USING LASER SCANNING AND 360 DEGREE PHOTOGRAMMETRY TECHNIQUES TO GENERATE POINT CLOUD DATA: A COMPARATIVE CASE STUDY

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family – thank you for all your support and pushing me to do my best

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AR	Augmented Reality
AV	Augmented Virtuality
BIM	Building Information Modeling
LOD	Level of Detail
LS	Laser Scanning
MR	Mixed Reality
PCD	Point cloud data
PG	Photogrammetry
TLS	Terrestrial Laser Scanning
U.S.	United States
VR	Virtual Reality

Abstract of Thesis Presented to the Graduate School
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In the present technology-driven world, where papers drawings and binders are being replaced by Building Information modeling and iPads, the concept of employing Photogrammetry and Laser Scanning for reality capture is not new given the fact that it has been in the construction industry for over decades. Information is paramount, and the concept of information quality is subjective and context dependent. Obtaining information from a batch of data points in space is called a ‘point cloud’ and this paper aims at analyzing the point cloud information from images obtained using 360-degree photogrammetric cameras by setting the point cloud information from Laser Scanning as an accepted technique. A multidisciplinary approach towards the comparison of point clouds from two different techniques is reliable, when location, time and other affecting factors are constant, thereby quantifying the relationship between them. Although the objective is to better visualize the reality and extend the result towards understanding the difference in performance, quality, and reliability. One factor that distinguishes necessity for perfection from luxury is the price tag associated with it. Cost plays a vital role in the industry especially where the practice of construction technology should not

be omitted and be a hindrance in achieving quality and perfection. The proposed method is to be analyzed for its information accuracy, return on investment and utilization in the reality capture industry to encourage its use and thereby extend further research using 360-degree Photogrammetry techniques.

CHAPTER 1
INTRODUCTION

1.1 Overview

The Laser Scanner market for the forecast period from 2017-2022 is expected to be appreciated at 5.06 billion U.S. Dollars from the year 2022 (Zion Market Research, 2017). Leveraging the power of reality capture for Buildings and Construction is the next thing technologists are gearing towards. A meticulous three-dimensional mapping of the area of interest, enables more accurate decision making for all stakeholders. Moreover, there is a growing demand to document the existing or “as built” state of buildings and their immediate surroundings. Builders often require detailed reliable spatial data sets, which can be stored, analyzed or distributed digitally. To create a 3D space or a map, usually excessive number of points are measured and documented. The latest developments in photogrammetric methods allow transforming semi-automated recordings of high-resolution spatial data into a “cloud” of fully three-dimensional data points called the point cloud (Ferenc Acs, 2014).

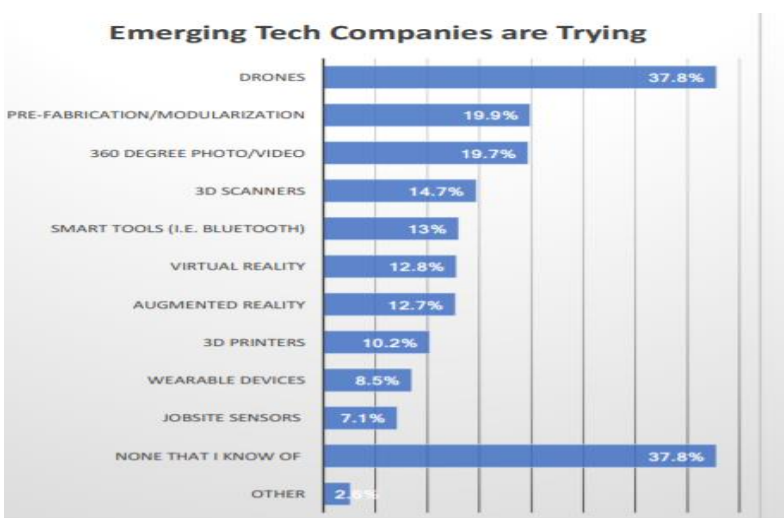


Figure 1-1. Efforts taken by emerging Tech firms. Source: 2017 Construction Technology Report, survey from 2,600 builders (Reprinted with permission from jbknowledge.com website, 2018)

Often, Reality capture is a service that General Contractors provide to their clients in the form of progress tracking, obtaining accurate as-builts, quality checks and site mapping, etc. These applications are wide spread with the numerous options available and often it becomes a choice that is suitable to the organization unlike Engineering soil tests or load bearing tests that is affordable as well as a prime necessity in demand. Developing countries fall short of such privileges due to a price tag that these technologies come with. Several applications such as Building Information Modeling, Augmented reality or Reality Capture, etc. is being used to support their business with the stakeholders. For example, a detailed 3D model can provide value for beyond the time, effort and money saved right from pre-construction (design phase) to the post-construction phase. The way how a construction firm uses a model gives them a competitive edge in the market. Likewise, the way how Construction sees Technology to leverage the productivity gives them an edge in the development sector. The facts underlying these benefits is one of the factors why constant research is evident in the Construction Technology industry.

Photogrammetrists were the ones who played a key part in the exploitation and progress of Laser ranging for the generation of Digital Terrain Model (DTM) (Baltsavias, E. P., 1999). 3D Laser Scanning Technique is an additional versatile tool to choose from rather than considering it as a competition. Development and standardization of high-quality workflows for the entire processing chain concentrating on the postprocessing phase (items optimization, extraction and organization) by collaborating with other prominent applications-technology and by integration of other sensors is often encouraged and expected to be contributed by Photogrammetrists towards ongoing research.

Although this study revolves around the use of two Reality capture techniques dominant in the industry, it focuses on the broader picture of helping the industry professionals in achieving their project management goals. This paper will help in understanding the differences in the workflow, conflicting parameters, and assessment of the results obtained from the point cloud generated through these techniques. The importance of this research extends to deliver an overview of the difficulties of reality computing tools in the real-time construction industry. The results from the review may help reality computing tool manufacturers in taking these factors into consideration while choosing their tool for a task in addition to providing an insight on the level of detail 360-degree Panoramas can be possible of as compared to their Laser Scanning counterparts.

1.2 Organization of Research

The study has six chapters. Chapter 2 presents the Objectives and motives for conducting the proposed study on reality capture techniques. Chapter 3 presents a detailed literature review which shows the earlier studies conducted in the same field, restrictions and possible explanations of the study. It also represents the status on this field and opportunities for further research. Chapter 4 discusses the research method used for this hypothesis and elaborately presents the workflow followed in getting the results. Chapter 5 analyzes the information obtained from the processed data obtained as a part of the pilot study. Lastly, Chapter 6 summarizes the study and delivers recommendations for future scope of work.

CHAPTER 2
OBJECTIVES AND MOTIVES

The underlying motives of this proposal points towards virtual information generated through reality capture data for use in AEC field. The Project Management triangle revolves around Time, cost and Quality and the scope of work involved. To primarily understand the expectations from 360 Photogrammetry as compared to the standard procedure of reality capture through Laser Scanning technique, a pilot study is fabricated as a part of the research to meet the objectives.

2.1 Scope of Research

The prime emphasis of this research is to assess how the triple constraints: Time, Cost and Quality and Workflows vary from the standard technique to the 360-degree Photogrammetry. At the same time, the research also concentrates on analyzing the point cloud information that is beneficial to test the hypothesis. Level of detail obtained with these two techniques can be compared with real site to understand the percentage of accuracy or error as compared to the accepted technique.

2.2 Objectives

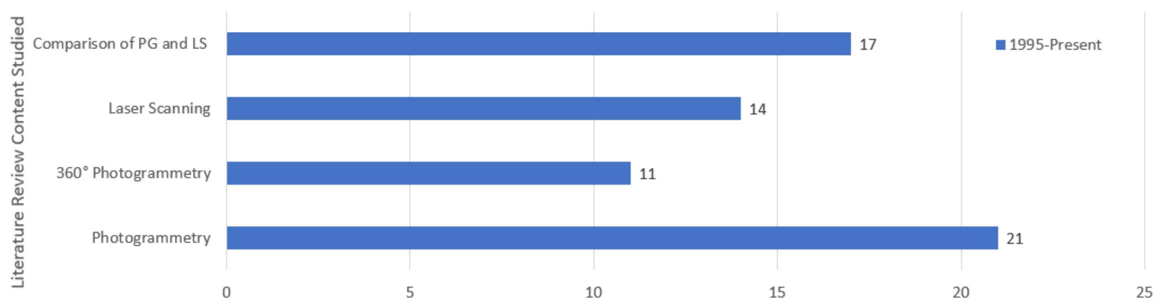
The objective of this research is to estimate information from a set of generated point cloud obtained through 360-degree panoramic images to understand the current use as well as the possible future use of 360-degree Photogrammetry in construction by setting the point cloud obtained from Laser Scanning as an industry accepted technique given its history of use. The specific research objectives are to investigate:

- Study current use of 360 Panoramas in AEC
- Study current use of Laser Scanning and Photogrammetry in AEC
- Conduct a comparative study of point cloud generated by 360 Panoramic Photogrammetry vs 3D Laser Scanning

CHAPTER 3
LITERATURE REVIEW

3.1 Reality Capture

Laser Scanning and Photogrammetry are two of the main technologies traditionally used for documentation tasks based on reality capture. Historically, professionals and researchers from both sides have discussed comparative suitability and performance. Over the last decade, Laser Scanning has become the dominant technology for reality capture. The rapid improvement of camera systems, software, and computer capabilities have increased the competitiveness of Photogrammetry, especially when considering cost differences. Source of internet opens efficient, diverse sensors that makes source data become less expensive or sometimes entirely cots-free. With advancements in cloud storage platforms, efficiency of image storage is improvised and can quickly progress to become a non-cost issue. Nevertheless, it is not the aim of this paper to argue for one or other side, rather explain the comparative results which can be obtained from both technologies for the same urban environment, using standard capture and processing conditions. Figure 3-1 below represents the Literature review content versus number of papers studied for this research.



	Photogrammetry	360° Photogrammetry	Laser Scanning	Comparison of PG and LS
1995-Present	21	11	14	17

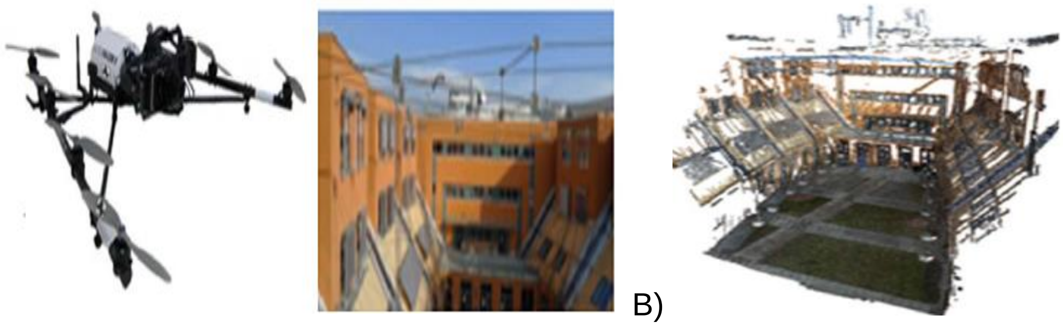
Figure 3-1. Number of papers studied for Literature review in each domain (Source: Courtesy of the author, 2018)

3.2 Photogrammetry

Photogrammetry is a digital imaging technology used for taking measurements and calibrations by capturing images using multiple image sensors in a single device (Moffitt, F. H., 1967). “Photogrammetry”, as a term was invented and first used in the mid-19th century for surveying various buildings, man-made objects or terrain. The imagery proved to be a valuable instrument in the hands of spatial science professionals ever since (Grimm, 2007). In the case of Photogrammetry, the generation of 3D spatial data is performed by the photogrammetric processing of digital images taken at the site due to its wide area coverage. Luhmann, T., (2010) explains the varied field of different hands-on encounters that it can overcome by employing Industrial Photogrammetry in terms of cost-performance ratio, measurement speed, specified accuracy, automation of work performed, process integration, device integration and breakdown. That study reports certain specific available on-line and off-line systems in those times that can be used to deal with turnkey classifications for different measurement activities and other general-purpose systems. Recent and future developments aim at keeping the higher accuracy and lower costs ratio while concentrating on sophisticated dynamic applications, multi-sensor solutions and integrating systems into production chains.

3.2.1 Application Areas in AEC

Leberl, F. et al., (2012) explains the contrast between LiDAR systems that are widely used and claims that LiDAR’s do not deliver information that is superior to digital photography. The foremost application of Photogrammetry is plotting the huge areas on surface of the Earth in addition to an effort to reduce the cost of previous approaches. That research employed aerial Photogrammetry where an octo-rotor MAV in under 10 minutes captured an atrium space with more than 300 high quality images to generate a dense point cloud as shown below in Figure 3-2.



A) B)

Figure 3-2. Representation of the pilot study A) An octo-rotor MAV and the Atrium space B) Resulting imagery (Source Leberl, F. et al., 2012).

The study explained the design and proposed an end to end computerization to attain the transmission from a huge assemblage of overlying 2D images to a 3D geometric model of an object or an area of interest. As compared to previous manual methods, a price advantage by order of two magnitude was noticed in that research. One such test was conducted using aerial photography for getting the roof details. The results showed that the roof planes and specifics have possibility of being obtained from airborne photographic techniques and the success rates from the three-dimensional point clouds was noticed to be from 78% to 92%. The result of that study was dependent on the specific job used for the study and by counting on the captured aerial images with 25 to 100 pixels per meter square. It concluded to promise that Aerial photography could solve issues due to its capability to support texture and color-based breakdown, accessibility of edge and line information and superior point density in construction, urban planning and industrial approaches.

