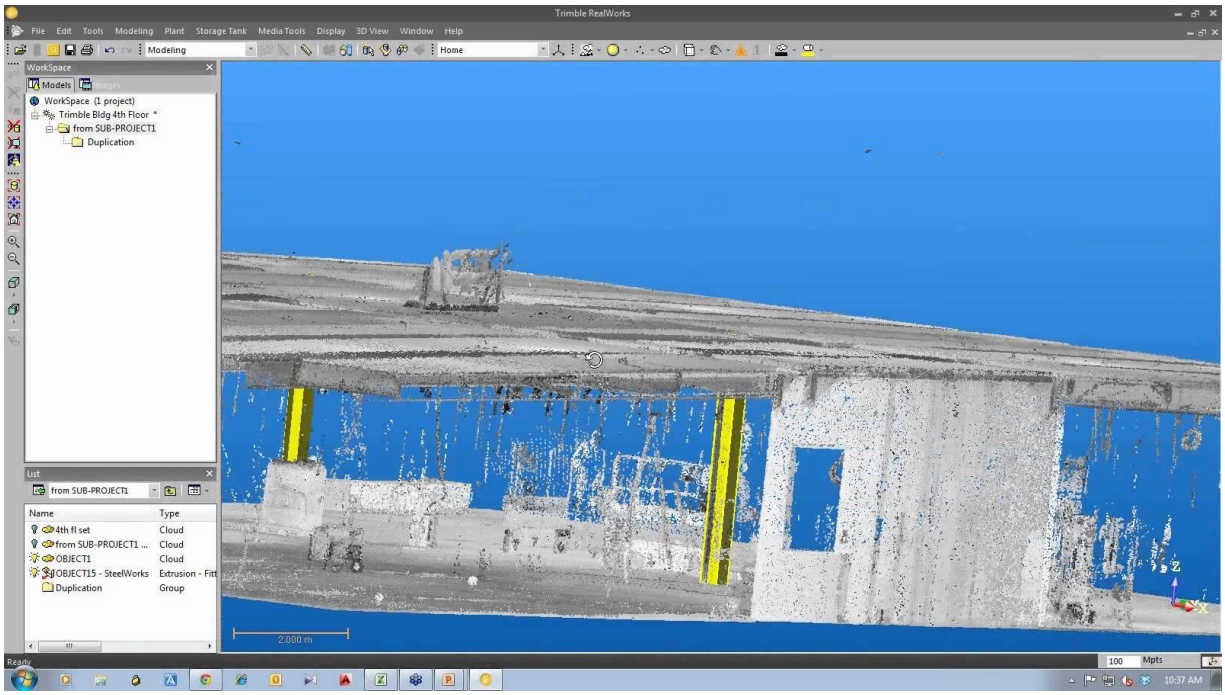


Inspecting some filters in MeshLab.

Description	Meshlab is a free, open source program for processing point clouds. The program supports filters for reducing points, and the ability to cut out extraneous points.
Cost	Free
Compatibility	Imports PLY, OBJ, XYZ, and XYZRGB.
Pros	Meshlab is free and useful for visualizing and editing point clouds.
Cons	Meshlab has an unfriendly UI and is prone to crashing.

Conclusion	Meshlab is a good free point cloud editing tool to prepare for post processing; however, the tool provided by the scanner company (Cyclone, RealWorks, SCENE) is more friendly and easier to use.

