# THE USE OF LiDAR POINT CLOUD DATA FOR FACILITIES MANAGEMENT

by

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# ABSTRACT

GEORGE POULOS. The Use of LiDAR Point Clouds for University Facilities Management (Under the direction of Dr. Glenda Mayo)

The use of 3D LiDAR technology has been consistently in demand. 3D scans are used for many different applications including documenting assets and creating as-built drawing of current buildings. However, a significant hurdle is that there is no industry standard or recommended way of using the scan data. In this small case study, 50 buildings were scanned on the campus of The University of North Carolina at Charlotte (UNC Charlotte). With this data, three methods were identified and used to present options to facility managers for how to make the scan data accessible to the employees that can use it in their work with operations and decision making. The identified methods were examined for applicability, cost, ease of use and overall effectiveness. Each method was presented to a small group of university facilities management representatives and a short survey was completed after the presentation. The survey data showed that most of the responses indicated that exploring the Scene 2go method could bring useful information to the department to support what 3D scanning can bring to UNC Charlotte. The research also helped to quantify scan times and data collection needs, which may also assist new users in the planning and implementation process for 3D scanning.

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TABLE OF CONTENTS

## LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

| | |
|---|---|
| AEC FM | Architecture, Engineering, Construction & Facilities Management |
| AECO | Architecture, Engineering, Construction, Owner |
| AIR | Asset Information Registration |
| BIM | Building Information Modeling |
| BMS | Bride Management System |
| CAD | Computer Aided Design |
| CMMS | Computer Maintenance Management System |
| FM | Facilities Management |
| gDT | Geometric Digital Twins |
| GIS | Graphic Information System |
| IWMS | Integrated Workplace Management System |
| LiDAR | Light Detection and Ranging |
| MEP | Mechanical, Electrical, Plumbing |
| O&M | Operations & Maintenance |
| RRDS | Rich Room Data Schedule |
| RUP | Reginal Utility Plant |
| UNC Charlotte | University of North Carolina @ Charlotte |

# CHAPTER 1: INTRODUCTION

## 1.1 Background and Significance

3D scanning is a valuable tool that can be used to inform Facilities Management (FM) staff regarding space and assets. A 3D scanner collects points of the object or building being scanned. These points are then grouped together into a database that has the 3D point clouds that are collected from the scanning process. A point cloud is created by sets of 3D points that have an X,Y,Z coordinates (Wang et al., 2020). The point clouds (group of points) are extremely accurate and can be processed together to create a model of the element being scanned. Light Detection and Ranging (LiDAR) is the main type of 3D scanning used for architecture and construction. The LiDAR scanner collects hundreds of points a second to document an object or space.

The use of 3D scanning is on the rise in the architecture, engineering, construction and owner (AECO) disciplines. There are multiple uses such as for as-built models of existing buildings and during construction to measure the flatness of a slab. The use of 3D scanning has not fully made the technological “leap” into the facilities management field. Being able to prove to facility managers that 3D scanning is the new way of documenting assets as well as the buildings that they are managing is a difficult task. Potential reasons could be the concern of learning a new technology or not wanting to make a significant investment on training and equipment. However, there are many uses for 3D scanning that can directly benefit facilities management. One primary benefit is the creation of accurate documentation of a building for future renovations. Additionally, the benefits include collecting information of assets, even allowing for maintenance staff to view what is in the building before physically going to the building to perform work orders.

## 1.2 Objectives and Scope

Like many educational institutions nationwide, the University of North Carolina at Charlotte has over 80 buildings that are maintained by the university facilities management department. When managing so many buildings, the need to document the buildings and their assets is very important to support operations and decision making. Currently the university is using an IWMS (integrated workplace management system) that includes a CMMS (computerized maintenance management system) component called Archibus. Archibus data includes floorplans, as well as information of the classification of the rooms and assets. But there currently is no image of any assets or what the current state of the room is in terms of assets to be managed.

The goal for this project is to identify 3D documentation options for the facilities management department and then showcase how 3D scanning can help assist them for better management of the buildings on campus and their assets. The ability to collect scans of assets as well as the ability to create an accurate as-built plan for future renovation of buildings can assist to expedite many of the processes in FM. Futhermore, being able to look at a 3D model of the building or room before maintenance personnel enters the building will help with the efficiency of performing maintenance. Using 3D documentation may require additional time to learn the process but there are studies showing significant gains in adopting scanning procedures.

In this study, the mechanical rooms of 50 buildings on the campus of the UNC Charlotte were scanned. After scanning, the mechanical rooms were processed to create a

3D point cloud model of the mechanical room. Once the model was created, an exploration of the best methods to get the information into the hands of the people that are in the field was conducted. The ability to have these models in platforms that are free (no cost) to view and can be useful for maintenance personnel is a very important aspect of the research. This study is an applied study with a goal of assisting UNC Charlotte and the FM department with the next steps in implementing the use of scanning technologies.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Documentation of Facility Assets

### 2.1.1 Importance of Facility Documentation

It is very important to collect data to inform and guide operations and maintenance of all assets. Utilizing the data as well as monitoring the performance of the data is critical (Munir et al., 2020). The lack of standards provided from the industry for documenting assets is a challenge. It is critical for the AEC industry to create a list of standards and create the requirements for BIM based data (Munir et al., 2020). The standards need to be created from the construction process and in the operations phase, this will help with showing personnel the importance and value that BIM can create (Munir et al., 2020). Owners are often primarily concerned with the initial cost of the building but do not fully realize the costs associated with operations and maintenance (Love et al., 2014). Since this article in 2014, owners have begun to realize this but continue to struggle with financial implications of asking for specific deliverables from the design team and the contractor.

### 2.1.2 Documentation of HVAC

The architectural, engineering, construction and facilities management (AEC-FM) industry has not adapted to new technology practices effectively (Kalasapudi et al., 2014). The AEC-FM has recently changed to and adapted to using Building Information Modeling (BIM) and also 3D scanning in their work. They are using this technology to look at the lifecycle of the buildings as well as projects. One of the most challenging things the AEC-FM has had to deal with is adapting in the mechanical electrical and plumbing (MEP) objects in a buildings system into BIM. The MEP costs of the building add up to be a large part of the building's initial and reoccurring costs. Tracking and managing these spatial changes in the MEP system is essential, but difficult. Spatial changes include dislocation of objects or deformations and also removal of some objects. Using BIM technology can help coordinate between the construction and maintenance phase of the building system. Mechanical equipment rarely has dimensional data to locate components. Therefore, it is especially beneficial in the case of MEP information that 3D scan documentation can be used for collected as-built information. Also, scans can be used to track construction progress using the 3D data and looking at Scan to BIM applications. As-built documents are a poor method for documenting the actual as-built conditions of the building (Kalasapudi et al., 2014) but 3D scanning is a more accurate method of documenting how a building is constructed compared to the design.

2.1.3 BIM in Facilities Management

BIM models transform how building can be designed and constructed, and also how the building can be managed after handover (McArthur, 2015). Using BIM technology can also help with quantity takeoff, scheduling and estimating. BIM can also help Facilities Management by giving information of the building. BIM has also transformed to be used with asset management (Munir et al., 2020). There are four typical issues with BIM for facilities management, which include: identifying critical information, modifying or creating new BIM models for the buildings, transferring information, and handling incomplete building documentation (McArthur, 2015).

As an example, at Kerr Hall East on the University of Ryerson, there were many renovations completed to the building. The building make up included 38 percent of the building used as laboratories, 20 percent classrooms, and 10 percent offices. There were no original design drawings or as-built drawings for the building (McArthur, 2015). The most accurate floor plan was a space description and ownership data in Archibus (McArthur, 2015). They proposed a 7D BIM development framework. This framework will allow for FM to collect all data into a single place. It starts with data analysis and collection. This included construction documents, surveys and condition reports, historical records, and model base geometry (McArthur, 2015). Second, was a needs analysis, which identified the interface with FM systems, identified missing data, and expanded rich room data schedule (RRDS) to facilitate data. Third, is room data schedule update, which created data fields for FM systems. Fourth, was to collect system and site data and verify. Fifth, was to update the BIM model and push updates to BIM and FM system. Lastly, the team must demonstrate, evaluate, and review the implementation (McArthur, 2015).

Using these BIM models will assist with sustainability goals of the building. When facilities management uses the concepts of BIM, they are able to get information of equipment and clustering the equipment according to maintenance intervals (Marzouk & Ahmed, 2019). As another example, when looking at a water treatment plant, there are many different places where failures can occur. The critical purpose of a water treatment plant is to produce the required amounts of treated drinking water (Marzouk & Ahmed, 2019). In Egypt, facilities management staff collects data on paper for documentation (Marzouk & Ahmed, 2019). Being able to integrate data collected with BIM would enhance the productivity of maintenance (Pocock et al., 2014). If the 3D BIM models were created, then it would be easier to find an issue with the connection between the model and the actual current state. Doing this could reduce the costs associated and also reduce the risk of the projects.

The fact is that there is an increase of 3D scanning technology, and this technology was used to assist the treatment plant managers collect data in a more cost and time effective method (Marzouk & Ahmed, 2019). Using laser scanners allows for a lot of data to be collected in just minutes. The 3D scan image is collected by the scanner by the laser flight. The time of travel of the laser from the scanner to the object being scanned and then back to the scanner allows for the 3D image to be collected. For a water treatment plant there is a big network included in it. This network is primarily documented in a Geographic Information System (GIS). GIS has the data of the regions that the plant serves. Planning the 3D scans is a very important step because the number of scans needed to capture around the entire object or room being scanned will present useful data. When developing the maintenance information model, the pumps for the treatment plant were included in the scan. Gathering the important non-geometric asset information for the pumps, then the pumps were tagged in the model with this information in the appropriate places. The maintenance information that was collected for each pump included: country of manufacture, pump type, and specific capacity. Other added information was the information of the maintenance need to be performed on the pump from a daily to yearly basis (Marzouk & Ahmed, 2019).

BIM is also a great tool to help near maximum efficiency of gathering data as well as improving how assets are managed (Munir et al., 2020). BIM will also improve the structure and access for searching for information, which will help speed up the control process for maintenance and reduce the amount of reactive maintenance. The technological benefit that BIM brings to the facilities management is getting the real time data from the models (Munir et al., 2019). This is a great benefit to see what is happening with the assets and making sure that they are working properly.

The visualization of the asset data and the precise level of reporting is also collected and used (Munir et al., 2019). The business value that BIM brings to asset management is a great tool that can be used. When creating a BIM model there is a lot of information that is not needed that is added, this causes issue when looking back at the model for specific information and not being able to find it. This causes confusion and a waste of time if the model in not built efficiently. Being able to combine BIM with facility management systems would allow for verification and collection of data for the buildings lifecycle (Matarneh et al., 2019).