3.2.2 Dense Point Clouds Photogrammetry to Map Low Rise Buildings

An investigation of the capacity of dense point cloud Photogrammetry to map a low-rise building for architectural purposes was conducted using a Conservatory as a pilot study at Australia in 2014. Data acquisition by terrestrial Laser Scanner, high precision total station and a Canon EOS 600D SLR camera was employed with an average 85-90% overlap along the building façade. The results of the project proved that it is feasible to map and post process dense point cloud data of man-made structures with the use of common digital camera imagery and readily available Photogrammetry software (Ferenc Acs, 2014). The collection of the captured RAW images can be considered as a multi-purpose data which can be reprocessed using different methods or to use for entirely different purposes than originally intended. A comprehensive and high-resolution digital photo documentation of a building can be considered as a product of the study.

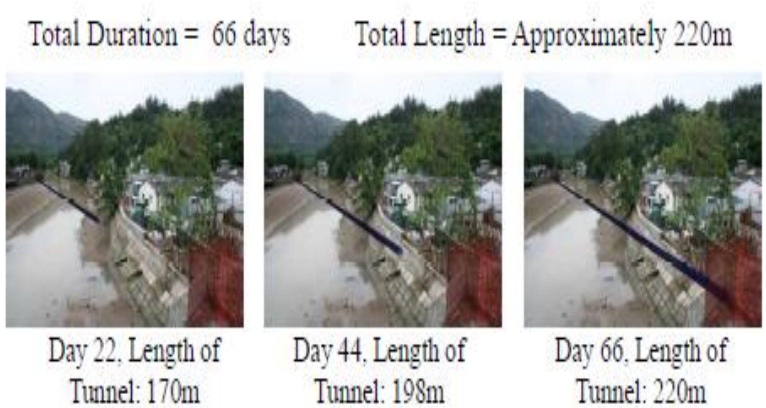
3.2.3 Close Range Photogrammetry

Close range Photogrammetry originates from the surveying discipline and is an systematic depiction of a processing mechanism that can extract spatial evidence through computation using several photos put together. It is practice that can be relied on as a cost-effective, simple, yet easy to use on-site mechanism (Fei Dai et al., 2013). Wang, C. et al., (2010) in his study involves close range photogrammetry as it is a low cost, automated photogrammetric technique in practice. They further state that these techniques have the probability of becoming habitually feasible for monitoring flexible structures in the future. Wang, C. et al., (2010) investigated the use for application at all phases of membrane structural engineering. The applications ranged from material testing through measurement control in prefab placement as well as in as-built monitoring from pre to post construction. According to the study, a complete understanding of the ability of close-range Photogrammetry is essential to develop a low cost, basic structural monitoring arrangement. Dynamic examining of flexible resources in a laboratory test setting was the focus which was followed as a next step upon receiving satisfactory results that let the research move forward. The competence of this arrangement for dynamic monitoring was widely scrutinized. The study then later decided to let the system be set out-of-doors for real-world trials and prove the ability of that photogrammetric resolution for structural monitoring.

3.2.3.1 Using close range photogrammetry for reality capture in CM applications

Fei Dai et al., (2013) explains reality capture as the method of delivering three-dimensional data of a body in its original as-built condition. AEC industry has increasingly started to demand as-built information or detailed 3D model for its use in numerous activities such as quality control, project inheritance documentation, bill of materials and quantity take-off, as well as progress measuring of construction activities. A successful transfer of a building project involves accurate details and on time capture of as-built data of the site conditions, which portrays a significant role. Fei Dai et al., (2013) also reviews the state of prevailing technologies and the basics of Photogrammetry in that research. A clear presentation of the research efforts has been provided followed by the review in applying Photogrammetry to space organization, measuring building products, model site graphics, and visualizing variations and progress of activities in the construction sites. That study also presented the challenges faced in applying this technology in real world practice where market growth and trends are given value before accepting a technology that has immense potential.

Though market trends fail to understand the advantages of this inexpensive, easy to use, efficient technique, they often compare the existing Laser Scanning and total station sensor techniques and ignore introducing a newer surveying method. Fei Dai et al., (2013) also explains the study efforts of applying close-range Photogrammetry towards visualizing the progress of an active construction site and measuring the building areas around the hazardous area which is inaccessible by humans (example: Tunnel construction progress visualization used in the paper) shown in Figure 3-3. This technique immensely helped in quality control and creating augmented reality for underground infrastructure for better visual dynamics.

A) 

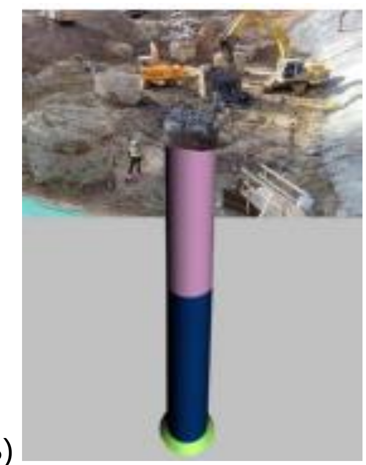
B) 

Figure 3-3. Progress of Tunnel construction A) Progress tracking of an active tunnel construction site, B) Augmented for quality control of the bored pile (Source: Fei Dai et al., 2013)

The research outcomes demonstrated the potential of the inspected procedure in resolving day today construction jobsite difficulties. This grants the means to photogrammetric explanations for three-dimensional modeling, quantity surveying in complex buildings, and augmented reality for AEC practices. They are the preliminary phases towards the futuristic progress of programmed photo-based three-dimensional geometric measurement of as-built construction and infrastructure elements.

3.2.3.2 Close range photogrammetry for bridge measurement

A practice that has unique advantages such as a nondestructive or non-contact measuring technique, which often is less labor intensive along with the ability to record a huge area of geometric information in a time saving fashion has a preference compared to the other techniques. Close-range Photogrammetry is one such technique that offers all these advantages along with the possibility of performing additional analysis later with the captured data and performing a regular progress check on the same activity (Jiang, R. et al., 2008).

Often, components of a bridge are verified for its deformation properties and durability as a substitute of the entire bridge for its cost-time constraints and additional difficulties associated with heavy construction. In such cases, close-range Photogrammetry has a boundless potential for bridge engineering applications due to its potential of performing as a fully digitalized system. Several successful examples can be found related to the field of measuring bridge distortions and close-range photogrammetry monitoring, among which maximum studies attained an order of accuracy of about 1 mm.

As compared to the traditional surveying methods, the research states that photogrammetry has reduced field work by over 50% while sustaining the equivalent level of accuracy for bridge geometry measurements. In addition to general bridge measurements, it has been useful for test monitoring 3D deformations. Close-range Photogrammetry also shows use in understanding the behavior of the bridge elements failure, which helps in shear, bending, axial and torsion experiments. The study concludes Close-range Photogrammetry as an influential tool for dimension problems, historic bridge documentation and rehabilitation in addition to a diverse range of bridge engineering applications (Jiang, R. et al., 2008).

3.2.3.3 Close range PG for progress measurement of construction activities

Kim, C. et al. (2011), researched the development of the photogrammetric information from digital Photogrammetry with high density and resolution for construction progress measurement, where the research experimented on the feasibility of the hypothesis. To develop a technique for progress measurement, 3D as-built data acquisition was performed using digital cameras. An outline was presented which contained 3D related photogrammetric data procurement, enhancement of photogrammetric data, and for detecting structural components involved. The accuracy of the projected technique was confirmed by assessing the value of the registered 3D data with respect to density. The initial experimental result concluded that the applications of photogrammetric data for advanced and automatic construction progress measurement were possible.

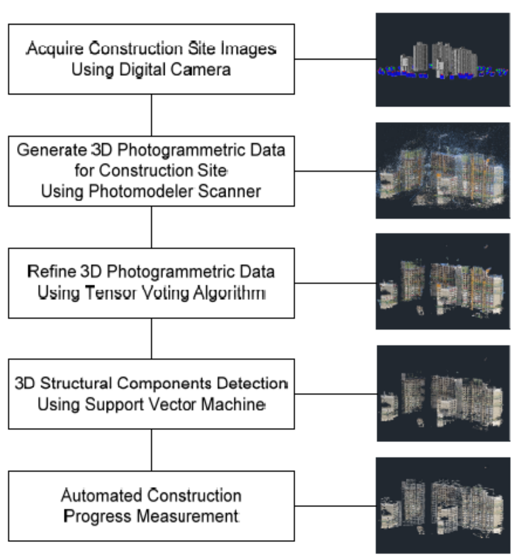


Figure 3-4. Procurement and Registration of 3D photogrammetric data (Source: Kim, C. et al., 2011)

In that part of the study, the data collection and Registration of 3D information from Photogrammetry was described by conducting an experiment on a construction site under construction. Photo Modeler scanner, a photogrammetric processing software was used to register the images obtained from the construction sites. The acquisition of 3D information from a set of images were tested to generate a point cloud model. Figure 3-4 represents the workflow that was followed to get the primary experimental results. Upon analysis, it validates the possibility of extraction of 3D spatial data from images as well the feasibility of construction progress measurement applications by using close range photogrammetric techniques. It also gave way for a model comparison between as-built structural elements and 3D CAD model of the ongoing construction activity for tracking its progress. Kim, C. et al. (2011), focused on further research to conduct a detailed analysis on the accuracy of the extracted processed data.

3.2.4 Application in Study of Mammals

Photogrammetry has been in use for long to minimize intrusiveness and for capitalization on the accuracy of volume assessment (Beltran, R. S. et al. 2018). Earlier studies have described a constant optimistic bias in the photogrammetric volume assessments and the objective of that study involved in evaluating a suitable method to estimate mass of marine mammals using Photogrammetric techniques since it is a non-destructive evaluating method. An experiment was conducted to test the hypothesis on female seals although it was subjected movement of the subject captured.

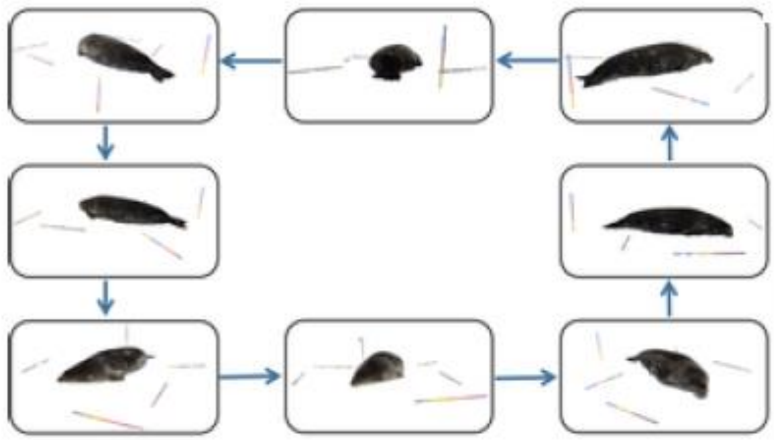


Figure 3-5. Directions of photographs taken of the seal (Source: Beltran, R. S. et al., 2018)

3D photogrammetric analysis was one method in the comparison study for density calculation that was performed by capturing 8-12 photographs of 56 female Weddell seals from all probable viewpoints such as kneeling, upright, etc. by slowly circling the seal. Former to site work, a Canon EOS Rebel T3i digital camera was calibrated. The photographs were processed using Photo Modeler Pro, Autodesk Mesh mixer as well as Bender. Each seal was taken as an exclusive Photo modeler project related with the calibrated camera.

3.2.5 Photogrammetry for Reverse Engineering

Literature review shows fabrication of artifacts and replication models were possible with 360-degree photogrammetric concepts by using DSLR cameras to convert 2D images to 3D CAD spatial representations and using 3D printing technology or additive manufacturing, geometrical representations of original artifacts can be reverse engineered by fabrication. Kaufman, J. et al. (2015), documented three pilot studies namely; the reproduction of a trivial modern clay statue, 3000-year-old Egyptian antique sculpture and an Ammonite fossil based on single camera Photogrammetry by employing a Nikon D3100 camera and a user-friendly software called Photo Scan to process the images and were successfully recreated (Kaufman, J. et al., 2015).

A) B)

Figure 3-6. Original specimen vs. dense point cloud A) Original Artifact, B) High Resolution Point Cloud Image (Source: Kaufman, J. et al., 2015)

3.3 Photogrammetry by Employing 360-Degree Panoramas

A Panorama, a word that was coined in 18th century; is any wide-angle sight or depiction of a geometric area, also in simple words, called as a 360-degree visual medium. A Panorama captures everything visible from different positions, increases the capabilities of the human visual system, gives a sense of immersion, and can create highly realistic and detailed representations of the environment (Paul Bourke, 2014). Recent developments have shown panoramic images to be used for improvising augmented reality in the construction domain. It is evident from the numerous 360-degree camera available in the market over the recent years (Table 3-1).

Table 3-1. 360-degree cameras available in the market

Name of the camera	Price range	Features	Stills resolution
Detu Twin	$ 80.00	Wi-Fi remote control	8 MP
Samsung Gear 360 (2017)	$ 80.00	Horizontal correction, geotagging	8.4 MP
LG 360 Cam (LGR105)	$ 150.00	360 and 180 images	13 MP

Table 3-1. Continued

Name of the camera	Price range	Features	Stills resolution
Kodak PixProSP360 4K	$ 220.00	2 required for 360 capture	17.52 MP
Samsung Gear 360 4K	$ 230.00	4K Video	15 MP
Insta360 One	$ 300.00	Free capture and bullet time	24 MP
360fly 4K	$ 300.00	easy 360 footage	12 MP
Ricoh Theta V	$ 330.00	4K video and live streaming	14.4 MP
Yi 360 VR	$ 400.00	Crisp 360 images	16 MP
Nikon Key Mission 360	$ 500.00	Remote access/Android, iOS	23.9 MP
GoPro Fusion	$ 600.00	5.2 K resolution	18 MP
Vuze 3D VR	$ 650.00	4K UHD	16 MP
Garmin VIRB 360	$ 800.00	5.7K resolution	15MP
Vuze+ 3D 360 VR	$ 950.00	8x F/2.4 fisheye lenses	16 MP
Insta360 Pro 8K	$3,500.00	8K UHD	60 MP
Orah 4i Spherical VR	$3,500.00	4K UHD	2.8 MP

Notes: Information obtained as of current date (09.24.2018)

The market growth of 360-degree panoramic camera is driven by high demand for a profitable camera to aid growth in the progressive photography market, increase in the digital market, and rise in demand for safety and security measures in public as well as the corporate places. However, higher cost and more expensive nature of the 360-degree panoramic camera than the conservative cameras, and accessibility of inadequate software support services are estimated to hinder the market growth. The high dynamic range of 360-degree panoramic camera offers significant features which add traction to the market growth. Figure 3-7 below explains the outline of 360-degree Photogrammetry workflow.

