Using Laser Scanning to Determine As-Is Building Conditions

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When developing design documents for improvements to existing spaces, architects often rely on as-built drawings of existing structures as the basis for design. However, there are often discrepancies between as-built drawings and as-is building conditions. These discrepancies often lead to constructability issues that precipitate field modifications or design alterations, which in turn, can be a source of delays and increased project costs. To mitigate errors in as-built drawings, contractors have begun utilizing laser scanning to help generate as-built drawings that accurately depict the location of building components post-construction. This, however, does not mitigate the risk posed to the construction process by basing new designs on inaccurate existing as-built drawings. By utilizing laser scanning prior to the commencement of construction, designs drawings can be compared to as-is building conditions, allowing clashes and discrepancies to be identified and mitigated prior to installation. This paper presents two case studies where laser scanning was used before construction activities began to identify discrepancies between design drawings and as-is site conditions to mitigate conflicts associated with structural steel members.

Key Words: Laser scanning, as-built drawings, as-is conditions, clash avoidance, constructability

Introduction

It has been common in the construction industry for over 100 years to provide the owner of a project with a set of as-built plans upon completion of the project (American Institute of Architects 2014, January 21). The intent of as-built plans is to provide a set of plans that depicts the dimensions and locations of building components as they were actually installed. As-built drawings oftentimes begin with the construction documents used by contractors to construct the structure, but will include field changes and work altered by change orders. As-built drawings, however, often contain errors. Either changes in plans are not incorporated or contractors fail to update the final drawings to incorporate design or field changes. All to common, as-built drawings “produce too much information, the wrong kind of information, or both” (Clayton et al, 1998).

When repurposing a space, as is the case with tenant improvements, architects oftentimes start with as-built drawings as the basis of design. This allows the architect to start with a set of drawings that should represent the space as it currently exists. However, because of errors associated with as-built plans, they often do not perfectly represent the as-is condition of the building. The errors in the as-built plans get carried through into the next generation of construction documents. When contractors base a bid or proposal on plans with errors, field modification and change orders tend to occur, which can impact the duration and cost of the project.

To check the conditions of the construction documents provided by the architect and other design professionals, general contractors and subcontractors will often perform site surveys to verify field conditions. These site surveys may involve sophisticated surveying equipment, such as total stations, but they routinely employ rudimentary tools like tape measures. Imprecise methods of measurement oftentimes fail to reveal the errors in plans based on inaccurate as-built plans.

Once construction begins, these errors can metastasize into clashes between major building components, such as the building’s existing or retrofitted structural elements, mechanical, electrical and plumbing elements, building partitions, and many others. These clashes may require extra field coordination and change orders, which may lead to project delays, additional costs or both.

Constructors have been using laser scanning to improve the quality of as-built plans at the conclusion of construction activities. However, for buildings with existing inaccurate plans, contractors need a tool to confirm the as-is conditions of the building and to verify and correct the most current set of construction documents as necessary. This paper suggests that laser scanning is an effective means for determining the as-is condition of a building prior to construction, which in turn, allows contractors to uncover any design issues early in the construction process and mitigate any potential cost and schedule impacts. Empirical observations at two case study projects demonstrates that early laser scanning can avoid clashes and change orders and improve constructability.

Laser Scanning

Laser scanning is the use of a controlled laser beam to measure distances at every pointing direction to capture the shapes of the objects within and around a structure. A laser scanner works by rotating in a horizontal plane (typically 360-degrees) and in a vertical plane (typically 270- to 300-degrees), sending an invisible laser beam that reflects back from a surface. This is repeated millions of times per minute, sending spatial data back from every surface within the scanner's range and line of sight. "Targets", 3D (spherical) or 2D (flat checker board) reference points with known dimensions, are set to validate the spatial data being captured by the laser scan. Once the data points are captured, they are aggregated into a "point cloud" and assigned X, Y and Z coordinates. After collecting the spatial data, some laser scanners have the capability to switch to a digital camera and rotate 360-degrees once again to capture a high quality panoramic image of the structure being scanned.

