# Lessons Learned from 'Scan to BIM' for Large Renovation Projects by the U.S. Army Corps of Engineers

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**Abstract –**

**The U.S. Army Corps of Engineers (USACE) Savannah District recently invested in the adoption of a process of transferring 3D Light Detection and Ranging (LiDAR) scan data into a Building Information Model (BIM), a process commonly known as Scan to BIM. This research explores the challenges and benefits of adopting and using this technology for large renovation projects in USACE. Two buildings were evaluated as part of the study. The BIM for one building was developed using traditional methods of physically capturing dimensions. In the second building, data captured from LiDAR scanners were used to develop the BIM. Lessons learned from the development of Scan to BIM process and a comparison of how this is accomplished in USACE is discussed. Key issues identified from interviews with stakeholders include reduced labor for documenting existing conditions and improved accuracy of the data captured. Participants also identified the cost of equipment, cost of training and development of organizational standards as being important for future use of Scan-to-BIM technologies.**

**Keywords –**

**USACE, Laser Scanning, LiDAR, Scan-to-BIM, Renovation Projects**

## 1 Introduction

The U.S. Army Corps of Engineers (USACE or the "Corps") is the design and construction agent for all U.S. Army and U.S. Air Force facilities and infrastructure worldwide. As such, the Corps is one of the largest construction owners in the world and frequently undertakes the development of designs for large renovation and repair projects (greater than $3 million estimated construction cost) using "in-house" design teams. This paper will investigate a technological approach of capturing the existing conditions of facilities to develop architectural Building Information Models (BIM) which are then used as the basis for the renovation design. Recently the USACE Savannah District invested in adopting the process of transferring 3D 'Light Detection and Ranging' (LiDAR) scan data into BIM, a process commonly known as Scan to BIM [1]. This research will explore the challenges and benefits of adopting this methodology more widely for large renovation projects within the organization.

Since 2013, Building Information Modeling (BIM) has been required on all vertical construction projects by the Corps (US Army Corps of Engineers, 2013). The requirement was renewed and refined in 2018 under Engineering and Construction Bulletin 2018-7, Advanced Modeling Requirements on USACE Projects. That document requires the use of BIM on all projects which exceed 5000 gross square feet or a construction cost of $3 million or greater [2]. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle [3].

LiDAR scanning technology has the capability to efficiently capture the 3D geometry of a facility in the form of "point clouds" [4]. These point clouds can then be used to construct digital 3D models or a BIM of a facility. And since a laser scanning process is the fastest method of 3D data acquisition for existing buildings [5], a review of the potential benefits and challenges associated with the adoption of the Scan to BIM process by the Savannah District to develop the architectural BIM for large renovation projects is a test case within the US Army Corps of Engineers.

LiDAR, laser, or 3D scanning is a means of using a laser scanner to map an area with high accuracy (Ellis, 2020). It has emerged as a useful tool in documenting existing conditions of buildings and has been referred to as a "mantra" to solve the issue of developing and analyzing existing facilities for renovations [6]. Integrating laser scanning with BIM can yield significant advantages over traditional approaches by facilitating fast and accurate data acquisition of existing conditions [7].

## 2 Literature Review

According to Bortoluzzi and his co-authors, most of the research regarding BIM generation for existing buildings focuses on three areas: 1. Laser Scanning and Photogrammetry; 2. Translation of 3D point clouds to BIM; and 3. Automated conversion of 2D plans to BIM [8]. The process of converting point cloud data into an ‘as-is’ BIM is known as “Scan-to-BIM” [8] [6] [1]. This process has become an established and widely used method of acquiring the geometry of a building to generate ‘as-built’ or ‘as-is’ building models in the AEC industry. Geometric surfaces or volumetric primitives are fitted to a 3D point cloud to model walls, floors, ceilings, columns, beams, and other structures of interest. The modeled primitives are annotated with semantic information including identity labels (e.g., wall) and meta-data, such as the surface material (e.g., concrete), and spatial and functional relationships between nearby structures and spaces are established [9]. It is basically a practice of creating a digital representation of existing conditions of the building with its physical and functional characteristics in a BIM. A laser scanner is used to capture an accurate 3D point cloud which is ultimately imported into 3D BIM software (e.g., Autodesk’s Revit, Graphisoft’s ArchiCAD, Vectorworks, etc.) to create accurate as-built models [10].