A key issue for facility management is not having real time information and accurate data to perform routine maintenance (Matarneh et al., 2019). There are opportunities to gather and use data in the operation and maintenance (O&M) phase from a BIM model. Often the models are created but the full potential of the model is not used. Knowing what to exactly use the model for can be difficult. Growing past this point and using the opportunities of BIM data will be a great benefit for O&M. Gathering up to date information to put in the BIM model will allow for facility management to have a greater benefit from the model. All of the information that is actually needed and being able to transfer the needed information into existing facility management system is difficult. A base line of the needs for facility management is not known. Currently, the only information that facility management has is recommendation of the information that should be collected and what method is correct to use. One standard that was created to identify information requirements for BIM is PAS 1192-3. PAS 1192-3 states that “Asset Information Requirement (AIR) document should be produced” (Matarneh et al., 2019). PAS 1192-3 include information for management in the operation and maintenance phase of work (Matarneh et al., 2019).

Facility management teams need to formalize their needs for the information that needs to be collected. For BIM to support facility management, information needs to be acknowledged early, this will make the interchange between facility management and BIM work better (Matarneh et al., 2019). There are many facilities management tasks that could be tackled with the use of BIM, but BIM is not being used in operations and maintenance. This is because the information needed is not all collected, the cost and legal issues around BIM, and also the technology needs (Dixit et al., 2019). The technology needed to tie BIM and facility management is not available in one package. (Dixit et al., 2019) stated that 75 percent of people having multiple software would place issue for workflow. Hiring a BIM manager that can show their team the usefulness of BIM and also capture the correct information would be a great benefit in the operations and maintenance phase (Dixit et al., 2019).

## 2.2 Documentation with LiDAR

LiDAR (light detection and ranging) sensors are used to measure distances of items by a laser hitting and object and measuring the reflection of the laser back to the unit. With the use of LiDAR scanning point clouds can be collected and be viewed in Computer Aided Design software (Rosell et al., 2009).

### 2.2.1 Overview of 3D Scanning

3D scanning is used as a non-invasive, non-destruction method to record 3D Images of a building (Kalasapudi et al., 2014). A 3D scanner is any device that collected 3D coordinates of a given region of an objects surface (Boehler & Marbs, 2002). The 3D scanner sends out laser points at an extremely high rate hitting multiple surfaces. The results will come in almost real time after scanning. Scanners can be in a fixed position and then moved to capture a scan around a whole object. Scanners can also be an airborne system for topographic applications. A laser pulse is sent out hitting surfaces around the scanner. Scanners will use rotating devices to get angular deflection from a surface (Boehler & Marbs, 2002). The field of view for most fixed position scanners is 360 degree horizontal view and a vertical view of +/- 320 degrees (Smits, 2011). Scanners can be placed in a closed room and collect large amount of data without the operator in the view of site of the scanner (Boehler & Marbs, 2002). Registration devices can used to combine scans when there are multiple points of scanning involved. Targets in the objects space will be used to detect the points to combine the scans (Boehler & Marbs, 2002). Scanning software is used to combine the scans and should be fast and simple. Using the software will allow for combining multiple scans together. Things like automatic target detection and control points are some of the more sophisticated features in scanning software (Boehler & Marbs, 2002).

If large objects are detected in the scanning site, they can also be recorded as registration points clouds (Boehler & Marbs, 2002). There has been a lot of development in the 3D scanning world. Characteristics such as accuracy and speed have been improved over the past years. 3D laser scanning can be used for scanning elements such as ceilings, floors, walls, and assets inside of a building (Smits, 2011). Point Clouds are created from the scanner hitting and surface that is detected and resulting images. Scanning has been very effective with getting images of curved features and undulating surfaces, that can’t be achieved with photogrammetry. Fixed scanners can be set up in buildings and especially mechanical rooms with process plants or boiler rooms, that have many areas that the laser can target including ductwork and pipe to record accurate 3D mapping. Fixed scanners can be placed inside of buildings and record data in minutes. Precision of the scans is based on the scanner and also the skill of the operator. Also, the scanners resolution and processing place a roll in precision. The accuracy of the scans depends on the distance of the objects from the scanner, the color of the surface, and the surface. The brightness of the light and weather also should be considered when scanning. There is a major lack in 3D scanning for the industry. The three factors are that the cost is very expensive, the laser scanning industry hasn’t educated owners and design services, and scanners have mostly been used for land surveying (Smits, 2011).

### 2.2.2 Procedures of 3D Scanning

The accuracy of the scans as well as the decrease cost of 3D scanners have been the key points to adapt 3D scanning (Kalasapudi et al., 2014). There are many documents that the USIBD creates for owners. Templates and specifications for owners and documentation services are available from the USIBD.

#### 2.2.2.1 Point Clouds

3D point clouds collected from 3D laser scanning capture the 3D surfaces of an object (Wang et al., 2020). The collection of 3D point clouds of assets and buildings allow a project manager or facilities manager to make better decisions of what is needed to be done. The use of 3D point clouds allow for more accurate measurements as well as a more efficient way to collect data than the older traditional methods. These traditional ways of measuring data are very costly on time and also provides more room for error. In the construction phase of a project point clouds can collect data to show the existing conditions. The point clouds can then be used to check the blueprints or a BIM model to see and discrepancies. Using point clouds in the operations and maintenance phase is another great way to conduct inspections of the building and assets. Point clouds reduce the time of inspection and repairs also, being able to reduce the costs of operation and extend the life of a facility. BIM models can be created from the point clouds and provide a more efficient way to look at a building and used in the renovation stage of a building, improving the quality of work and efficiency of renovations. Point clouds allow facilities management to improve the quality of the building and improve the efficiency and performance of the building (Wang et al., 2020).

#### 2.2.2.2 File Formats of 3D Scanning

When collecting data with the use of a 3D laser scanner and processed by Scene software files can be saved in many types. fls and rcp files are usually used to save from the Scene software and can be used to create Revit models. The use of a rcp file can be directly imported into Revit. Once in Revit the file type with change to a rvt file type.

### 2.2.3 Benefits of Capturing 3D Scanning Data to Document Assets

In the bridge and roadway maintenance sector, data is often collected, stored, and used in the Bridge Management System (BMS). Visual inspections of bridges are still the most common method for checking the condition of a bridge (Lu & Brilakis, 2019). Once the visual inspection is complete by personnel it is then entered into the BMS system. If the bridge sector collected Geometric Digital Twins (gDT) they could use that for collecting damages of the bridges (Lu & Brilakis, 2019). A 3D representation of the bridge collecting point clouds will help create these gDT (Lu & Brilakis, 2019).

### 2.2.4 Scanning Software and Issues

A significant contribution of BIM technology is that the model data can be used across all phases of construction – from design, to construction and also in the maintenance phase of a building. Some of the issues that come with BIM is that there are different types of BIM software as well as the integrations of the systems not working together (Munir et al., 2020).

## 2.3. Use of Graphic Information System

### 2.3.1 Graphic Information System and Building Information Modeling

The use of Graphic Information System (GIS) and Building Information Modeling (BIM) together results in a very powerful tool. It was reviewed in this context simply because many scanning efforts result in the need to also map the information, which requires a GIS application.  There is a natural connection because both GIS and BIM collect spatial information to create models (Kang & Hong, 2015). The differences are that BIM are used in a relatively micro level of the real world e.g. buildings and handles mainly ‘indoor’ data. GIS on the other hand is used in a macro level of the real world e.g. terrain, river, land parcels and focuses on ‘outdoor’ data. Being able to integrate GIS and BIM together would create a very powerful tool for facilities management to use since there is often a need to use both indoor and outdoor location data. When integrating BIM and GIS the process should be automated to reduce cost and margin of error. If the software programs are not automated there are additional tasks for data integration that has to be completed manually. GIS systems could be effected by the detail of the GIS model thus causing systems to slow down and hard to collect the needed information, whereas BIM standard models usually do not have this issue (Kang & Hong, 2015).

### 2.3.2 Graphic Information System for Facilities Management

Over the past decades the use of GIS has increased in the public sector (Valcik & Huesca-Dorantes, 2003). GIS in the past has been used by urban planners to help created visualization tools for data sets on maps (Donk & Taylor, 2000). Having an accurate measurement reported of the space of public universities is very important. This is because the university’s obtain funding based on the space data for renovations and new building (Valcik & Huesca-Dorantes, 2003).

Usually, space usage is found by conducting surveys every three years (Valcik & Huesca-Dorantes, 2003). Many universities calculate the square footage of the spaces by hand and then input them into a system, this is a time-consuming method. There are many reasons for the use of GIS systems, there are many things that GIS can be used for. The biggest factor of GIS systems is that the reporting process is a lot faster and is usually more accurate. Also, the mapping technology used when using GIS can be used for many different reasons. Students and departments can use these maps for teaching applications, facilities management can use the maps for upgrading systems and also new construction (Valcik & Huesca-Dorantes, 2003).

GIS is a very efficient way to conduct many different operations for campus. GIS also allows for forecasting of a new building being constructed with looking at the space needs, enrollment, and the land use of the campus (Valcik & Huesca-Dorantes, 2003).

Another important feature of GIS is locating where hazardous materials are located on the campus as well as cut-off water valves and fire protection equipment (Valcik & Huesca-Dorantes, 2003). The hazardous material can be assigned properties that show in the data base the exact rooms the hazardous material is located (Valcik & Huesca-Dorantes, 2003).

For the use of the GIS information there is connectivity between the facilities database and equipment inventory that can be georeferenced to the floor plan (Valcik & Huesca-Dorantes, 2003). Ownership of each room will also be shown in the data base thanks to GIS (Valcik & Huesca-Dorantes, 2003). Having a geodatabase error can be caught very quickly if there is an issue with a room or the room does not exist the room cannot be selected. Assets being located all over the place presents owners and asset management challenges of managing those assets. If more integrated information technology was used assets could be found at the correct location Which means, there would be an increase of quality of service on the asset as well as a reduction in maintenance mistakes (Zhang et al., 2009).

GIS is defined as “an information system that is designed to work with data referenced by spatial or geographic coordinates” (Huxhold, 1991). Two of the biggest advantages of GIS is the ability to do geographical analysis and graphical navigations whereas CAD cannot (Zhang et al., 2009). GIS could be integrated with an asset management system which would present many benefits (Zhang et al., 2009). An infrastructure map can be created using GIS to help with a variety of items like; analyzing spatial relationships, improvements of efficiency, and better decision making (Zhang et al., 2009).

Collecting the spatial relationships is one of the most important items for GIS (Zhang et al., 2009). GIS use give a specific location of the map of where the asset is located. Satellite images can also be collected of the asset to give better visualization of the asset (Zhang et al., 2009). GIS has been used to help with planning and infrastructure maintenance because of its powerful spatial data (Zhang et al., 2009). GIS also allows for visual and analysis of assets which can be used for tracking and maintenance (Zhang et al., 2009). GIS it a tool that helps asset managers answer questions like; “Where are company’s assets located?”, “How can assets be best modelled ‘what if’ scenarios?”, “How can assets be planned routes for the facilities?”, “Where are the distributors and suppliers?”, and “How can we maximized revenue potential? What risk/security plans are needed?” (Zhang et al., 2009).

