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LASER SCANNING TECHNOLOGY AND BIM IN CONSTRUCTION MANAGEMENT EDUCATION

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SUMMARY: *Laser scanning technology has emerged as a useful tool in documenting existing conditions of buildings. The main application for such documentation is to assess current as-built conditions of existing, mostly historical, buildings. The technology can also be used as an integral part of construction progress documentation in new projects. In order to equip students with knowledge on the latest technologies in the industry, laser scanning was introduced to students in a BIM course. Students were given a thorough demonstration on how the equipment functions. After that, several campus buildings' exteriors were scanned. Students had the chance to see the scanning in action. More importantly, the generated point-clouds from the scanner were given to students as part of the final project. Five teams were formed and each team was given a set of floor plans, with minimal details, of an existing campus building. The teams were then asked to take measurements from the point-clouds and model the buildings in Autodesk Revit. The lack of marked elevation drawings did not prevent the teams from modeling the buildings fairly accurately. The point-clouds gave the students a large amount of information that were lacking in the provided documents. Even though the learning curve for navigating such point-clouds was a bit steep, the extracted information helped the students better understand the buildings' envelopes and appreciate the real value of laser scanning technology.*

KEYWORDS: *Laser Scanning, Construction Management, Education, Virtual Design and Construction*

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1. INTRODUCTION

Building information modeling (BIM) and virtual design and construction (VDC) technologies are on their way to becoming the standard in the construction industry today (Yee et al. 2013). The return on investment for deploying such technologies has been measured through a variety of outcomes including realistic project scheduling, system clash avoidance and comprehensive as-built project documentation. Laser scanning has emerged as a tool for BIM professionals as they work to gain access to increasingly accurate and detailed information during the BIM process. Building information models are only as accurate as the information used to create them, which has a parallel impact on their usefulness. In this regard, the data collected through the laser scanning process has found use throughout the lifecycle of a project in a range of ways, due to its accuracy and quantity of data points. Laser scanning has a variety of applications on construction projects ranging from new construction to renovations, and the captured data can be useful to the entire project team, including the architects and engineers, from project conception through project turnover.

Laser scanning enables the development of as-built point cloud models, at a given stage in the lifecycle of a building, with great accuracy and speed. The accuracy made possible through the use of laser scanning is unparalleled by manual measurement and traditional field surveying techniques. Furthermore, human interpretation of field conditions impacts the accuracy of documentation due to the means and methods of capturing, as well as during the conversion of field measurements to digital models. Even through the use of professional surveying equipment, such as a total station, the collection of the quantity of data available through a laser scan would be time prohibitive and unrealistic. Laser scanners can approach data collection rates of one million points a second, leading to comprehensive data sets of a given target. When laser scanning is correctly executed, model accuracy can achieve ¼” (6mm) of variance, or less. In addition to increased accuracy, time and cost savings can be realized by the project team when laser scanning is integrated into their project workflow. All of these factors have led to the increased popularity of laser scanning and the increased utilization of point clouds as part of the BIM process industry wide.

There are many considerations which must be made when utilizing laser scanning, with cost and required expertise being two of the most important. The construction industry is largely driven by cost, and all of the benefits of laser scanning cannot hide the expense incurred when initially investing in laser scanning within a company. When laser scanning technology first became commercially available it was cost prohibitive for most companies, making the data and project control capabilities unobtainable. Over the past decade laser scanning has become increasingly accessible to a wider range of professionals and for those not interested in owning or operating their own scanner, there are laser scanning sub-contractors who can be hired to complete this work. As laser scanning data is utilized for an increasing number of projects the quantity of research involving this technology has also increased along with the discovery of new uses for the resulting data. The increased proliferation of laser scanning throughout the construction industry has led to a demand for employees proficient in conducting and managing laser scanning operations. This demand has created an opportunity for students completing construction management degrees to expand their knowledge and gain marketable skills making them stand out as they graduate and enter the industry to begin their careers.

