

Case Study

POINT CLOUD APPLICATIONS FOR DISASTER REMEDIATION: A CASE STUDY

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ABSTRACT

Photorealistic, LiDAR-based 3D imaging provides accurate and precise documentation of existing conditions and measurable geometry. The quality and accuracy of the data generated by LiDAR cannot be economically recreated using more traditional measurement and CAD techniques. While earlier forms of this technology have been used for many years, recent innovations have provided opportunities for numerous new uses that will soon change the way many professionals obtain, analyze and process data. The use of 3D scanning equipment for new applications is gaining momentum and one such application, its use for disaster mitigation, was explored in a case study. The study reviews scanning industry applications and improvements for precision and also includes a case study in the application of a historic church post disaster, which was documented with the beneficial applications (such as safety and time savings) as well as what the authors believed to be future research areas for similar projects.

Keywords: LiDAR; 3D Scanning; Point Cloud; Facilities Management; Disaster Recovery

INTRODUCTION

There are numerous uses for point cloud 3D scanning data which range from pre-construction, to post-construction documentation. Post construction, owners are scanning facilities to document as-built conditions (ClearEdge, 2016 and University of Chicago, 2016) and to aid in the preservation of historic facilities and monuments (Quagliarini et al., 2016). The technology is also used for monitoring construction progress, and to assess compliance with project specifications. On occasions when disputes and litigation arise long after construction is completed, the 3D point cloud data can be revisited and compared to the current conditions reported and to show jurors the critical areas in a virtual and photorealistic manner. For forensic engineering and insurance-related cases, 3D scanning provides accurate modeling that is useful for determining causation, scope of damage, scope of repairs and may also assist with cost estimating. It is anticipated that the future use of Lidar-based 3D imaging will reduce the unnecessary redundancy of measuring, documenting and data collection, and will improve the accuracy of damage assessment and material take-offs. More importantly, scanning capabilities assist to improve safety and reduces the need for multiple personnel traveling frequently to job sites. However, one area of point cloud use with minimal documentation pertains to the use of 3D scanning in cases of reconstructive design for disaster recovery. By utilizing 3D laser scanning, the designer may collect usable data at a safe distance while also reviewing portions of the structure that can be saved. The benefits include not only safety aspects, but also a time savings and

an increased level of accuracy for the information for reconstructive purposes.

BACKGROUND – SCANNING USES

The scanning industry uses for point cloud data appear to be increasing in terms of the numerous industries finding applications. A survey (n=110) sponsored by ClearEdge3D (2016) reported that a majority of the respondents (78.7%) expect their scanning and modeling business to expand within the next year. Structural design for reconstruction after a disaster such as fire, wind or seismic activity is likely no exception. Literature which outlines case uses of 3D scanning for redesign generally addresses the similar benefits to those found in this case study, which is a combination of a faster, safer and a more economical methodology.

Literature examples include benefits in use cases for the contractor and for real estate and insurance industries. Shih (2006) found benefits in using point cloud data for measuring during the construction process. During construction, the measurement function was used to inspect working tolerances and construction errors. For existing structures, Quagliarini (2016) utilized scanning technology to scan a church in Italy to begin documentation and analysis of the current condition of the structure. Traditional methods for capturing measurements include laser measuring equipment and tape measures, but also requires the assessor to climb or maneuver in the building to obtain accurate measurements. Quagliarini (2016) noted that the data can be acquired from far distances which were safer, and also in a quicker time frame. The acquisition of

TABLE 1.—Summary of LiDAR uses and benefits

Author	Uses	Benefits
Quagliarini (2016)	Deviations to assess changes/damage	Safety, and ability to conduct investigative work without revisiting the site.
Shih (2006)	During construction	Quality control for working tolerances and construction errors.
Mahdjoubi et al. (2013)	Insurance industry	Time savings if there is a need to use the model to obtain measurements without re-visiting the field.
USIBD (2015); Oskouie et al. (2016)	Structural integrity	Quantifying structural integrity.
Giammanco (2017)	Damage assessment	Determining quantifiable levels of damage.

dense and accurate point clouds and high-resolution digital images can provide the foundation for further investigative work. The needs for assessing the structural integrity after a disaster was also a noted benefit. Quagliarini (2016) was able to detect “out-of-plane” areas that documents the damage caused most likely by numerous seismic events.

