2021 MCAA

3D Scanning Technology Research Report

Part of the
MCAA Technology Research Series

Performed by
MEP INNOVATION LAB
for exclusive use by MCAA

JBKLABS
Based in part on research originally performed by JBK Labs in 2016

3D Scanning Technology Refresh Update

Part of the MCAA's Construction Technology Research Series

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Committee Chairman's Note

3D Scanning was one of the first areas of new construction technology that the MCAA Construction Technology Committee chose to research in 2016. Since then, there have been dramatic improvements in existing scanning methods but also new methods of scanning that have gained traction. With these new methods came varying levels of accuracy in the scans. While some scanners might not offer precision for fabrication, other contractor use cases were identified that a lower level of accuracy was perfectly suited for.

What we also learned from our last report is that it is difficult to perform side-by-side comparisons of 3D scanners. While there are other factors such as scan time, processing, software and flexibility in viewing and sharing scans to consider. To make this research more effective, we needed to develop a way to create a scientific comparison to measure the scanner's accuracy. To measure the level of accuracy, we worked with the MEP Innovation Lab to create a control rig with a standard set of conditions that contained multiple types of plumbing, piping and sheet metal.

To improve our comparison, we also wanted to develop a way for contractors to not only read about the findings but also visually experience them in a way that could provide a greater demonstration of the scanner's results. The platform we decided to work with is Revizto, and free licenses are included with this project for anyone to see the results displayed in 3D or virtual reality. Now you can walk through the scanning results of different equipment in different conditions, almost as if you were walking through a museum. As more research is completed on new scanners, we will upload it to the Revizto space as well as update the report. That should make both areas a living report.

Some scanning technology, like photogrammetry and LiDAR, are better demonstrated in spaces, rather than objects. While we tested them on the standard test rig, we also used them on spaces and imported them into the Revizto site as well.

While we understand that we could use these technologies in their current iteration for fabrication level scans, we wanted to show how they could document job sites, create real-world as-builts and document space being maintained in facility agreements.

I look forward to tracking how this technology develops and new use cases that MCAA members can come up with for its use.

Stacy Zerr, Director of PreConstruction Services, Waldinger Corporation, MCAA Construction Technology Committee Chair

Report Information

MCAA's Construction Technology Research Series

Members of the MCAA stand to greatly benefit from the rapidly evolving technologies in 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. We'll also explore the potential value of these tools 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?

The MEP Innovation Lab updated this report. JBKnowledge, Inc.'s research and development team, JBKLabs wrote the original report.

Focus on Readily Available Technology

This study focuses on technology that is available for practical use at the time of writing.

How JBKLabs and MEP Innovation Lab Conducted Its Research

The research was conducted through a combination of hands-on analysis of tools and interviews with manufacturers. We then shared their findings with industry experts with knowledge of the process to make sure the 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 several dimensions:

- **1D - 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 the cost of materials can be observed through time
- **6D BIM:** As-built is introduced, so the state of the space after construction is represented, including maintenance, operation, specifications, photos, warranty data, etc.

BIM Adoption

BIM has already become a critical component of the construction process. Between layout, Quality Assurance/Quality Control (QAQC), and as-built, BIM expedites project completion and significantly cuts costs. In 2014, three-quarters of construction firms reported a positive return on investment (ROI) on their BIM program investments, and a majority reported a reduction in errors and omissions on work done. BIM-related work is expected to increase by 25 percent each year, so the time for BIM adoption is now.

What is Scanning?

Scanning is the process of capturing *reality data*, that is, the actual 3D state of a space in time. Traditionally, *reality data* is captured using a measuring tape, pen and paper to make measurements and construct a two-dimensional drawing of a scene. With scanning, contractors can automate this process. Introducing automation to capture *reality data* serves four primary 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
3. To extend the number of measurements taken to include substantially more points of data
4. To capture color/image information

Scanners are devices that use one or more types of capture technology to automate measurements. Once the contractor captures these measurements and reality data, it can be transformed into more conventional formats such as 2D CAD drawings, 3D BIM models, or virtual environments.

What is *Reality Data*?

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

- Point cloud: a cloud of points, each point representing a point of measurement from a scan of a space (add better PIC)

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 angles of the real space are estimated in geometric form.

In this example, the mesh is indicated during the scanning process. Scan taken with an iPhone 12Pro (LIDAR).

Once the framework of a space is determined using photogrammetry or LIDAR, a photo mesh is overlayed to digitally represent the space.

Registration

Registration is the process of “stitching” several point clouds together to form a single point cloud. This process is necessary when a contractor wants to capture a large area because scanning equipment 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 maintained sub-millimeter accuracy. This process has become automated with algorithms that compare overlapping areas with recent software improvements. However, contractors still employ targeted registration regularly to assure good registration or tie scans to specific coordinates.

Materials and reflective surfaces within a space can produce false data points that cause automatic registration to fail or return poor results. Using targets, placards, and spheres to indicate common points of reference eliminates concerns about reflections or false data points. In rare cases, manual registration can also be performed to address problem areas. In manual registration, the operator will select matching points, planes, or lines that are common to two scan locations.

Scanning Spheres and Placards

Reference spheres and placards are visual indicators that provide common reference points for registering point clouds from multiple scans together.

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

(image by Laser Scanning America)

- Placards: checkerboards placed on walls, floors, or ceiling to provide a visual reference point for registering point clouds. Placards are effective up to 30-degree angles

(image by Laser Scanning Europe)

Difference Between a Robotic Total Station and a Laser Scanner

A Robotic Total Station (RTS) accurately measures the distance from itself to a point in space or a prism one measurement at a time. A 3D 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. Robotic total stations can be used for data collection but need to be used in a targeted way by collecting critical points of interest.

There is a new breed of hybrid total stations that are capable of functioning as conventional single-point lasers and producing point clouds of specific areas. This process tends to take longer than gathering a point cloud using a laser scanner. This style of total station also has automated collection routines that can be used to automatically produce critical points for floor plan creation.

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, LIDAR, and photogrammetry enable low-cost scanning for projects where the tighter tolerances of sub-centimeter total station or laser scanner measurements are not required.

"First Pass" Scanning
A great use for 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-building, "first pass" scanning can provide a good starting point for the layout and determine which spaces need a more precise scan.

Scanning vs. Processing
While it does require some training, running the equipment is often the easier portion of the scanning process. Processing (stitching or registering) scans into completely accurate point clouds and further into usable drawings, point clouds, or BIM is a significantly more difficult endeavor.

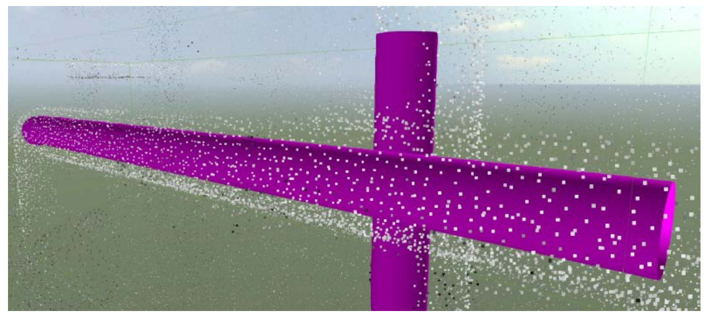
Over the last two years, there has been a revolution in scan processing and registration to make processing faster and easier. Several scanners now offer "On-Site Registration" so that the stitching process can be performed simultaneously with the collection of the reality data. This process allows for fewer return visits and reduces the time required to deliver usable data to BIM and other down-stream groups in half. These enhancements also help eliminate the need for higher paid technicians and allow operators to see the quality of the reality data before leaving the location.