### 2.1 Increased Use of Scan to BIM

Scan to BIM has been in use since the 1980s [11]. Since then, developments in the technology and workflow processes have resulted in more widespread use of the process to gather in situ geometric data [12] [13] and improvements in the reliability of that data [14]. The sheer amount of current research on the topic illustrates its increased use for numerous facility management activities including, ‘reverse engineering’ [15], energy efficiency and sustainability [14] [5] [16] [17] [6], material reuse/recycling [16], cost estimating and control [8] [6], structural analysis [18] [14], historical building information modeling (HBIM) [19] [14] [20] [21], safety, decommissioning, and renovation designs [18] .

In their journal article “A Survey of Applications with Combined BIM and 3D Laser Scanning in the Life Cycle of Buildings” Liu and his co-authors compared current methods of integrating 3D laser scanning with BIM, applications in a building’s life cycle, and impacts of the continued development of the technology [17]. They found that more and more researchers are focusing on Scan to BIM applications. The researchers went on to state laser scanning has become “common technology” to acquire point clouds due to its high precision and accuracy. This finding was also supported by others who claim that laser scanning is used in most cases to obtain an existing building’s geometry [22]. One clear reason for this is the intrinsic value of geometric and spatial information upon which to base renovation designs [6].

### 2.2 Benefits of Scan to BIM

Current literature clearly documents the reductions in the amount of time it takes and the costs of collecting ‘as-is’ conditions of existing facilities as a primary benefit of the Scan to BIM process. Not only is the process faster but it also reduces the cost of data collection over manual methods, e.g., multiple architects physically measuring and sketching the facility. The reduced time and/or cost to collect existing condition data is cited frequently in the current literature [5] [6] [15] [13] [1]. In a systematic literature review of 194 papers discussing HBIM it was concluded the use of laser scanners accelerated data collection and decreased errors and claimed it would result in cost and time savings not only during data collection, but also during design, and construction [22]. Skrzypczak et al. also found that laser scanning is more efficient and reduces time and costs of data collection over conventional or manual methods [11]. Additionally, recent advances in laser technology have made acquisition of point clouds even faster and more effective [18].

The other clear advantage of laser scanning is the accuracy of the data collected. Antova and Tanev state manually measuring a facility with measuring tapes is accurate to 25 – 75mm (approximately 1 – 3 inches) [18]. This level of accuracy is clearly not suitable for large renovation planning and design. On the other hand, Terrestrial LiDAR Scanning (TLS) can achieve accuracy within several millimeters [17]. Mellado and his co-authors concluded laser scanners can produce models with + 2mm accuracy at 250 meters [6]. Skrzypczak and his colleagues analyzed the accuracy of three different buildings and found that scanning significantly enhanced the accuracy of the BIM and had a level of error of + 1cm [11]. Hossain and Yeoh also claim the degree of accuracy is within 1cm to 1mm [23]. And Sanhudo and colleagues conclude accuracy up to 0.6mm at a 10m range [13].

Safety is another benefit of the use of laser scanning to capture existing conditions because capturing data in hard to reach or inaccessible areas can be accomplished without the need to expose personnel to unnecessary risks [11] [24].

Laser scanning provides 3D documentation of a facility and access to images and photos during design development [11] and it can be used in low light conditions [23] [12]. Another benefit is the facilitation of design development in an efficient manner, evaluating various design alternatives, decision making, and cost estimating [6] [13]. Laser scanning also allows a wider range of measurements at higher resolutions than photogrammetry techniques [12] and it offers the potential of some degree of automation in the BIM development [13]. Perhaps the most fundamental statement regarding the value of Scan to BIM was provided by Merckx who stated, "Laser scanning is the best way to document the indoor environment of a building" [25].