Reconstructive design is of particular interest to the insurance industry as well. Insurance companies provide surveys and evaluations based on data collected in the field and often with simplified checklists and photos. Mahdjoubi et al. (2013) noted that many of the drawbacks of manual surveying and resources outlined by the Royal Institute of Chartered Surveyors (RICS) led to the need of finding new ways of surveying in the real-estate industry. The use of 3D scanning has gained momentum due to the benefits in the ease of documentation. Insurance underwriters can have complex and high-risk structures documented without the need to process the scan data until future needs dictate. Risk managers for critical infrastructures, historical structures, and monuments can create base-line scan models that can be compared to subsequent scans in order to evaluate the structures for movement and damage that has taken place since the initial scans. Similar uses in areas of retaining walls have been used to identify degradation of the structural integrity (USIBD, 2015; Oskouie et al., 2016). The Institute for Business and Home Safety (IBHS, 2016) reports that more than two million hail loss insurance claims were processed from January 1, 2013, through December 31, 2015. IBHS research is currently reviewing opportunities to assess hail damage by assessing surface deviations in impact scans (Giammanco, 2017) because assessing hail damage to determine legitimate insurance claims are often based on subjective opinions of the individual insurer and their internal claims practices. A summary of the uses and benefits are summarized in Table 1.

BACKGROUND – NEW RESEARCH

There are multiple add-ons to the software packages that are used to analyze point cloud data such as those which can detect flatness and camber directly in the point cloud file. Disaster recovery efforts often include situations where an assessment of structural members that are burned or warped and are past the point of documenting sizes or lengths is needed. Yeung et al., (2014) used an algorithm to

compare the binary image of the scanned data with the binary image of a filter (or simplified geometries of the steel shapes). The research indicated progress in automating the process of steel identification with the results of the procedure (analyzing 9 structural members) showing the capability to predict two of the members correctly and the remaining seven members had errors of between 15% to overestimate and 41% to underestimate the sizes. However, the difficulty in the areas of disaster recovery exists in the reality that many of the steel members are difficult to capture due to the overall effects of the disaster (See Limitations and Figure 1) and the overlap of the steel members.

SCANNING STANDARDS AND ACCURACY

Although there are areas of new research for point cloud data analysis, there has also been the need to develop the standards for documentation and reporting results. The U.S. Institute of Building Documentation (USIBD) is a nonprofit organization that reviewed many of the existing standards in the design and construction industry and discovered that there were also no existing standards for documenting existing conditions, which impacts the facilities management industry. In 2014, the first release of the C120 (v.1) Guide for Level of Accuracy (LOA) Specification for Building Documentation was released, and since has been updated to the v.2 version in 2016 (USIBD, 2016). The guide is also a study resource for the LOA Certification course, but was primarily developed to enable professionals to articulate the accuracy of the represented existing conditions to their customers. The scan LOA was intentionally structured to be like the BIM Forum Level of Development (LOD) in that there are five increments of a hundred. For the LOA, there are five increments of ten to organize their levels of accuracy with LOA50 indicating the highest level with an upper range of 0-1mm accuracy. LOA10 ranges from “user defined” to 5cm. the level of accuracy which is something that the AECO industry has continued to struggle with as it relates to the owner’s existing conditions building documentation (USIBD, 2016). For facility managers, the level of accuracy is important since future requests to measure and model buildings will require that the owner utilize their contract documents to articulate the desired accuracy, and ultimately the resulting cost of the documentation and



FIGURE 1.—Site photos of initial damage scan and after demolition scan areas.

building model (USIBD, 2015). But until recently, there were no resources for documentation obtained by LiDAR.