Trimble RealWorks



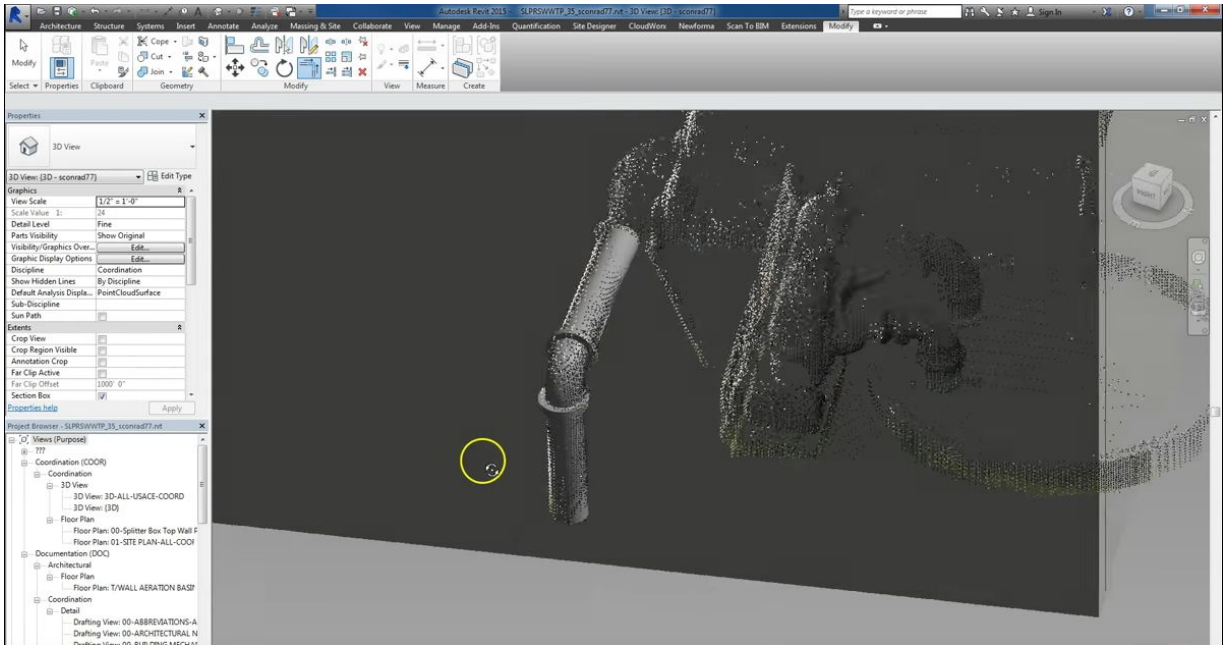
Inspecting a scanned building floor in Trimble RealWorks

Description	Trimble RealWorks is Trimble's point cloud editing software. The software allows for registration, cleanup, and export to postprocessing.
Cost	~ $14,000 a seat (contact Trimble)
Compatibility	Supports importing from most standard point cloud formats (but significantly slower for non-Trimble scan formats).
Pros	RealWorks supports automatic extraction of spheres and placards for registration, as well as feature-based registration.
Cons	RealWorks has a slow import for non Trimble scanners[5]. Registers either using targets or just features, not a combination of the two for extra references.

[5] Franz, Gregg, *Who is using Trimble RealWorks?* http://www.laserscanningforum.com/forum/viewtopic.php?f=47&t=8810

Conclusion	RealWorks is a good processing suite for use in a Trimble scanner's workflow. Although it cannot register quite as efficiently as other software (lacking combination of targets and features), it can handle registration of hundreds of scans together.

Leica CloudWorx



CloudWorx in Revit, showing some piping captured in a point cloud (image by Stacey Conrad).

Description	CloudWorx is another processing tool for Leica scans. Rather than a stand alone suite like Cyclone, CloudWorx is a plugin for a number of CAD and BIM suites like AutoCAD and Revit.
Cost	< $7,500 (contact Leica)
Compatibility	CloudWorx is compatible with AutoCAD, Revit, 3DS Max, MicroStation, and PDMS. The plugin can import Leica scans to these softwares and facilitate modeling over the point cloud.
Pros	CloudWorx is a good plugin for modeling in familiar toolsets (AutoCAD, Reit) rather than using a comprehensive suite (Cyclone). CloudWorx includes clash detection. CloudWorx also has the ability to show all points in real time, rather than having to decimate when rendering.
Cons	Some fitting tools, but not comprehensive.

Conclusion	CloudWorx is a great solution for using a familiar toolset like AutoCAD without having to migrate to an entirely new suite like Cyclone for processing Leica point cloud data.
More reading	Leica datasheet

Post processing software

Post processing software is used to expedite 3D modeling with the use of reality data captured from a 3D scanner.

"Honestly, in the long run, investing in efficient post processing software IS a "cost savings measure"." Mulkey Engineers and Consultants[6]

FARO 3D Software PointSense Plant

[6]Karen, Mulkey Engineers and Consultants, http://www.laserscanningforum.com/forum/viewtopic.php?f=23&t=4956#p34126

We used PointSense Plant to model structural steel and plumbing on a scan taken with a FARO X330.	
Description	PointSense Plant is an add-on to Revit and Autodesk 360 Plant 3D to allow easy snapping of cataloged components over point cloud data. Clash detection and "Walk the Run" guided pipe, elbow, tees, and inline fittings based on catalog.
Cost	< $10,000 / seat (contact FARO 3D software)
Compatibility	PointSense Plant (formerly a Kubit software before its acquisition by FARO) integrates with AutoCAD for 3D modeling that snaps to point cloud reality data.
Pros	Intuitive steps for modeling or deriving connection points for piping systems and steel construction and linking to industry standard piping design software packages. No need for expensive, complex software outside of AutoCAD.
Cons	Not quite a full suite for laser scanning, doesn't include target acquisition or registration.
Conclusion	PointSense Plant can easy expedite modeling by allowing the user to snap cataloged components over reality data. The constructed BIM model can not only be designed faster, but can also be snapped to ideal plan conditions, or snapped to the reality data point cloud to capture inaccuracies in angles and placement in the as-built.