The inclusion of laser scanning in construction management courses is not currently a requirement for accreditation and as such students often receive limited exposure to such technology. In order to solve this problem, and better equip students for their roles in the construction industry, laser scanning was introduced to students in a graduate BIM course at the University of Florida. Students were provided a thorough demonstration of how the equipment functions, as well as the overarching technical concepts it uses to collect data. Following the introduction, students were guided through planning for scanning activities and completing scans of several exterior facades of campus buildings. Students had the chance to see the scanning process first hand and experience some of the field conditions which can impact the scan outcome. More importantly, the generated point-clouds from the scans were provided to the students as part of their final project. During the class, five teams were formed and each team was given a set of floor plans, with minimal details, of an existing building on campus. The teams were asked to use the provided plans, supplemented with measurements they obtain from the point-clouds, to model the assigned buildings in Autodesk Revit. The point-clouds gave the students a large amount of information that was lacking in the provided drawings and would have been unobtainable through field measurements taken from the ground. Even though the learning curve for navigating the point-clouds was a bit steep, the extracted information helped the students better understand the buildings’ envelopes and appreciate the real value of laser scanning technology for as-built documentation. Through this process students gained experience with one form of laser scanning device, but more importantly developed an understanding of the concepts used by a variety of laser scanning and reality capture devices.

There is a wide range of laser scanning technology and other reality capture devices which seek to develop 3D point clouds of buildings or spaces. In addition to traditional laser scanning techniques there are researchers and emerging companies developing technology which can collect and process the data with equipment that is much less expensive than traditional laser scanning. Infrared scanning and photogrammetry are making great strides as they seek to offer an acceptable supplement and alternative to traditional laser scanning devices. Regardless of the capture method, laser scanning and associated capture techniques are becoming more prevalent in the construction industry. In this regard, laser scanning knowledge and proficiency will prove beneficial to professionals and students alike. Education for students and professionals is a crucial step in unlocking the benefits of laser scanning within the industry and discovering more ways to improve the building process.

2. LASER SCANNING TECHNOLOGY

2.1 Laser Scanning Types

In order to develop an appreciation for laser scanning technology it is crucial to have a basic understanding of the operating principles at work. There are two common operating principles for laser scanning, Time of Flight and Phase Comparison, or Phase Shift, laser pulse (Böhler and Marbs 2002). Time of flight laser scanning calculates the coordinates, in 3D space, of its surroundings based on the amount of time it takes a single laser signal to return to the device after being reflected. This operation occurs thousands of times until the given range of data collection is met. Current algorithms and devices render at an accuracy with a standard deviation of a few millimeters using the time of flight calculation method (Böhler and Marbs 2002). The phase comparison method can be more accurate, while not requiring any different knowledge from the user, however the more complicated signal analysis can lead to slower measuring rates (Böhler and Marbs 2002). The phase comparison method transmits a laser beam which is modulated by a harmonic wave. When the modulating beam returns to the device the phase difference between what was transmitted and what was received allows for the calculation of distance (Böhler and Marbs 2002). Both of these methods are effective and are used in commercial laser scanning equipment, depending on the intended use case for the device. Fig. 1 shows the point cloud model developed of a mechanical room through the use of a phase shift laser scanner.

FIG. 1: Point Cloud of a mechanical room captured using a traditional phase shift laser scanner.