SCANNING LIMITATIONS

The use of 3D scanning has gained momentum due to the benefits in the ease of documentation but there are also cited limitations. Although laser scanning is less time consuming than traditional methods of measuring, the need for reconstructive design introduces difficulties for developing design documents that are not present when designing for new construction. Shanbari et al. (2016) discussed occlusions present during scanning which can limit the collected data. This can be the case when there is a crowded area above a drop ceiling, and certainly for disaster recovery efforts. Since a major effort in the disaster recovery work includes the collection of dimensions, areas that are not captured during an initial scan may require a second phase of the data collection process after demolition (which was the case for this study). Research in the uses for 3D scanning typically identifies an explicit purpose for the scanning tasks but most also describe an extensive process (Lu and Lee, 2016; Luis, 2015) once the scan data is collected and primarily in the transition of the point cloud to a CAD or BIM. But in disaster recovery efforts there may also be options to use the point cloud data directly, and in some cases the user may not need a full as-is BIM to effectively determine reconstruction needs. The combination of hardware and software tools have also impeded wide adoption due to the costs of the hardware and software and additionally regarding time issues, when the end goal also includes a Building Information Model (BIM). In a real-estate case study, Mahdjoubi et al. (2013) surveyed users of the technology and summarized the limitations of 3D scanning to BIM method is the cost, inadequate knowledge, and a mistrust of the performance of the technology but these issues may be reduced in time as more users enter the industry and there are more options for training.

CASE METHODOLOGY

This case study was conducted after a fire damaged much of the interior portions of a structure. The roof fire affected the 100% of the roof, a large portion of the interior components and a small percentage of the basement. Therefore, the engineering required analysis on three levels to assess areas that needed to be protected from the elements - and as soon as possible. The initial intent for this project was to utilize the 3D scanning technology to assess the potential to reduce the amount of time (and costs) associated with a typical reconstruction project and to additionally, review future options for improving the process.

The ClearEdge3D (2016) survey reports that the average capability is approximately 6-10 scans per hour, but depending on the setting for accuracy and the type of scanner, project scan times can vary significantly. For this reason, the comparison of the traditional collection methods for 3D scanning have not been quantified to date. The collection of the point cloud data utilized a Faro Focus3d Series scanner. The scans took approximately 5 hours for the exterior and 2 hours for the interior for the initial scans. The scans were collected using ¼ resolution and 4X quality which were within the time range provided in the ClearEdge3D (2016) report.

A primary difference in reconstructive design is the urgency to get to the site, assess damages and to make recommendations on the safest and most economical way to secure the structure and protect it from the elements. The faster the assessment takes place, the higher the probability in saving remaining portions of the building. As indicated in the literature, scanning for as-is documentation typically includes the scanning process, registration and then a selection from various software applications and methods to create a BIM. In the case of reconstructive design, the data collection process consists of an initial scan to assess mitigation efforts for further damage due to exposure to the elements for the preparation of shoring and demolition plans, and for possible insurance documenta-

tion. For both the traditional method of collecting measurements as well as the scan method, some of the areas were inaccessible at the time of the first visit and required a second visit to confirm and gather additional dimensions. Once demolition was completed, a second scan was conducted to create a new starting point for redesign and determine any changes that may have occurred to the structure during the demolition phase. This duplication of scanning efforts also contributed to a larger time commitment, but also added to quality assurance measures since the exterior walls had already been documented in the first scan and were then be verified. Figure 1 provides photos of both the areas for the initial scan and post-demolition scan.

RESULTS

This study explored the applications of point cloud data used for documentation purposes as well as for information needs in disaster remediation cases. The study indicated beneficial applications in the data collection process (such as safety and time savings) as well as what the authors believed to be future research areas for similar projects. The benefits include an increased level of information to determine what must be included in the demolition effort and to evaluate the saving as much of the original structure as possible. The perceived benefits from the project are discussed specifically below.

Safety - The project team noticed immediately that measurements and point cloud data could be obtained from a safe distance. The use of a scanner provided for an easier and quicker means of beginning the plans for shoring and safety, and the identification of structural members as well to assist with shoring analysis (and to determine any salvageable parts of the structure). The scanning provided safer access and documentation where the roof structure had collapsed and the interior was filled with debris and many of the areas would have been difficult to reach for the traditional measuring.