Using BIM is a great resource for gathering information about a facility and a reliable basis for the life cycle of the building (Zhang et al., 2009). 3D modeling is just one part of BIM, the database that are created using the 3D model can be used with other software’s to assist with estimating, quantity take off, and structural design. The main use of both BIM and GIS is to create visual representations but can also be used for other applications. GIS used geographic coordinates system and maps that are world map projections and use two dimensional points (Zhang et al., 2009). BIM uses coordinates that are in relation to what is being modeled and not to a real location but, objects are in three dimension (Zhang et al., 2009). Using both GIS and CAD together with a database can show accurate representation of the asset management portfolio (Zhang et al., 2009).

One of the most important factors for asset managers to know is the location of where their buildings and assets are located, once assets are in known locations a value of the assets should be found (Zhang et al., 2009). When all assets are known, and value is assigned to them the current condition of all the assets should be known (Zhang et al., 2009). Doing this will help with getting current condition of the assets and being able to compare against the other assets owned (Zhang et al., 2009). Doing this the life of the assets as well as a plan for maintenance can be determined (Zhang et al., 2009). Being able to collect all this data and use it is very important for keeping your portfolio up to date. Using GIS and asset management together will give asset managers a great visualization of all of the assets on a map (Zhang et al., 2009).

## 2.4 Optimization of 3D Data

### 2.4.1 Software Issues for Facilities Management

Many stakeholders believe that 3D scanning is as simple as scanning the images and then all the data is collected. As discussed in (Rocchini et al., n.d.) there are a lot of available software tools to use when stitching the scans together but, the software tools are incomplete and are inefficient solutions. Especially with commercial software the tools that are given from the software to management are very unsatisfactory (Rocchini et al., n.d.). The issue with 3D scanning is that the industry is reporting the software for showing the scans is not meeting expectation. There is a lack of automation and that multiple software packages are needed and that the platforms cannot communicate with each other (*Cornerstone Report CSR003-Software*, n.d.). Only 3% of the respondents are pleased with their software (*Cornerstone Report CSR003-Software*, n.d.). Also, there are no common practices or standards for documenting a building (*Cornerstone Report CSR003-Software*, n.d.). A survey showed that it takes about 4 different platforms to accomplish the deliverable goal (*Cornerstone Report CSR003-Software*, n.d.). 69% of the people who reported in the survey have reported that each software operator needs 2-3 licenses (*Cornerstone Report CSR003-Software*, n.d.). On the positive side there are a few free view platform systems that will do the work but something better is needed (*Cornerstone Report CSR003-Software*, n.d.). Asset management software in the future should be more integrated so that buildings assets can be managed through the whole lifecycle of the building (Zhang et al., 2009). There is an availability of many different software's to link facility management to BIM but the incompatible file exchange for the formats pose a great issue (Dixit et al., 2019).

# CHAPTER 3: METHODOLOGY

## 3.1 Introduction

The methodology of this research is to collect 3D LiDAR scans of 50 of the building on the campus of UNC Charlotte, with the main concentration being on the mechanical rooms inside of those buildings, then utilizing the data for documentation of assets. These buildings are all state appropriated buildings which means that the money to maintain the buildings is appropriated from the General Assembly of North Carolina. For these buildings, it is critical that a true evaluation is completed to get adequate funding needed from the state. The ability to collect 3D scans of the mechanical rooms will show the current condition of the mechanical room assists, the design team can use this data when renovations are needed. To enable showcasing each example in a consistent manner, building number 70, the Regional Utility Plant (RUP) 3 will be used. This is one of five Regional Utility plants that power the University. The RUP 3 building was selected because the majority of the building is a mechanical room. Also, outdoor scans were performed to also show the need for exterior data and to provide a means for the entire building (inside and out) to be modeled. Therefore, the Regional Utility Plant 3 provided the most appropriate choice for this study.

### 3.1.1 Campus Needs for 3D Scanning

There are many uses for 3D scanning starting in the planning and design phases, the construction phase, and to the time when the building is turned over to facilities management. For the UNC Charlotte there are a few reasons to collect 3D data. First, being visual documentation of mechanical rooms on campus. Being able to have a model for a maintenance technician to look at a mechanical room before going out and performing any work can increase productivity. This includes looking at all the equipment in the room and seeing what kinds of tools and parts are needed to complete the job. Using 3D scans for renovation purposes is another reason for the university to want to collect these 3D scans. FM can use these scans to be able to create as-built drawings. Once the scans are processed the actual condition and location of assets is known. These models of the mechanical rooms can then be provided to the architect designing the renovation to know where all existing assets are located. 3D scanning can be used for training on campus and as well as for future modeling of the buildings and equipment in each of the mechanical rooms.

To further justify the campus needs, an informal method of obtaining “what if” figures for future documentation was conducted. Table 3.1 showcases a comparison of outsourcing the scanning duties to a consultant vs. conducting scans in-house. The current effort to scan campus HVAC rooms was conducted jointly with the UNC Charlotte BIM Manager, however, the table does not reflect personnel time. The BIM Manager at UNC Charlotte collected data from different consultants to get an average price of what it would cost a consultant to come in and scan the university. The cost for the student workers came from payment to the workers and the data collected when scanning. Data was collected to see the average square footage that could be scanned by students as well as using the cost that the students are paid. With the use of students preforming the data collection it is very beneficial to the university. It is about $0.56 a square foot cheaper for the university to hire students. As an additional benefit relevant to the purpose of the university, the students gain the benefit of learning 3D scanning technologies.

TABLE 3.1: Estimation of Outsourced Costs for Campus Scanning

| | | |
|---|---|---|
| Consultant | | |
| Low Cost | $0.25 | / sq ft |
| High Cost | $1.00 | / sq ft |
| Average Cost | $0.63 | / sq ft |
| | | |
| Student Worker Costs | | |
| Hourly Rate | $16.50 | / hr |
| Hours Per Day | 6 | hr |
| Daily Rate | $99.00 | / day |
| Scan Area Per Day | 1,350 | sq ft / day |
| Cost | $0.07 | / sq ft |
| | | |
| Student Savings | $0.55 | / sq ft |

## 3.2 3D Scanning

### 3.2.1 3D Scanning Equipment

The scanner that was used for data collection was a FARO Laser Scanner Focus X 130 shown in Figure 3.1. The FARO Laser Scanner Focus X 130 can scan +/- 360 degrees. The scanner is set up at the starting location of the room. A sequence of operation was developed for the scanning process. The preparation included charging the batteries and preparing an SD card with optimum storage capacity. The scanner can collect points up to 30 feet from the location of the scanner. It is best to make the distances between scanner locations closer to allow for enough overlap of scans. A scan sequence is outlined to ensure that all data needed is collected. The day of the scan, the scanner is placed onto a tripod and leveled as shown below in Figure 3.1. If the area being scanned is large and repetitious, objects, called targets, can be placed to serve as locations for scan images to ensure the connection of the correct scans during registration. There are two types of targets checkboards and spheres, these are shown in Figure 3.1. The checkboard targets are printed targets that are 8 ½” by 14”. They are typically fixed to a flat surface and can also include a number sequence for reference. The sphere targets are magnetic targets that can be placed on the ground or attached to door frames (and anything magnetic). When using targets, it is critical to not move the location of the targets until the scanner no longer has the target in range. When beginning to scan, using a floor plan of the area and marking locations of where each of the scans will take place can assist to expedite the process. This helps to make sure that the entire area will be captured as well as help in the processing part of scanning. Parameters for the scanner can be adjusted for any type of scans. Parameters will be different for indoor and outdoor scans and the size of the area. Parameters include the resolution and quality of the scans. Also, the scanner will allow the user to take color pictures while scanning. This scanner will take about 85 photographs per scan.

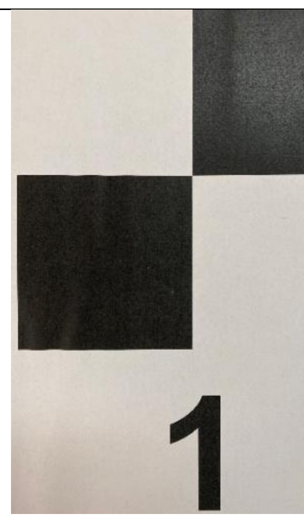
| | | | |
|---|---|---|---|
|   |   |   |  |
| Figure 3.1a: FARO Laser Scanner Focus X 130 | Figure 3.1b: Scanner Set Up | Figure 3.1c: Checkboard Targets | Figure 3.1d: Sphere Targets |

FIGURE 3.1: Scanner and Targets

3.2.2 Set up and Process of 3D Scanning

To start the scanning process, the scanner was placed on the tripod at the start location. The battery and SD card were inserted into the scanner. If needed, place the sphere or checkboard targets in the area being scanned to help capture. The scanner was then turned on the and the settings of using color images and GPS was turned on. Next, the parameters of the scans needed to be set. For this study the resolution on the scanner was set at 1/8 and quality was set at 4x. Figure 3.2 shows the information selected on the scanner.

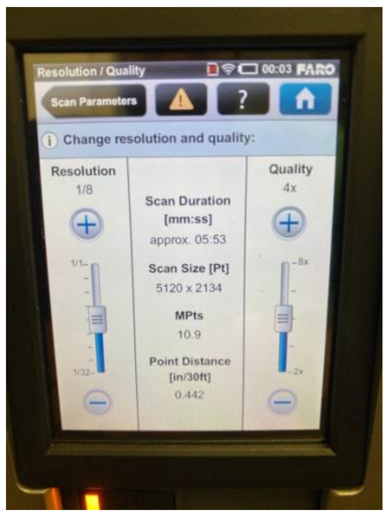



FIGURE 3.2: Scanner Resolution and Quality Set Up

It took about six minutes to complete one scan at project selected resolution and quality. The naming convention of the building will be placed on the file for organizing scans. Start the scanner at the first location after the scanner completes the first scan in six minutes carefully pick up the scanner and place it in the next location. Repeat this process until the area is completely scanned. After scanning is complete clean up all targets and place scanner and tripod back into their cases to ensure safety while transporting. An Excel spreadsheet was used to track each scan and scan location. The spreadsheet was used to track the scans in each of the rooms, the total square footage for each room being scanned per room type is collected as well. To assist FM personnel with future decisions regarding the purchase of a scanner and potential time investments, the total time of scanning of the mechanical rooms was tracked and a total calculated average square foot per scan will be reported.

Below, Table 3.2 and Table 3.3 shows the information collected from Regional Utility Plant (RUP) 3. These tables were created for each building to ensure that all data for the building can be collected efficiently. Also, the collected data can be used to get averages of all the building scanned to estimate how long it would take to complete an entire building and on average how many square feet could be captured per scan.

The Building Room Asset Codes are regulated by IES NCES 4.3.1 codes for space. In RUP 3 there are two different mechanical room asset codes. The first is YYY, a room asset code labels as a YYY is a mechanical room that is classified as general. This type of mechanical room is nonassignable space that will hold mechanical units and utilities (*Postsecondary Education Facilities Inventory and Classification Manual (FICM) - 4.3.1 Space Use Codes*, n.d.). The second type of room in RUP 3 is a Y65.This is a mechanical room classified as a mechanical/electrical room. This type of area can have both types of mechanical and electrical features.