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 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 and Conversion as a Service

Some contractors who need to spend time on-site already may wish to perform the scans themselves and use a processing or conversion service to build CAD drawings or BIM models from their scans. This process goes beyond registration to the conversion of reality data to BIM objects and families. This process tends to use expensive software and requires technical expertise beyond that of a standard operator. It also requires information on the existing area to define conversion rules.



Pipe conversion accounting for insulation

For example, insulation and other outer coverings need to be subtracted from measured points to produce pipe runs. Some scanning service providers will work with contractors to help them purchase scanning hardware, train on its 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 without the need to tie back to a common survey point (control). Because the station is free to be moved, it requires the operator to stitch the scans together relative to the control points (*registration*). This stitching can introduce some inaccuracy. Conversely, traverse scanning automates this process 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 during manual registration. Over the past two years, traverse scanning has become less necessary as software registration has improved.

Types of Reality Capture:

- **Phase-Based:** Phase-based scanners work by sending out a constant laser from the device and measuring the return phase's difference from the initial phase. These scanners can generate up to a million points a second, but their range is shorter than Time-Of-Flight style scanners. These are best for shorter distance environments like building interiors, and enclosed spaces.

- **Time-of-Flight:** Time-of-flight scanners work by sending out a laser and measuring the time it takes for the light to come back to the scanner. By knowing the speed of light and the angle of the scanner, it can accurately predict the distance to objects. These scanners have a longer range but slightly slower data acquisition, so they are primarily employed for outdoor use. As the technology has improved this style scanner has increased in speed and dropped in price.

- **Structured Light:** Structured light scanners work by using a pair of projectors and cameras to project patterns onto a surface. The surface will distort the patterns which will allow the camera to track the surface and reconstruct it into a 3D model more accurately.

- **LIDAR:** LIDAR is similar to both time-of-flight and phase-based, where it sends out light pulses to an object and records the difference in phase and the time it takes to return. It That information is then used to generate 3D models. LIDAR range scales based on the size of the device.

- **Photogrammetry:** Photogrammetry is a process in which cameras are used to take pictures of an object from all angles. Software is then used to mesh the images together based on similarities in the images.

- **UAV (Drone):** UAVs are becoming a more popular option for scanning large open areas. These offer a slight risk to the scanning device if the drone has a flight failure. They typically utilize photogrammetry to develop 3D scans.

To Buy, Rent, or Outsource?

The decision to purchase a scanner will depend on the type of scanner needed, the frequency of scans and the workflows that will be impacted.

Purchasing LIDAR, optical scanners, or a drone will generally provide a quick return on investment. These types of scanners are inexpensive and easy to transport. It is, however, important to include training and software costs when considering the purchase of an optical scanner. Furthermore, drones require insurance and a license to operate. These scanners also have limited uses based primarily on the need for accurate measurements, so it is essential to define the intended workflows before deciding to purchase.

The purchase of laser scanners is generally very costly upfront, and some scanners are difficult to transport and maintain. Purchasing a laser scanner (and all the other requisites: training, computers, and software) requires frequent scanning to achieve a positive ROI. In the past, it was often more economical to rent the equipment from a rental service. However, the cost of hardware, operation, and maintenance have dropped significantly in recent years. This price decrease has made the primary criteria for purchase more dependent on the workflows and processes that the equipment is targeted to create or enhance. Organizations focusing on BIM and prefabrication will see significantly better returns on a purchased unit than on a rental. On the other hand, companies with limited BIM use may be better served to rent a unit until reality capture is efficiently incorporated into their workflows.

In the last report, we pointed out that laser scanners become outdated and are often replaced within five years of purchase. However, we have found that this replacement is often in favor of an even faster or more accurate system. Older scanning equipment typically remains in use beyond five years or is sold. Used units can help those looking to get into scanning to do so with lower upfront investment. Indeed, ten-year-old FARO 120 scanners are still capable of producing usable and reliable data. An internet survey of used scanners showed discounts in the range of 70 percent of the cost of a new version of the model[1].

When the cost can be shared between organizations or team members, consider outsourcing reality capture. While prices vary, a typical day of scanning that produces useable data will fall between $2000 and $4000[2].

A good time to rent equipment or outsource is when generating data for marketing or business development. In these cases, a visually attractive result is paramount. Scans can be very realistic, but that level of realism requires high-end equipment and a technician with the time and expertise to create great-looking reality capture data. Most

[1] Please note that features and processes for a 10-year-old scanner will be very different than current models.

[2] Prices will vary based on location and labor rates. Range determined in 2021.

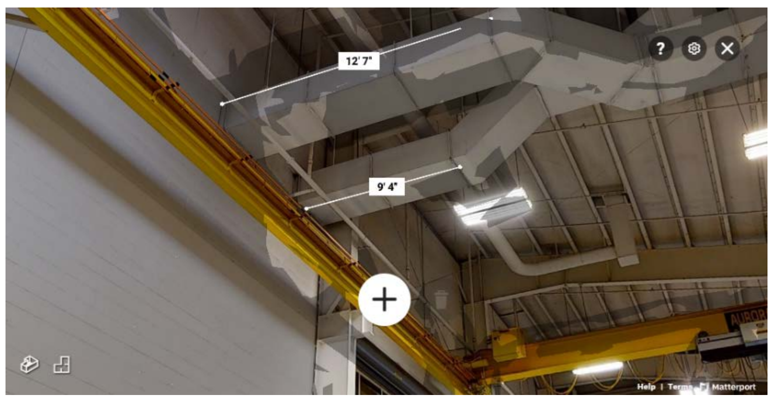
of the practical uses and workflows for scanning in construction do not require great-looking data, and it can be hard to justify those expenses in-house.

Workflows:

This section outlines some standard workflows that rely upon—or are enhanced by—reality capture. These are also referred to in the matrix where they are matched to the types of reality capture that they employ. Following each description, brief ROI-focused statements are included. These statements are not the only ROI but rather a starting point for understanding the value of the processes involved.

Estimating and Bid Measurements

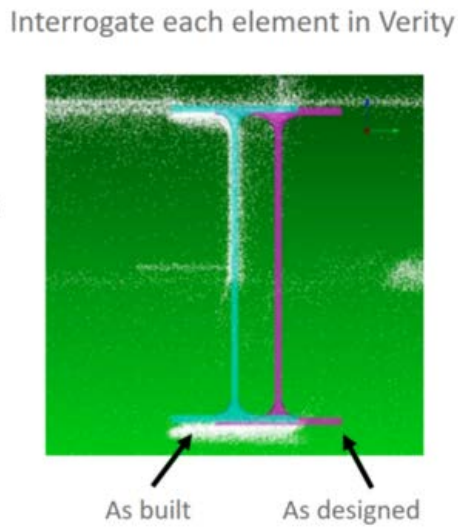
Good estimates of existing work often required the measurement of on-site objects, piping, ductwork, building structure, and existing conditions. This is the perfect place to employ low-resolution high-speed scanning technology. It is usually possible to capture most of the relevant on-site information with 360 cameras, LIDAR and sometimes drones. From here, using stitching software can produce rough measurements even in areas that are not accessible without additional equipment. This process also quickly documents the measurements used in the estimate for later review during the execution of the project.



ROI Focus: Minimizing on-site survey time and capturing more accurate measurements in an easily reviewable manner.