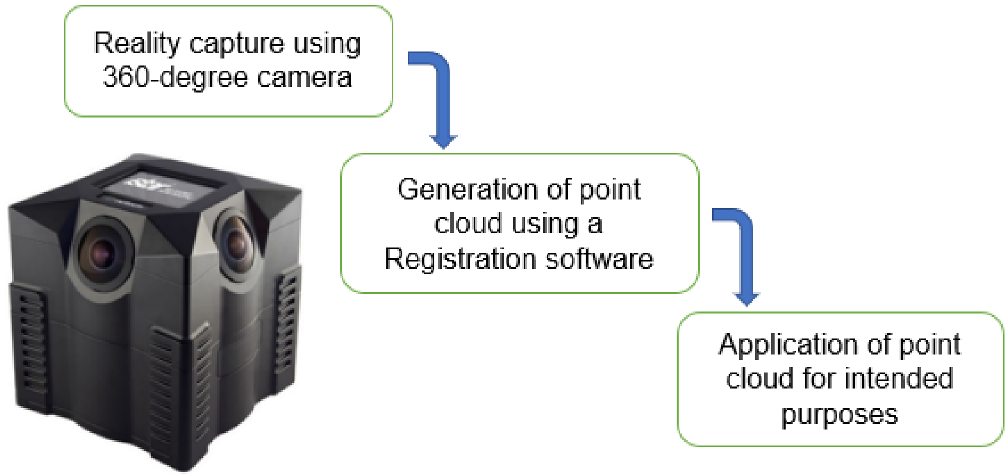


Figure 3-7. Basic sketch of how 360-degree panoramic camera works (Source: Courtesy of the author)

The 360-degree panoramic camera is a secure camera that delivers an area of exposure in 360-degree resolution. It can be used to detect activities in a huge area, track the movement of humans, and help in improvising area management. The ability to capture wide-angle 360-degree high-quality images using a single panoramic camera delivers outstanding efficiency while increasing overall security and situational awareness. Multi-sensor cameras provide a higher level of overall situational awareness and security. They can record the entire field-of-view all the time. The use of a multi-sensor camera allows these operators to effectively view significantly more area, improving his or her ability to view multiple areas of interest.

3.3.1 Application Areas in AEC

Regular 2D photos are often time consuming when it comes to documenting an activity on the construction site. When a 360-degree camera can easily capture its entire surroundings in one click, industry prefers to familiarize with its applications since its arrival to global market. Advanced progress measurement and clear communication in the site is the topic of interest and Panoramas comes into effect with these needs.

3.3.1.1 Construction safety education

Many research works have effectively implemented computerized 3D model model-based VR to provide adequate safety information for students. Pham, H. et al. (2018), in his research geared towards energy efficient education system, a new web-based panoramic system was introduced for collaborative construction safety education.

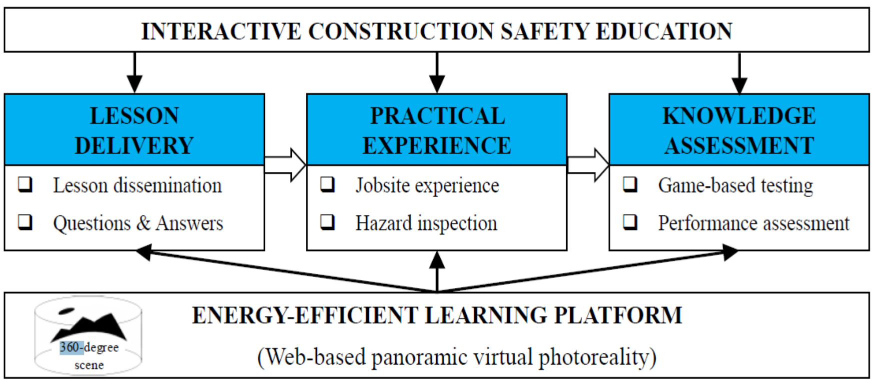


Figure 3-8. Collaborative constructive safety education (eCSE) framework (Source: Pham, H. et al., 2018)

A framework (Figure 3-8) was proposed involving both 3D VR based testing as well as Cooperative constructive safety education (eCSE). A 360-degree technique captures the jobsite situation in a 360-degree angle easily on any mobile displays that is conveniently portable. Both functional and technical evaluation was conducted on a set of 30 students each to test the effectiveness of both systems.

As an extension to the previous research, Pham, H. et al. (2018), extended the construction safety education by proposing the Virtual Field Trip system (VIFITS) for portable building safety teaching using a 360-degree panoramic virtual reality. Three main operations introduced were 360-degree panoramic field trip rendering, framework development and customization of scene-based functions. It was tested in a building construction as a supplementary course. The proposed framework involved the comparison of learning outcomes between the VIFITS and the traditional paper-based examinations to evaluate system effectiveness. Preliminary results reveal the VIFITS to be a powerful educational method for effectively providing practical experience and safety knowledge education for students.

3.3.1.2 Safety training using panoramic augmented reality

R. Eiris Periera et al. (2018), in his study on using panoramic augmented reality, developed a virtual safety training environment to indirectly prevent construction accidents by helping workers identify safety hazards in advance and to motivate safety conscious decisions. The research involved the use of 360-degree pictures with augmented safety related facts to provide an immersive visualization of hazardous situations within a real environment context. Steps involved capturing the data on site using fish eye lens camera, authoring the data, immersion and distribution of information through an external hardware such as computer, tablet, etc. A pilot study was conducted in a commercial building construction site to enable real world training. Several fall hazards were capture using the NCTech iStar Fusion camera to create a fully interactive 360-degree experience. This study enhances hazard identification skills of workers and professionals by creating a trainee-centric exploration of construction environment, high level of jobsite interaction and a channel for feedback regarding training progress. Figure 3-9 represents an example used from a commercial construction site for interactive Panorama training.

Figure 3-9. Example of ladder hazard identification within an interactive Panorama (Source: R. Eiris Periera et al., 2018)

360 panoramic augmented reality can never fully imitate the true reality but has a high demand wing to the necessity for computationally intensive graphical representations, while concurrently justifying the requirement for a user to be in any specific physical setting. R. Eiris Pereira et al. (2018), framed a development method for an interactive usability testing of a construction safety training portal for designated Fall (one among the Focus Four) hazards based on 360-degree augmented reality platform. By proposing that method, the framework promoted the idea wherein a trainee can have a true-to-life understanding of an active construction jobsite with absolutely no contact with the actual site, i.e., no restrictions or compromise on safety features.

A panoramic augmented reality platform was created where the panoramic images were complemented with interactivity using a game engine, Unity 3D® that could allow learners to operate the augmentations confined in the platform. Platform usability testing was conducted in the form of a pilot study that involved a three survey namely; pre-test, a test for hazard identification and a post identification test. This platform was tested among construction management and architecture students in the University. The developed platform then provided a hazard identification index that could evaluate the aptitude of individual participants who took the survey. The results showed that an average of 52% of fall hazards were predictable by the participants of the study who were primarily undergraduates and graduate students. It was also noticed that those findings were solid with past studies demonstrating the fact that most of the hazards on active construction sites remain unrecognized. Since unrecognized hazards are usually the foremost reason for fall safety hazards, further research in creating awareness using 360-degree platform was proposed.

3.3.1.3 Panoramas for online course delivery

Panoramas provide an instinctive understanding that simulates the actual atmosphere for those users who require location specific information for their day-to-day activities (Masoud Gheisari et al., 2015). The research introduced augmented Panoramas for Massive Open Online Courses (MOOCs) and a workflow for creating an augmented panoramic environment that is better than the existing MOOCs.

Figure 3-10 represents the workflow for the development of augmented panoramic view and Gigapan EPIC Pro camera was used to capture the Panoramas for the ease of operation and automation. The development typically works for mobile users by installing the application called Argon. Upon signing in, the users are required to choose the location of the augmented Panorama on the map. The augmented Panorama channel loads and the user can experience the augmented panoramic environment. When the users click on the highlighted structural element in the building, an associated free body diagram opens, and the details are viewable in a PDF format for ease of interaction.

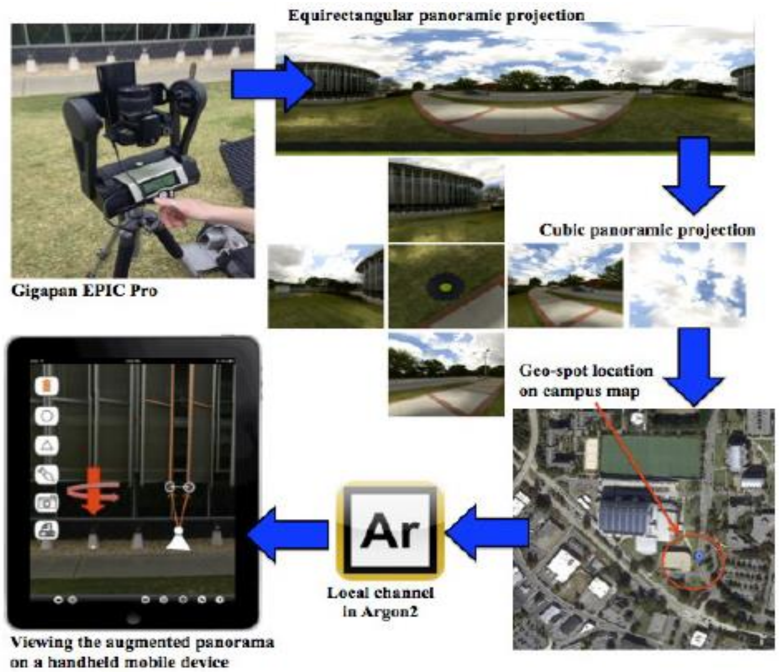


Figure 3-10. Workflow for the development of augmented panoramic view (Source: Masoud Gheisari et al., 2015)

Augmented panoramic environment brings physical locations closer to online users in a natural way and is an example of how ubiquitous computing which has the potential of transforming traditional MOOCs can help to overcome the obstacles of implementing MOOCs type of appropriate learning environment in construction domain through these online methods.

3.3.2 Applications in Space Research

A 360-degree panoramic camera can be used for high precision applications ranging from archeology to Mars exploration. J. Maki et al. (2012), explains the engineering camera properties, position on the vehicle and the application of the camera for surface explorations and operations used by the NASA's Mars science

Laboratory rover for its mission of landing a rover on top of surface of Mars. The data obtained from the panoramic cameras were used to pilot the rover and to precisely position the rover robotic arm. The application of these panoramic cameras extended to ingesting of samples inside the rover sample processing system.

3.4 Laser Scanning

Laser Scanning technology has developed as a beneficial tool in documenting prevailing conditions of buildings and the site. Laser Scanning has become a standard data acquisition method which had rapid development since the mid 1990's. It has become the dominant technology for reality capture in due course of time. Light Detection and Ranging, also known as LiDAR is a process that analyses the real-world scenario to acquire data. LiDAR is used by shooting laser beams followed by distance measurement at every pointing direction. A Laser (Light Amplification by Stimulated Emission of Radiation) scanner is a device that works by releasing a laser beam to the projected direction and receives it back. It then uses the beam to measure distances from the sensor to the targeted object (Pfeifer & Briese, 2007). The collected facts can then be utilized to construct reliable 3D models. The Laser Scanner market for the forecast period from 2017-2022 is expected to be valued at 5.06 billion U.S. Dollars from the year 2022 (Zion Market Research, 2017). Laser Scanning has been established as a valuable technique in documenting accurate construction data of buildings and prevailing conditions to control their impacts on surrounding systems. The foremost application for such documentation is to evaluate existing as-built settings of old buildings that lack a proper or accurate drawing (Klien et al., 2012). The point-clouds obtained from Laser scans provide a large volume of information that were lacking in existing documents of a building. It is suitable for measurement volumes below $1m^3$ up to areas of thousands of km2. In this intellect, it falls well within the realm of Photogrammetry (Pfeifer, N., 2007)

3.4.1 Application Areas in AEC

Often, traditional methods of gathering data for a construction activity becomes both labor intensive as well as time consuming. Y. Y. Su (2006), explains that the resulting information obtained from Laser Scanning technique will aid in providing an unparalleled level of detail on the as-built site situations. The use of this practice expands to commercial or urban excavations for delivery of required data to civil engineering disciplines related to that include areas such as construction engineering management, structural and geotechnical engineering. Below illustration shows the workflow for obtaining data for an urban excavation over the period of 4 months.