It is good to know which operating principle your laser scanner uses but more important is the quality of the data collected. Scan accuracy is an important consideration when deploying and using the data from a laser scanner which must be considered prior to purchasing a scanner or conducting scanning activities. Boehler et al. (2003) explored the accuracy of a range of laser scanning devices manufactured by five different companies. The study demonstrated that the operating principles of the device were not the only way accuracy was impacted. Rather, the accuracy varied greatly based on the manufacturer of the chosen device and not as much due to the underlying operating principle. The required measurement accuracy for a given job is something that must be determined by the project team at the onset of laser scan operations as part of the construction workflow. While laser scanning is capable of reaching accuracies of a few millimeters, sometimes that level of accuracy may not be required, which allows for a wider range of scanner options to be considered. Furthermore, the settings on the scanner can be adjusted to reduce the resolution or quality of the scan and the subsequent amount of data being collected, thus decreasing the overall scan time for a given project. This can be especially helpful if a laser scanning sub-contractor is to be used for a project, since they may charge by the hour or day for their services. When seeking to include laser scanning as part of a project workflow it is important to consider all aspects of its operation including who will operate it, when it will be operated, what areas are to be captured and what level of detail is required. As is the case with any technology, it should be used where advantageous and carefully planned for throughout the process. Deciding when and how to employ laser scanning is important and users should be aware that laser scanning itself is not always the best solution, since it is only the means to an end rather than the final product itself (Barber and Mills 2007). In this regard, it is important to understand that laser scanning is a tool which can lead to more accurate models when integrated with other computer modeling programs to produce more detailed deliverables. Depending on the intended use for the scan data, a traditional laser scanner might not be the best option, and the project team may consider emerging photogrammetry based devices.

2.2 Alternative Image Capture Methods

In addition to laser scanning, there are emerging technologies which aim to supplement, and in some cases replace, traditional laser scanning techniques. The most prevalent techniques involve the use of photogrammetry. Simply put, photogrammetry is the taking of 3D measurements from a 2D images. Through the combination of thousands of these measurements a 3D model can be generated and is a standard output of photogrammetry operations. In recent years multiple companies have developed methods and software which convert 2D images into 3D point cloud or mesh models. These point clouds can be used in the same way that traditional point clouds are used but can be developed at a fraction of the cost through the use of a digital camera or integrated visual capture devices. This form of point cloud development, which falls into the same reality computing category as laser scanning, is continuously improving and is becoming a viable complement to the laser scanning and reality computing practices currently in the construction industry.

Golparvar-Fard et al. (2012), for example utilized unordered daily construction photos as part of an automated progress monitoring system. They demonstrated the possibility of utilizing job-site images, as collected by field personnel, to develop a point cloud “as-exists” model which can then be superimposed onto an as-built BIM in order to determine construction progress. In the two trials only 112-288 photos were used and the new algorithms developed, based on the principles of photogrammetry, were able to compare and color code the progress of the job with the planned progress through the combination of the project schedule and BIM model, or the 4-D model (Golparvar-Fard et al. 2012).

Models and point clouds developed using traditional photogrammetry methods can only be as accurate as the image quality allows and cannot match the millimeter accuracy expected from traditional laser scanners. However, this may not be a concern depending on what level of accuracy and detail is required for a given project. As an alternative to the use of traditional digital images there is work being done which combines the concepts of video based photogrammetry with infrared technology to develop models with increased accuracy. Paracosm, a company based in Gainesville, FL, has successfully combined infrared technology with traditional video based photogrammetry methods and is seeing success with high levels of accuracy using inexpensive commercially available devices (https://paracosm.io). Since hardware is readily available to capture infrared and standard video data simultaneously, the only components that need to be developed are the algorithms and software which produce the 3D model. Fig. 2 is an example of a point cloud generated using video based photogrammetry and infrared reality capture techniques developed by Paracosm. The same mechanical room captured in Fig. 1 is shown in Fig. 2 to allow for comparison of various capture techniques within the same space.

The accuracy of the scan in Fig. 2 was lower than that of the scan in Fig. 1, by less than two inches of deviation for spans of ten feet, however the data would still be useful for the development of an as-built model of the mechanical room. Such accuracy would surpass that created through manual measurements and will continue to increase as the technology is further developed. Additionally, the scan in Fig. 2 was completed in less than five minutes in one pass. On the other hand the scan in Fig. 1 took multiple setups and approximately ten minutes per setup. These images provide an example of the tradeoff between accuracy and time which exists among the various capture techniques. The emerging reality capture methods discussed in this section are continuously evolving and offer an alternative to traditional laser scanning. A project team must carefully consider their needs when selecting what type of device to use and it is important to understand the options which exist in the industry today. Through education and exposure to such technology both professionals and students can make informed decisions during the construction process, which can improve their BIM workflows and project success.

