Trimble Buildings

Laser Scanning for an Integrated BIM

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Introduction

The application of laser scanning technology has been popular in the geospatial and survey industries for many years now. However, recent advances in hardware technology and building information modeling (BIM) are helping to usher in a new level of scanning utilization for the building construction industry. Scanning for building construction is being applied most often to existing structures, but is also seeing an advent of applications relating to new construction work. Scanning technology is becoming a critical function necessary to complete the integrated BIM cycle and provides a clear value-add for the integrated BIM workflow.

This paper will serve as a practical guide to understand how scanning technology can be applied to the BIM workflow for building construction. Throughout this document readers will begin to see and understand the many different ways that scanning technology can be used to optimize the building construction process, while also reducing project risk, cost, and time to complete. It is the author's intent that readers of this paper will come away with a practical understanding of applications for laser scanning as it relates to object models and their utilization in BIM.

To understand how scanning technology can be applied to the integrated BIM workflow we must first take a moment to understand what laser scanning is and what basic functions it intends to serve. At the highest level, scanners are used to send out a high density of laser beams for the purpose of positional measurement. Laser beams project outward from the scanning hardware and are measured in time of flight or phase shifts as they return to the source. The hardware measures the return time of the laser and can tell how far away a physical element is. Current scanning technology has the ability to send out thousands of beams per second, resulting in a "point cloud" of data. Scanners can also identify the R,G,B color value for a more intuitive display of point cloud information. Resulting point clouds can include millions, even billions, of data that reflect the physical environment being scanned.

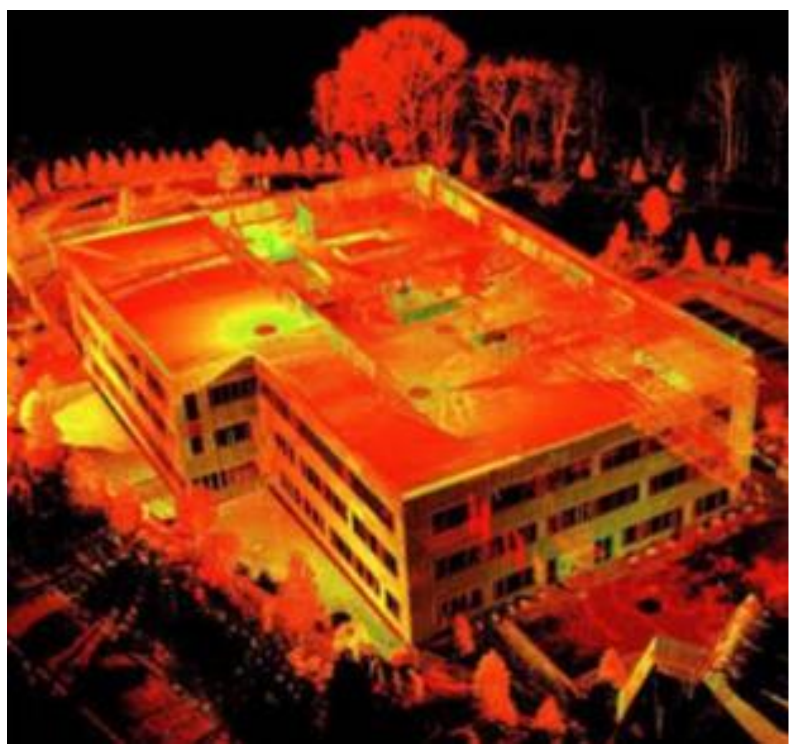

Figure 1: Building point cloud

Planning

Point clouds resulting from scan data are immensely powerful for analysis on their own; however this paper assumes that the point clouds will be converted to object-based BIM models. Converting scan data into BIM models is traditionally a three step process: First, multiple scans are captured from different scanning stations. Second, data from multiple scanning stations is stitched together in what is commonly known as the post processing or registration stage. Next, CAD or BIM software can be used to author object models while referencing the point cloud. Some registration software, such as Trimble RealWorks, has the capability to create content from within the point cloud by running algorithms across the data points and recognizing surfaces from it. Creating objects within the registration software offers the benefit of rapid creation but has some limitations surrounding the accuracy and metadata acceptance of modeled objects. Creation of object models using external authoring applications is slower and more manual but has the benefit of detailed object representation and increased metadata acceptance.