Analysis - The results of the scan project (the point cloud scan data) was used to create an overlay in AutoCAD to determine the configuration of existing structure. The CAD files were created based on the initial scans, and verification of the dimensions in the newly created CAD file were also checked to the second scan files (Figure 2). By using this combined method of traditional CAD development with the scan overlays, the project team could use an



Initial Overlay of Point Cloud



Design Process

FIGURE 2.—Overlay of cloud data to assess structural damage and for redesign. (Provided by Crump Engineering Works, PLLC.)

incremental approach to scan data without the full cloud-to-Revit conversion. The project included sessions between the technicians and the engineer to verify dimensions which were measured directly from the point cloud, and used to compare to the dimensions estimated by the engineer using the overlay process. An additional unexpected benefit was realized when the researchers obtained vertical sections of the building at the top of the basement elevation and again near the floor elevation. Structural tubing supports appeared to be damaged and were noticed after the comparisons of the elevation slices indicating an offset between the top and bottom of the column. It is unlikely that this issue would be been detected with the traditional measuring and visual inspection method. Due to the complexity of the structure and the destruction of the

TABLE 2.—General comparison of scanning methods.

Task	Traditional	Scan	Scan Benefits
Site visit (scanning or measuring)	2 days	7 hours	Safety, time savings, and collection of more information with greater accuracy
Register scans and create point cloud model	n/a	1/2 day	Time savings – including registration is less than traditional method
2nd site visit (scanning)	Numerous visits to collect missing information	4 hours (exterior re-scan was not required)	Time savings
Create CAD or Revit	Created from field sketches	*Created from point cloud	Increased accuracy

* Basic exterior walls created, not a full model.

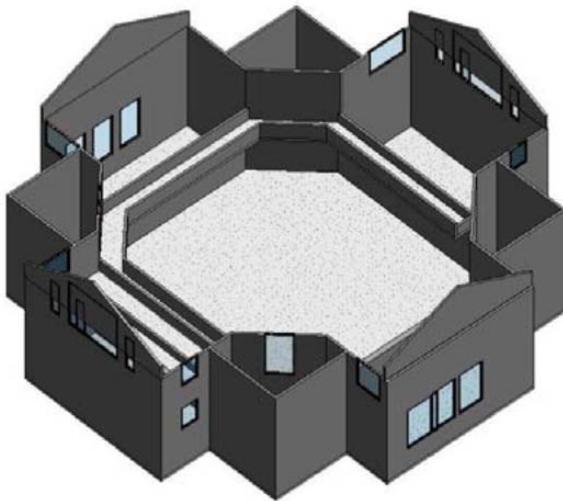


FIGURE 3.—Revit model for dimension check.

wood members, cross sections were analyzed to determine the physical properties and layouts of existing structural components (framing member cross sections for example, as shown in Figure 4). Attempting to re-create the existing structural design allowed the engineer to remain true to the original design while ensuring the integrity of a new design.

Accuracy - The average deviation from the overlay to what the technicians obtained in measuring the point cloud directly was a three-inch difference. The most extreme case was one foot over the 50'-3" roof span. Due to detection of this significant difference, the team utilized the set of scans taken after interior demolition and created a simplistic