Building Validation

To have an accurate coordination model, coordinators need to validate the space for modeling and fabrication. This means that they need to check that the structure being built matches the model of the structure it was coordinated against. For this reason, scanners are deployed during the critical points of structural erection to capture large beams, girders, and all the steel that is going in along with the concrete. At the same time, checks should be made for deviations in floors, sagging concrete, and other structural or non-modeled elements that will have an impact on what we have done for coordination.



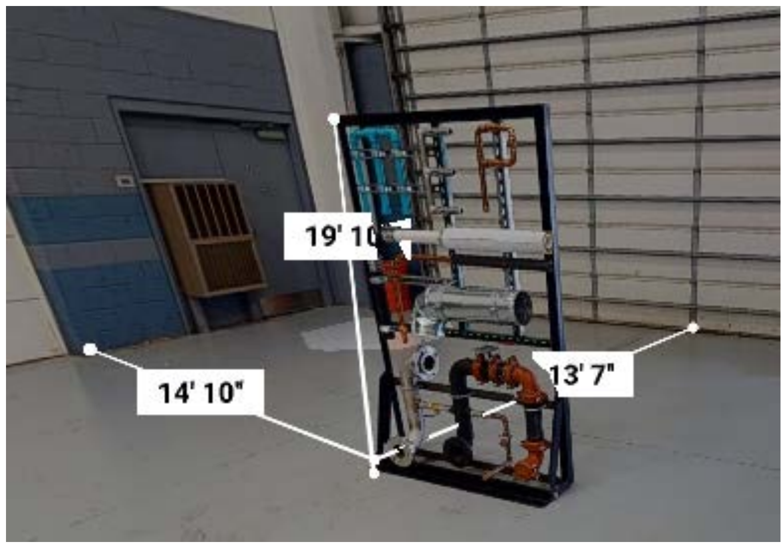
Another part of building validation is determining which walls or physical structures are the best to measure from. By scanning the building and comparing it with the model, it can determine which areas are safe to measure from. This can prevent miscommunication in the field. Because building validation is used to dial in all the measurements, data being made by the scanning equipment must be accurate.

Building validation can be done with an accuracy of 1-3 cm. This margin of error allows contractors to use high-speed scanning equipment. Critical or highly congested areas require more accurate scans. As do areas where the scan measurements will be used for prefabrication. Validation of measurements for congested areas or prefabrication should be targeted to avoid investing extra time collecting data in areas where small inaccuracies in measurement will not affect construction.

ROI Focus: Building components not included in coordination, out of square, or in the wrong location have significant impacts on installation and planning. Effective coordination, layout, and planning rely upon the accuracy of the building shell plans and model. Validating the building protects the investment in those areas.

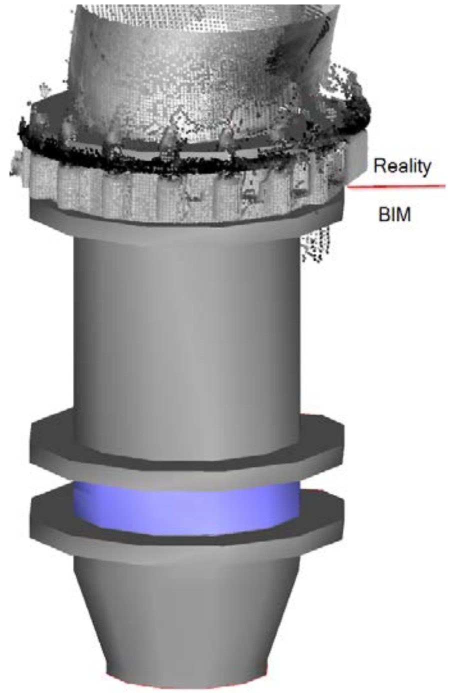
Planning Documentation

Creating planning level documents LOD (Level Of Detail) 200 can be done in early coordination and planning. When contractors and coordinators produce planning documents at this level, photogrammetry or LIDAR can be used. In general, during the early planning phases, you want to go in with the low-level equipment as soon as the clients have defined the scope of the project to plan out work and look for any significant issues. Later, it will be necessary to return with more accurate equipment to recapture those areas at a level of detail necessary for coordination (1-3 centimeters for early coordination and less than 1 cm for final installations in fabrication). It is often straightforward to take plans created by the early scanning and slice them in such a way as to produce floor plans and other detailed planning documentation without actually having to draft or add additional digital items beyond new equipment.



ROI Focus: Preplanning and risk mitigation are important to focus on in planning documentation, but having accurate reality information to plan with is the main focus. Minimize modeling and drafting of existing conditions at this stage.

Fabrication-Level Verification (Measurement)



One of the most widely used processes involving reality capture is fabrication-level verification. This is using the scanning equipment to take very accurate measurements to accommodate off-site fabrication and manufacturing. These measurements need to capture key points of tie-ins and items that are likely to cause collisions or deviations from planned routing. It is important to remember that many environments are temperature-dependent, as are piping and vessels.

When a contractor performs validation, they need to account for size deviations based on temperature and rate of expansion. They also must look for objects that are out of position like drooping pipes or moveable equipment.

Beyond the environment, fabrication requires verification of the parts that are being used to fabricate and the fabricated items if they are connected. While low-cost photogrammetric or LIDAR scanners can suffice for small fabrications such as spools or small skids, the accuracy that laser scanners provide is needed for fabrication-level verification in nearly all other cases.

Most MEP contractors have been successful in employing laser scanning to verify and layout fabrication. The biggest challenges to that success tend to be obstructions, movement, or other changes to the environment after the scans have been completed. Foreman and other installers should have access to the scans and perform a visual check for changes to the space before installation.

ROI Focus: Eliminating the need for field cuts and corrections should be the focus in this stage. The accuracy of the scans can reduce or eliminate the practice of leaving ends long for field fit. The need for several field operations welds and brazes should be dramatically minimized.

Progress Documentation

In terms of reality capture, this workflow has one of the lowest barriers to entry. Most project documentation can be done with 360° cameras, photogrammetric, and other low-cost reality capture equipment. The biggest questions to ask when completing progress documentation are what level of accuracy you wish to have on the individual captured items and how much data—in terms of file size—do you want to maintain in your library. The repetitive nature of progress documentation typically means that the reality capture workflow should be optimized for rapid collection and smaller file sizes.

Repetitive capture lends itself to higher speed, low-cost alternatives. The general ballpark cost for this workflow would be somewhere between $500 and $2,000, excluding labor to get the equipment and software. However, the expense of tracking progress is often tied to an interval or number of capture points required for the project.

An artful but expensive workaround for this issue is to use the Boston Dynamics Spot set to capture areas on a rotating basis or drones on a fixed flight plan for exterior locations. More often contractors are utilizing software specific to project documentation through photogrammetry. Software like OpenSpace and StructionSite can utilize a range of 360 cameras to create 3D models tied to construction documents. Other platforms like Matterport can use both 360 cameras as well as their proprietary scanner to create interactive 3D models with relative accuracy.

ROI Focus: Project and installation tracking can be used to support progress payments and the establishment of a "measured mile" to use to assess losses due to delays or other progress disruptions.

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Existing Conditions Documentation

Documenting existing conditions provides an easy win for off-site fabrication or work in remote or hazardous areas. This workflow is heavily influenced by the LOD needed and the intended use of the point cloud.