TABLE 3.2: Collection of RUP 3 Data

| Building Code | Building Name / Room # | Room Asset Codes of RUP 3 (Units are in SF) | |
|---|---|---|---|
| 70 | RUP 3 | YYY | Y65 |
| Scan 6-7, 9-11 | 60 | | 425.75 |
| Scan 8 | 61 | | 64.91 |
| Scan 47-58 | 63 | 1453.37 | |
| Scan 28-44 | 64 | 1719.91 | |
| Scan 59-66 | Roof | | |
| Scan 00-5, 12-14, 16-27, 45-46 | | | |
| | Total SF/Type | 3173.28 | 490.66 |
| | Total Scans/Type | 29.00 | 6.00 |

TABLE 3.3: Calculations of RUP 3 Data

| Mechanical Rooms of RUP 3 | | | | | |
|---|---|---|---|---|---|
| Total # Scans | 35 | | | | |
| Total SF | Scan/SF | Total Time (Mins) | SF/Min | Total Time (Hours) | SF/HR |
| 3663.94 | 104.68 | 210.00 | 17.45 | 3.50 | 1046.84 |

3.2.3 Processing 3D Scans

Once all scans of the desired room were completed, the SD card contained the data to process the raw scans. A folder for each building and each room was created. The Scene software was used to process the scans. Scene is broken down into six areas, Project, Import, Processing, Registration, Explore, and Export. Figure 3.3 below shows the main sections of Scene.


FIGURE 3.3: Scene Project Bar

First, Scene was opened, and a new project was created in the Project tab. In the create a new project window select the location of where to save. This will be the building and room folder that has been created. For example, enter the name, the name will be building number – room number. This naming convention was created to keep each room separated in each building file. Figure 3.4 shows how the project tab is laid out for this project.

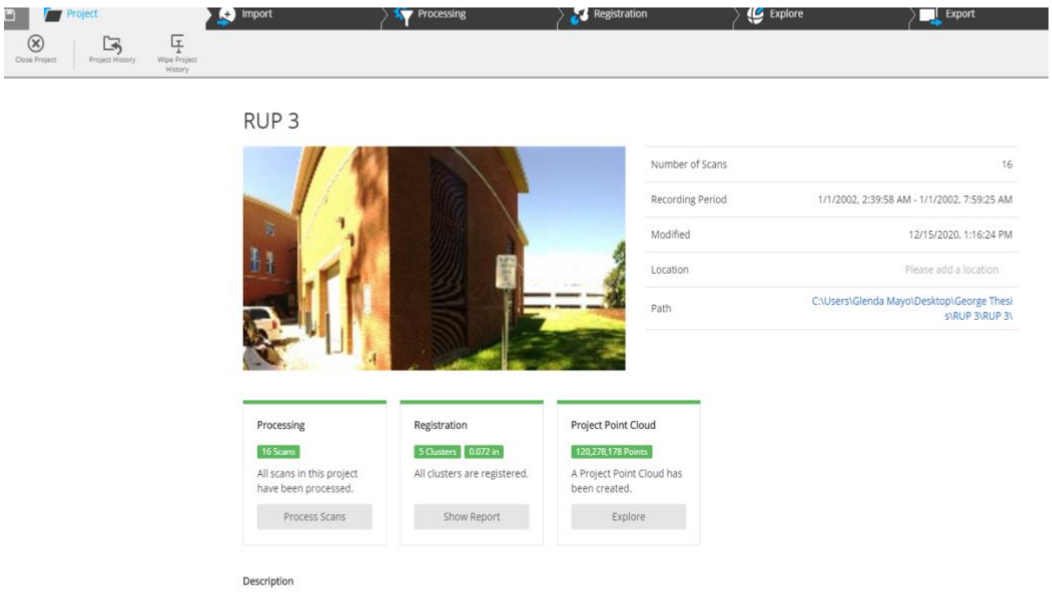



FIGURE 3.4: Scene Project Tab

Once the project is handed over to UNCC FM it will be easy to access the room they are looking for using this method. Once this is completed the first step to process the scans is to import the scans from the SD card. Go to the Import tab and select the scan numbers that correlate with the room that was scanned and select import. Figure 3.5 shows an example of the scanned that were imported into the RUP 3 project.

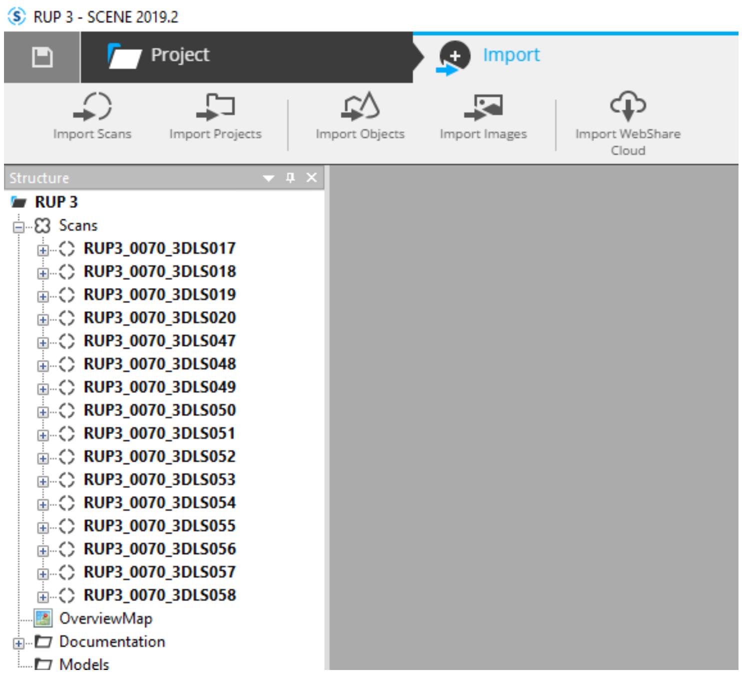



FIGURE 3.5: Scene Import Tab

Once the scans are imported, they will need to be processed, this is under the Process tab in Scene. Select process scans and the configure processing screen will come up. Under configure processing selecting “Find targets” is critical for allowing the software to find the targets that were placed when scanning. As shown in Figure 3.6, a list of each scan being processed will show. If the scan was processed correctly it will show a green bar on the left had side and also say “Fully Processed”.

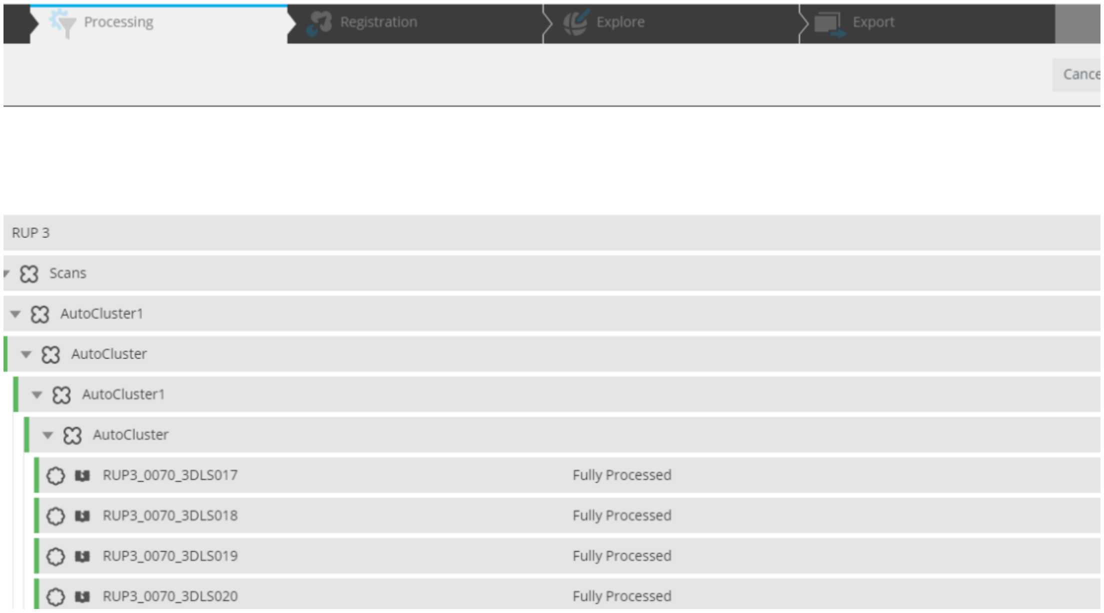



FIGURE 3.6: Scene Processing Tab

After the scans have been processed correctly, they will need to be registered. Under the registration tab there are options for Automatic Registration and Manual Registration. Using Automatic Registration will allow the software to register all the scans together. In the Automatic registration tab make sure that Top view Cloud to Cloud is selected is very important. Next, register and verify the scans. Sometimes, the software will not allow for Automatic registration because of not enough overlap in the scans or not enough points in multiple scans can be found. If this is the case, then Manual registration will have to be used. Manual registration will allow you to select two scans and select targets that are in both of the scans. This process will continue until all of the scans are combined into one. Scan can break down into different clusters as showed in Figure 3.7, this is not an issue the clusters just need to be manually registered together.

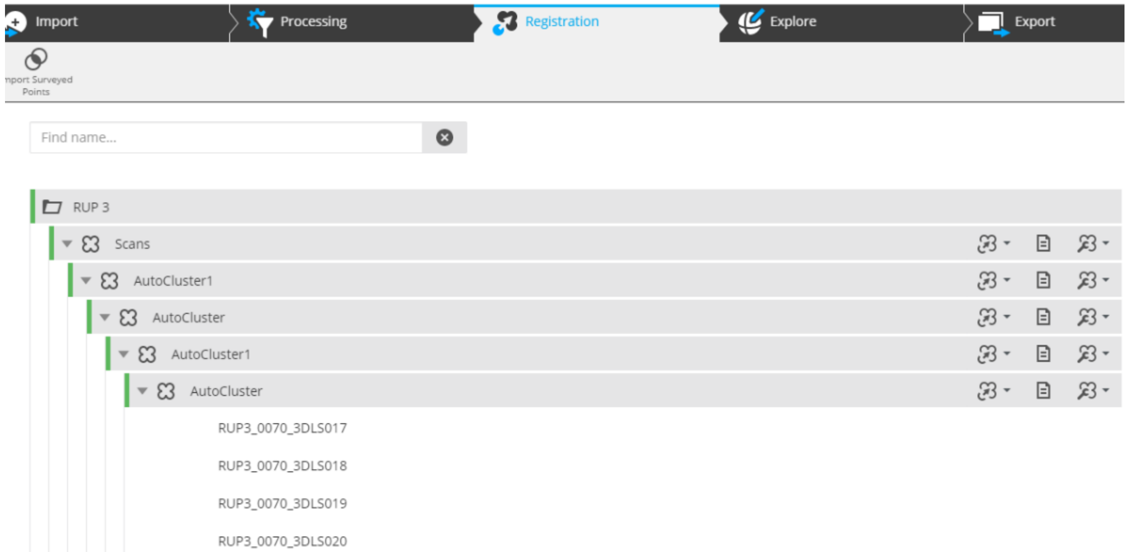



FIGURE 3.7 Scene Registration Tab

Once, scans are registered a report will be generated to show the maximum and mean point of error. If they errors are above about .3 inches, then there could be an issue with not having enough scans or an issue with one particular scan. An example of the report can be viewed in Figure 3.8.