Trimble / ClearEdge EdgeWise Plant

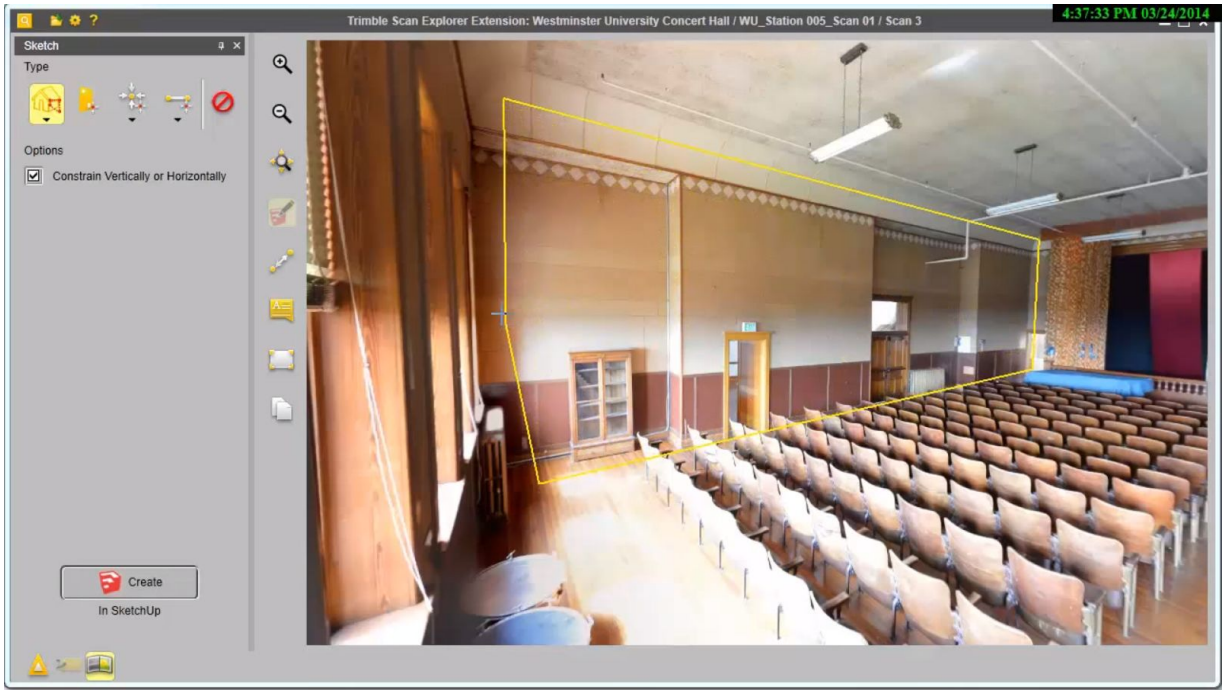
Automatically generated pipes from a captured point cloud. Note that the piping is not catalog-based, but it provides a faster starting point for cataloged modeling (image by Trimble).

Structural steel and piping generated from the point cloud (image by Trimble).

Description	Trimble EdgeWise is Trimble's post-processing software for accelerating modeling over point clouds. The software can extract MEP elements from the point cloud and export to Revit. Plant is an add on package that allows for spec driven pipe
Cost	< $10,000 (contact Trimble)
Compatibility	EdgeWise can import from Trimble RealWorks. After extracting and modeling features, EdgeWise can export to SketchUp, Tekla, Vico Office, CAD, and Revit.
Pros	EdgeWise has algorithms to extract pipes automatically. The software claims 85% of pipes can be captured automatically.
Cons	The 85% extraction accuracy can only be achieved with a perfect point cloud captured by a skilled scanner. Sometimes exporting to Revit will cause issues.

Conclusion	For a Trimble workflow, EdgeWise is a great tool for automatic extraction of some piping, conduit, and ductwork from a RealWorks processed point cloud.
More reading	EdgeWise and TX8 Webinar

Trimble Scan Explorer



Trimble Scan Explorer can be used to directly import points and edges from a Trimble point cloud into Sketchup Pro (image by Trimble).