For levels 100 through 200, you can use simple photogrammetry and LIDAR. As you move to 300 and up, you want to use reality capture equipment at a similar level to laser scanners. There is some LIDAR equipment that can perform at the lower levels of the 300 LOD, but in general, from 300 LOD up to 500, you need laser scanning equipment to document those existing conditions. It should be noted that oftentimes when you are documenting existing conditions, there is no need to do a 3D model unless it is requested. If the client is not requesting that you create a 3D model, you can usually select the reality capture information to allow them to get through the planning and layout purposes and draw what they need rather than drawing everything.

ROI Focus: Capturing existing conditions extends the footprint of prefabrication services and minimizes the on-site time. It can also go a long way to reduce modeling time if the point cloud is used versus a model. Finally, the capture will help determine if changes are made to the space between design and fabrication.

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Structural Piping and Vessel Deformation

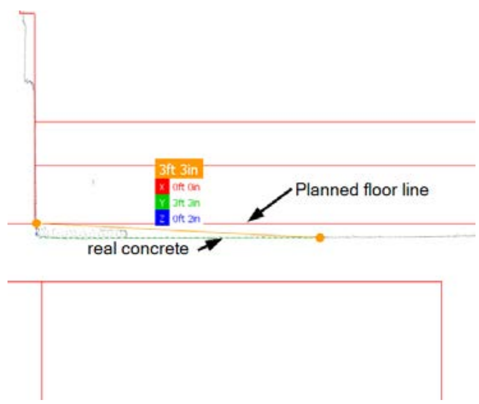
Measuring deformation is typically a multi-step workflow where the contractor scans the same object at various points during installation. Slight movement can occur as loads are applied to the structure and piping as well as when vessels are put in operation. Scans are done and compared to the original to measure any shift. Control points located on trusted fixed locations must be maintained during the process so that accurate comparisons can be done.

Laser scanners are necessary for the accuracy of this process. Robotic total stations can also be used to monitor fixed points or objects if scanners are not available. Deviations can be visible by overlaying the scans and measurements taken. There are also several programs to assist in this process. In general, the programs that measure the deformation of the deviation compile reports to validating that the structure is not overloaded and that any vessels and piping are not deforming beyond allowable limits.

ROI Focus: This is a specialized workflow and is often outsourced. However, it can also easily be added to the list of available services offered and can be grouped with other validation workflows to provide greater value from the point clouds being collected.

Floor and Deck Deformation

Like piping and vessel deformation, the contractor can scan before and after stress is applied to the deck and do a comparison. This process is separated from the vessels and structure workflow because floor deformation is fairly common. It also significantly impacts the installation of prefabricated items and the coordination of congested spaces. Hanger prefabrication is heavily impacted but general measurements made from the floor or ceiling are also affected.



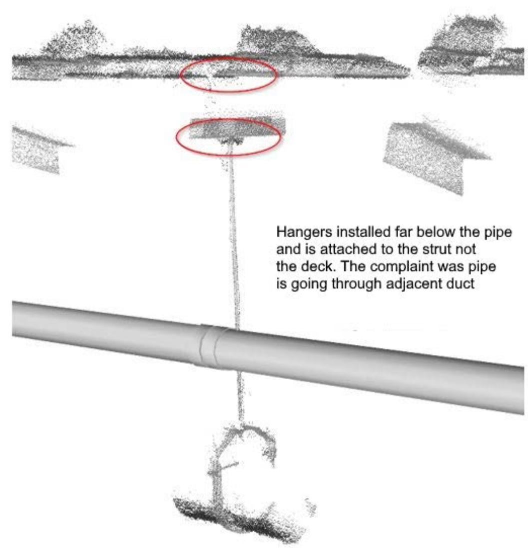
ROI Focus: This is focused again on ensuring the work done in coordination is not abandoned or deviated from without understanding the cause and possible cost impacts.

Safety Survey

Safety surveys follow a similar process to progress documentation. While this process can be done by any reality capture equipment, it is probably a waste of time and data to use anything beyond 360 cameras, a Matterport or a basic LIDAR scanner. Phase-based scanners should only be considered if the data collected is being used for other workflows.

> ROI Focus: This type of attention to safety will have a measurable impact on company safety metrics and the job site's overall safety.

Quality Control and Forensics



One of the more common uses outside of construction for scanning equipment is forensics. The registration software, SCENE (FARO), is named in reference to crime scenes. Within construction, the need to measure and identify the sources of problems, accidents and errors is similarly essential.

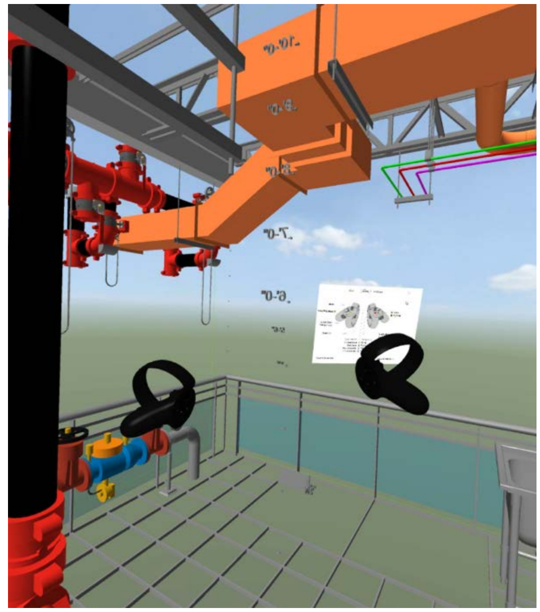
Using a scanner to capture the environment where an install has gone wrong or coordination has not worked helps us identify whether the problem is in design, fabrication, coordination or was caused by an unforeseen issue. Often, issues with off-site fabrication are corrected on-site without the identification of the cause.

Capturing the space where these issues occur allows those in BIM and planning to identify the problems and make necessary changes to avoid perpetuating the issue. It can also be used to identify deviations from coordination, giving those impacted a chance to recoup any associated costs.

> ROI Focus: Documenting changes to BIM means and methods that are a result of this workflow and earmarking the change orders generated is essential when assessing the impact of this type of situational review

Creating VR Environments

Since VR software started supporting point clouds, programs have become available to produce quick digital meshes. Now, reality capture has become a quick and effective way to produce virtual environments for planning, training, and design purposes. The basic workflow is to use reality capture equipment, transfer images into a digital mesh, and put that digital mesh into a program that can display that format. Some programs based on Unity and Unreal Engine (programming platforms) can support point clouds, so at this point, even making the digital mesh is not always necessary.



ROI Focus: VR environments provide a safe and effective replacement for training within hazardous or remote work areas or activities. While drawings and models offer similar opportunities, studies find that immersive environments provide significantly higher rates of knowledge retention.

As-built Documentation

For as-built documentation, many clients will specify the level of detail required. If you are dealing with LODs that are in the 400 and 500 ranges, it will require point burst reality capture with a laser scanner. If the LOD is in the 200s or 300s, LIDAR and photo-based scanning will likely be adequate. Typical contracts will often only ask for red-line drawings on the existing PDFs. These have a very low level of accuracy and detail. In addition, producing the redlines can be a challenge on jobs where significant changes have occurred, and several drawings would need to be compared to create the redlines. In cases like this, offering low-resolution scans, formatted to plan view, can be a more accurate and useful alternative. The creation of these scans can often be accomplished in a fraction of the time needed to gather information for red-line drawings. Even if redlines are required documentation, the use of low-resolution scanning and photo documentation can provide draftsmen and other modelers the information they need to draw up a simple 2D as-built.

When the requirements are at LOD 400 or 500, it is worth asking if the client will accept the point cloud overlay on the model as as-built. Particularly for the locations of smaller and incidental items like hangers and supports. Excluding those items from the modeling requirements can create significant savings.