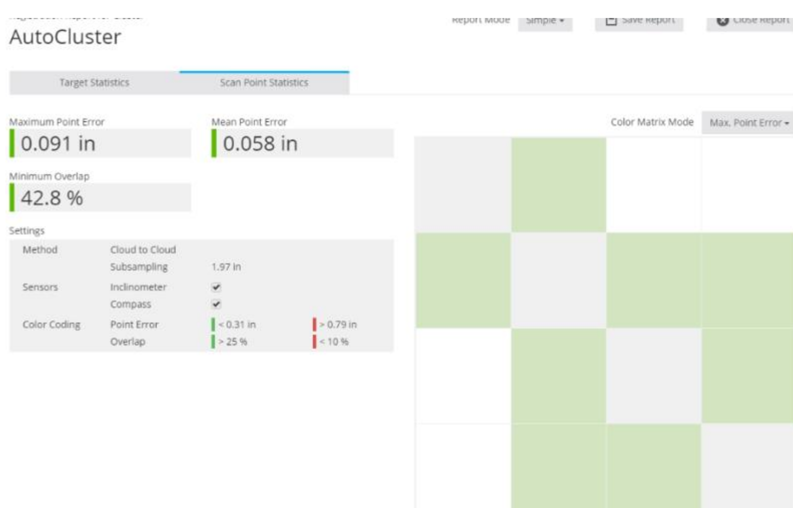



FIGURE 3.8: Scene Registration Report

The next section in Scene is the Explore section. The explore section allows for the first view of the model completed. There are many things that can be done in the explore tap like creating a clipping box so that only one section of the room is shown or even cleaning up the scan. Measurement between two point and even screen shots of sections of the model can be taken in the Explore tab. Figure 3.8 Shows an example of the Explore tab in Scene.

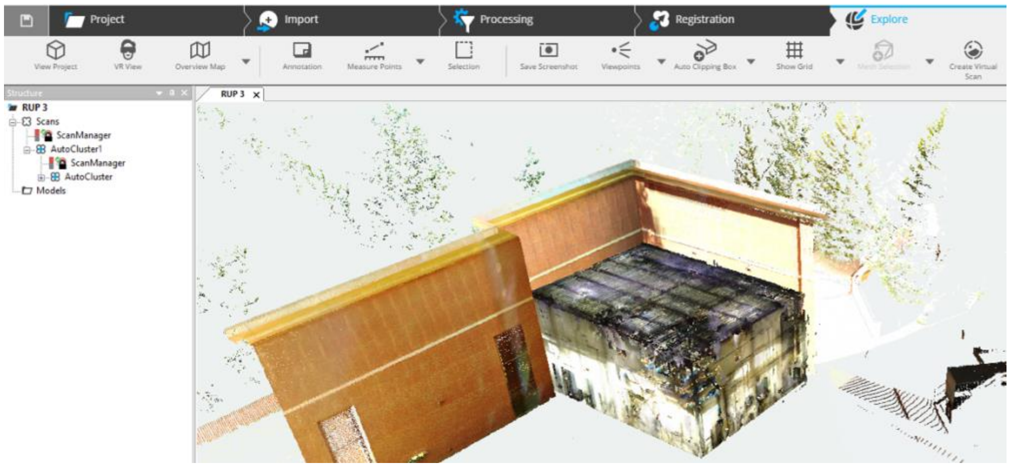



FIGURE 3.9 Scene Explore Tab

Finally, when the model is viewed in the explore tab and everything correct, the model must be exported. Next, in the Export section of Scene the Project and Scans must be exported with the project being exported first. When exporting the project, the folder for the room must be selected and export of the project will be completed. When exporting the scans, the scans must be exported in order and named with the naming convention of building number – mmyyyydd – room number (as previously discussed regarding naming convention). Once this process is completed the model has been created and saved.

### 3.2.4 Difficulties of Using 3D Scan Models

Once the 3D scan models are complete in Scene, they are functioning 3D models; however, there are difficulties with these 3D models with regards to it use. The model is created but only available to be viewed in the Scene software. Scene software provides a single user operation. This makes it extremely challenging for the facilities managers that actually want to use the models to have access to view them. This is one of the known difficulties discussed in the literature. A PDF view will allow for easier access to view these models.

Another difficulty with the 3D scan models is that the scanner can only see what can be viewed unobstructed from that location. If there is obstruction in front of what is to be scanned, the scanner will not collect that data. Multiple points in close proximity will have to be taken to try and collect all of the data. For example, if there are two pipes on top of each other with the scanner placed below. The scanner will not be able to collect the full data of the above pipe. However, there are software packages that assist to "fill in" missing points for gaps in obvious situations – like pipe runs.

### 3.3 3D Presentation Methods for Facilities Management

Existing literature details the current issues with using 3D scan data; however, there are ways to help resolve some of the issues. The methodology used will explore three different methods to create visuals outside of the software packages that limit the viewing capabilities for those in the field. The **first method** will be the transfer of the 3D model to create a BIM model which will allow an opportunity to create the missing elements or continuing the elements to locations that were not able to be captured. BIM models can also be viewed by more people in FM using viewer tools.

The **second method** explores getting the 3D model into a 3D PDF. This would allow for almost everyone to be able to view the model and get it in the hands of the people that can actually use it. There is also further potential for PDFs to be loaded into the IWMS/CMMS for a wider distribution. The **third and final method** explores using

GIS to locate the buildings as well as their rooms and assets. For the data set that collected for this case study, the campus will have documentation for all mechanical rooms; however, without GIS, there is no way to connect those rooms to determine what utility plant serves each building. Therefore, GIS will review how a mapping component can be used to assist owners to disseminate the needed information.

For this case study, Regional Utility Plant (RUP) 3 was used as an example for each of the purposed methods. After discussion with UNCC FM personnel it was decided that RUP 3 would be a favorable building choice to demonstrate the proposed methods. Also, RUP 3 was selected because almost all of the building is a designated mechanical room which is the main focus of this study. Since most of the building is comprised of the mechanical room components, scans of the roof and exterior of the building provided a complete model inside and outside allowing for a complete model. This would provide a very accurate representation of what could be performed on other buildings in the future. The RUP is also a critical building with regards to the UNCC system of buildings. It supplies utilities to the Student Union and new UREC building. Capturing these scans and process the scans will allow for a .rcp file to be created. The .rcp file can then be exported using As-Built modeler with Revit to create a BIM model. Which then can be viewed in the Autodesk Viewer or exported to a 3D PDF. Also, from straight from Scene it can be exported to Scene 2go which is a free viewer of the processed scan information.

### 3.3.1 Creating 3D Model

Once the scans are processed in Scene software there is a Scene project created. The use of this file can only be viewed and changed in Scene. To be able to get a model that can be used the project will need to be created in BIM. For this process Faro As-Built modeler with the use of Revit was used. To transfer the 3D scan models to BIM, As-Built software by FARO will be used. The SENCE file was exported into a .rcp file that both As-Built Modeler and Revit can properly read.

Once the file is uploaded in both software's a connection is made between Revit and As-Build Modeler so any changes made in As-Built Modeler will automatically update in Revit. As-Built modeler is a powerful tool that can create objects of actual data that was collected from the point clouds of the scans. These include walls, doors, windows, pipes, structural elements, and mechanical elements. As-Built modeler make is process of creating a BIM modeler more accurate of the exact sizes of asses and can help with creating objects that are not fully seen by the scanner. Once the model is complete there are two methods that a price effective, that everyone in FM will be able to view the model. To achieve this the Autodesk Viewer and creating of a 3D PDF will be used.

3.3.2 3D Viewer

Transferring a 3D scan model to BIM can be very beneficial. In BIM (Revit), an as-built model can be created from the point cloud model. Once the Revit model is completed, it can be used by FM as a visual for each building and can see the layout of the room and assets. Also, the models could be provided to an architect that can be used for showing a floor plan and location of current assets for future renovations. Autodesk Viewer is a free viewer that will allow for viewing Revit models for free. The Autodesk Viewer can be used on many different devices which makes it easy for anyone in FM to have access to view the model from anywhere. No major changes can be made to the model from the Autodesk Viewer which makes it safe for people that do not have full understanding of 3D modeling to change or alter the model.

### 3.3.3 3D PDF Model

A 3D PDF will allow for BIM models to be transferred to a PDF that anyone with a PDF viewer can use. Once the Revit model is created from the use of As-Built Modeler and Revit, an extension for Revit can be purchased to export the model to a 3D PDF. Once the model is completed with the use of ProtoTech Solutions 3D PDF exported a PDF can be created. This is a very powerful tool because facilities managers can open models of the mechanical rooms of each building and view the 3D model from almost anywhere. Any device that has a PDF viewer will be able to access the file. This is a very cost-effective method as well with the subscription of the 3D PDF exporter only costing $100. Another benefit of the 3D PDF is that all normal PDF functions are available to be used. This is a great factor because notes about assets can be added into the PDF as well as when technicians are in the field, they are able to make mark ups and add comments to the PDF documents they have downloaded.

### 3.3.4 Scene 2go

Scene 2go is a software that give access to view the projects that were created in Scene. This is a free viewer that can be accessed from a viewer on the computer. There is no download required to be able to view the project. Annotations can be created and view as well as photos and supporting documents that were added into the model. Scene 2go allows you to select different places that the scanner was set up at and look at the project from that view as well. Scene 2go also has a feature to be able to measure assets inside of the project.

## 3.4 Facilities Management Assistance

As stated, this applied research will assist the UNC Charlotte Facilities Department in their need to further expand their scanning capabilities and to get information to the field. Additionally, this research may be used by other organizations who are also attempting to establish their own LiDAR efforts. Because this research is applied in nature, there are three main questions to be answered. What is the industry standard for the use of Point Cloud Data for FM use? What is the benefit of the partnership in the collection of data using student assistance? What direction should UNC Charlotte take in the next steps to get mechanical room data into the hands of those that need it?

To try and answer some of these questions, a presentation was made to UNC Charlotte FM personnel explaining the three methods found. Then, a short survey was posted to get input from the personnel that may use this technology in their everyday work. The main purpose of this survey is to obtain feedback from FM on their thoughts of implementing the purposed methods into their programs. The survey asked what each person thought about each method and what may look like an optimal solution for their everyday tasks.

# CHAPTER 4: RESULTS AND CONCLUSIONS

The results of this research are reported to answer 3 questions.

1) What is the industry standard for the use of Point Cloud Data for FM Use? (from Literature Review and reported in Chapter 5).
2) What is the benefit of the partnership in the collection of data using student assistance? (Data collection process and reported in Section 4.1 and Table 3.1)
3) What direction should UNC Charlotte take in their next steps to get mechanical room data into the hands of those that need it? (Chapter 5: Summary)

## 4.1 3D LiDAR Scanning

With 3D scanning there are several hurdles that new users must be aware of such as the assurance that all equipment is functioning properly, and all settings are correct. While processing the scans it is difficult to process large rooms because certain objects can obstruct the view of the scanner. Therefore, crowded rooms may require a lot of overlap of the scans to capture the assets in the room. If care is not taken during this setup process, there can be issues with processing which will create the need to rescan the entire project.