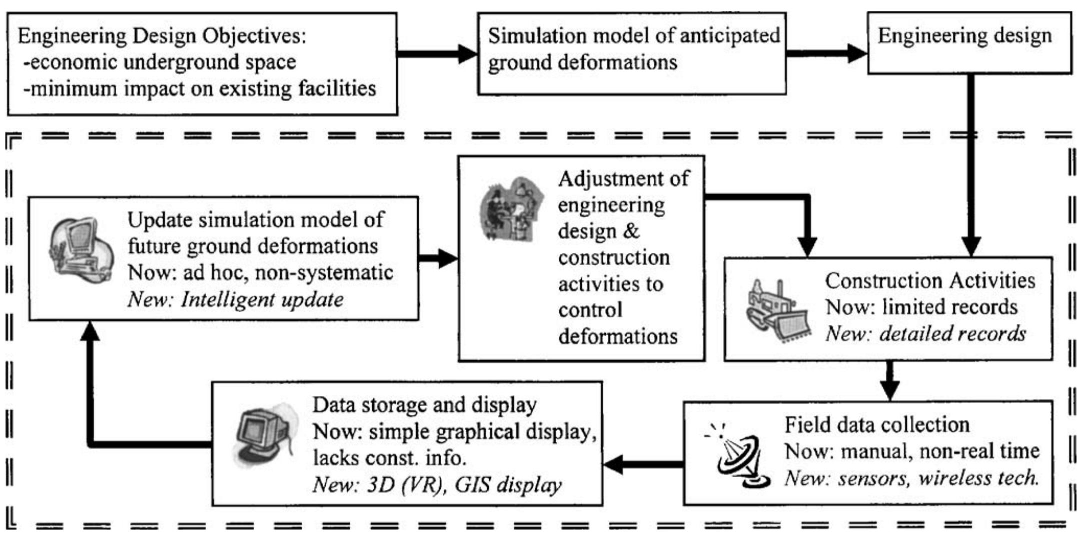


Figure 3-11. Integrated framework for urban excavations for use in field monitoring and control deformations (Source: Y. Y. Su, 2006)

Since urban diggings poses an exclusive challenge to various disciplines, primarily to regulate the entire process of mass excavation. Often, engineers have the necessity to gather accurate construction data to interact with different engineering disciplines for controlling the impacts on surrounding systems. 3D Scanning technique provides appropriate and precise as-built data that is used for construction project management, quality control of activities and other civil engineering disciplines such as geotechnical and structural engineering (Y. Y. Su et al., 2006).

3.4.1.1 Laser scanning for geotechnical applications

It is possible to apply laser scanning technique in the form of terrestrial survey technique as compared to other survey methods for 3D modeling of a structure and has shown to obtain amplified quality and extensiveness of initial data (Kanashin, N. V. et al., 2017). The main aim of these surveys is to create three dimensional models of the structures using the processed point clouds. That study involved the integration of vector models into the point cloud with the assistance of standard functions that is present in the 3D AutoCAD program.

3.4.1.2 Construction management and geometry documentation of highway tunnels during excavation

Studies have shown tunnel construction activities to have been benefited and supported by Laser scanning techniques due to its capacity to gather high-fidelity information. Gikas, V. (2012), thoroughly examined the potential and applications and has stated it as a radical technique for high precision, three-dimensional mapping and documentation for manmade structures. The location and measurement of many point clouds were obtained in an automated manner by Terrestrial Laser Scanning (TLS). Electronic distance measurement aided the TLS procedure which provided globular polar coordinates of the points in view of the instrument in an indigenous synchronized system. The position of the device is changed during the data capture with kinematic Laser Scanning. The angle, distance measurement and the motion of the Scanner gave a 3D point cloud. The research followed a protocol of methods of cross-section extraction and generation of mesh models (Gikas, V. 2012). The sequence involved in the construction was more transparent, faster and reliable with the 3D mapping using Laser Scanning than by traditional methods of the excavation site. In concerning votive and project management perspective, TLS proved respected for accurate measures of quantities estimation, equipment resources planning and management of the layout.

3.4.1.3 Monitoring the structural elements of large dams using 3D Laser scanning

Structural monitoring involves studying the static and dynamic performance of buildings or structures. Large dams fall under high risk and heavy construction category and has always been a topic of interest whenever Technology is considered, because often these structures influence the landscape where they are constructed (González-Aguilera, D. et al., 2008). It is essential given the impacts of damage that a dam failure could cause. González-Aguilera, D. et al. (2008), Laser scanned a dam at Spain at three different intervals varying from dam being completely empty to dam being completely full. The results obtained because of this experiment helped the team to analyze expected and unexpected deformation patterns when the dam is emptied or filled.

3.4.2 Applications in Other Fields

The application of laser scanning has extended to collection of forest inventories by terrestrial laser scanning techniques. Moskal, L. M. et al. (2012), presented a voxel-based point cloud slicing method to convert images obtained from terrestrial Laser Scanning (TLS) to a usable point cloud model (PCD) that can help in extracting volume of tree canopies, area covered by a specific variety, etc. in addition to the basic parameters such as length, breadth and height. This made way to further research questions regarding its accuracy for biomass estimating and evaluation of canopies as a prospect to use TLS as a standard tool was put forward in that field to study individual tree characteristics. Gross errors and noisy obstructions were experienced while viewing the point cloud data obtained from Laser scanning and it was evident that it could capture only 18% of the total tree volumes. Although, there are substantial associations between other forest inventory data captured by the TLS, thereby giving promise to the utility of an alternative scanning approach.

3.5 Generating Point Clouds

A point cloud is an immense collection of points that are placed on a three-dimensional coordinate system. The data obtained from a field survey is usually a collection of data with various attributes and their spatial distribution. The collected data determines the 3D positions of points; the x y z values. The more complicated the subject of the measurement is, the more points are selected and measured. Employing Photogrammetry or Laser Scanning technology when it's needed, the spatial resolution of the point data can be extremely high. The full 3D data produced by these technologies usually is called as point cloud or dense point cloud (Ferenc Arcs, 2014). Previous studies on Photogrammetry and Laser Scanning highlighted the scope for further research to improvise and update the existing technology in Construction. Acquisition of information have been useful in documentation, design and visualization. Processing of point cloud information has been one such construction technology.

3.6 Applications Comparing Laser Scanning and Photogrammetry

Features that were generally compared include;

1. Accuracy
2. Time
3. Cost
4. User friendliness
5. Scope for future upgradation

Studies show the importance of comparison of technologies for betterment of construction projects. El-Omari, S., et al. (2008), unified 3D Laser Scanning and Photogrammetry towards progress quantity of construction work, where the incorporation of 3D Scanning and Photogrammetry were performed to volute the precision of data collection from construction sites. The study involved the integration of limitations associated with both technologies and carried out an experimental analysis for both, to alleviate the constraints which pertained to digital photo imaging and 3D Scanning. To test the hypothesis, they used an active construction site at the Concordia University, Montreal. They estimated the extent of work completed at the end of each day by modeling the images that were laser scanned. There were several factors such as site limitations and range which affected the resolution of the images captured. A digital camera was installed on an upper portion of a Scanner that was synchronized with the scan procedure. The Scanning configurations were varied to check the accuracy of the data generated. The scanned images were exported to the software where the point cloud information was generated.

That technique could avoid a customary of limitations related to the individual practice of Laser Scanning and digital photogrammetry. That study on 3D Scanning recommended a method for mechanical site data acquisition that employed Photogrammetry and Laser Scanning for progress support and the documentation of as-built data. With regards to the amount of work completed at the end of every day, cost-effectiveness and timely extraction of valuable data was obtained in that research was recorded. These numbers provided an estimate of completion (in percentage) and a report on the progress made on site (El-Omari, S. et al., 2009).

Table 3-2. Advantages and disadvantages of Laser Scanning and Photogrammetry as observed in literature review

Content	Advantages	Disadvantages	Author
Laser Scanning	One Scanner location provides 3D data	Time consuming to obtain and process data	Kolecka, N., 2012
	Comprehensive, repeatable and non-destructive way	Not practical to use LS as an operational field tool due to weight, Scanning speed and instrument costs	Moskal, L. M., 2012
Photogrammetry	high-quality equipment is inexpensive	At least two locations are necessary	Kolecka, N., 2012
	Portable, camera locations can be selected more conveniently		Kolecka, N., 2012
	Field work takes comparatively less time, minimizes costs and allows immediate registration		Kolecka, N., 2012
	Does not have range limits	Not sensible to large displacements	Valença, J., 2008
	Low cost technique		Valença, J., 2008
	Accurate and fast results	Prior planning of data acquisition required	Valença, J., 2008

A pilot study that involved comparison of two different methods shall consider the performing it in the same location and conditions for maximum accuracy as reported by Kaartinen, H. et al. (2012) while researching on tree detection and tree extraction methods from the data captured using airborne laser scanning techniques. Forest inventory management have found laser scanning as a good practice to record the measurement of tree growth, either based on individual tress or a set of same species. This data can later be used for telecommunication planning or a virtual visualization of the existing conditions of the forest. That study involved two test sites that were chosen close to each other for performing the pilot study using airborne LS. The accuracy of the generated model from different methods were compared to the reference models to check the measurement accuracies. The results of the study represented the laser point density to have less effect on individual tree detection and the key factor that influenced the achieved accuracy was the extraction method.

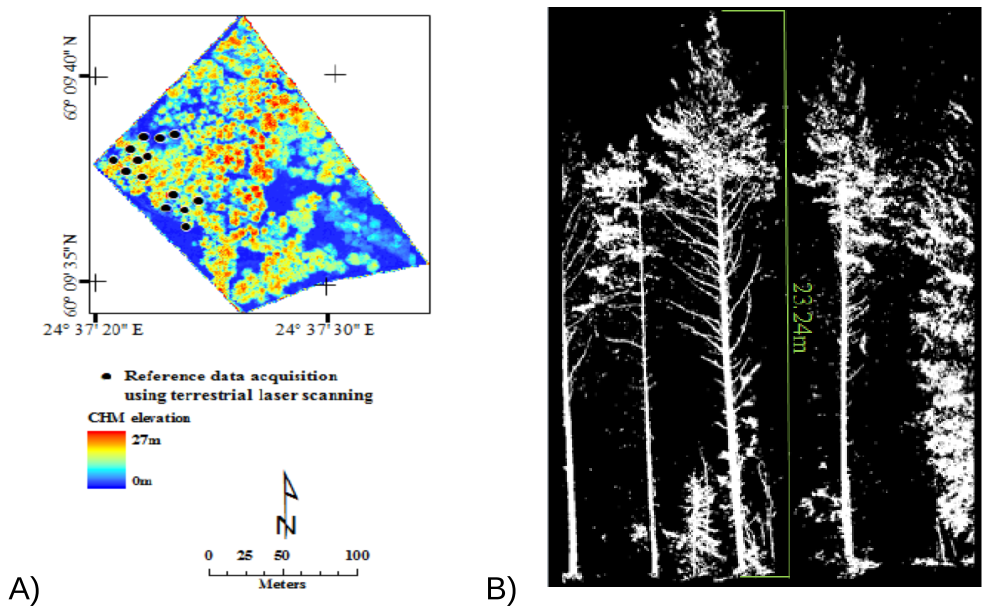


Figure 3-12. Representation of tree canopy documentation A) Color coded to represent the heights in meters, B) Example of a tree height reading

3.6.1 Laser Scanned Point Clouds for Automatic Reconstruction of As-Built BIM

Tang, P. et al. (2010), explains the advantage of using Laser Scanners for reality capture that helps in extracting building information for geometric representation of the as-built conditions. The resulting point cloud data can be treated like a 3D model that is obtained from CAD drawings and is subjected to change with progress in construction. At the post construction stage, the 3D model generated from 2D CAD drawings no longer represent the actual construction on-site. Scan to BIM for a facility in present practice may take several months depending on the complexity of the facility ad modeling requirements. That study analyzed manual and automatic construction of as-built BIM models in addition to evaluating the performance of using the data capture for choosing the best method for progress tracking and geometric measurements.

3.6.2 Laser Scanning and Photogrammetry for Data Collection Techniques

Kolecka, N., (2012), presents a comparative study by modeling data acquired from Terrestrial laser scanning as well as Photo based scanning of a steep mountain wall. Nikon D80 and Riegl Laser profile measuring system were used to gather data at different occasions. A reverse engineering software processed the two datasets, where noisy points and gross errors were corrected for better readability and interpretation. That step was time consuming and demanded manual interaction before allowing it for automatic mesh creation. The pilot study chose triangular irregular mesh creation to characterize the true 3D surface with relative accuracy. That was achieved by comparing the distances from two known points and the comparison results showed the differences to not exceed 2 mm. It proved that both TLS and terrestrial Photogrammetry had similar accuracy and level of detail although both had distinct advantages and disadvantages over the other, it could efficiently serve as a supplement to a very high-resolution Digital Terrain Model of the mountain areas.

3.6.3 Archaeological documentation using Laser Scanning and Photogrammetry

Activities that require geographical and geometric information have at some point considered Photogrammetry and laser scanning amidst the different sources available. Archaeological sites have special attention as it aims at conservation without intervention. Lerma, J. L. et al. (2009), validates the potential of integrating Terrestrial laser scanning and Photogrammetry to provide both accurate digital surface models as well as photo-realistic outputs for documentation. The case study involved two data acquisition techniques for studying the texture of a complex cave, engravings on different sections of the site, etc. A combination of both models could provide the users with the required information to proceed with data storage and generation of 3D models with high photo-realistic quality. The processed data from obtained scans can be used to help in improvising the archaeological understanding of composite caves as well as prehistoric art containing tiny engravings.