### 2.3 Challenges with Laser Scanning

The primary challenges identified in the literature reviewed are the time and cost to develop the BIM from point clouds, the modeler's skill and experience, and the insufficiency of automated or semi-automated modelling to identify and record semantic information.

Developing BIM for existing buildings from a point cloud is "complex, tedious, time consuming, and costly" [30]. This observation is shared and articulated by numerous researchers [18] [26] [5] [24] [16] [17] [26] [27] [15] [13] [12] [1]. One survey stated setbacks during BIM development are common and 80% of respondents to a survey agreed that the modeling step is the most time consuming in the Scan to BIM process [15]. And as one would expect, the complexity, time, and costs increase with an increase in the level of detail (LOD) required and the model's intended use; for example, BIM for a renovation project will require a much higher level of detail than a model to be used strictly for operations and maintenance or facility management requirements [23]. Higher quality and more accurate models involve a higher cost of development. Therefore, a tradeoff should be made to balance the model's reliability and development costs [1].

Despite advances in automated modeling, creating BIM from point clouds is often subjective and requires skilled modelers with specific expertise [28], [23]. Moreover, modeler qualifications have a large impact on the quality of the BIM developed [24] and different modelers will create different models using the same software and data [12]. Researchers provided a quantitative analysis of the accuracy of 25 modelers and demonstrated the benefit of training as well as the use of semi-automated methods to develop the BIM [28]. The training alone produced dramatic results decreasing the standard deviation by 330% and average absolute modeling error by 260%. The paper concluded that standardizing manual modeling techniques can provide significant value regarding the accuracy and precision of BIM developed from laser scanning.

Automatic modeling is currently being used for common building elements including structural, mechanical, electrical, and plumbing components as well as the exterior facades of buildings [17]. Many advanced algorithms have been developed to automate portions of the modeling step although the process is still semi-automated at best [28]. A thorough summary of research to advance automated modeling over the past 10 years was completed by others [29]. They discussed software designed to automate geometric modeling including Edgewise, CloudWorx, Faro Scene, Autodesk Recap, and RealWorks. Despite the vast amount of research on the topic of automating the process researchers points out additional work is needed as noise and occlusions in their case study proved challenging for the semi-automated process [22]. Wang et al. [1] stated "although numerous studies are reported for semi-automatic or automatic 'as-is' BIM reconstruction from laser scan data, the existing techniques still have room for improvement regarding accuracy, applicability, and automation", concluding it is difficult to achieve high accuracy and high levels of automation.

## 3 Methodology

A qualitative methodology was chosen for the purpose of this study. This methodology allowed the researchers to probe implementation issues in detail. Interviews with design and construction professionals within the USACE and industry designed to assess and understand their experience and opinions regarding existing condition data collection and BIM development for large renovation projects. Profile of the interview participants is shown in Table 1. All participants are employees of the Corps except one private owner who is the principal at a private firm. Participants included chiefs of engineering, construction, and design branches from five USACE districts. From an organizational standpoint, USACE is comprised of nine divisions with multiple districts under each division.

Table 1 Interview Participant Profile

| # | Position, Title and Experience |
|---|---|
| 1 | Chief of Engineering - 31 Years |
| 2 | Chief of Construction - 25 Years |
| 3 | Chief of Design Branch - 19 Years |
| 4 | Senior Architect, Design - 20 Years |
| 5 | Senior Architect, Design- 13 Years |
| 6 | Chief of Design Branch - 37 Years |
| 7 | Chief, of QA Branch - 24 Years |
| 8 | Chief of Architecture & Design - 15 Years |
| 9 | Chie of Engineering - 35 Years |
| 10 | GIS Analyst - 14 Years |
| 11 | Chief of Research, CAD/BIM - 13 Years |
| 12 | Researcher, CAD/BIM - 3 Years |
| 13 | Owner (Private Industry) - 13 Years |