In every mechanical room that was scanned, data was collected. Each room was documented to include the square footage (SF) and the number of scans. Once the building was completely scanned data was collected for the entire building, the results were providing a good predictor for the amount of SF that could be scanned per hour. Table 4.1 shows the averages of the scan times for the entire campus. With the current tools and process of scanning, about 1,585 square feet can be scanned every hour. This data is useful because it can be used to estimate future projects on campus. See Appendix A for the full list of scan times and locations.

TABLE 4.1: Totals for All Building Scanned

| Rooms Scanned | Total SF Scanned | Total Scans | Scan/SF | Total Time (Mins) | SF/Min | Total Time (Hours) | SF/HR |
|---|---|---|---|---|---|---|---|
| 267 | 216067.47 | 1364 | 158.41 | 8184 | 26.4 | 136.4 | 1,584.07 |

Space storage for the files was also an area of concern for the research as it was one of the biggest challenges. The raw scans hold a lot of information and when it is on your desktop as needed to process the scans, it became readily apparent that the computer system being used must be robust. Once the scans are processed, they can then be saved to an external drive. However, care should be taken to ensure that all of the files stay together in the folders that are created by the Scene software to allow the full functionality. With a campus a large as UNC Charlotte, being able to store all this data proved difficult but in the case of UNC Charlotte, the University Facilities' S drive would be a suitable location to save and store the large files.

## 4.2 3D Presentation Methods

Three different methods were selected based on ease of use and access to available software packages. The first of three methods used a software by Faro (manufacturer or the scanner used) called Scene 2go. The Scene 2go software was used to create a project from the point clouds and then add the desired information. The second method exported the 3D model into a 3D PDF using a third-party software. The third method used the Autodesk viewer to be able to view the model that was created. All three methods provide a way to take the processed scans and put them into a format that can be shared with those not familiar with the Scene software (specific to 3D scanning needs). Figure 4.1 shows the overall process of conversions from raw scans to completing the formats showcased in the three methods.

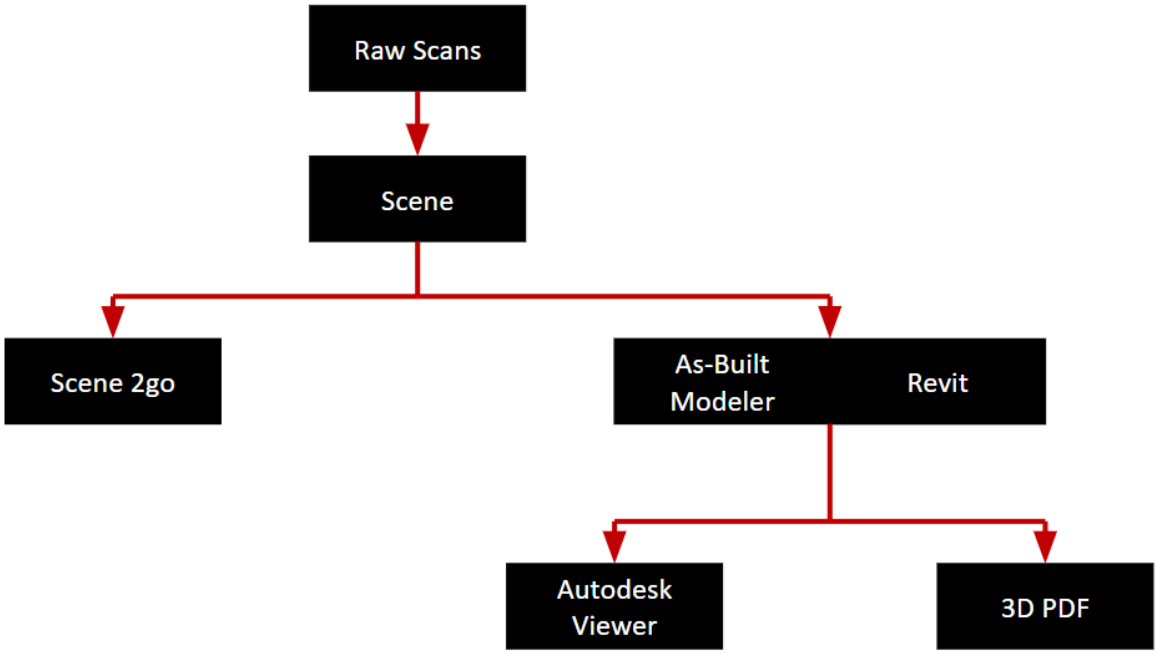



FIGURE 4.1: Flow Diagram of Methods

4.2.1 Creating 3D Model

To be able to create a 3D model, the registered scans must be exported to a .rcp file. This can be done by directly exporting from Scene to a .rcp file. There are numerous file types that may be used but, .rcp is a recognizable file type. Once the .rcp file is created it may then be opened in both Revit and As-Built modeler for two of our presented options. As-Built Modeler is a platform provided by Faro (what is called a Revit Add-in) which provides a way to convert the imported rcp file into a more usable Revit file. Also, Revit operates in a multi-axis platform but when importing from other file types, the data is not yet usable in the true sense of enabling the modeling process. The bridge must be made between Revit and As-Built modeler so that when changes are made in either Revit or As-Built modeler they will update in both software packages automatically. The bridge is made by having both Revit and As-Built Modeler open and using As-Built Modelers link tool in the toolbar. Once in Revit the point cloud needs to be created and rotated to the correct orientation and level. After orientation and the correct level is placed on the point cloud it can then be locked. Subsequently the point cloud cannot be moved or altered so that additional modeling will not affect the original point cloud.

Floor plans then can be created to model different sections of the building. Walls are typically the first thing to be modeled, so that the building can be enclosed and then the floors to follow. When the floor and walls are modeled, the remaining assets can be modeled. These include doors, windows, piping, mechanical, and structural components. Most modeling can be done in both As-Built Modeler and Revit, and typically this is a decision made internally depending on staffing and capabilities in determining the most efficient means to model the assets. However, As-Built modeler gives the ability to design the asset in the precise location based on the point cloud. For owners that prefer exact dimensions, using As-Built modeler may be the best option. With the use of the point could most types of assets can be modeled in their exact state.

When the model is complete there are options for additional Revit tools that can be used to refine the model and then can be viewed using a variety of viewer options. The viewers that we selected for this study were Autodesk Viewer and a 3D PDF. It should be noted that the ability to use As-Built Modeler and Revit will take training. This is a difficult software to learn because there are so many features in both software packages. However, once the model has been created viewing the model is very easy- and the purpose of the research is to find the most practical solution to utilize point cloud data in a similar “easy-to-use” viewer. For this case study only an example of some of the elements that can be modeled are shown, there were three different methods to produce an example of each.

### 4.2.2 3D Autodesk Viewer

The Autodesk Viewer is an Autodesk downloadable software that may be used to view the files that were created in Revit. This is an easy setup process, and the software is free and often used in the construction industry to share 3D Model data (BIM files) with owners or subcontractors. Once the Revit file is completed it can be downloaded and opened inside of this viewer to be enable general access the model. An example of the created model viewed in Autodesk Viewer can be see below in Figure 4.2.

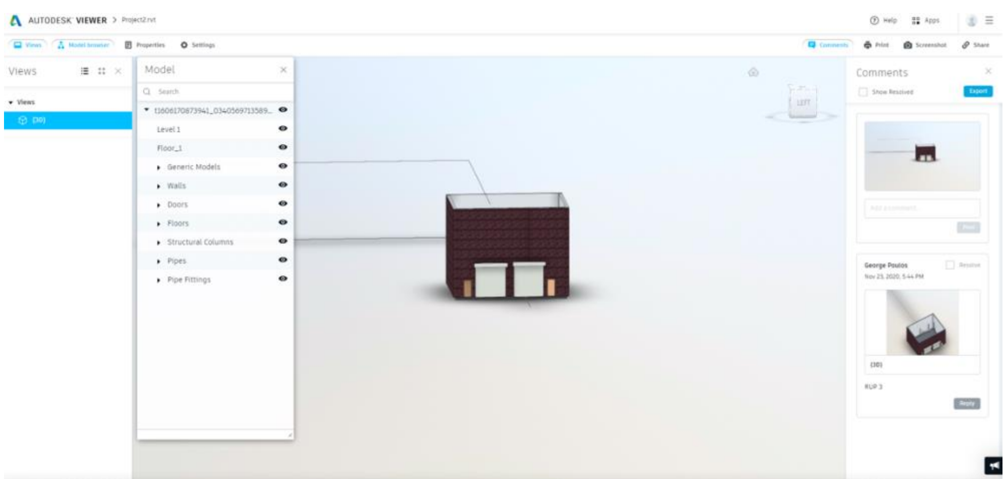



FIGURE 4.2: Autodesk Viewer

### 4.2.3 3D PDF Model

The 3D PDF enables the export of the files that were created in Revit to a PDF platform. The extension is purchased from ProTech Solutions (https://prototechsolutions.com/product-category/3d-cad-plugins/3d-pdf-exporter/) and is downloaded and added as an extension to Revit. Once the Revit model is complete and saved, the 3D PDF creator will export the Revit model into a PDF file that can be easily accessible. Once exported to PDF, the file will work like any other PDF document/file that is very easy to use. All typical PDF readers can open this type of 3D PDF. The 3D PDF created for this method can be seen below in Figure 4.3.

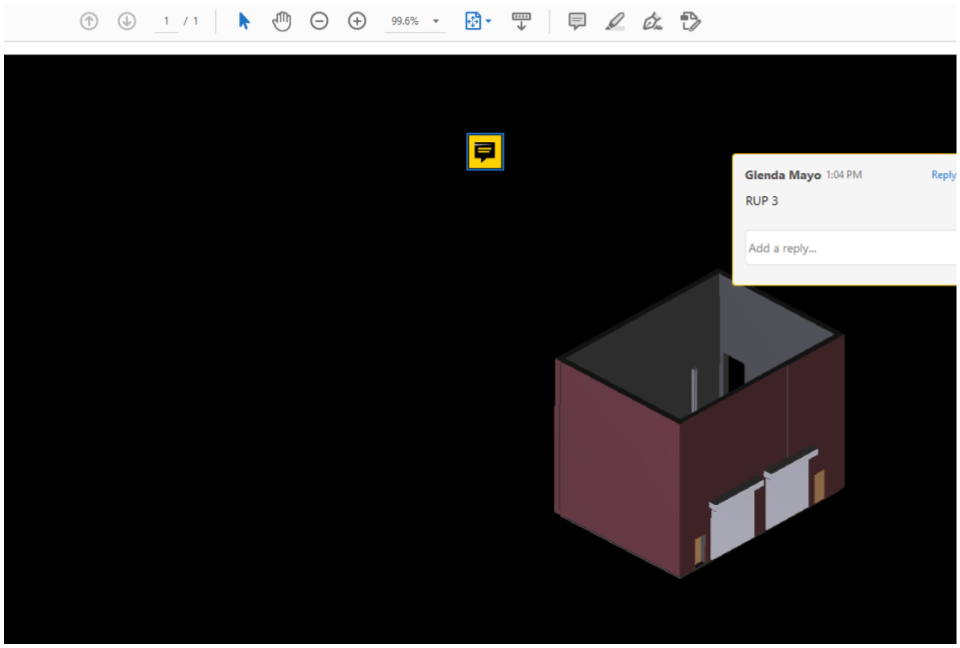



FIGURE 4.3: 3D PDF

4.2.4 Scene 2go

Scene 2go was an option explored to provide a quick way to get the Scene Project into the hands of the FM employees. There is no work to be performed inside of Revit, making it a quicker method to go from scan to useable data. A benefit of this option is that itis a very quick method because once the scans are processed, a Scene 2go app may be used for viewing. This method was easy to use and allows for information to be added to the project. For example, asset photos and notes are items that can be added that provides data in a single resource for employees. Multiple file types such as warranties in .pdf format, or photos in .jpg format, or even PDF files. Figure 4.4 shows an example of the annotation window of Scene. This is where all files and information can be added to the project.