Table 3-3. List of hardware and software used from literature review

Publication and year	Content	Hardware	Software
Kim, C. et al., 2011	PG**	Nikon D90 with fixed lens Focal length (f 18mm)	Photo Modeler Scanner
Wang, C. et al., 2010	PG	AVT Oscar F-810C / 8-megapixel with a 12mm f1.4 lens and Nikon D300 / 13.1-megapixel with a Nikon AF 28mm f2.8D lens	Photo Modeler Scanner Version 6
Khoramshahi, E. et al., 2018	PG	Canon EOS Rebel T3i, 18-55mm lens	Photo Modeler Pro (Version 2013.0.3, EOS Systems Inc.), Autodesk Mesh mixer (10.2.32) and Blender (2.70)
Ferenc Arcs, 2014	LS* and PG	Leica NOVA MS50 MultiStation (MS50) and Canon EOS 600D SLR (Canon 2014b) camera	Agisoft Photo Scan v.1.0.4
Kaufman, J. et al., 2015	PG	Nikon D3100® DSLR camera	PhotoScan Pro
Valença, J., 2008	PG	Nikon D70 SLR, Olympus C8080	Not listed
Lerma, J. L., 2009	LS	FARO LS 880HE	FARO Scene
Lambers, K., 2007	LS and PG	Riegl LMS Z420i and CCD NIKON D100 camera	RiSCANPRO
M. Sturzenegger, 2009	LS and PG	Optech ILRIS-3D Laser Scanner, Canon EOS 30D digital camera	Polyworks software package (Innovmetric Software Inc., 2006).
Kanashin, N. V. et al., 2017	LS	Riegl VZ400	Leica
Sharaf Al-kheder, 2009	LS and PG	GS100 Scanner and Nikon D2X camera	Polyworks package (Innovmetric Software)
Paulus, S., 2013	LS	Perceptron Scan Works V5, Perceptron Inc.,	Geomagic Studio 12

*LS = Laser Scanning, **PG = Photogrammetry

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Purpose of the Study

The primary purpose of the research is to generate point clouds and determine the differences in the workflows, cost, quality and time factors for 360-degree Photogrammetry as opposed to Laser Scanning techniques. The secondary purpose is to determine the utilization of these techniques for the progress of construction industry.

To investigate the proposed study, a pilot study was conducted. The mechanical room was chosen for the experiment due to its complexity that represents an actual commercial or industrial construction scenario. It is practically time consuming to field measure every pipe or HVAC system required for further installation of systems in such an intricate facility. Often, Laser measures are preferred over conventional tape measures for safety reasons.

4.2 General Workflow

The workflow for two Reality capture techniques was framed and the overall experiment will be compared for quality of the point cloud, time consumed in setting up the equipment, capturing the scans or images, processing the data to a usable format. Laser Scanning techniques has been in use for more than a decade owing to its reliability. This experiment is to test the point cloud generated from 360-degree panoramic images and to compare it against the point cloud obtained from the Laser Scanning technique thereby considering it as an accepted standard. Figure 4-1 below represents the methodology adopted to perform the experiment, compare the results and present an analysis.

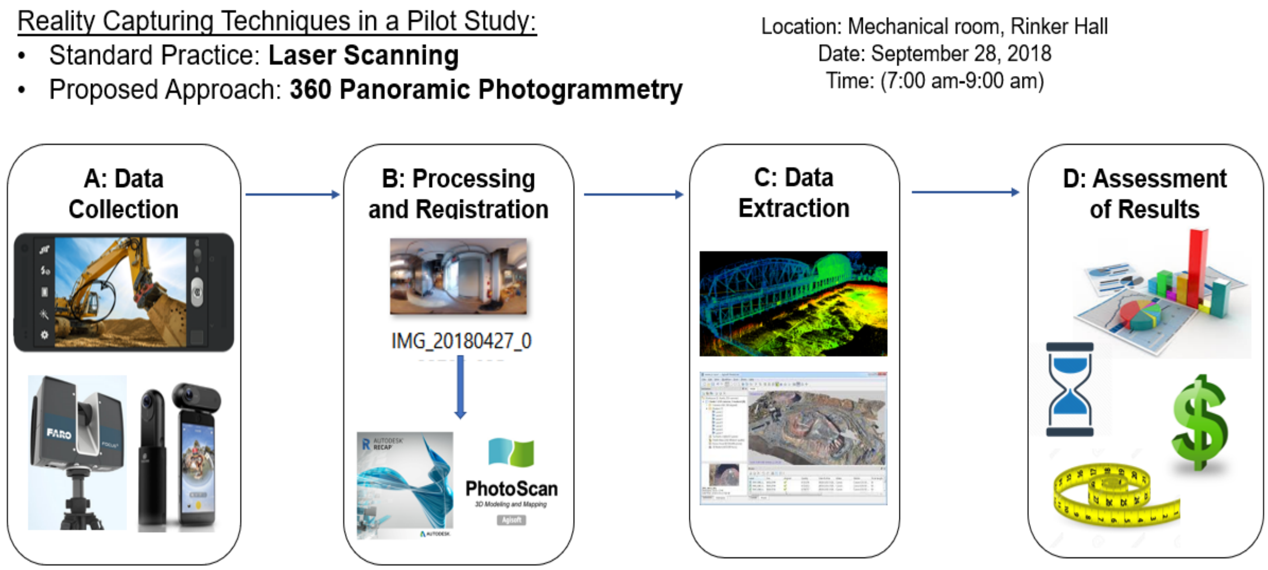


Figure 4-1. Research methodology for the proposed study with a Pilot study (Source: Courtesy of the author, 2018)

4.3 Location of the Experiment

The experiment was conducted in Rinker Hall at the University of Florida, Gainesville. The underground mechanical room was selected as the location for the pilot study. The size of the room is approximately 1500 sq. Ft. and is owned by the UF Facilities department. The location was well studied before performing the experiment for its shape and use, hence would justify the purpose of the study. The 2D drawings for the room was taken into consideration for the complexity of everyday construction work involving complicated systems and routing. The 2D drawings were issued during November 2001 for Rinker Hall, Gainesville and was the 26th building in the United States to have been qualified as a LEED Gold building by the U.S. Green Building Council during the year, 2003. Figure 4-2 below represents the interior of the Mechanical room.

A) B)

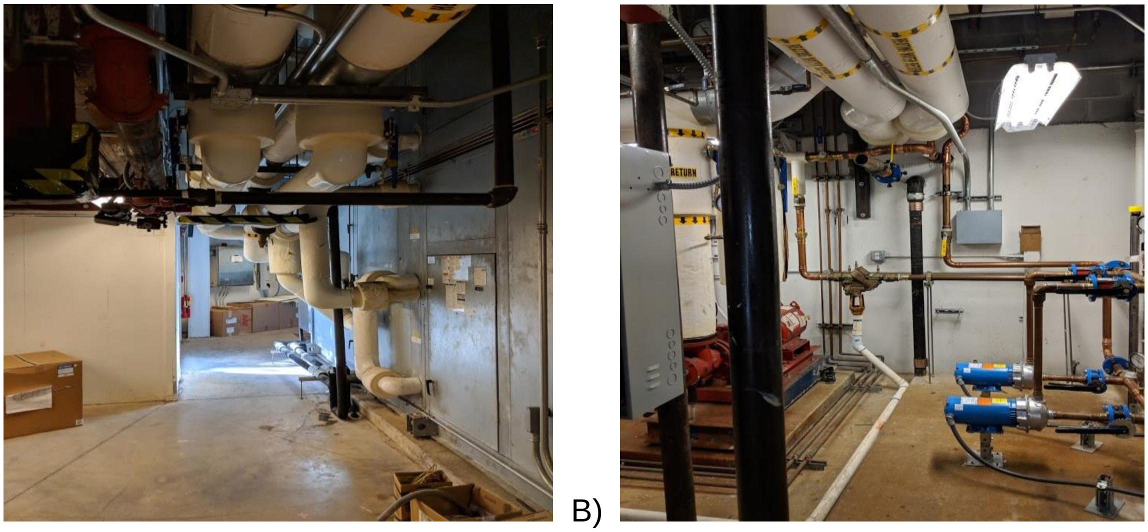


Figure 4-2. Mechanical Room, Rinker Hall A) West facing and Figure B) East facing (Source: Courtesy of the author, 2018)

4.4 Hardware Specifications

4.4.1 Laser Scanner

The Laser Scanner used for capturing the chosen location is the Focus 3D 120 manufactured by FARO Technologies and is a phase-based Laser Scanner. The Scanner comes with an accuracy of up to 1mm and the range is from 0.6 to 120m. The resolution is up to 70-megapixel color and comes with an intuitive touchscreen display. It has been classified as Class 54 for environmental protection. It comes with two batteries and a 32 GB SD card. Per full charge, it can last for about 4.5 hours. The equipment was owned by the University of Florida and maintained by the CACIM under Rinker School of Construction Management. The initial setup was performed before conducting the actual experiment. Scanner settings were used as tabulated below.

Table 4-1. Laser Scanner settings used for the experiment

Profile	Settings
Resolution	¼
Scan Duration	Approx. 11.15 minutes
Scan with	Color
Quality	4x Indoor HDR
Additional Devices	Tripod

4.4.2 360-Degree Panoramic Cameras

Two cameras were used to obtain 360 images of the same location at the same time namely, Ricoh Theta camera and Insta 360 camera that can capture panoramic images at a time. The camera was available at the University of Florida with Rinker School of Construction Management. Both the equipment was set in a tripod like the Laser Scanning techniques. It comes with charging ports and SD card as well. The camera holds sensors on two directions to capture the perfect 360 images and captures effortlessly with any personal iOS devices such as an iPad or iPhone. Insta 360 One holds 70 minutes of continuous use upon full charge. The initial setup was performed, and Table 4-2 settings were used for the pilot study.

Table 4-2. Camera settings used for the experiment

Profile	Settings	
	Ricoh Theta	Insta 360 ONE
Resolution/Exposure	HDR/Indoors	HDR/Indoors
Scan Duration	40 seconds	10 seconds
Scan with	Color	Color
Quality	16 MP	24 MP
Devices used	Tripod	Tripod, iPad

4.4.3 Computer Specifications

The data processing and point cloud generation was performed on Dell Inspiron laptop with 1.70 GHz processing speed and 8 GB installed Random access memory (RAM) with Intel ® Core™ i5 – 4210U CPU processor. The system type is 64-bit operating system, x64 based processor with 10 touch support points. The Windows operator is 64-bit Windows 10 Home Operating system. The device is about 3 years old from the time of purchase.

4.5 Description of the Experiment

The scans and images obtained from the specified devices were processed for creating 3D information models using Autodesk Recap Pro and Recap Photo for Laser Scanning as well as photogrammetric techniques. The diagram below represents the workflow for the performed experiment at the mechanical room.

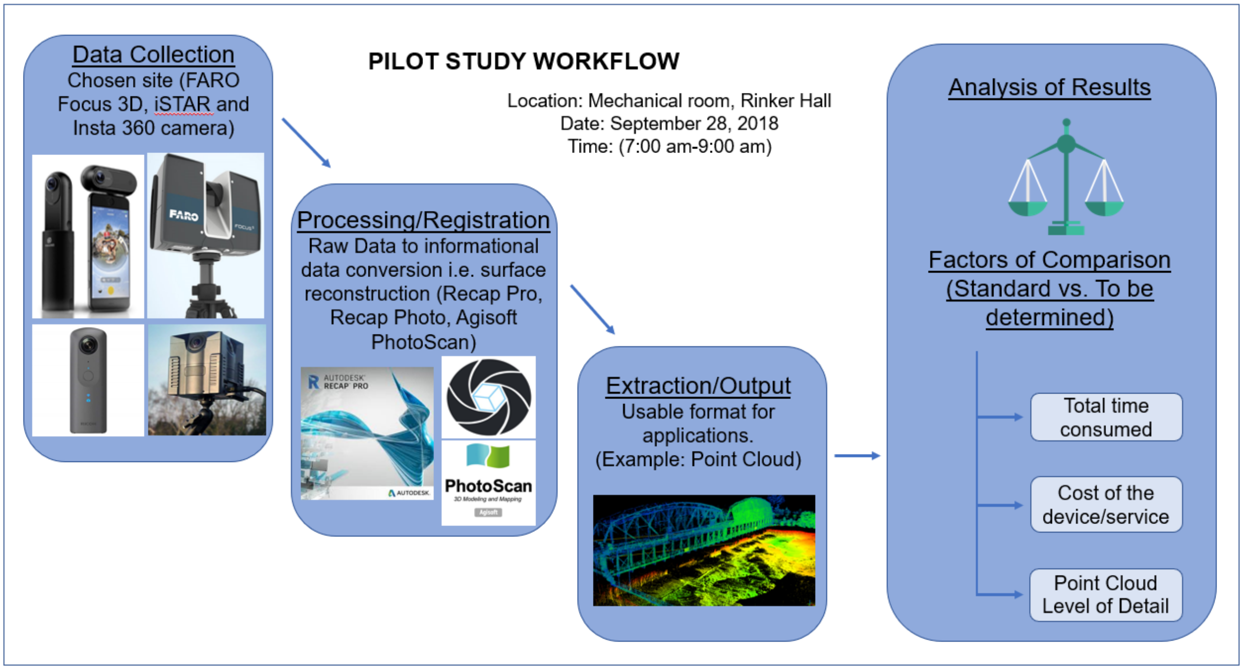
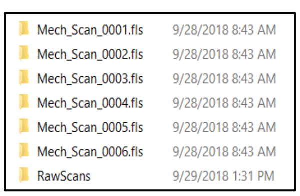


Figure 4-3. Experiment workflow used for the pilot study (Source: Courtesy of the author, 2018)

4.5.1 Data Collection using FARO Focus 3D (Laser scans)

The equipment was calibrated for its initial settings as tabulated in Table 4-1. such as creating a folder as denoted in Figure 4-4, changing the resolution and quality as in Figure 4-5, enabling sensors and color settings, etc. preferred for the intended scan location. Table 4-3 represents the time taken to perform each step as time is one of the factors considered for comparison in the experimental study.