## 4 Results and Discussion

Each year the Savannah District develops multiple architectural BIM models as the basis of design for large renovation projects. These designs are then used to procure construction contracts with private industry. For the purposes of comparison, the researcher limited information on the time and cost necessary to develop BIM to two nearly identical projects at Ft. Gordon, GA. In 2021, the design branch completed the design and specifications for a barrack renovation project at Ft. Gordon, Building 315. In 2022, a similar design was done for barrack Building 317 at Ft. Gordon. The existing conditions of both buildings were captured using manual methods of 'as-is' building data collection. However, the existing conditions for Building 317 were later also captured using LiDAR scanners as part of an initial training curriculum developed specifically for the Savannah District by educators from an accredited institution of higher learning. Preparing these designs in the shortest amount of time, at the lowest cost, and as free of errors or omissions as possible, is one of the organization's primary goals. The workflow adopted to capture existing data and develop design documentation for buildings 315 and 317 is shown in figure 1. In the case of Building 315, designers needed to return to the site obtain missing information that was not captured during the original site visit, whereas that was not required in the case of Building 317.

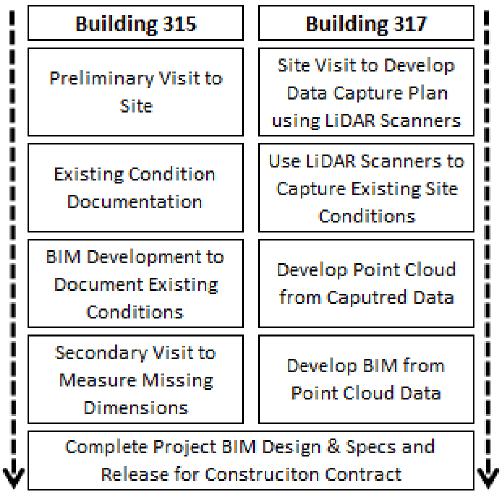


Figure 1: Project Workflow for Building 315 and 317 BIM Development

In late September 2021, the existing as-built conditions of Building 315 were manually measured, and an architectural BIM was prepared to complete the renovation design. Building 315 is a 41,165 gross square foot, 3-story building that houses 136 Soldiers. In February 2022, the existing as-built conditions of Building 317 were captured using laser scanners. Building 317 is a 68,851 gross square foot, 3-story building that houses 224 Soldiers. The buildings have nearly identical floor plans, the primary difference is Building 317 has two additional 'stacks' of barrack rooms as can be seen in Figure 2 below.


Figure 2. Buildings 315 and 317, Ft. Gordon, GA

In October 2021, face-to-face interviews were held with the Savannah District Engineering Division Design Branch Chief, Architectural Team Chief, BIM Manager, and a senior Project Architect Engineer (PAE). The results are presented in Table 2. The purpose of the discussion was to determine current processes, costs, challenges, and the amount of time it takes to develop an architectural BIM model for large renovation projects. This data was used later to contrast to compare thoughts of key personnel upon conclusion of the study after using laser scanners.

Table 2 Preliminary Interviews Summary

| Question | Response Summary |
|---|---|
| • What procedure is currently used to record existing conditions and develop architectural BIM for renovation designs? | Four (4) architects spend four (4) days at the building site manually measuring and recording the 'as-is' conditions of the facility. |
| • What are the challenges with this method? | Missing or omitted data identified after the team returns and completion of the architectural model frequently requires one or more personnel to return to the site to capture the missing data. Exterior elements require lift |

| | |
|---|---|
| | capability to measure. |
| • How much time is required to develop the architectural BIM? | It takes one architect approximately 8 hours per day for 5 days: 40 hours total. |
| • What is the cost of developing the BIM? | The approximate cost using $125/hour as a standard hourly rate is $5000. |
| • How accurate is the data collected? | The final model is considered accurate enough to use as a baseline for renovation design and construction contract award with unknowns minimized to the maximum extent possible. Unknowns are in inaccessible spaces or missed measurements. |
| • What are the challenges? | The primary challenge is compiling measurements from multiple sources and in various formats. Wall widths are often 'backed in to' by using exterior overall dimensions and room widths. The width of utility chases is estimated. A great deal of professional judgement is used when developing the model and the accuracy of these assumptions varies based on the employee's experience and expertise. |

Laser scanning data collected in February 2022 was used to develop the BIM model for building 317, as shown in figure 3. Upon completion of the process a second round of interviews were held with a wider group of stake holders, as identified in Table1. Interviews consisted questions designed to elicit responses regarding the respondent's level of experience with large renovation project designs, current 'as-is' data collection methods and associated challenges, familiarity with other data collection techniques (e.g., Scan to BIM, photogrammetry) anticipated benefits of Scan to BIM, and their thoughts on the future use of Scan to BIM in the USACE. A summary of the issues identified from the interview data is presented below.