The basic process associated with laser scanning is shown below in Figure 1. Laser scanning itself comprises of steps 1 and 2. Once the point cloud is created, it can be compared to both as-is building conditions and as-built drawings (should they exist). Lastly, building component geometry can be used to build fully functional building information models (BIM) that not only provide accurate dimensions of the as-is building, but precise locations of the building's components.

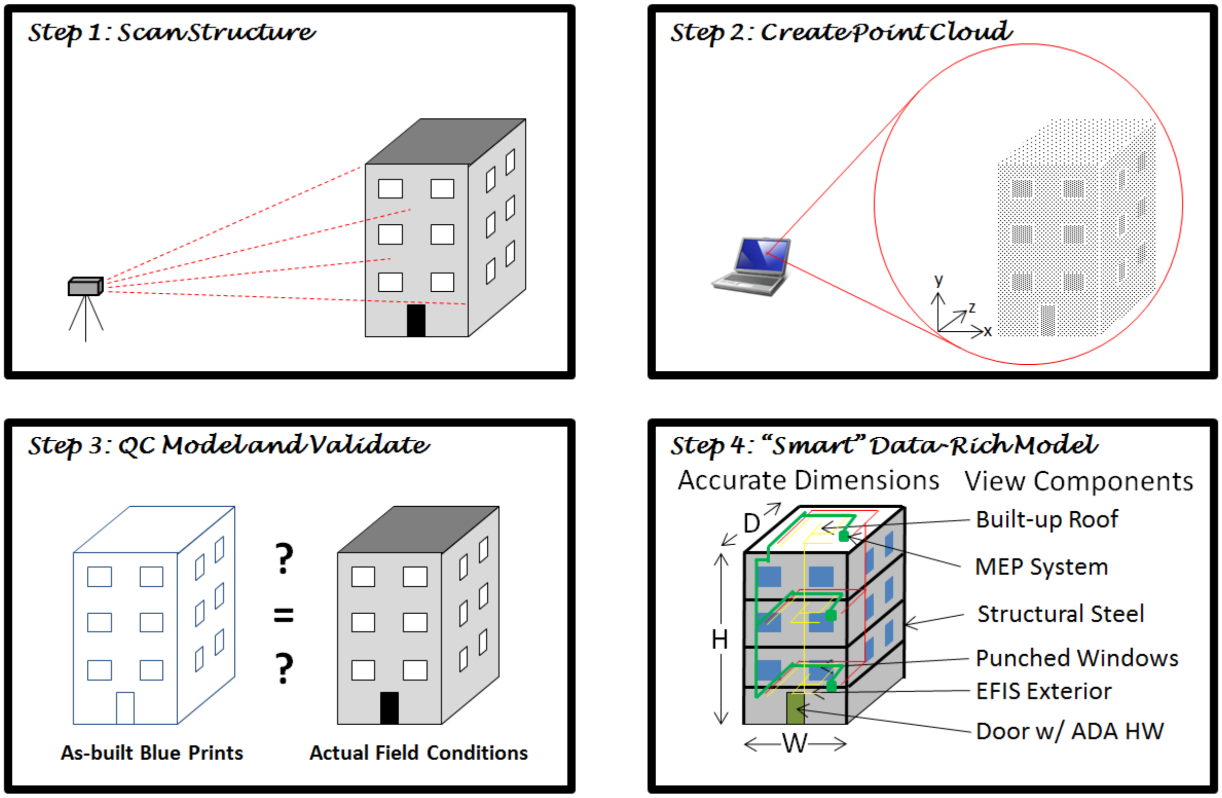

Figure 1: Steps For Creating a BIM Model from A Laser Scan

If the laser scanner can "see" a static object, it can image it. The quality of the scan is affected by the following variables:

- *Geometry of the targets:* Targets, either 2D, 3D or a combination of the two, should be set at varying heights and locations. The more random the target placement, the better the quality of the laser scan.
- *Distance of the Targets:* The closer the targets are to the scanner, the better the resulting scan.
- *Resolution:* The desired resolution for the scan can be set on the scanner. The greater the resolution of the scan, the higher the image quality.