Table 4-3. Laser Scanning steps performed on the day of pilot study

#	Step	Description	Time taken
1		Leveling and setting up the tripod and device individually for reliability of the scans	To start device: 2 mins To set device: 1 min To set tripod: 1 min To level device: 0.40 mins
2		Location of the Scanner is same as the location for 360-degree camera experiment	To chalk mark 5 locations: 0.10 mins
3		Capturing the location based on line of sight and maximum overlap between the current and the successive scans	Each scan: 11.30 mins # of captures: 5 Total time for capture: 57.30 mins
4		Raw Scans transferred from SD card to computer	Scans transfer = 1 minute
	Total Time	Setting time + Capturing time + Misc. time = 75 minutes	

The FARO Scanner was set on a tripod as shown in the Table 4-3 in one corner of the mechanical room. Laser scans were captured from 5 different locations to cover the total area of the room shown below in Figure 4-4. Every scan location was chosen to guarantee optimum overlap with the successive scans taken. This line of sight with previous scans ensure tightest registration possible. The five scans that were saved on the SD card in its “fls” format were then copied to the computer for processing the raw data into a point cloud. Figure 4-4 displays the Scanner location of the Mechanical room.

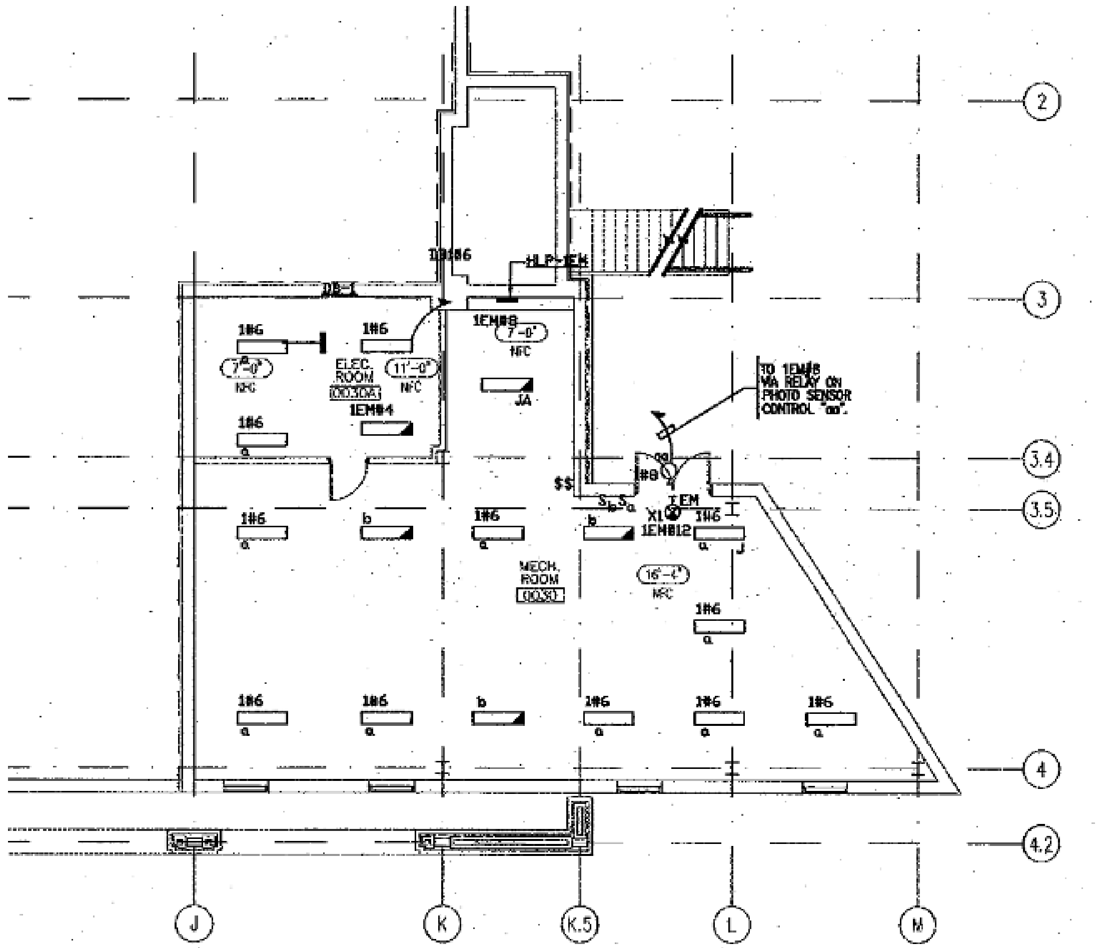


Figure 4-4. Mechanical room 2D Drawing with scan locations numbers 1 through 5 (Source: Mechanical room Lighting Plan reprinted with permission from University of Florida, 2018)

4.5.2 Data Processing and Registration of Laser Scans

The scans were transferred from the SD card to the computer to begin processing. The default format (.fls) is imported on to the registration software Recap Pro. The State plane coordinate system is set to Florida and “auto registration” is selected to begin merging the scans together. Auto registration works better with lesser area or those that areas can be easily identified by the software without possible errors. Manual registration is generally used for those with larger areas and targets/control points are required for easier registration.

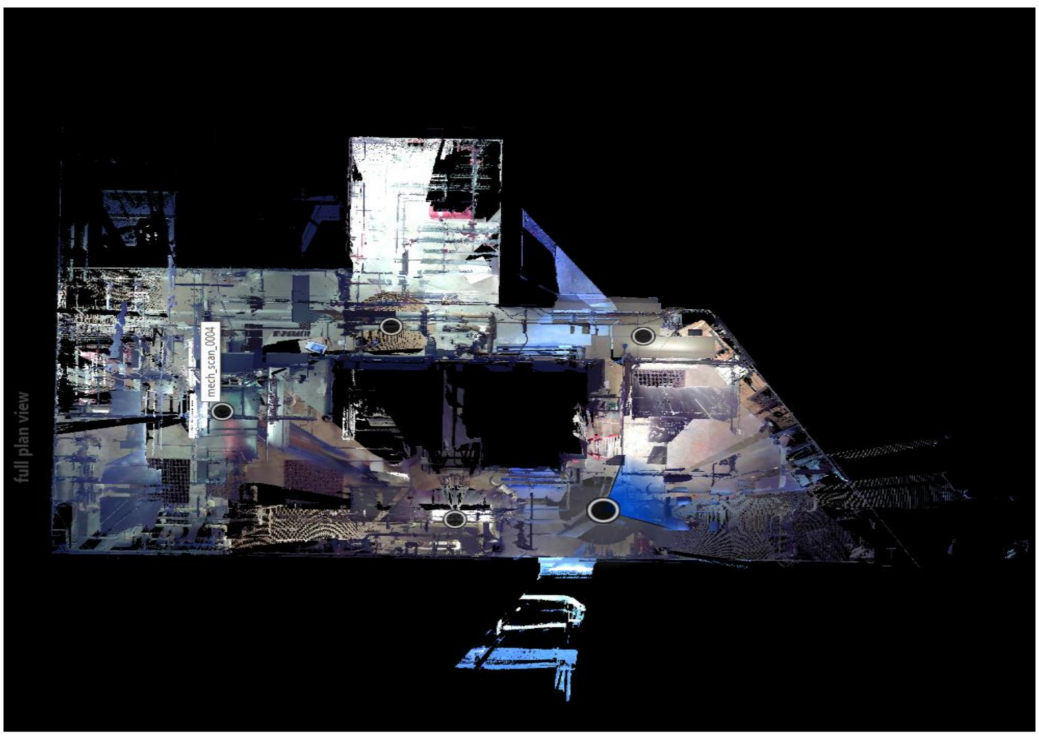


Figure 4-5. Generated Point Cloud of the Mechanical Room (Source: Courtesy of the author, 2018)

Autodesk Recap Pro 5.0 version was employed to generate the point cloud shown in the Figure 4-5 which consumed approximately 60 minutes in the computer specified under Section 4.4.3. The process involves merging the scans to creating a complete 3D model by understanding and merging its surroundings.

Figure 4-6. Comparison of view from a scan location A) Real view B) the point cloud 3D view from Recap Pro (Source: Courtesy of the author, 2018)

Geolocation of the model can be done by entering the x, y and z manually to lay on any Navisworks or Revit model. This way the point cloud serves as a reliable real site informational model that can serve its purpose in Design-BIM and Construction-BIM. This step is otherwise termed as “setting survey coordinates”. These survey coordinates can be easily taken from a total station by surveying that specific area on the site and entered even after the project is generated.

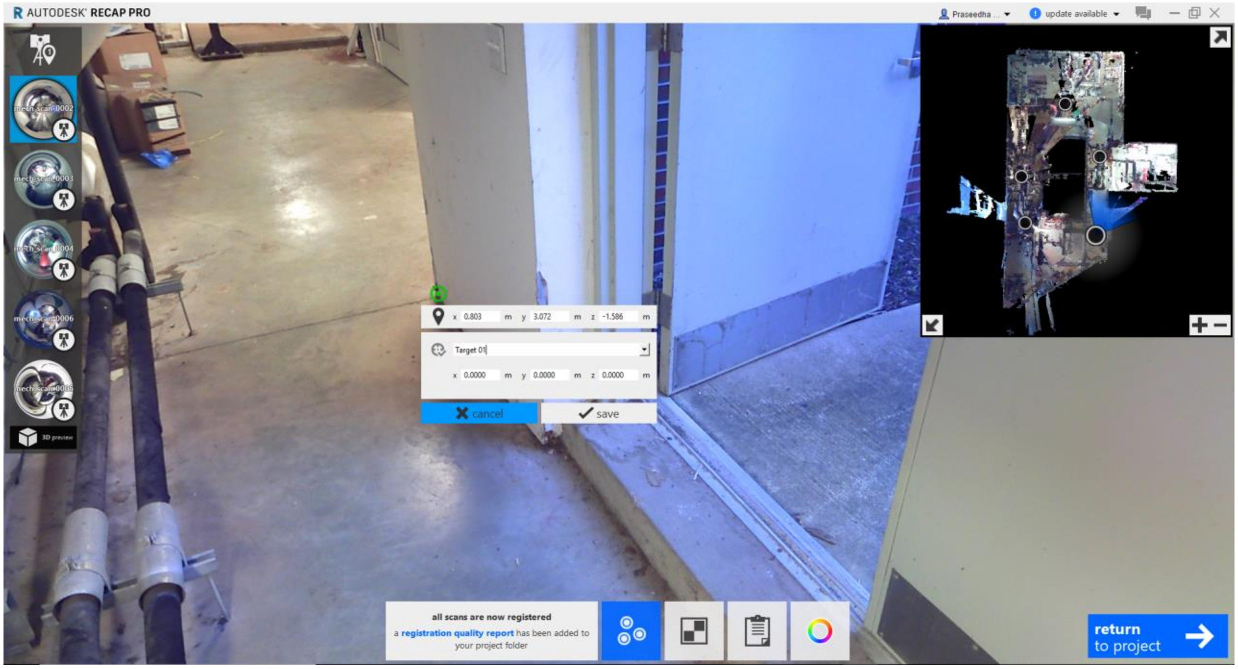


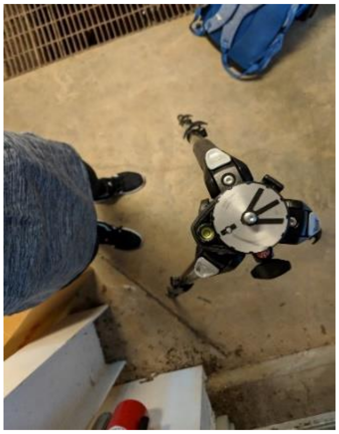
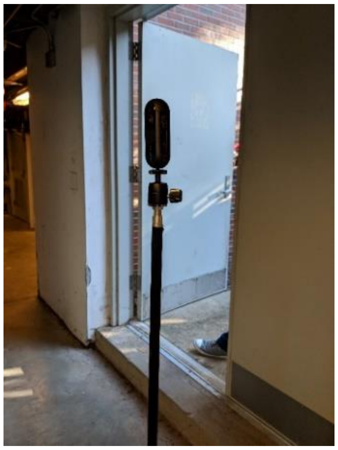
Figure 4-7. Setting survey points for geolocation of the point cloud (Source: Courtesy of the author, 2018)

The above Figure 4-7 represents the Recap page that highlights the survey coordinates along with the scan locations and the number of scans taken for this experiment. Recap Online viewer is a provision that Recap has enabled to view the scans without having to install the Recap software in the system.

4.5.3 Data Collection using Insta 360 One and Ricoh Theta Camera (360 images)

Insta 360 ONE camera was set per the preliminary adjustments represented in the Table 4-2. It was mounted on a tripod which comes along with the camera. Firstly, the Insta 360 ONE camera was leveled and placed at the same location as the Laser Scanner previously chalk marked. The device and the tripod were levelled and mounted approximately at the same height as the Laser Scanner. An iPad with an application installed for Insta 360 camera was used along with the device.

Table 4-4. 360-degree Image capturing steps performed on the day of pilot study

#	Steps	Description	Time taken
1		Leveling and setting up the tripod and device individually for reliability of the scans	To start device: 0.10 mins Initial setting: 0.50 mins To level tripod: 1 min To level device: 0.10 mins
2		Capturing the location based on line of sight and maximum overlap between scans	0.10 mins # of captures: 5 Total time for capture: 0.50 mins
	Total time	Setting time + Capturing time + Misc. time: 10mins	

The Insta 360 camera was operated using an iPad that belongs to the University of Florida and HCTC Lab to capture 360-degree images from the same location where the Laser Scanner was placed. The iPad application could capture images from a distance by enabling the Bluetooth feature. No extensive settings are required to start capturing as most of the it is preset. The workflow procedure that was followed for the Laser Scanning technique is being followed in taking the rest of the images for generating the point cloud from the Photogrammetry technique. The Ricoh Theta camera was operated using the iPad like the Insta 360 camera. It was connected via Bluetooth to enable checking the surrounding before clicking the image.