## 4.1 Current Data Collection Methods and Challenges

Nearly all the respondents (92%) identified labor and manpower as a primary challenge with current data collection techniques. Personnel from five different USACE districts were interviewed and asked about their current data collection techniques for gathering 'as-is' building conditions for large renovation projects.

Figure 3. Laser Scanned Model of Building 317 at Ft. Gordon, GA

All districts included requesting any available scanned paper or CAD files from the installation's Directorate of Public Works (DPW) or Base Civil Engineer (BCE). As-built drawings received often included numerous additional drawings reflecting the renovations completed since the building was built (in some cases, more than 20 years of minor renovations). After the drawings are coordinated, a field investigation is conducted to verify the accuracy of the as-built drawings. This process involved varying numbers of personnel in various design disciplines. Most frequently, the team collecting as-built conditions included architects, and electrical, mechanical, and structural engineers. The duration for data collection varies according to the size of the building and district processes but can range from 1 day to weeks. 85% of respondents discussed the availability and accuracy of as-built drawings as an issue. In all but one case, respondents uniformly agreed current as-built drawings are generally out of date, inaccurate, and often very challenging to secure. Multiple respondents also mentioned that hidden building features were not captured and many also mentioned the amount of data that is missed during these field investigations. One respondent shared that often during design the building owners want additional items added to the renovation project scope and invariably that data would not have been collected during the initial site visit and a return trip would be required.

## 4.2 Challenges of Using Scan to BIM

Nearly two thirds of respondents identified challenges with the actual LiDAR scanning including the inability to capture hidden or occluded items such as pipe networks above the ceiling and behind walls. Many of them noted these features would not be identified using manual methods of data collection either. One respondent highlighted the value of having architects physically on-site to see and tour the facility and become familiar with the materials. Over half of the respondents identified challenges with BIM development from the point cloud generated from LiDAR scanning. Specifically, they mentioned the inability of Autodesk Revit to model deflections and the necessity for a conscious decision to be made by the designers to determine deflections which could be ignored such as the undulation in non-load bearing walls, and those which needed to be identified and addressed in the renovation design, e.g., structural deflection of floors or ceilings. The lack of semantic data automatically modeled by the software used to convert the point cloud into a format which can be imported into Autodesk Revit was also mentioned. Although, as the literature review discovered, software manufacturers are making progress on the inclusion of automated modeling capabilities in their products, and this is anticipated to continue. Nearly 40% of respondents discussed data management as a challenge as well. This included the computing power necessary to process the raw point cloud and cybersecurity requirements. Those requirements are of particular importance to USACE because of the stringent security standards software and any cloud-based programs must meet to be allowed on the organization's network. The initial and maintenance costs of adopting Scan to BIM were also mentioned by roughly 1/3 of respondents. Concerns included the initial investment and budgeting for future upgrades in scanner technology and software improvements. It should be noted here that several respondents also believed the benefits will far outweigh the costs.