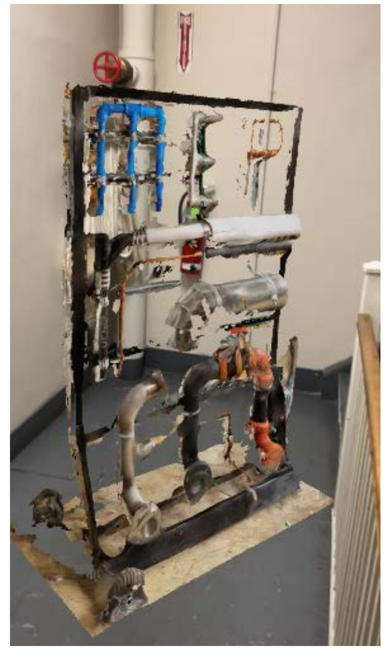
Reality capture of a building done in a one or two-day operation can take weeks to translate into BIM objects. There are several products and solutions on the market for this. FARO's As-Built and Edgewise’s ClearEdge 3D are two popular products that focus on MEP and structural items. These solutions will allow quicker translation, turning your scans into digital objects.

The other option is to change point data to digital meshes. This can be done with programs like Cintoo. The focus in performing these translations should be accuracy and fulfilling the client’s expectations or contract requirements. Communicating to the client the cost impact of as-built requirements is also important along with getting an understanding of how as-built information will be used after the project. It is common for clients to require as-built information they do not have the ability, or even the desire, to use.

ROI Focus: As-builts are often a barrier to final payment and are a part of the BIM or drafting work that doesn't give a return on project execution. Minimizing efforts in this area cuts direct costs and adds to the available time in BIM. The level of data captured by scanned as-builts often lends itself to more use than the traditional red-line drawings and can be used as an incentive for further work..

Relocation of Existing Equipment

One of the easiest ways to gain value from using scanning devices is found in the virtual relocation of equipment. By scanning existing equipment at its current location, separating that scan into a mesh, solid model or even a point cloud itself, and moving it to a new location. This function is one of the focuses of the LIDAR currently available in the Pro product lines of both the Apple iPhone and iPad. These products use augmented reality to locate the scanned items in a space. While this is fast and convenient, for this to be useful at a fabrication level, the scans need to be captured by laser equipment capable of picking up smaller mechanical details.



iPhone Pro AR relocation to check clearance needed to get skid up stairs

ROI Focus: This method is quick and improves confidence that equipment will fit accurately in their proposed new location. It can reduce measurement requirements for relocation projects. Visual representation also enables machine users to comment on potential practical issues before moving the equipment.

Business Development and Marketing

Scans can be a great way to represent existing renovations and environments to potential or existing clients. The ability to communicate intent and visualize areas of work can go a long way toward securing a contract, as can the additional capabilities that come with the use of reality capture. However, the creation of visually stunning point clouds introduces a significant number of challenges in terms of equipment, software, and operator training. It can be a significantly more expensive point cloud to produce compared to those used in the other workflows. For this reason, this is one of the few workflows where we recommend outsourcing. A lower-cost alternative can be the use of panoramic photo-style walkthroughs with modeled objects superimposed.

Service contractors or companies that perform facility maintenance find it easy to take a 3D scan for their existing customers with low-level scanners like the Matterport. They can then share the scans with customers to provide an as-built scan of their building. Allowing them to communicate effectively on upcoming service work, know what equipment is already in place and add work orders to equipment. Service techs working on the equipment in the future will have a record of the previous service.

ROI Focus: The focus is on getting work and generating client interest in what you and your technology can do for them. Reality capture can be a significant differentiator for your business.

Photo Panoramic Walkthroughs

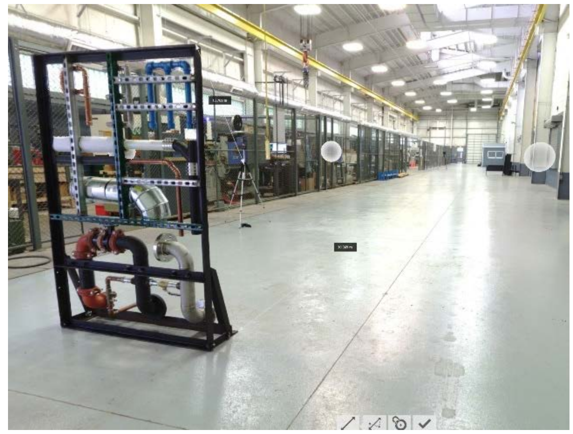
The panoramic walkthrough is a great way to share reality data easily. In many cases, relating the information gathered by reality capture can be difficult and involve specialized software.

This is not the case with panoramic photos and walkthroughs that can be accessed via a web page and have many tools needed for basic measurement and planning. The files created are also significantly smaller than those made by both digital meshes and point clouds. Most laser scanners include the option to produce a panoramic as a smaller export file.

ROI Focus: For this workflow, the focus is on limiting time spent in overhead, sharing reality data, and making the data easier to use.

Comparison Testing

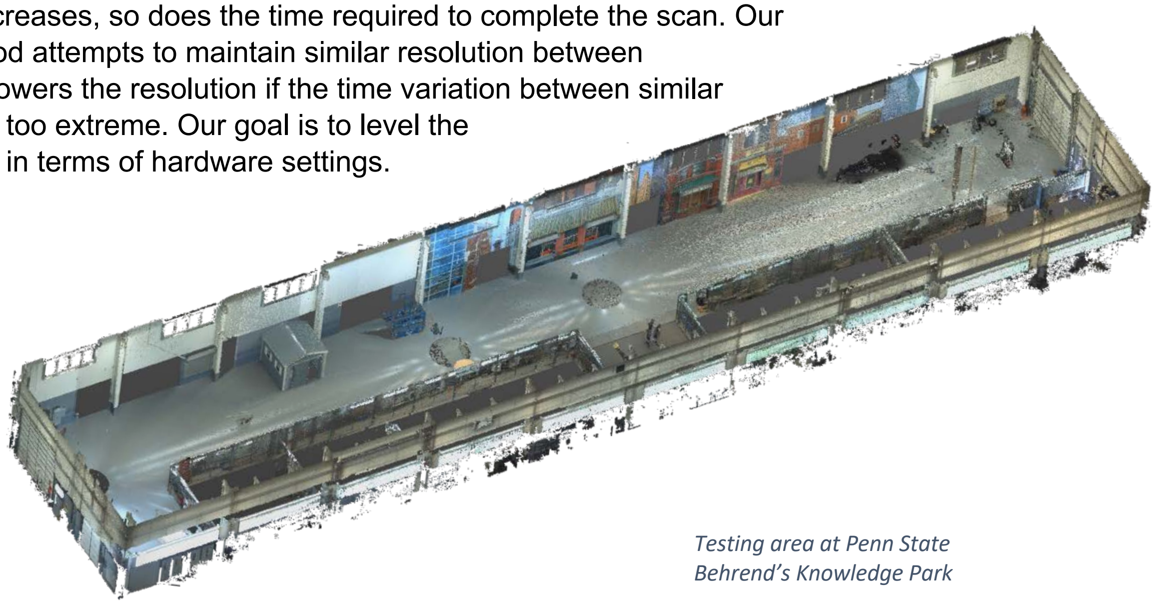
Purpose: It can be difficult to determine what output to expect from various scanning and reality capture equipment.