The use of laser scanning was originally pursued to speed the collection of spatial data and improve its accuracy. There are differing types of laser scanning, including LIDAR and other terrestrial laser scanners that are primarily used to collect spatial data over large areas. By being able to scan large areas, resolution is sacrificed. Newer laser scanners have been developed for use inside of buildings that have the capability of quickly producing very accurate resolution scans.

Use of Laser Scanning in Construction

When first introduced to the construction industry, laser scanning was applied to transportation projects, such as roadways and bridges (Jaselskis, 2005 and Slattery et al, 2008) and monitoring excavations (Laefer et al, 2006). These initial studies highlighted some of the potential benefits of employing laser scanning as a surveying tool, but also some of the limitations, such as resolution and cost and time requirements. Initial uses of laser scanning in commercial building construction were applied to the development of post-construction as-built drawings (Tang et al, 2010, Giel & Issa, 2011 and Liu et al, 2012), but again, the benefits of the technology were presented alongside the limitations, such as accuracy. As adoption of laser scanning became more widespread, concerns regarding the accuracy of laser scanning persisted (Golparvar-Fard et al, 2011).

Most recently, however, improvements in laser scanning technology has shifted the focus of research away from questions of inaccuracy to those of making laser scanning more accurate and commercially viable and for specific uses, such as creating accurate as-built drawings (Tang et al, 2011 and Shen et al, 2013), better facilities management (Eybpoosh et al, 2012) and better streamlining of the laser scanning process to produce better as-built BIM models (Tzedaki & Kamara, 2013). This shift in research demonstrates that laser scanning is gaining in popularity and concerns regarding accuracy are waning.

While the bulk of literature regarding laser scanning involves its utility towards creating more accurate as-built drawings, laser scanning has been used to assess the as-is condition of existing structures. Laser scanning has been applied to determining the as-built conditions of bridges for purposes of inspection (Tang & Akinci, 2012), scanning building façades to monitor construction (Martinez et al, 2012) and measuring the scaling of concrete bridges caused by freezing weather (Mizoguchi et al, 2013). Anecdotal information collected by Jacobs (2007) shows that as laser scanning has improved, both in terms of resolution and cost, its use on projects to assess building conditions has increased, although these claims have not been substantiated by peer-reviewed studies.

The existing literature covers some of the commonly known benefits of utilizing laser scanning in the construction industry, focusing primarily on using laser scanning towards the end of construction to yield accurate as-built drawings. What is missing from the current body of literature is a discussion of how laser scanning is being employed to determine as-is conditions before construction activities begin and compare them to plans for proposed improvements of existing spaces. This is an application of laser scanning that is currently being employed by general contractors.

Method

Case studies involving the use of laser scanning on two projects are presented below. The author started with a pool of six projects for which laser scanning had been performed by a general building contractor within the past six months (approximately the time it had owned the laser scanner). Laser scanning for the six projects had been performed prior to the commencement of construction activities. Two of the six projects were not used as case studies because the laser scanning employed was for a limited scope of the structure (the roof for one project and an architectural arch for the other). Two additional projects were not used as case studies due to a lack of as-built drawings for which to compare the laser scans. The two remaining projects, both located in northern California, involved medical facilities that were to receive major renovations. These two remaining projects were similar in terms of project type, modifications to be made, owner, and end user.

Medical facilities are difficult projects in general due to an abundance of mechanical, electrical plumbing and other specialty piping and wiring coexisting in limited space. In California, seismic requirements and code compliance further complicate the construction process of medical facilities. The lead-time for design changes to be reviewed and approved by the California Office of Statewide Health Planning and Development (OSHPD) is long, so field modifications and design alterations are avoided if possible. Due to the complexity and space limitations created by mechanical, electrical and plumbing (MEP) and structural steel elements, field modifications and design alterations are time consuming and costly and often precipitate additional changes downstream.