### 4.3 Benefits of Using Scan to BIM

100% of respondents highlighted the advantage of the data collection process as a primary benefit of the use of Scan to BIM for large renovation projects. The efficiency of data collection, the sheer amount of data collected, and the accuracy of the data were of particular importance. Reduced opportunity costs were an additional benefit mentioned frequently. This allows design engineers and architects to continue to complete design work on other projects while data is being collected. This goes hand in hand with the reduced manpower requirements to capture existing 'as-is' conditions. For example, the Savannah District sends up to four (4) architects and mechanical, electrical, civil, and structural engineers to a facility to collect existing information for multiple days to collect as much data as possible about the building. It is anticipated that the use of Scan BIM would allow manpower needs to be reduced to one architect and a scanning technician for a day or two, depending on the size of the facility. This obviously results in reduced labor and travel costs. Time savings during data collection and BIM development was considered another primary benefit by those interviewed. One respondent provided an example of capturing existing conditions of a 160,000 square foot facility in one week and estimated it would have taken a team of architects up to six (6) weeks to manually measure and record the building and its features and develop an initial BIM. Data management, particularly 3D documentation and information sharing, were identified as benefits of the process as well. The 3D documentation was considered particularly important because the scope of renovation projects frequently changes after original data collection is completed. The point cloud will have a record of everything captured and interview respondents considered it to be of value to refer to during design development. The ease of use and relative effectiveness of the various software used to register, clean, trim, and import the point clouds into Autodesk Revit was also considered a benefit by some. Only one quarter of interviewees mentioned a potential reduction in unforeseen and differing site conditions during construction because of the use of Scan to BIM.

### 4.4 Future Uses of Scan to BIM

Respondents discussed their thoughts on the future use of Scan to BIM and resulted in several use cases being identified. Use cases included renovations, civil works projects, damage assessments, and one respondent discussed its value for aircraft hangar and powerhouse renovations. Scan to BIM on these types of projects was of value because the structure is normally open, and piping networks, duct work, and other building systems are generally visible and not hidden behind walls or drop ceilings. Damage assessments, structural evaluations, scanning during construction to develop true as-built BIM, and the use of Scan to BIM to develop as-built drawings were also identified by the respondents as potential future uses of the Scan to BIM technology and workflow. A point cloud's contribution to the development of a 'digital twin' was also mentioned by one interview participant.

## 5 Conclusions

Large project renovations within the military programs of the USACE are a large portion of the work the organization executes. In many cases, it is most of the work performed and is anticipated to continue to be. This is especially true given the recent focus on the living conditions for the nation's soldiers and airmen that reside in barracks and dormitories. Initiatives to improve the execution of design development and construction for those and other projects is a continual process and goal. Based on this research, interviews, and case study, it is clear the adoption of Scan to BIM will improve the Savannah District's efficiency and ability to deliver successful renovation projects to the U.S. Army and Air Force. The authors believe it is reasonable to assume similar benefits may be realized in other USACE districts. The literature review identified the extensive use of Scan to BIM and the rapidly advancing state of the technology and workflows to continue to improve the process. The key advantages of developing BIM from laser scans include the efficiency of data capture, the accuracy of the data captured, improved safety during data collection, and the facilitation of design development. All these benefits were also identified by subject matter experts interviewed particularly within the sub-theme of data collection. Without exception, the interviewees touted the benefits of data collection efficiency realized using Scan to BIM. This includes the amount of data collected, the accuracy of that data, the 3D documentation the point cloud provides during the entire project lifecycle, and the reduced manpower, labor and opportunity costs associated with the use TLS to capture 'as-is' building conditions. In the case of building 315 and 317, participants acknowledged that certain risks of unforeseen site conditions remained due to assumptions made by the problem of occlusion.

The main contributions of this research include the following:

- This research has shown yet again that challenges to scan-to-BIM identified in the literature review such as the lack of semantic information in the resultant point cloud, the ability to capture occluded, hidden, or hard to reach building features, the digital file size of the point cloud, and the lack of quality and accuracy standards continue to hinder design and construction professionals. USACE professionals identified the need for investment in equipment and training at the organizational level and the development of standard operating procedures
- Despite the challenges presented by the use of point cloud data, the study has shown that seasoned industry professionals agree that it has significantly improved accuracy of the BIM developed from the data, as shown in Building 317.
- In the case of USACE, participants agreed that investment in scan-to-BIM technology will improve the organization despite the high adoption cost and potentially reduce data collection costs and minimize design changes after the award of contracts.
- Point cloud data can identify physical features that are easily missed by manual data collection, as shown in the excessive floor deflection found in Building 317, which was missed in Building 315.

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