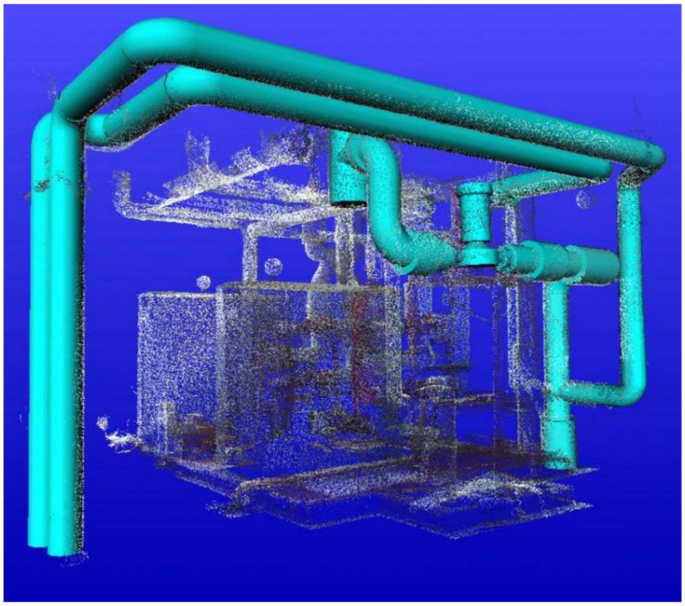

Figure 2: Point cloud with object hybrid

Scanning can be a time consuming endeavor, resulting in very large and/or complex datasets, so it is recommended that any team wanting to apply scanning technology plan their effort very carefully. First, the desired outcome of the scanning application should be clearly identified. In many cases the desired outcome is to identify precise locational (X, Y, Z coordinate information) about physical work in place. Next, a team must consider what they will do with the knowledge that comes from the work in place information. For example, 3D information is often used in design validation. Further, element information can be leveraged to extract 4D time information and 5D cost information. Last but certainly not least, objects can be further populated with 6D facility management information. Detailed examples of each use case will be outlined further along in this paper.

A scan plan should be made after the project objectives have been clarified. A scan plan is a set of information that outlines the scope and approach that will be taken to capture the data on-site. Often times a scan plan starts with detailed analysis of precisely which elements need to be captured. In the case of scanning new work in place most scanners will desire to capture the position of each and every element. In the case of renovation work, scanners will often have specific scopes of work about which they need more information. Identifying the exact scope of elements to be scanned helps the on-site team to prioritize their efforts and mitigate time spent capturing unnecessary elements. With a clear scope in mind a document can be created that identifies the optimum equipment location necessary to capture the desired information.

Figure 3: Scan plan with stations identified

As well as knowing which elements to capture, scanners will also want to know the precise level of detail at which the information should be gathered. Many projects will recognize that there is only a significant need to capture elements of a certain size, such as 2” and above. Attempting to capture smaller elements is often impractical and unnecessary. With these tolerances in mind the scanning hardware can be dialed in to precise operational settings to regulate the fidelity of the laser beams, which is known as the resolution and quality settings.

During the scanning process a series of targets will be used to assist in the post processing effort. Targets for scanning can be paper-based hatching patterns that are placed onto a flat surface or spherical objects that can be set onto a surface. The intent of targets is to provide a minimum of three common points of reference across scanning locations so that each reference can be joined with its previous scan presence. Increasing the number of common targets increases the accuracy of the final registered scan. Failing to have enough targets can greatly hinder the post processing effort and will result in a low quality registration. Further, failing to have enough targets may require additional site visits and cost. Proper target placement is fundamental for successful scanning!

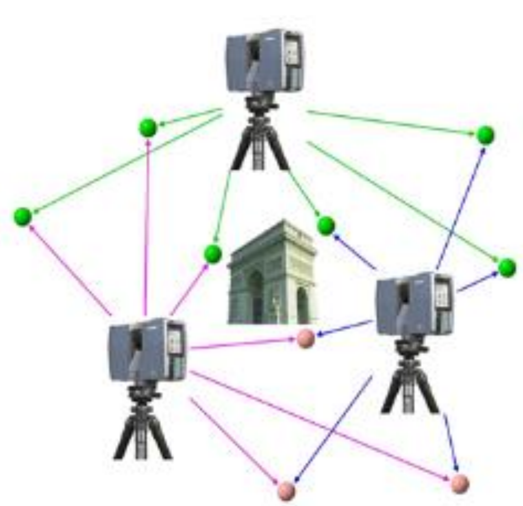

Figure 4: Connected scanning targets

3D Modeling

Once on-site scanning is complete and the multiple scans have been registered together, the object model creation process begins. Again, object creation can occur in the registration software or in external modeling applications. The choice of which tool to use for modeling should depend upon the desired scope outcome. For detailed scopes, such as complex structures, specific authoring applications like Tekla, Revit, and ArchiCAD are often used. Less detailed scopes can be very quickly represented using authoring applications such as SketchUp. Using external authoring applications requires a methodical approach to model creation whereby elements are created systematically and in order of importance pertaining to the scope. Attempting to recreate every single element in a single area can lead to loss of focus and failure to meet the broader objective. Many projects will see that structures are modeled first; existing to remain architectural features modeled second, and mechanical systems follow. In the case of renovation work, modelers will be well advised to include some kind of "existing to remain" delineation so that those model elements can be viewed separately throughout the BIM use cycle.