Because only two projects were used, there was not a statistically significant data sample available to perform quantitative analyses regarding the cost to perform a laser scan, the cost/benefit ratio of laser scanning, the time required to perform a laser scan, etc. Even if all of the six projects from the original pool were used, the amount of data would still not be available in large enough sample sizes to draw statistically significant conclusions. As such, case studies were pursued as a means of demonstrating how discrepancies in as-built drawings can be revealed by laser scanning. While the lack of quantitative analyses is less than ideal, the demonstration can, nonetheless, be achieved.

Case Study 1: Ambulatory Care Center

The project includes development of an ambulatory care center (ACC) and administrative office space in an existing 160,000-square-foot office building. The existing space was previously occupied by a commercial bank. The general contractor’s scope of work included numerous seismic retrofits, removal of large concrete bank vaults, concrete deck in fills, a complete demolition of all interior partitions, leaving just the core and shell of the existing building. The revamped structure will house urgent care, laboratory, and imaging departments, as well as standard physician clinics and administrative support spaces. The project’s construction contract value was $24 million.

After demolition was complete, the general contractor utilized laser scanning to do a complete survey on existing walls and structural steel. The intent was to use this information in a BIM model for coordinating MEP installation activities. The output of the laser scanning also revealed that many dimension listed on the as-built drawings were incorrect and that structural elements were not located as indicated on the as-built drawings. Figure 2 demonstrates one of the particular discrepancies associated with an atrium. The deck along the edge of the atrium was actually two feet wider on one side of the atrium than was indicated in the as-built plans. The deck was also thicker due to the shape of the metal deck the concrete was poured into. The structural steel beam supporting the deck was also incorrectly located in the as-built drawings. The discrepancies around the atrium represent just one example of incorrectly located structural members. In other places, the location of the exterior walls and shear walls were incorrectly located in the as-built drawings.

For a project that involves a significant seismic upgrade, the location of structural elements is of high importance. Because of tight site logistics and constrained access into the building, structural steel elements had to be downsized to accommodate small access points. Structural steel coordination required tight control that would not have been possible if the new design was based on as-built drawings that did not properly represent actual field conditions. The spatial data assembled by laser scanning the building allowed for proper coordination of structural steel work and several other trades prior to the commencement of those work packages.