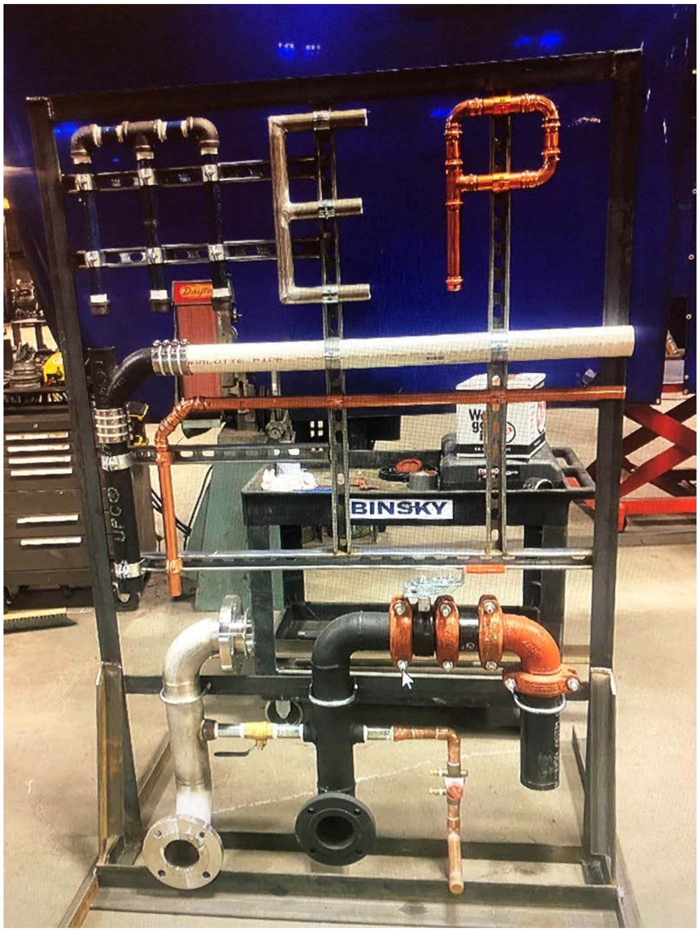
The quality of the scan data is determined by surfaces, colors, shapes and reflectivity. Almost all the examples provided by manufacturers tend to vary considerably in content. In addition, post-processing, lighting and editing can clean up data sets and give a false impression of performance. For this purpose, we decided to create a common real-world data set to test equipment against. With the Permission of Penn State Behrend, we also were able to use a test space within their research and business park, Knowledge Park, that provided consistent lighting. All equipment was therefore tested in identical conditions.

It should be noted that the scanning was done in a conventional way, involving no special workflows. It is not possible to be completely consistent with the workflow used given the different styles of scanning equipment, but efforts were made to normalize the process as much as possible. This can cause the points to appear lacking in refinement and filtering. This is done intentionally so post-processing can be addressed separately from the hardware test.

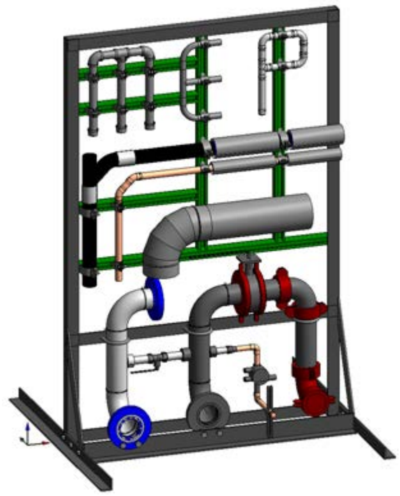
We recorded the distance from the skid and used the manufacturer’s recommended settings for that distance. Most scanning equipment can be set to scan at much higher resolutions, but as resolution increases, so does the time required to complete the scan. Our testing method attempts to maintain similar resolution between devices but lowers the resolution if the time variation between similar equipment is too extreme. Our goal is to level the comparisons in terms of hardware settings.



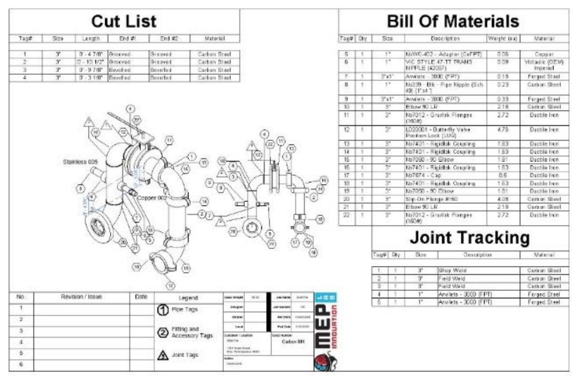
Testing area at Penn State Behrend’s Knowledge Park



Skid at Binsky Mech Fab shop



Original Revit Model



Spool for Prefabrication

About the Test Skid

The test skid was prefabricated and assembled for MEP Labs by Binky Mechanicals fabrication shop. The skid plans were generated in Revit (LOD 400) along with detailed spool drawings. The skid was designed to have a wide variety of surface types and materials, all relevant to the MEP trades. The other major design concern was mobility. The skid was designed to fit the bed of most pickup trucks and easily fit on a trailer. Finally, wheels were added for ease of movement due to the weight of the skid.

Packed for transport

Scanners and Equipment:

Trimble X7	
 Trimble X7 (Image by BuildingPoint)	
Scanner Type	Time of flight
Mounting Accessories	• Tripod • Boston Dynamics Spot • Custom carts
Cost	$40,000 (Including tablet)
Registration Software	Trimble RealWorks Autodesk ReCap
Pros	• Price point • Mobility • On-site registration • Low point density highlighting • Easy tie in to local survey points • Shares a battery with other Trimble total station products. • Remote operation
Cons	• Reduced range vs the TX8 • No onboard control panel • Requires tablet for operation
Conclusion	• The Trimble X7 is an affordable scanner that will allow for timely accurate scans. It is a leader at this price point and supports most MEP reality capture workflows.

Trimble TX8

Trimble XT8 (Image by Trimble)

Scanner Type	Time of flight
Mounting Accessories	• Tripod
Cost	$76,500
Registration Software	Trimble RealWorks Autodesk ReCap
Pros	• Reducible scanning area • Rapid Scans • Direct link/Wired power options • On Screen options • Rugged case
Cons	• Size • Weight • Does not include camera so point files are gray scale.
Conclusion	• Trimble XT8 is more targeted to long distance exterior scanning • Trimble X7 is likely a better choice for MEP workflows

GeoSLAM ZEB HORIZON	
 GeoSLAM ZEB HORIZON (Image by Spar3D)	
Scanner Type	LiDAR
Mounting Accessories	• Handheld • Vehicle Mount • UAV
Cost	$53,000
Registration Software	• ReCap • GeoSLAM
Pros	• Rapid Scanning • Minimal registration • Ease of use • Lightweight • Scanning range
Cons	• Low Resolution • Use limited to 20-minute bursts
Conclusion	The GeoSLAM is targeted at high-speed low resolution reality capture. This is very effective for exterior site measurements and General information, but lacks the accuracy to needed for several of the more common MEP workflows

FARO S70	
 FARO S70 (Image by FARO)	
Scanner Type	Phased Based
Mounting Accessories	• Tripod • Drone • Boston Dynamics Spot
Cost	$40,000
Registration Software	• SCENE • Autodesk ReCap
Pros	• Price point • A high volume of points • Weight and size • Onboard control panel • Remote operation • Ease of use
Cons	• Impractical to run while wired • Limited range • Longer scan durations
Conclusion	The FARO S70 is an affordable scanner that will allow for timely accurate scans. It is a leader at this price point and supports most MEP reality capture workflows.