The existence of 3D models immediately opens up an abundance of use cases for the new data. One very common use case is the creation of traditional 2D documents in areas that were not otherwise documented. 2D documents can be shared with other project team members to convey the complex scan data in a more traditional and familiar way. Through the use of 2D documents, or the model itself, design creation or validation can take place. Architects or engineers are able to reference the as-built data to create designs that complement the existing constraints. In the case of design validation, new design information may already exist and is cross-referenced with the existing conditions to look for discrepancies.

Of special importance for design validation efforts is the support of the coordination process. Oftentimes renovation projects include a mixture of existing to remain elements with newly placed elements. The scan and model data is capable of providing detailed information about points of connection that may exist between these two work scopes. Having exact points of connection between the two work scopes allows for a more accurate coordination process.

Stemming from accurate coordination is the ability to prefabricate. Many project subcontractors are very sophisticated in their ability to create physical work assemblies in off-site locations and then bring them on-site in large clusters for rapid installation. Prefabrication offers many benefits, including safer working conditions, controlled environments, and automated machine usage. However, prefabrication can only be successful when used in conjunction with accurate information about the destination of the final installation, which laser scanning provides.

Also stemming from accurate data capture and coordination is the ability to easily check for complex and nuanced code requirements, such as equipment clearances and ADA accessibility. Understanding existing to remain work and how it will interface with new work allows modelers to pull detailed measurements from within the BIM to ensure that tolerances can be satisfied. Code and tolerance checking is of fundamental importance to project success because use and occupancy permitting will be withheld by local inspection authorities if the minimum requirements are not satisfied, thus resulting in delays and cost overruns for the project.

4D Scheduling

Having an accurate 3D representation of elements from scanned data allows for further use of the data when considering the 4D time aspect associated with each construction element. Specifically, the quantity and position of each element can be leveraged to create detailed location-based schedules. Location-based schedules have a significant advantage over traditional schedules in that in they use detailed quantity and position information to represent the true work volume and position to take place during construction. Location-based scheduling is a concept that further extends into the ability to perform production control on-site and make teams proactive when managing a project schedule. The combined pro-activeness of scanning information and production control is a key component to mitigating schedule delays on renovation projects.

A significant increase of schedule accuracy arises when delineating the schedule activities associated with existing to remain and new work because the separate scopes require different work tasks. For example, in the case of new ductwork tasks often include the: setting of hangers, placement of duct, sealing of connections, insulating and testing. On the other hand, existing to remain ductwork tasks include the: stripping of old insulation, cleaning and reinsulating. Only one of these sub-tasks, insulation, has a consistent production rate across new and existing work and so should be clearly delineated. Further, a different subcontractor may be required for the cleaning task and will need to be brought into the work plan and managed on-site.

Additional variances in schedule activities may be recognized when considering tasks such as connecting newly designed pipe systems to existing pipes. In the case of these tie-ins, it may be necessary to isolate, shut down, drain, and make safe the existing pipe system before a new connection can be made. Because pipe systems often stem from a central location or plant, the shutdown of a system for a new connection in one location can have a dramatic impact on downstream functionality of the pipe system. An additional challenge could exist when making these sorts of tie-in connections is the discovered that the existing to remain pipes are not of suitable quality and have to be replaced. Therefore, scanning and scheduling renovation work prior to commencement should offer the opportunity to put schedule buffers surrounding tasks that integrate new works with existing works.

The combination of scanning and scheduling has already demonstrated significant benefit in specific cases of phased renovations of occupied spaces, including renovations of healthcare and manufacturing facilities. Scanning of work allows for a macro view of the mechanical systems than is often not available when "poking around" in an occupied space before construction. The macro perspective of the system allows for a more insightful schedule plan, again because the system uptime and performance can be viewed as a whole and then accurately delineated into the individual work spaces using the location-based methodology of scheduling. Using integrated software for these purposes, such as Vico Office, also allows the planner the ability to produce schedule simulations. Schedule simulations are a great way of communicating to owners how construction work will impact their facility. This offers significant value to building operators who must accommodate for shut downs by maintaining new paths of travel across the facility, or new locations for production equipment uptime.

5D Quantity and Cost

Scanning of work before construction has also proven to be a value-add as the quantifiable information coming from 3D elements allows for more detailed cost planning, or 5D as it is called. Scanning of work produces the 3D models and allows for the accurate delineation of cost assemblies associated with new and existing work. Cost components relating to the two different phases of construction may include different unit rates, different crews and different cost buffers in order to arrive at a more accurate project estimate.