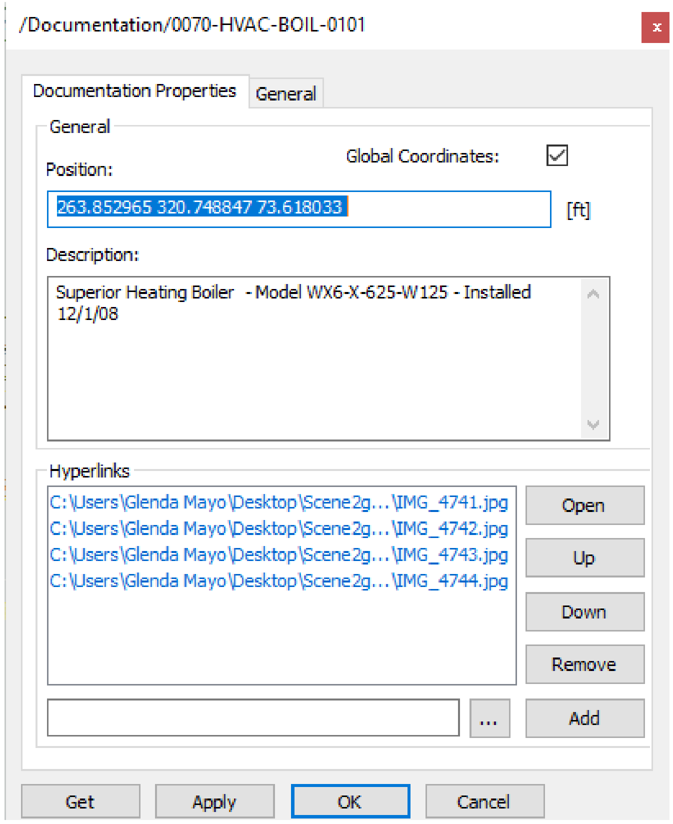



FIGURE 4.4: Scene Annotation Window

Once the project is created it can be opened using a Scene 2go app or web viewer, which is free of charge and requires no download of software, but it does require to the user to download the files onto their device. Once on the web additional items can then be "linked" into the Scene 2go platform. An additional benefit is that there is the ability to measure objects directly in the app thus providing a means for personnel to view and measure without going to the field. Also, Scene 2go allows you to select the assets that were annotated, and the information attached as well as look at locations of different scans from the view shown in Figure 4.5.

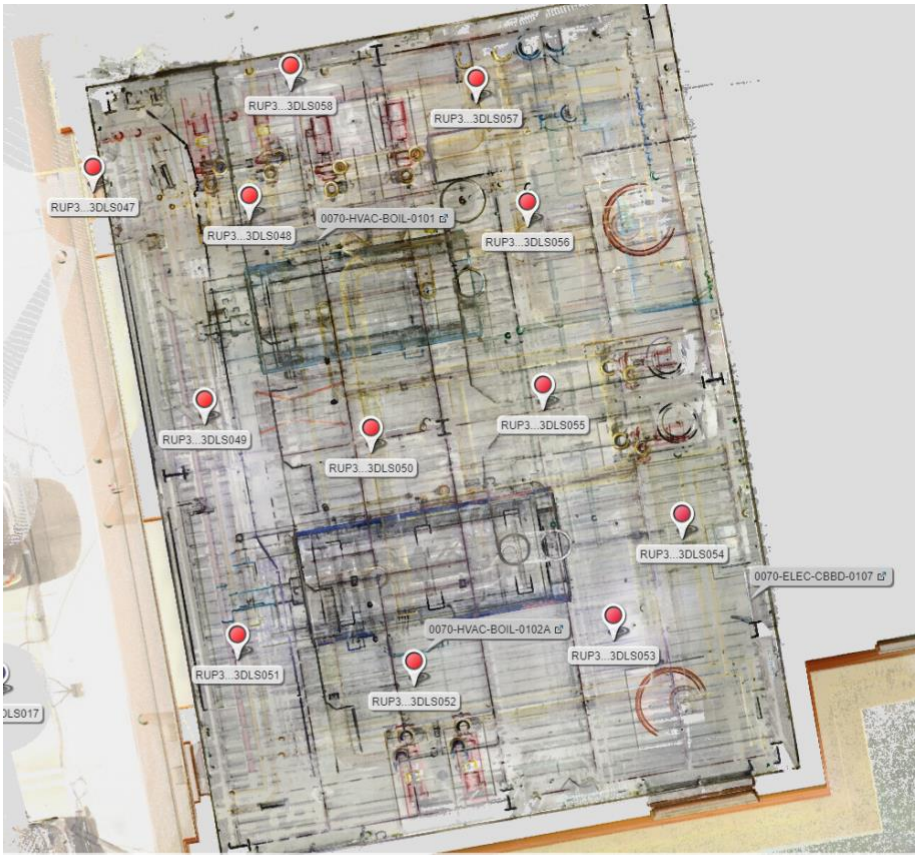



FIGURE 4.5: Scene 2go

4.3 Research Results and Validation

To better understand the software that was used in this project, Table 4.2 below summarizes the major considerations for each of the software packages needed for the research. As shown in Table 4.2, FARO owns three of the software packages used in the project. Instead of noting exact costs, Table 4.2 indicates any packages that are greater than $1,000 in current price. Autodesk owns Revit which is over $1000 to use and Autodesk Viewer which is free. Lastly, Protech Solutions 3D PDF creator is an addon to Revit that is easy to use and comes with a very low cost. With the use of Figure 4.1, and Table 4.2 highlights a summary of the path, cost, and learning difficulty/process of getting raw scans to the finished product.

TABLE 4.2: Comparison Matrix of Options

| | Scene | Scene 2go | As-Built Modeler | Revit | Autodesk View | 3D PDF |
|---|---|---|---|---|---|---|
| **Software Creator** | FARO | FARO | FARO | Autodesk | Autodesk | Protech Solutions |
| **Download Type** | Download to Computer | Addon (Scene) | Download to Computer | Download to Computer | No Download needed | Addon (Revit) |
| **Learning Process** | Training needed | Easy to use | Training Needed | Training Needed | Easy to use | Easy to use |
| **Cost** | > $1,000 | Free | > $1,000 | > $1,000 | Free | $100 |
| **Time to Complete** | Depends on Size of Building | Depends on info. needed for project | Very time consuming | Very time consuming | Very quick | Very quick |

In an effort to provide UNC Charlotte Facilities Management with a recommendation for "next steps" a survey was conducted with facilities personnel who each have an interest in using scanned data. On Tuesday November 24, 2020 a presentation of the three researched methods were presented to FM. There was a small panel of FM employees that were invited, and each was encouraged to interject with questions during the presentation.

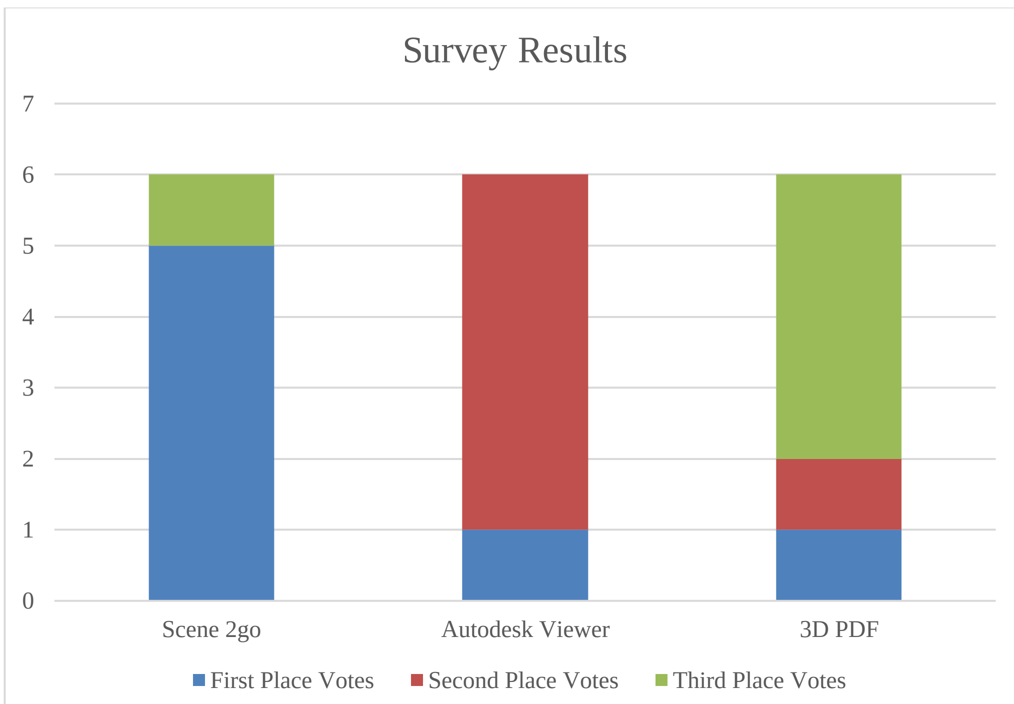
At the end of the meeting a short 4 questions survey was sent to the attendees as well as to several personnel who had conflicts and were unable to attend. The purpose of the short anonymous survey was to provide a means for employees to express their ideas and thoughts regarding each of the methods. There were six responses to the survey and of the methods proposed, Scene 2go ranked highest. There were five individuals who stated that it seemed to have the most potential and was their first place vote. The survey can be viewed in Appendix B. Table 4.3 show the amount of first, second, and third place votes each of the methods received.  Some of the beneficial comments included:

"Scene 2go could be time saving and was the most job site friendly tool.  It was so versatile."

" It is the most real looking application of the space. I like that the items can be tagged and linked to endless documents. I would like to see exploded diagrams of the assets such as valves, pumps, exhaust fans, motors, chillers, and boilers."