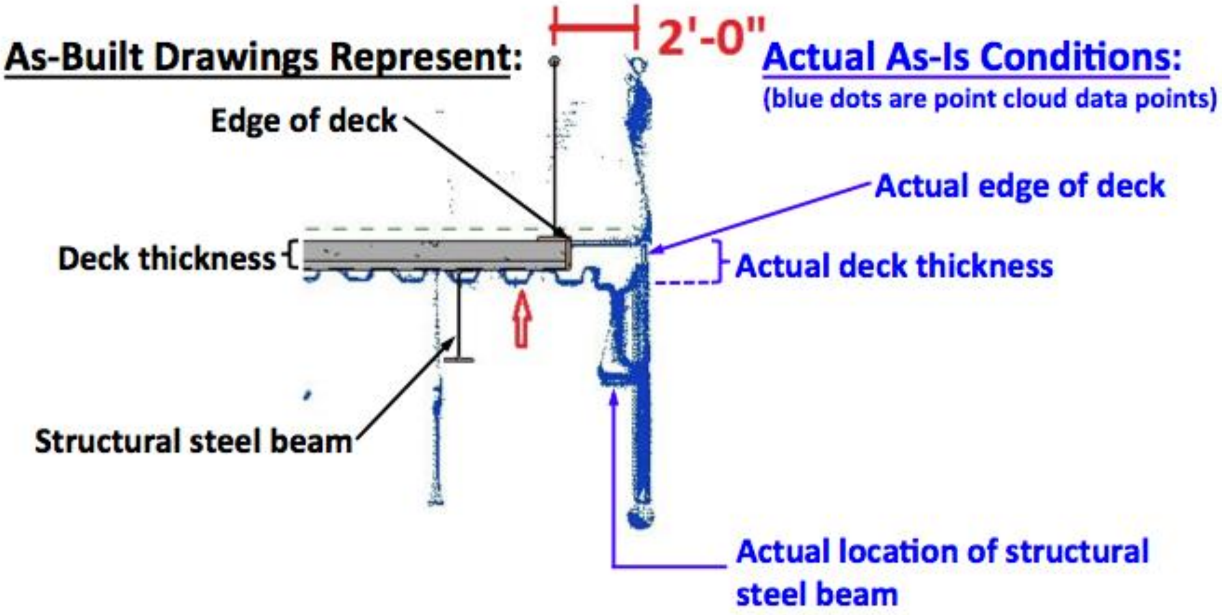

Figure 2: Dimensional discrepancies around the ACC atrium

Case Study 2: Medical Office Building

The medical office building (MOB) consisted of four floors of above-ground parking ringed by offices with a fifth floor that covers the entire integrated structure. The existing ambulatory service center (ASC) is on the fifth floor of the building and will be combined with the surgery center on the fourth floor, creating a combined upgraded center. The four-phase project will create five operating rooms, four procedure rooms and supporting spaces.

The top two floors of the MOB are in the design phase of a substantial renovation. Before construction documents were completed, the general contractor performed a laser scan of the space. The laser scan was then compared to the as-built drawings for the building from which the owner's architecture firm was working. The laser scan revealed that the structural steel beams were not installed with the proper upward camber, and upon completion of the building, the beams sagged several inches below the intended elevation, as depicted in Figure 3.

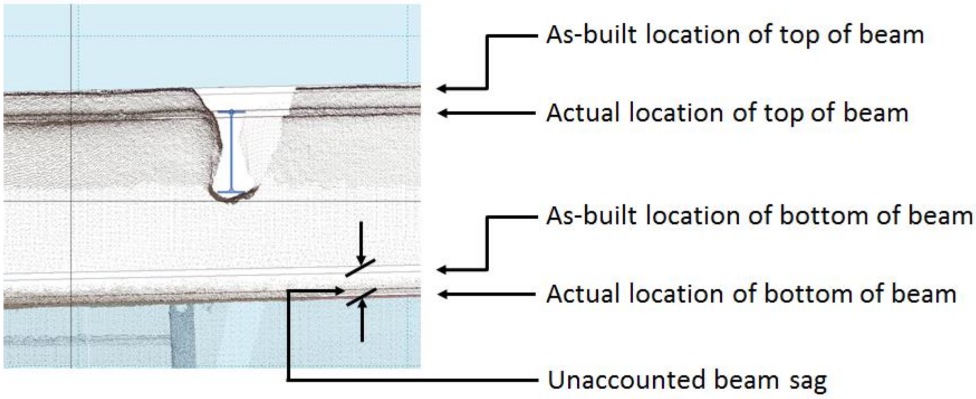

Figure 3: Discrepancy between the structural steel beam as located in the as-built drawings and its actual location as determined by a laser scan

The revelation that the structural steel beams were lower than indicated on the as-built drawings required a redesign of the ceiling heights inside the floor by the architect. The ceiling elevation was dropped to accommodate the high density of utilities necessary for a medical office. The discovery of improperly located structural steel beams in the field during construction would require substantial coordination among the project team and OSHPD approval, leading to additional costs and time. Discovering the discrepancies in the design phase led to relatively simple and cost-effective solutions for the client and avoided many of the typical problems that accompany inaccurate as-built drawings.

Results

In both of the case studies, it was revealed that the design drawings, which were based on as-built drawings from the original construction of the structures, contained inaccuracies. In both cases, the inaccuracies were determined before the commencement of construction, allowing for design remediation to take place before construction operations were adversely affected. In the first (ACC) case study, failure to determine that the structural steel and other structural members were incorrectly located in the as-built drawings would have led to constructability issues that could have led to greater costs and delays. Because of the tight control of steel installation needed due to the building geometry and the tight regulatory control over design and installation, field modifications would have been costly and time consuming to enact. In the second (MOB) case study, realizing that there would be less ceiling space to accommodate components due to unaccounted for sagging of structural steel beams would require a redesign of multiple MEP system components. These design changes would undoubtedly lead to cost increases and schedule delays. In both cases, the potential cost increases and schedule impacts were avoided due to early detection of clashes. The discrepancies between as-built drawings and as-is conditions were subtle and were only detectible by employing sophisticated surveying equipment. By overlaying the laser scan-generated point cloud over the as-built drawings, the discrepancies were easy to detect.