Similar to the duct example above, different work activities will be performed on new vs. existing to remain scopes and so will have different unit rates tied to the quantity of work. A unique line item for the cleaning of duct would be necessary for existing to remain elements, yet there need not be a cost line item for the placement of hangers and sealing of such duct work. It could also be recognized that the production rate, which is ultimately multiplied by the unit cost, for insulating new vs. existing duct may be different because existing ducts can be more challenging to access and so will have lower productivity.

Code	Description	Source Q..	Consump..	Waste	Qty	UOM	Unit Cost
000	Office building w MEPF	1.0	1.000	1.000	1.0		41,594.97
D	Services	1.0	1.000	1.000	1.0	-	41,594.97
D30	HVAC	1.0	1.000	1.000	1.0	-	41,594.97
D3050	HVAC Supply Air	1.0	1.000	1.000	1.0	-	41,594.97
23.31.13-ETR	Duct - Existing to Remain	1,352.0	1.000	1.000	1,352.0	SF	3.40
LDUC102	Duct - Cleaning Labor	1,352.0	0.050	1.000	67.6	HR	35.00
M23.07.13	Duct - Insulation	1,352.0	1.000	1.100	1,487.2	SF	1.50
23.31.13-NW	Duct - New Work	6,281.0	1.000	1.000	6,281.0	SF	5.89
LDUC101	Duct - Installation Labor	6,281.0	0.100	1.000	628.1	HR	35.00
M23.07.13	Duct - Insulation	6,281.0	1.000	1.050	6,595.1	SF	1.50
M23.31.13	Duct - Material	6,281.0	0.130	1.020	832.9	LBS	6.15

Figure 6: Cost plan of new vs. existing duct work

Savvy contractors have also found a way to be more precise when applying cost buffers to renovation work after scanning. All contractors recognize that there are many unknowns when doing renovation work and so put a buffer on the project cost to account for the unknown. Scanning and modeling the work before execution allows for the cost buffers to be tied to the actual quantity of work which is existing and/or new, and so may have a less dramatic impact on the overall estimate. Accurate vs. broad cost buffers tied to an estimate can be the difference between being awarded a project and losing a project.

6D Facilities Model

A clear benefit to laser scanning can be identified when considering the final deliverables that will go to the owner at the end of a project. Owners are responsible for operating the facility throughout its lifecycle and so are very interested in having as much detail as possible about the as-built condition of the building. Laser scanning can be applied at various stages of work commencement to measure the final position of work installed. Final element position can then be cross-checked with the BIM to ensure that the handover model truly reflects the installed position. Understanding the installed position of elements from the model allows facilities operators to be much more calculated when addressing problems because investigation can be performed from within the facilities office, rather than up a ladder in an occupied space.

Scanning at the end of work phases may sometimes require multiple scans due to the limitations of site that occur as systems become layered atop one another. This can present some unique challenges to the team managing the data and creating the BIM, however cases such as this present the optimum need for data capture and handover to the facilities team. Consider that if multiple scans are needed to capture and reflect element positions there is likely to be a scenario where facilities managers would be required to get “up into a space” to investigate problematic equipment that is located above other elements. This can be very unsafe, as there is rarely proper support up inside mechanical spaces for a human to navigate and rest upon when performing maintenance. Using a BIM model to investigate the space beforehand allows the maintenance personnel to be more tactful when planning their approach to the physical space and problem correction.

Several sophisticated owners have also opted to use laser scanning for the purpose of creating a facilities BIM model even when construction operations are not ongoing. This is because the sophistication of facility management software allow for a more proactive building management plan instead of the traditional reactive approach. Being proactive when managing the building offsets the cost of scanning because maintenance is done in a pragmatic manner beforehand and is significantly more cost efficient than emergency responses that include downtime.

Similarly, scanning may be performed on buildings that are not under construction for the purpose of capturing and maintaining historically significant features. It may be the case that a facility does not immediately have the funding to repair decaying features but can capture their condition before things get any worse. In this case, the scans can be retained and provided to the repairing contractor when funds are available for fixes, and the contractor has the ability to reference the scan data prior to fixes being made.

Summary

The implementation of laser scanning brings an entirely new realm of possibilities to an already powerful integrated BIM workflow. The ability to capture detailed information about elements in their physical space allows for more precise use of data. Whether capturing 3D information for coordination and prefabrication, or leveraging the quantity information for estimating and scheduling, laser scanning is surely a necessary endeavor to increase the accuracy of project information. Decreasing hardware costs and increased software capabilities have made scanning a competitive advantage for contractors willing to invest the time and effort into this fully integrated BIM workflow.