4.5.4 Data Processing and Registration of 360 Images

Several attempts were conducted to find an optimal image capturing technique. Since it was performed under artificial light, no issues were noticed with respect to lighting. To secure the necessary 80-90% overlap between images the camera was moved several times to capture several images.

Table 4-5. Panorama capture and use details

Camera (Artificial Light)	Number of Panoramas captured	Number of Panoramas used	Image Format
Ricoh Theta	32	9	JPG File
Insta 360 ONE	54	21	Insta 360 Panorama image (.insp) File

The Panoramas were transferred from the Micro SD of the Insta 360 One camera to the computer and Ricoh Theta camera images were transferred by using the USB cable. There is several Photogrammetry software to convert images to point cloud, but Agisoft Photo Scan platform was chosen for better comparison of the Laser Scanning point cloud with the Photogrammetry point cloud.

Figure 4-8. Fish eye view of the 360-degree Image (Source: Courtesy of the author)

The 360 images were saved in local disk and was imported to Agisoft (latest version 2019) application. The project was created by importing all the images as a 'chunk'. The first step is the alignment process which took about 10 minutes to get aligned. About 31 Ricoh Theta Panoramas were uploaded, and 9 of them aligned due to its GPS possibility closer to the doorway. The photo alignment matches common points on the images to determined 3D geometry of the point in the point cloud. Figure 4-9 below represents the working space of the Agisoft application which is a user-friendly interface.

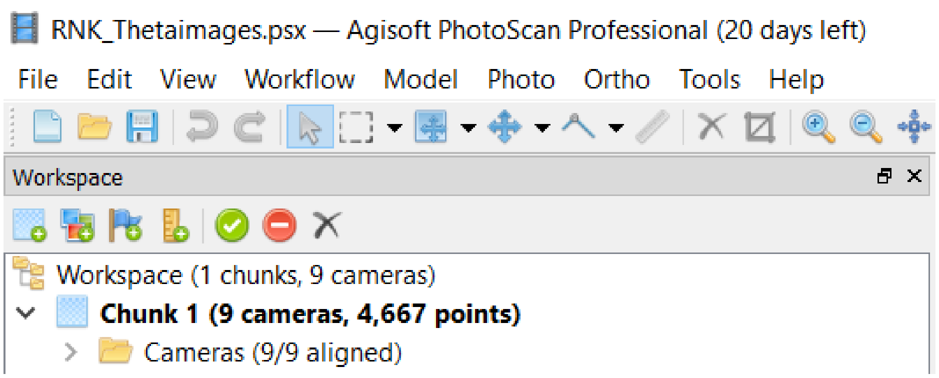


Figure 4-9. Alignment step of the AgiSoft PhotoScan (Source: Courtesy of the author, 2018)

Considering the size of the building, no targets were used. Targets or control points generally help in reducing the data processing time for manual or automatic alignment. Necessary re-alignment of photos can be performed after careful checks. The second step in the AgiSoft workflow is building the dense point cloud after optimization of the alignment. This process takes about 20 minutes for 9 images with the computer specifications used. At any point of the workflow, the model has an option to be exported to desired formats such as FBX, OBJ, etc. for further processing. The next step is to build the mesh. After the mesh is built, data extraction is possible by exporting the model produced. The data extraction also extends to presentation PDF file format that is an interactive 3D model readable format.

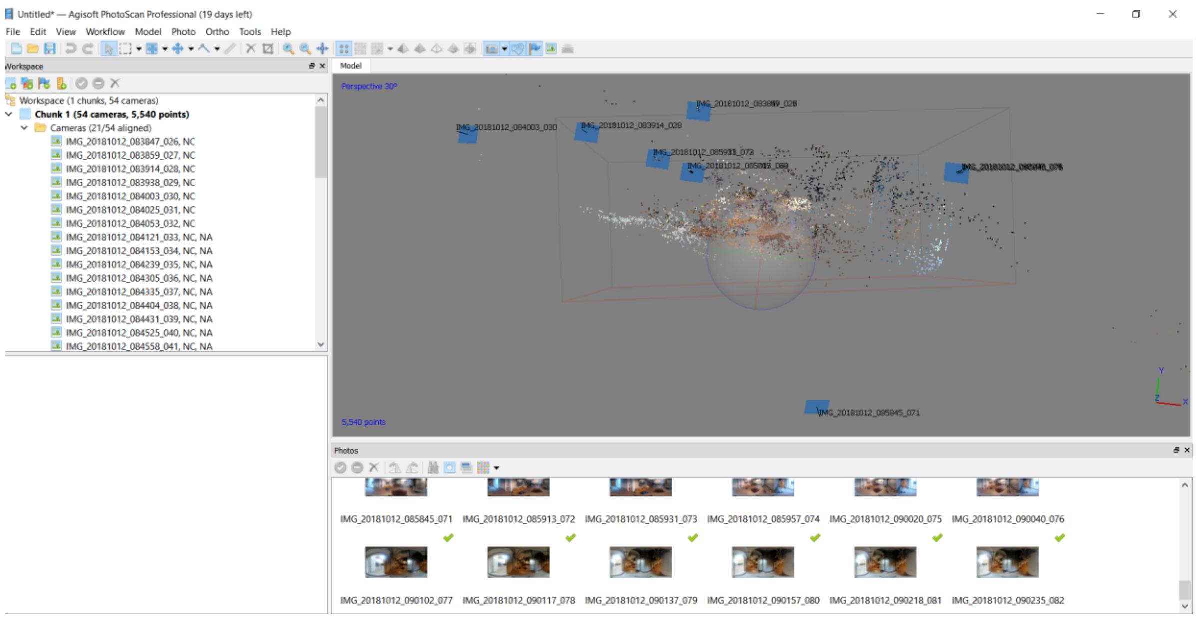


Figure 4-10. Alignment phase of the point cloud generation from Agisoft using Insta 360 images (Source: Courtesy of the author, 2018)

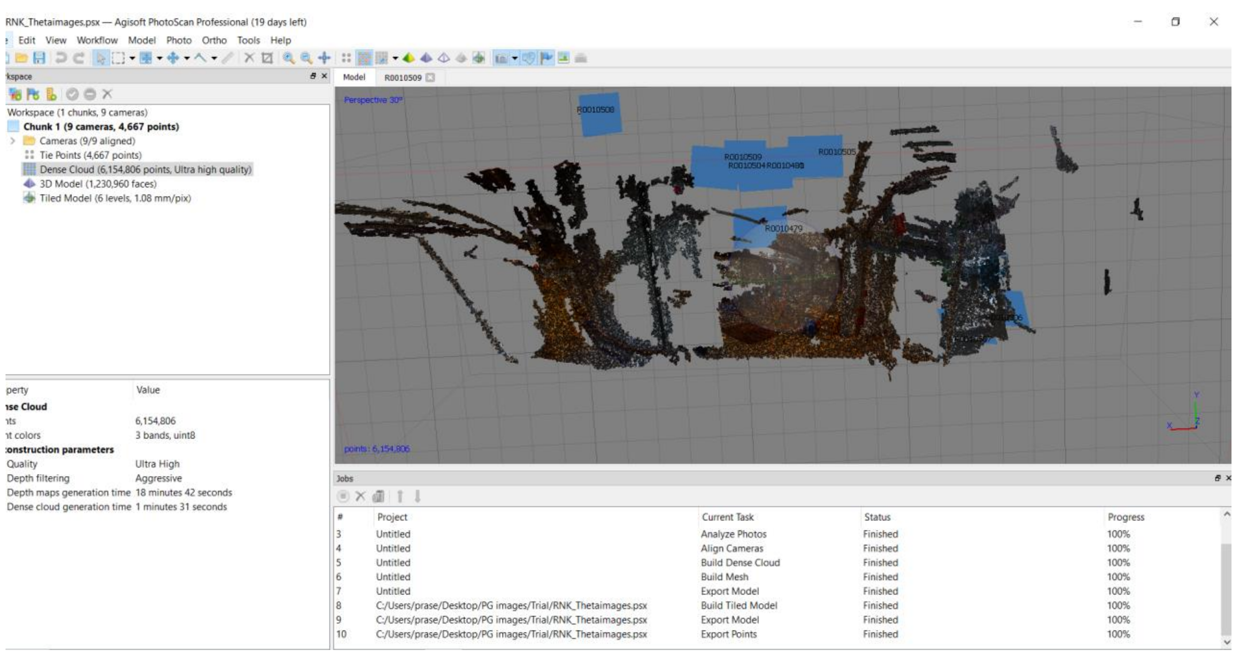


Figure 4-11. Dense point cloud developed with, ultra-high-quality setting in AgiSoft using Theta images (Source: Courtesy of the author, 2018)

CHAPTER 5
RESULTS AND DISCUSSION

The experiment with two technologies were conducted and the results were analyzed for further discussion. The workflows were similar in some extent to obtain the expected result of both the experiments. Since the experiment was conducted in the same location, date and time the results obtained is much more reliable for comparison of the 360 images with the standard Laser Scanning technique. Some of the factors considered for the analysis is listed below.

5.1 Time as a Factor

The experiment involved the Laser Scanning technique (Standard) and the 360-degree Photogrammetry technique (To be tested for). One of the main comparisons was the time involved in conducting the experiment and producing the results. From Table 4-3 and Table 4-4, the time taken to perform each task was noted and tabulated throughout. Based on the results, it is noted that Laser Scanning consumes enormous amount of time from setting up the experiment to generating the point cloud for use. Whereas, Photogrammetry techniques (from starting the device to generation of point cloud) take almost 1/3rd of the time invested by Laser Scanning techniques. In construction industry, work cannot be put to hold until one scans the data on site. Laborers prefer absolutely no hindrance to their work from personal experience. Hence, time does make a huge difference when it comes to saving the time taken to capture the reality in an active construction zone. Besides, safety is one reason why less time-consuming technique is preferred. The bar chart below shows the comparison between the standard and Photogrammetry with time as a factor.

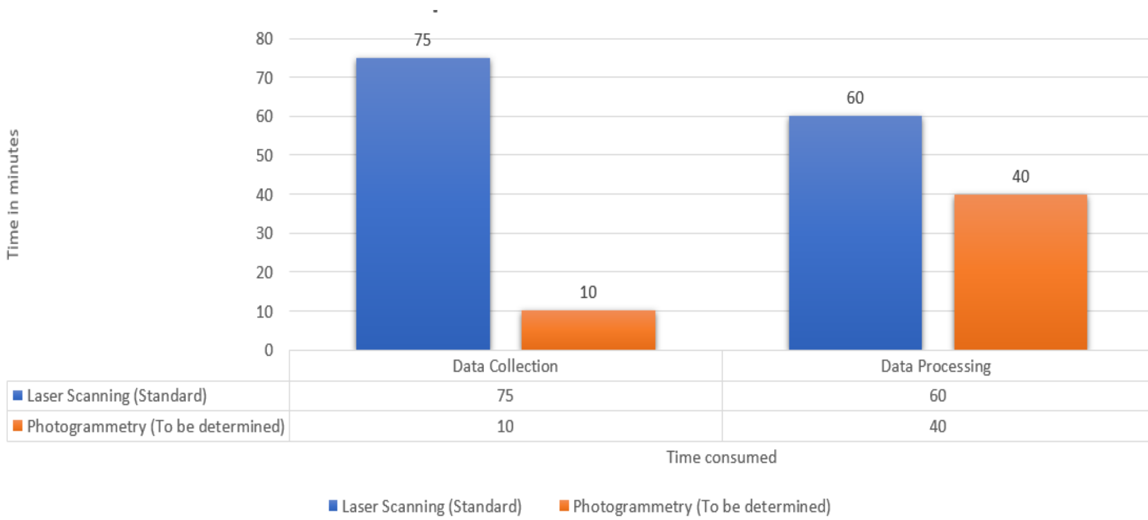
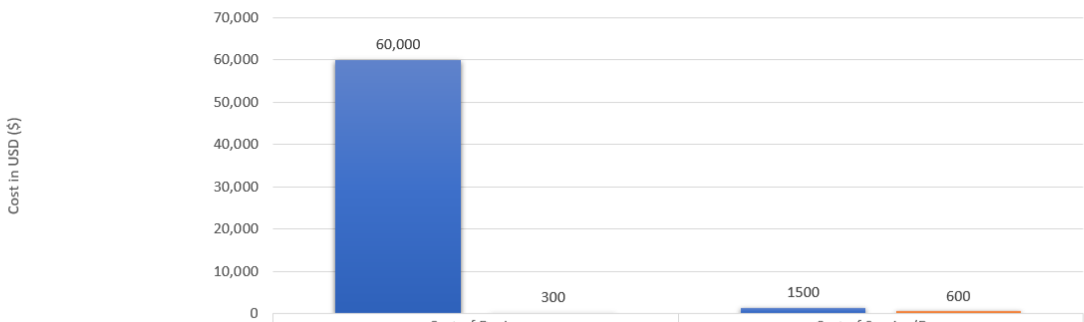


Figure 5-1. Time in minutes against Laser Scanning and 360-degree Photogrammetry (Source: Courtesy of the author, 2018)

From Figure 5-1, Photogrammetry consumed 50 minutes in total as opposed to 135 minutes by Laser Scanning method. It is a significant difference with time as a factor in comparison of the accepted method against the 360-imaging technique.