"Easy, free, and beneficial you can geolocate"

TABLE 4.3 Survey Results



# CHAPTER 5: SUMMARY AND VALIDATION

All scanning and processing of the point clouds were completed in house by graduate students with the help of a UNC Charlotte Facilities Management liaison. The process of scanning all 50 buildings and processing the scans took roughly 10 months. The data collected from each of the 50 buildings is attached in Appendix A. The students did not scan and process every day but instead worked based on a collaborative schedule with FM staff to obtain access to buildings. Depending on how quick the scans are needed, a consultant or an external company could scan and process the scans in a more regimented and reduced timeline. Chapter 3 has a summary of the comparisons between these options. All three methods have been performed by others. This study the methods were used to see how the university could best use the point cloud data collected. UNC Charlotte has not used any 3D technologies to date other than BIM models that are provided by the contractor. As highlighted in the literature, UNC Charlotte has found that these models are not always correct, and therefore the use of any of these methods could help in terms of obtaining accurate information.

All three methods, Scene 2go, Autodesk Viewer, and 3D PDF all received good feedback and have potential for UNC Charlotte use. The ultimate decision may require some additional exploration by facilities staff when considering variables such as expertise, available personnel and more importantly, the ability for this information to be integrated into the existing IWMS. However, the goal of the research concluded with the identification of the methods and the study was completed at an in-depth level to see what the software can provide.

Affordability was one of the major concerns at the onset of the research. Scene 2go is a free program and is an extension to Scene. Scene must already purchase to process the raw scan data. Scene 2go will just be added on to Scene and no download or space is needed. The ability of adding supporting documents to the Scene 2go project is very important. Once an asset is selected all supported information that was added to the project will be available to be viewed. Survey results indicated that a majority of the personnel on the panel also agreed that Scene 2go would be a good method for UNC Charlotte to explore further. Even though this case study was performed at a university campus level, the study can be reperformed at many types of facilities. The process can be done the exact same way to get the same clean result. Scene 2go shows the most promise of the three methods.

As discussed in Chapter 2: Literature review, there is no cohesive way that the industry uses 3D scan data. There is no standard on sharing the data and no recommendations regarding how to scan and process the data. This is an ongoing discussion in the 3D scanning community. The are many ways to scan and process the data and right now it is all completely up to the owner to complete the research and decide what software packages to use and how to implement the data into their current operations. The significance of this research showcased the time-consuming process to complete this type of exploration and also highlighted the need to try and reach some type of common ground.

Some recommendation that could be made to do this project again would be to walk through the rooms or building before scanning. This will allow for planning of scanner set up locations and even creating a graphic to do this efficiently. Also, collecting data similar Table 3.3 is very important when processing scan and knowing where each scan is located.

Future research will also need to include the consideration of GIS technologies. GIS is an important tool that is already widely used in Facilities Management Combining GIS and BIM is currently another prominent discussion in the FM industry and similar to scanning technologies, everyone is working in silos to obtain their own solutions. The option of exploring GIS and 3D scan data was considered but due to its extensive list of options, a comparison between methods could not be achieved. Therefore, this study was limited to the focus of the point cloud data and an efficient way to share asset data with others. Future research should explore the combined use of GIS capabilities and 3D scan technology.

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## APPENDIX A: TOTAL DATA COLLECTED FROM SCANNING OF BUILDINGS

| Building Code | Building Name | Rooms Scanned | Total SF Scanned | Total Scans | Scan/SF | Total Time (Mins) | SF/Min | Total Time (Hours) | SF/HR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Kennedy | 7 | 2014.00 | 25 | 80.56 | 150 | 13.43 | 2.5 | 805.60 |
| 2 | Macy | 2 | 668.84 | 8 | 83.61 | 48 | 13.93 | 0.8 | 836.05 |
| 4 | Atkins | 12 | 6717.54 | 37 | 181.56 | 222 | 30.26 | 3.7 | 1815.55 |
| 8 | Denny | 3 | 805.27 | 6 | 134.21 | 36 | 22.37 | 0.6 | 1342.12 |
| 9 | Garinger | 4 | 2107.60 | 14 | 150.54 | 84 | 25.09 | 1.4 | 1505.43 |
| 10 | Winningham | 2 | 647.42 | 6 | 107.90 | 36 | 17.98 | 0.6 | 1079.03 |
| 11 | King | 1 | 1158.33 | 6 | 193.06 | 36 | 32.18 | 0.6 | 1930.55 |
| 12 | Smith | 11 | 3702.62 | 26 | 142.41 | 156 | 23.73 | 2.6 | 1424.08 |
| 16 | Barnard | 4 | 991.06 | 9 | 110.12 | 54 | 18.35 | 0.9 | 1101.18 |
| 17 | Belk Gymnasium | 6 | 5248.92 | 28 | 187.46 | 168 | 31.24 | 2.8 | 1874.61 |
| 18 | Memorial Hall | 2 | 568.55 | 5 | 113.71 | 30 | 18.95 | 0.5 | 1137.10 |
| 19 | Rowe | 9 | 2648.20 | 20 | 132.41 | 120 | 22.07 | 2 | 1324.10 |
| 20 | McEniry | 11 | 5050.59 | 48 | 105.22 | 288 | 17.54 | 4.8 | 1052.21 |
| 31 | Cafeteria Activities Building | 3 | 905.68 | 12 | 75.47 | 72 | 12.58 | 1.2 | 754.73 |
| 32 | Colvard (Renovation soon) | 7 | 4841.60 | 42 | 115.28 | 252 | 19.21 | 4.2 | 1152.76 |
| 35 | Friday | 4 | 1994.84 | 14 | 142.49 | 84 | 23.75 | 1.4 | 1424.89 |
| 36 | Reese | 2 | 1694.91 | 9 | 188.32 | 54 | 31.39 | 0.9 | 1883.23 |
| 37 | McMillan Greenhouse *** | 1 | 276.16 | 3 | 92.05 | 18 | 15.34 | 0.3 | 920.53 |
| 38 | Burson | 3 | 4069.44 | 32 | 127.17 | 192 | 21.20 | 3.2 | 1271.70 |
| 41 | Storrs | 10 | 3326.23 | 33 | 100.79 | 198 | 16.80 | 3.3 | 1007.95 |
| 42 | Cameron Hall | 3 | 30227.18 | 121 | 249.81 | 726 | 41.64 | 12.1 | 2498.11 |
| 45 | Fretwell | 9 | 6079.51 | 30 | 202.65 | 180 | 33.78 | 3 | 2026.50 |
| 48 | Cato Hall | 4 | 380.37 | 5 | 76.07 | 30 | 12.68 | 0.5 | 760.74 |
| 50 | Regional Utility Plant 1 | 2 | 7864.47 | 54 | 145.64 | 324 | 24.27 | 5.4 | 1456.38 |
| 51 | Robinson Hall | 10 | 7496.45 | 62 | 120.91 | 372 | 20.15 | 6.2 | 1209.10 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 52 | College of Education | 17 | 5979.21 | 37 | 161.60 | 222 | 26.93 | 3.7 | 1616.00 |
| 53 | Regional Utility Plant 2 | 6 | 14348.00 | 75 | 191.31 | 450 | 31.88 | 7.5 | 1913.07 |
| 54 | Bissell House | 1 | 1299.15 | 12 | 108.26 | 72 | 18.04 | 1.2 | 1082.63 |
| 55 | Facilities Management & Police & Public Safety | 5 | 1588.78 | 17 | 93.46 | 102 | 15.58 | 1.7 | 934.58 |
| 56 | Woodward Hall | 11 | 39381.66 | 155 | 254.08 | 930 | 42.35 | 15.5 | 2540.75 |
| 57 | Duke Centennial Hall | 5 | 3713.63 | 14 | 265.26 | 84 | 44.21 | 1.4 | 2652.59 |
| 58 | Grigg Hall | 9 | 3623.65 | 33 | 109.81 | 198 | 18.30 | 3.3 | 1098.08 |
| 62 | Kulwicki Motorsports Laboratory | 1 | 1936.97 | 14 | 138.36 | 84 | 23.06 | 1.4 | 1383.55 |
| 63 | College of Health and Human Services | 11 | 3329.97 | 22 | 151.36 | 132 | 25.23 | 2.2 | 1513.62 |
| 64 | Harris Alumni Center | 2 | 231.00 | 3 | 77.00 | 18 | 12.83 | 0.3 | 770.00 |
| 65 | Student Health Center *** | 3 | 1698.37 | 12 | 141.53 | 72 | 23.59 | 1.2 | 1415.31 |
| 68 | Bioinformatics | 5 | 5555.21 | 22 | 252.51 | 132 | 42.08 | 2.2 | 2525.10 |
| 70 | Regional Utility Plant 3 *** | 4 | 3663.94 | 35 | 104.68 | 210 | 17.45 | 3.5 | 1046.84 |
| 71 | UNC Charlotte Foundation | 3 | 2022.37 | 14 | 144.46 | 84 | 24.08 | 1.4 | 1444.55 |
| 72 | EPIC Building | 13 | 4110.73 | 41 | 100.26 | 246 | 16.71 | 4.1 | 1002.62 |
| 73 | Center City Building | 19 | 9849.55 | 91 | 108.24 | 546 | 18.04 | 9.1 | 1082.37 |
| 75 | Motorsports Research | 2 | 364.78 | 6 | 60.80 | 36 | 10.13 | 0.6 | 607.97 |
| 81 | Regional Utility Plant 4 *** | 3 | 6661.26 | 49 | 135.94 | 294 | 22.66 | 4.9 | 1359.44 |
| 87 | Johnson Band Center | 2 | 431.31 | 3 | 143.77 | 18 | 23.96 | 0.3 | 1437.70 |
| 88 | Hauser Alumni Pavilion | 1 | 65.11 | 2 | 32.56 | 12 | 5.43 | 0.2 | 325.55 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 91 | Price Counseling Center *** | 2 | 582.11 | 9 | 64.68 | 54 | 10.78 | 0.9 | 646.79 |
| 92 | Facilities Ops and Parking (FOPS) | 4 | 1944.84 | 20 | 97.24 | 120 | 16.21 | 2 | 972.42 |
| 93 | Receiving and Stores | 2 | 815.26 | 11 | 74.11 | 66 | 12.35 | 1.1 | 741.15 |
| 95 | Admissions and Visitors Center | 4 | 1384.83 | 12 | 115.40 | 72 | 19.23 | 1.2 | 1154.03 |
| | Totals | 267 | 216067.47 | 1364 | 158.41 | 8184 | 26.40 | 136.4 | 1584.07 |

# APPENDIX B: FACILITIES MANAGEMENT SURVEY

UNC CHARLOTTE

**Default Question Block**

From the 3 examples shown, which do you feel should be further explored as an option for UNC FM? Rank in order of 1( best potential solution) to 3 ( least potential solution) .

1 Scene 2go

AutoDesk Viewer

3D PDF

Why did you rank the Scene 2go method as you did?

Why did you rank the Autodesk Viewer method as you did?

Why did you rank the 3D PDF method as you did?