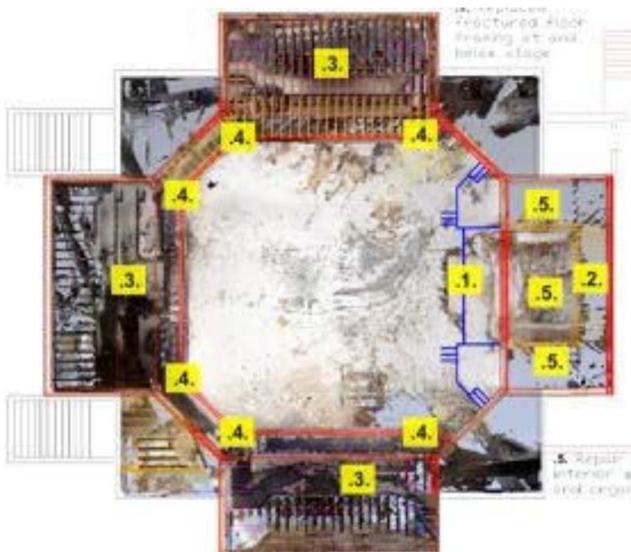
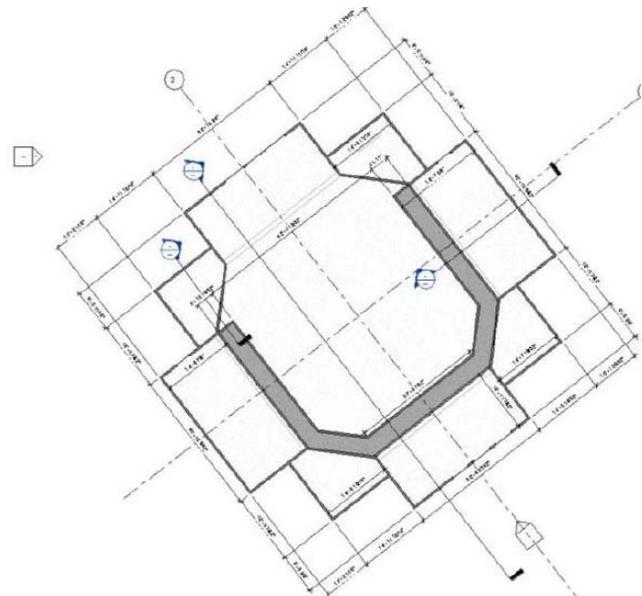


FIGURE 4.—Review of structural components for redesign. (Provided by Crump Engineering Works, PLLC.)



Revit model of the exterior walls for an additional method to attempt to confirm the dimensions, shown in Figure 3.

Time savings - The point cloud allowed for future measurements of the “virtual site” to be used after the site visit and during the analysis of the restoration project without the need to revisit the site, therefore eliminating some of the time and travel costs to the project. An additional benefit is the capability of experienced technicians collecting the hours of scan data, later to be used by the engineering team (as opposed to the engineer or an entire team spending the time on site as well). Capabilities for collaboration between the technicians and the engineer allowed for scenarios where the engineer requested that point cloud models be “sliced” into 2D sections for analysis as shown in Figure 4. Illustrations were created by the engineer from the sections and used for drawing production and to support the development of the safety plan for debris removal as well as for the reconstruction efforts.

The limitations for this project were evident in terms of the time to convert the point cloud to AutoCAD or Revit for use in the redesign, which is problematic when faced with the disaster recovery industry which requires an expedited process. This study primarily used the scan data directly as an overlay to the traditional CAD use and observed time savings when not including the consideration of the cloud-to-Revit process. Luis (2015) stated that, “The cost of this entire process can be high, both in price and in time, with the most laborious task on this process being the creation of 3D as-built models from laser scans.” However, the process is lengthy regardless of the use of traditional or scanned data but software packages like Edgewise provide a way to start with the point cloud data as opposed to beginning from scratch. Although a Building Information Model is ultimately the goal for future projects, this case study describes the notable benefits of using the point cloud model in an alternative and

supplemental manner to the traditional methods of post-disaster design.

SUMMARY

Several of the limitations outlined in literature were observed during the project including the time required for the cloud-to-Revit conversion. In this case, the researchers met time demands by using a CAD overlay and ultimately a simplistic cloud-to-Revit for just the exterior walls to confirm important dimensions. There were several goals identified for future research which included improving accuracy based on not only the new standards but also in refining the data collection process. The use of 3D scanning in disaster recovery efforts have both benefits and limitations and the primary benefit in this case study was the safety consideration of the collection process. Sites with hazardous conditions can be documented, measured and later analyzed without unnecessary exposure and risk to personnel. Additionally, the availability of the point cloud for continual reference by the engineer saved the team valuable time in the elimination of multiple trips to the site. Although the time savings were not quantified in this study, the research team recognized a benefit in the capability to quickly resolve questions and issues in the office setting that would not have been possible using traditional measuring methods. Initially, the team had not planned to use the cloud-to-Revit conversion, but it was ultimately needed to clarify several dimensions indicating that although the overlay process was helpful, it may not meet all of the needs for the engineer. In the future, the plan is to work to document and improve the cloud-to-Revit process. LiDAR documentation is a process that should be considered by any FM organization faced with disaster recovery or the need to complete a new design from an existing structure.

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