Matterport Pro2	
 Matterport Pro2 (Image by Matterport)	
Scanner Type	Photogrammetry
Mounting Accessories	• Tripod
Cost	$3,000+($70-$309) per month
Registration Software	• Matterport App
Pros	• Rapid Scans • Low Cost • Ease of use • Clarity of 360 photos • Cloud accessibility to data • Effective for room to room scanning • Effective in finished environments and areas where reflective surfaces are common
Cons	• Lacks accuracy and options needed to clean up por quality data • Subscription for registration software • Limited active projects • Minimal accuracy of mesh • Indoor use only
Conclusion	The Pro2 provides effective photo panoramic and basic measurements. It is a good option as secondary equipment to laser scanners.

iPad Pro w/ LiDAR and iPhone 12Pro	
 (Image by Apple)	
Scanner Type	• LiDAR • Photogrammetry
Mounting Accessories	• Handheld
Cost	$1,000 to 2,000
Registration Software	• Several apps available 3D Scanner app was used for testing
Pros	• Easy to use • Versatile • Synchronize with AR capabilities • Ever growing selection APPs
Cons	• Low-Quality Scanning • Not capable of easily scanning large areas
Conclusion	The Apple Pro Series products with LiDAR offer a great deal of possibilities for small areas and equipment scanning. The AR integration opens many possibilities.

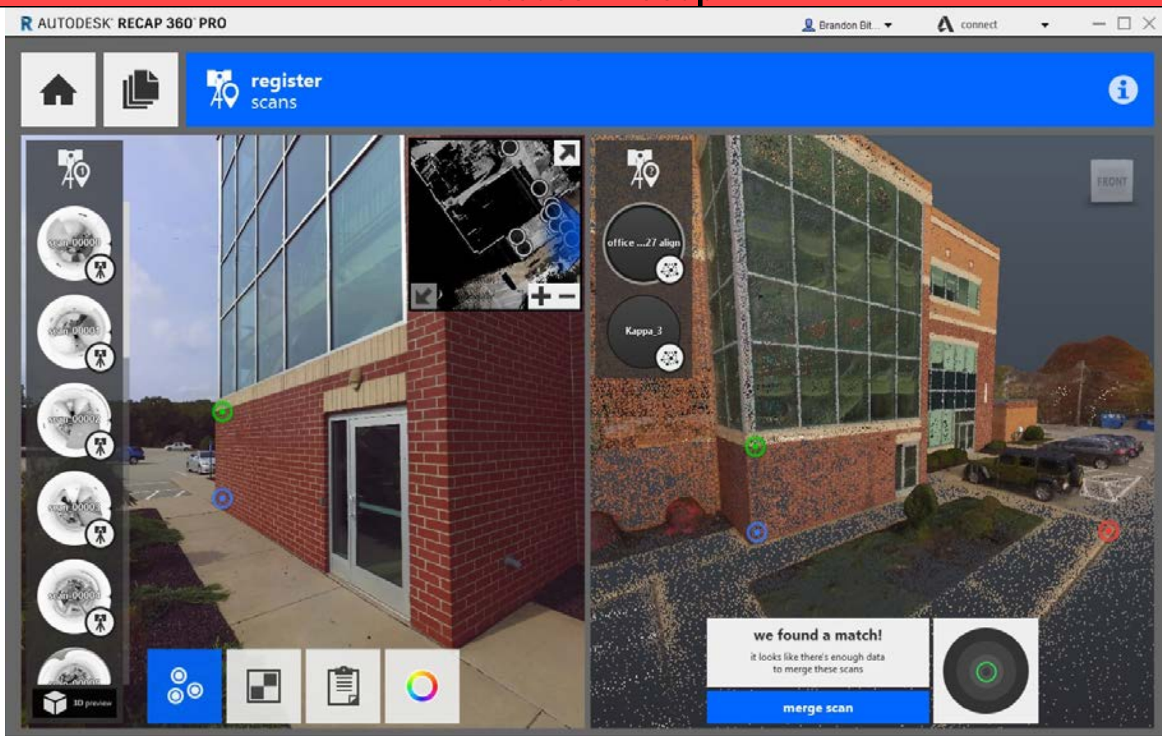
Insta360 One X

(Image by MacRumors)

Scanner Type	• Photogrammetry
Mounting Accessories	• Handheld • Tripod
Cost	$400
Registration Software	• None Specific
Pros	• Cost • Size • Ease of use • Video options • Large number of product integrations
Cons	• Accuracy of data • Clarity of photos and video
Conclusion	Provides effective photo panoramic and basic measurements. It is a good option as secondary equipment to laser scanners.

Registration Software:

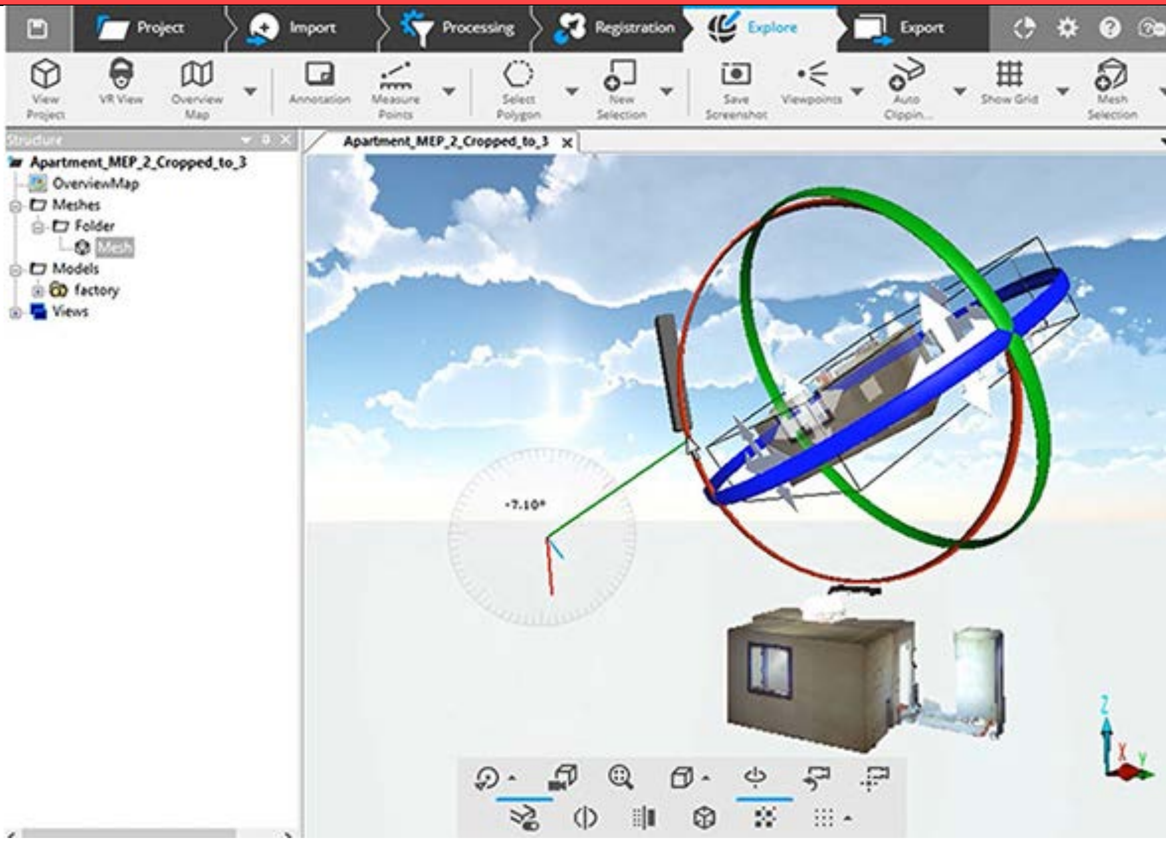
Autodesk ReCap



(Image by Autodesk)