Description	Trimble Scan Explorer is a Sketchup Pro plugin to facilitate quick modeling of basic Sketchup models over point Trimble point cloud data. Although the plugin facilitates quick modeling, note that it does not support use of any cataloged data.
Cost	Free
Compatibility	Compatible with Trimble-captured point clouds (via Trimble RealWorks conversion) and Sketchup Pro.
Pros	Trimble Scan Explorer is easy to use for fast basic modeling of point cloud data in Sketchup Pro.
Cons	Only compatible with Sketchup Pro. Does not reference any cataloged data, only useful for creating basic geometry based on point cloud references.

Conclusion	Trimble Scan Explorer is useful for quick modeling of geometry based on point clouds but has little application for MEP work.

Photogrammetry

Autodesk ReCap

We used ReCap 360 to generate a 3D model of our office block in Bryan, TX, which we then released as the Binary by Drone project on SmartReality+.

Workflow	ReCap 360 and ReCap 360 Ultimate can import digital camera photos into estimated point clouds and meshes.
Cost	● ReCap 360: $500 / yr / user ● ReCap 360 Ultimate: $2,000 / yr / user
Compatibility	Compatibility with most all laser scanners and Autodesk modeling programs.
Pros	Attractive price point. Simple to use.
Cons	Requires many photos to be taken to stitch together.
Conclusion	If you need to perform photogrammetric scans to 3D models, ReCap is a great solution, particularly if you use products in the Autodesk ecosystem.

Pix4D

Pix4D generating a point cloud from an aerial scan of a downtown area (image by Visual Aerials).

Description	Pix4D is a software that can process drone photos and videos into point clouds and 3D meshes.
Cost	● 1 Month: $350 ● 1 Year: $3,500 ● Unlimited: $8,700
Compatibility	Pix4D can import images or video taken by hand, drone, or plane. The software is conceivably compatible with any image or video produced by these platforms.
Pros	Pix4D supports videos as well as images for input. The $350 one-month license is useful for evaluation.
Cons	More expensive than alternatives. Pix4D can easily run overnight to stitch together a large amount of photos and videos to produce a point cloud. Pix4D can fail on less

	powerful computers.
Conclusion	While slightly more expensive than ReCap Ultimate, Pix4D provides a more robust set of tools for stitching photos into point clouds and meshes. The software is highly optimized to process drone data into the most accurate data possible, but can't be expected to have near the same quality as that which would be generated from a terrestrial laser scanner.

Not-yet-ready solutions

The following scanning solutions were disqualified as not ready for immediate use, either due to immature hardware or software. They may be revisited in future research as they progress.

Structure Sensor (non-laser scanner)

The Structure Sensor took great scans of small objects but failed to scan a room.

Google Project Tango (non-laser scanner)

Although Google Project Tango's hardware is great, it's very much a prototype. There was no software readily available to convert the Tango's recorded data to a point cloud. Expect some Google Project Tango commercial scanning apps in the next year.

Skanect (photogrammetry)

Skanect's software is good for small objects, but is not useful for capturing anything beyond a low quality small room.

Autodesk Momento (photogrammetry)

Autodesk Momento a simpler, free version of ReCap geared for general use. It lacks the depth of features of ReCap and simplifies point clouds into less precise and less usable models. Momento is not quite comparable to ReCap 360 for professional use.

What's next?

These solutions aren't yet available to consumers, but are up and coming and worth keeping tabs on.

Building Systems Planning (BuildingSP)

BuildingSP is a company founded by BIM-expert Brett Young based in California. The company is currently building a software product to use generative design in BIM system coordination. Generative design is the use of machine intelligence and computational power to produce solutions automatically. Brett explains his software best:

> "BuildingSP automatically routes and models mechanical, electrical, and plumbing (MEP) systems in 3D and without clashes. You can think of our work like Google Maps – if you provide a start point, an end point, and a series of parameters (go by car, bus, or bike, etc.), you get a routed solution".[7]

Expect a product release by BuildingSP this year.

[7] Young, Brett. *Set-Based Approaches to MEP Systems Using Generative Design*. https://www.linkedin.com/pulse/set-based-approaches-mep-systems-using-generative-design-brett-young?published=u.

References

This report was created with the aid of:

- Arizona Pipe Trades Apprenticeship
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- Kinetic Systems, Inc
- Matterport
- Paracosm
- TopCon Positioning Systems, Inc
- TruePoint Laser Scanning
- Mechanical Contractors Association of America