5.2 Cost as a Factor

Cost comes into play anytime technology is involved, as the general misconception is that all technologies comes at a price which is not affordable. By the comparison between the equipment used for this study, it can be noticed that Photogrammetry techniques are significantly cheaper compared to Laser Scanning. FARO Focus 3D 120 Laser Scanner which was used in the pilot study was bought for $60,000 in 2009 but its price has dropped to $11,200 in 2017 (FARO's Website, 2018) due to a very low demand for that old model. High quality laser scanners currently cost around $65,000 to $185,000 for construction purposes (3D Laser Survey Website, 2018) and the average cost of onsite Laser Scanning service is around $1,500 per day depending on the nature and amount of scanning required (e.g. Arrival 3D Website, 2018). For the 360 Panoramic Photogrammetry, the cost of the equipment used was around $300 and the average cost of onsite captures and photogrammetry are around $600 (e.g. DroneDeploy Website, 2018) for a day. In addition to analyzing current data and from literature review, it is evident that Photogrammetry techniques are less inexpensive as opposed to Laser Scanning techniques. The chart below represents the comparison between average cost of a Laser Scanner vs. average cost of a 360-degree camera.



	Cost of Device	Cost of Service/Day
Laser Scanning (Standard)	60,000	1500
Photogrammetry (To be determined)	300	600

Figure 5-2. Cost in US Dollars against Laser Scanning and 360-degree Photogrammetry (Source: Courtesy of the author, 2018)

5.3 Point Cloud LOD as a factor

The percentage of error from actual site is compared with the point cloud obtained from the Laser Scanning and 360-degree Photogrammetry to get reliable results for comparison. Autodesk Recap provides a Project report (Figure 4-10) that represents the overlap and percentage of balance between the scans processed. This information allows the generation of dense point cloud by adjusting the registration of scans. Percentage of Error can be determined by measuring on site using tape measure, measuring using the point cloud obtained by Laser Scanning as well as Photogrammetry.

$$\text{Percentage of Error} = \frac{\text{Accepted value} - \text{Observed Value}}{\text{Accepted value}} \times 100\% \qquad (5\text{-}1)$$

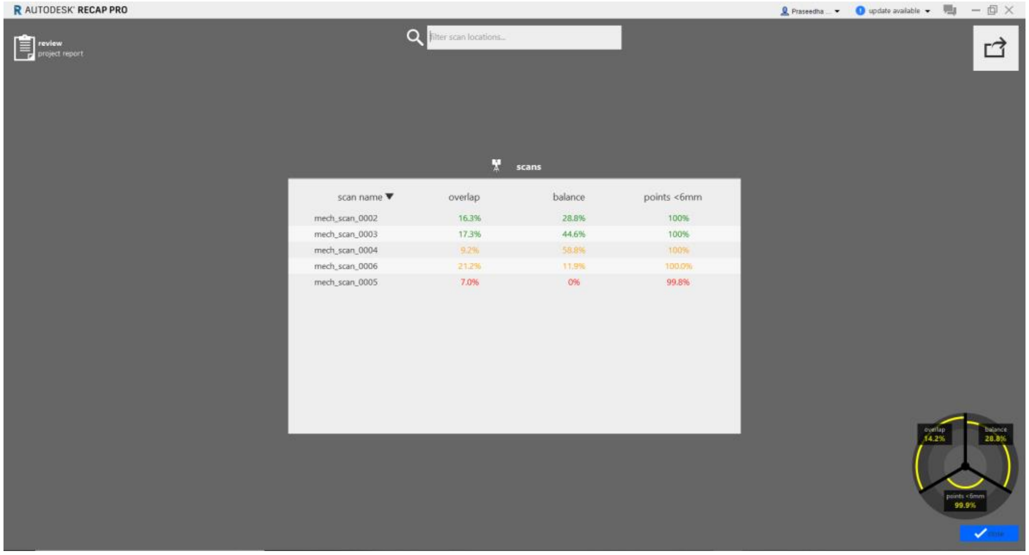


Figure 5-3. Project Report on the scans registration as obtained from Recap Pro. (Source: Courtesy of the author, 2018)

To determine the percentage of error or level of accuracy from the point cloud information, eight random locations or objects were selected onsite to take the tape measures and then the exact same locations or objects were measured in the point cloud data generated by both techniques. The average of the errors shows the quality of point cloud data generated through both techniques. As shown in Table 4-6, 360 panoramic Photogrammetry has around 5-6 percent of error while laser scanning is more accurate with around 2% of error. Figure 5-5 represents the LOD of Point cloud data vs. Laser Scanning and 360-degree Photogrammetry techniques.

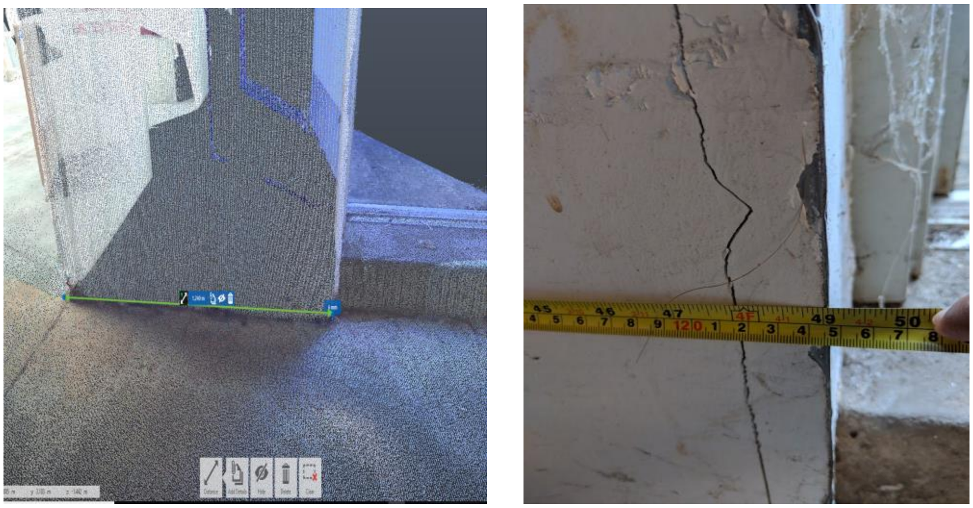


Figure 5-4. Measurement from Recap Pro and on site for Instance #1(Source: Courtesy of the author, 2018)

Table 5-1. Actual site data vs. Point cloud data

		Length in Feet			% Error	
#	Description	Onsite Tape measure	Agisoft (Photogrammetry)	Recap Pro (Laser Scanning)	360-degree PG	LS
1	Wall	4.149’	4.26’	4.068’	-2.67	1.95
2	Column Flange	0.81’	0.72’	0.79’	11.11	2.46
3	Column Web	1 foot	0.89’	0.964’	11	3.6
4	Electrical Box(L)	2.05’	1.93’	2.02’	5.85	1.46
5	Mech Duct (W)	2.5’	2.46’	2.49’	1.6	0.4
6	Exit signage (L)	1.4’	1.5’	1.34’	-7.14	4.28
7	Door (W)	3.5’	3.38’	3.57’	3.42	-2
8	VFD Box (W)	0.11’	0.10’	0.11’	1	0
				Average	5.47	2.02

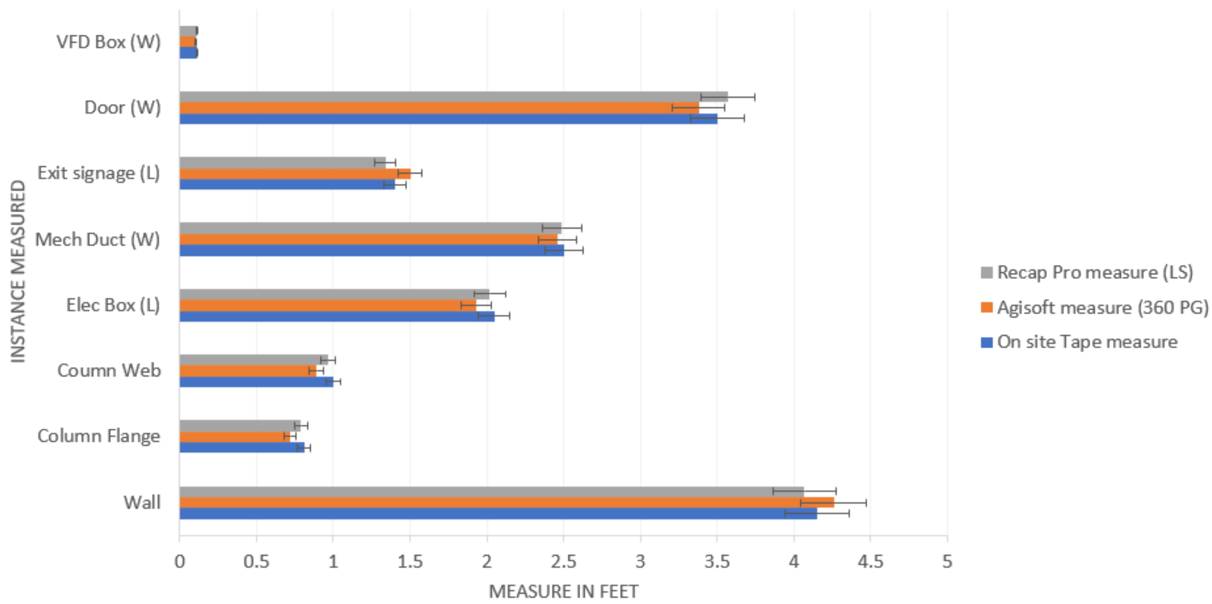


Figure 5-5. LOD of Point cloud data vs. Laser Scanning and 360-degree Photogrammetry techniques (Source: Courtesy of the author, 2018)

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The proposed study tested the hypothesis by comparison of two Reality Capture technologies, namely Laser Scanning and Photogrammetry techniques. Both techniques were tested for their level of accuracy that it can attain by analyzing the generated point cloud from Laser scans as well as 360 panoramic images. Factors such as time consumed, cost to experience each technology and the level of detail achieved from both were thoroughly studied. It has immense potential due to the rapidly recognizable growth seen in the construction technology industry. The primary effort in proposing this study is to bring out Construction technologies boons as affordable as possible to general builders, rather considering it as a luxury. Technology has always helped solve safety concerns and sustain the Project Management Triangle (Time, Cost and quality) in this business and will continue to become a necessity rather than an additional expense.

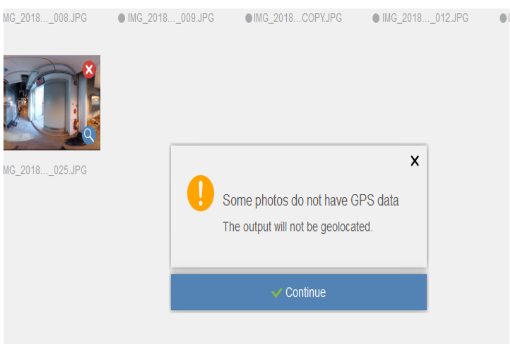
6.2 Challenges/Limitations

Computer Limitations. Computer did not have a graphics card that hindered the generation of the point cloud for Photogrammetry techniques to a certain extent. Although, no difference was noted for Laser Scanning techniques.

Software Limitations. Three software were tested for the 360-degree Photogrammetry techniques to process the images to create the point cloud data from 360 panoramic images and the limitations faced with every one of them varied by expectations as compared to the software available in the market for Laser Scanning processing techniques.

Table 6-1. Software limitations faced during the research

Software	Limitations
Agisoft PhotoScan	Trial version, few images could not get aligned due to GPS issue. Tie consuming as compared to the other two software.
Reality Capture 2018	The platform was user friendly but was a paid version to perform further steps. Reconstruction phase of the workflow could not process as the computer used did not have a graphic card.
Recap Photo V.19	Education version. Interior surfaces of a building could not be automatically aligned. Certain photos could not be registered due to GPS issue as shown in Figure 6-1.

A) 

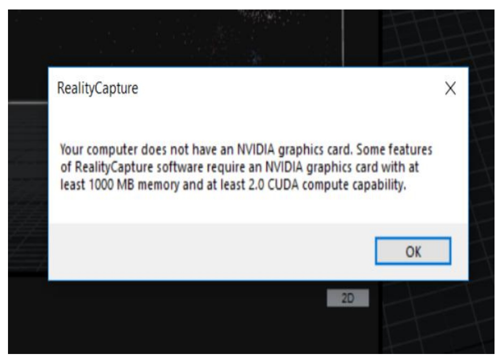
B) 

Figure 6-1. Error dialogues A) GPS issue noted from Recap Photo software, B) Graphics card issue noted from Reality Capture software (Source: Courtesy of the author, 2018)

6.3 Recommendations for Future Research

This research involved a huge learning curve as it progressed from data collection using the two technologies to processing them, comparing the point cloud for time, cost and accuracy factors. Since the pilot study was conducted at the mechanical room, point cloud generated through 360-degree Photogrammetry could not be fully utilized as the current software in the market supports Aerial and outdoor Photogrammetry as compared to interior registration. The computer used to process these data could have been better to avoid the graphic card issues that was seen. Software supporting 360-degree Panoramas can be more demanding than regular 2D images. Specific software does a great job in registering Laser scans given its history in the market. Likewise, training on Photogrammetry could lead Construction Technology driven companies to come forward with Photogrammetry tools that support various file formats as these techniques typically support construction industry in a way better aspect. Depending on the feasibility and continued research, 360-degree panoramic Photogrammetry could take lead in several problem-solving construction techniques.

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BIOGRAPHICAL SKETCH

Raised in Chennai, a major southern city of India, Praseedha Subramanian graduated with a B.E. degree in Civil Engineering from Anna University in 2016. She was fascinated by the way construction has evolved since she was a child and on one such occasion while working on an International project, she realized the lack of Construction management techniques in her country. She was determined to pursue her Master of Science in Construction Management from the University of Florida, graduating in 2018 and will continue to work in the construction industry to further her experience. She is interested in ways that technology can improve construction efficiency, safety, and lead to a more sustainable built environment. When she is not working, studying, or volunteering, she can be found exploring the wide vast world.