Description	
Cost	$880 (3 years)
Compatibility	•
Pros	•
Cons	•
Conclusion	

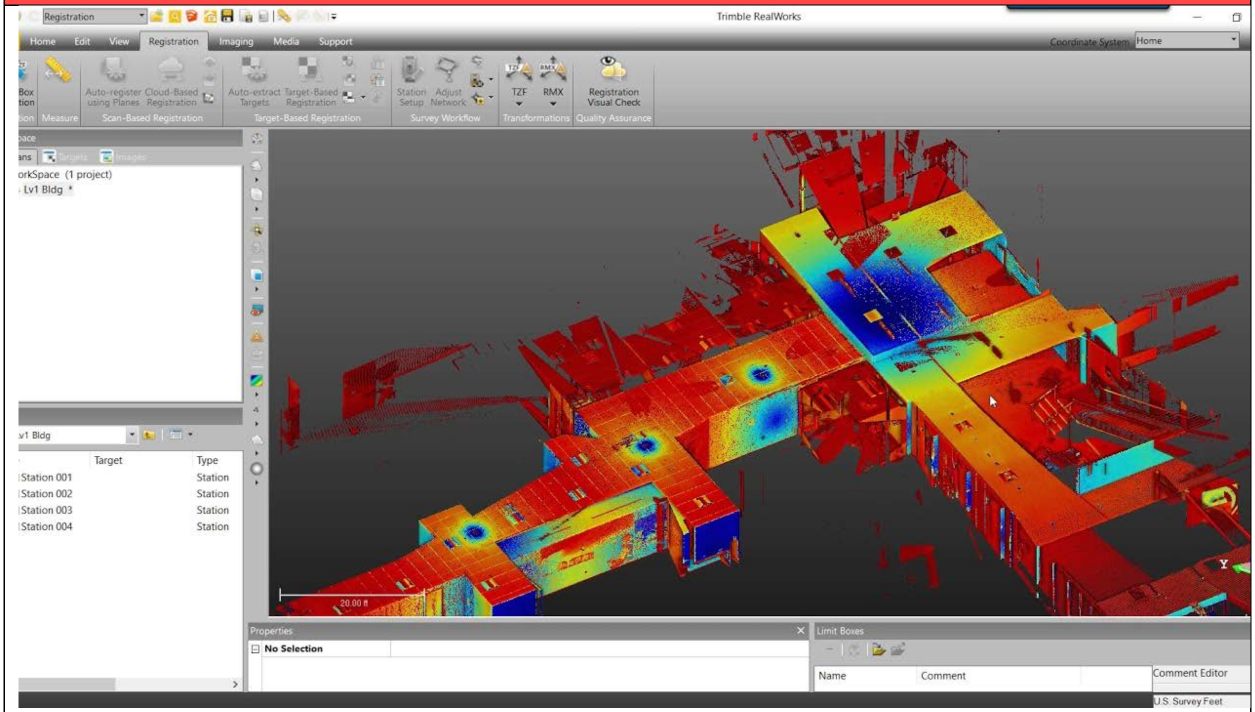
FARO SCENE



(Image by FARO)

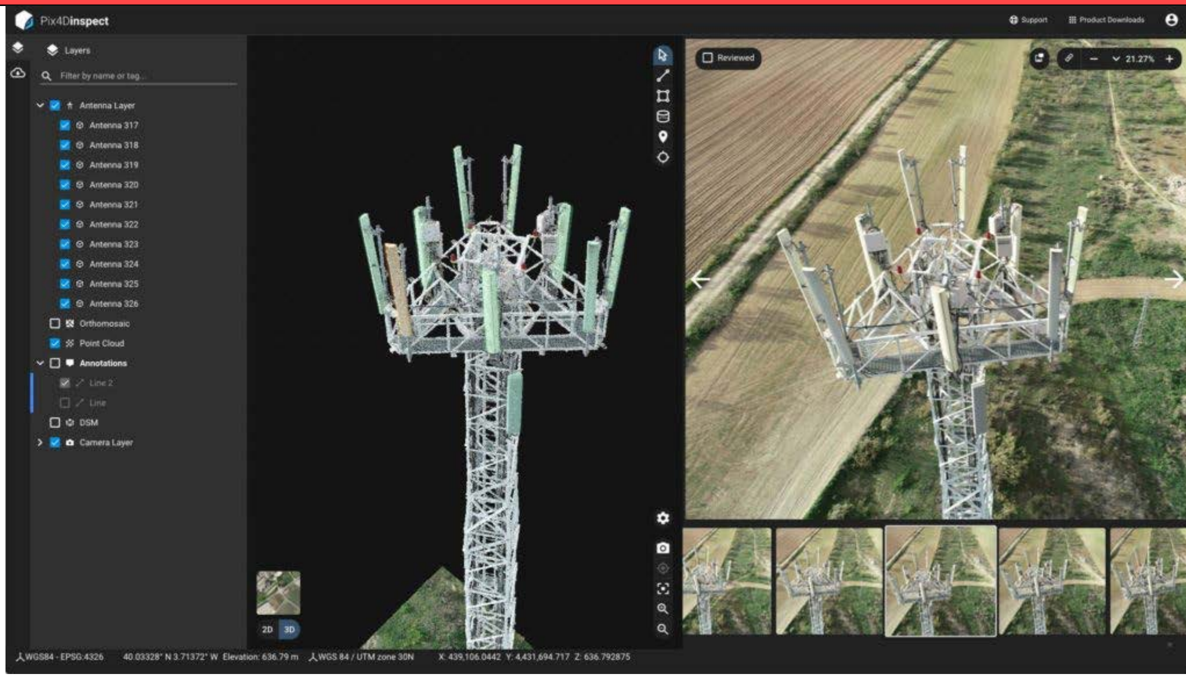
Description	
Cost	$6,110
Compatibility	•
Pros	•
Cons	•
Conclusion	

Trimble RealWorks



(Image by Trimble)

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 the automatic extraction of spheres and placards for registration, as well as feature-based registration.
Cons	RealWorks has a slow import for non-Trimble scanners. Registers either using targets or just features, not a combination of the two for extra references.
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 (a lacking combination of targets and features), it can handle registration of hundreds of scans together.

Pix4D	
 (Image by DroneLife)	
Description	
Cost	$160+ /month
Compatibility	•
Pros	•
Cons	•
Conclusion	

Cyclone

(Image by Leica Geosystems)

Description	
Cost	$850 /year
Compatibility	•
Pros	•
Cons	•
Conclusion	

Conclusion

The hardware and software evaluated in this report are a snapshot of their capabilities as of July 2021.

While the research was performed using processes as scientific and repeatable as possible, new software updates, improvements and capabilities are constantly being added. Any guidance from this report is meant to be paired with your own evaluation and experimentation.

As new products come to market or evolve, this report will be updated. While the report mentions that most of the equipment has a 5+ year useful lifespan, older models of the equipment were not evaluated in this study.

For questions regarding the report's findings or to request research be performed on new 3D scanning equipment, please contact Sean McGuire at MCAA.

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