Utilizing laser scanning before construction begins provides general contractors with additional information for making constructability assessments and avoiding clashes. This is particularly important among projects where field modifications are difficult due to site logistics and regulatory approval, as was the case for both of the case study projects. In the cases provided, structural steel members were central to the inaccuracies. Steel fabrication and installation is a trade where precision is necessary. Improper installation of structural steel may not only create delays and increased costs for downstream steel installation, but it may also often lead to issues with MEP installation, particularly in medical facilities.

By revealing discrepancies between design drawings and as-is conditions prior to construction, several other benefits may be realized. For architects, preemptively fixing discrepancies prior to the start of construction will require fewer responses to requests for information and issuances of architectural supplemental instructions during the construction phase of the project. For subcontractors, having the general contractor provide accurate spatial data regarding the as-is conditions of the structure eliminates the need for trade-specific site surveys. Subcontractors can plan their layout and base their shop drawings on the general contractor-provided point cloud generated from the pre-construction laser scan. Lastly, for the general contractor, preemptively identifying discrepancies between the design drawings and as-is site conditions reduces the amount of field coordination necessary to manage the project, which should lead to a reduction in the cost of general conditions. While it is difficult to determine the magnitude of the value of these unrealized costs, there is certainly value to general contractors in avoiding them. These benefits ultimately benefit the owner in the form of lower project costs and reduced project durations.

Discussion

Prior research indicates that there is value in using laser scanning in construction operations. The prior research centers on the use of laser scanning in creating accurate as-built drawings after construction has been completed. Improving the accuracy of as-built drawings is important as as-built drawings often serve as the design basis for future repurposing of spaces. Any errors contained in the as-built drawings will be carried forward into future designs and can be a source of field issues and change orders for future tenant improvements.

This study shows that there is additional utility in laser scanning if scans are performed before construction operations begin, specifically at a time when discrepancies between as-built drawings and as-is site conditions can be revealed and design drawings updated to rectify any discrepancies. As the cost and accuracy of laser scanning improves, laser scanning can become part of the constructability review of tenant improvement projects and be used to reduce clashes between building components. Laser scanning can be used as a cost-effective means for avoiding change orders and provides value to general contractors, subcontractors, architects and designers, and project owners.

There are limitations to this study. Foremost, it is difficult to make meaningful assertions regarding the value of pre-construction laser scanning based on two case studies. Despite the fact that it was demonstrated from the two case studies that laser scanning can highlight potential constructability issues and help contractors avoid clashes between major building components, further work needs to be performed to assess the full utility of laser scanning before construction begins. First, the cost/benefit ratio of scanning needs to be fully assessed. Change orders associated with structural and MEP elements are typically costly and time consuming, but do the benefits of laser scanning early in the project outweigh those cost and schedule impacts? Secondly, are laser scans necessary for newer buildings? If laser scanning is employed at the end of a project to help create accurate as-built drawings, then the new design drawings associated with later tenant improvements should be accurate. If this is the case, then are subsequent laser scans necessary? As post-construction laser scans for the purpose of creating accurate as-built drawings becomes more common, the need for pre-construction laser scans to determine as-is conditions should decrease. Lastly, the projects in the case study were selected for laser scanning based on several complicating factors, including tight coordination of structural and MEP systems, regulatory oversight, and aggressive schedules among others. In the absence of these complicating factors, is pre-construction laser scanning necessary for most projects? While the use of laser scanning is gaining in popularity on construction projects, these questions need to be answered before the full value of pre-construction laser scanning can be fully articulated.

Future studies are intended to address these outstanding issues. Yet, despite their presence, the research reported in this paper show that there is, at a minimum, promise in using laser scanning to determine as-is conditions and using that information to mitigate risks associated with inaccurate design drawings.

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