FIG. 2: Point cloud of a mechanical room captured using infrared scanning and photogrammetry techniques.

2.3 Considerations for Laser Scanning

In the construction industry safety is crucial and whenever a new technology is introduced all of its impacts on the jobsite conditions must be understood. Barber and Mills (2007) published a guide to laser scanning for archaeological and architectural applications. The advice provided in the guide described the limitations of the technology as well as the typical workflows which could be employed. In addition to utilization guidance, they also discussed laser safety, which is an important topic when considering using this technology on a job site or with students. Prior to deploying a laser scanning device it is important to know what class of laser is being used so that proper safety procedures can be implemented. In recent years companies have begun releasing laser scanners which have a Class 2 or Class 1 laser, rendering the device safe under reasonable conditions (Barber and Mills 2007). This demonstrates an improvement over the use of Class 3 laser devices, which were common during the onset of laser scanning technology, and required the use of eye protection to avoid injury. Class 1 laser devices are now the standard for commercial laser scanning devices and are safe under all operating conditions, eliminating a lot of the safety concerns associated with the use of a laser based device. When including laser scanning as part of the project workflow there are considerations beyond safety which must be made when collecting data in the field, which exceed those found when collecting traditional manual measurements.

One such consideration is that laser scanning requires contingencies for dealing with occlusions present during the scanning process, which can limit the available data if not properly addressed. Laser scanners cannot see through solid objects, which can cause a problem on jobsites or in buildings with excessive amounts of movable objects blocking the intended areas of capture. This can also be a problem if the laser scanning process is intended to be used to document utility and service infrastructure in a building where drywall and finishes are present or placed before a scan can be completed. Gao et al. (2012) proposed using progressive scan data obtained by scanning the target building at intervals throughout the construction process in order to develop a more complete point-cloud for use in creating as-built BIMs. A case study was conducted, utilizing the outlined progressive laser scanning technique, of a renovation project on a university campus. They concluded that progressive laser scanning provided a point-cloud which could be used to develop accurate as-built models of all building elements, including MEP elements hidden behind surfaces (Gao et al. 2012). Similar studies have been conducted using laser scanning at various stages of construction projects to aid in the development of complete as-built models. These models were then used to complete other work, such as the development of cost models to assess the cost of proposed building code changes.

There are many applications for laser scanning within the construction industry and more are discovered each year as the technology becomes more accessible and data is more plentiful. One of the most common applications for laser scanning is for as-built documentation. As-built models are an important deliverable for project teams at the end of a construction job and laser scanning has been proposed as a tool to increase the accuracy of this deliverable. The laser scanning data can be used to inform the BIM process and assist in the development of accurate as-builts which are useful for owners and facilities management after the completion of the project. The limited utilization of BIM for facilities management, and the subsequent maintenance of a building following construction, was the focus of a study conducted by Giel and Issa (2011). In that study it was determined that the accuracy of the model was a concern which impacted the use of BIM and laser scanning was identified as a possible means to assess the accuracy of the as-built BIM (Giel and Issa 2011). Through the development of an as-built BIM, based on 2D as-builts compared to a point-cloud, the researchers were able to identify the accuracy of the model and determine areas which needed to be updated to match as-built conditions. This work provides one use case for the integration of laser scanning technology into BIM workflows in the industry.

Fallon (2012) outlined the numerous uses and benefits derived from deploying laser scanning in the construction industry projects including transportation, utilities and process plants, offshore oil production facility development, forensic evaluation and building renovation. Laser scanning has a variety of applications and has come a long way over the course of the past decade. During the construction process for example, laser scanning can help reduce rework through its use for quality assurance (QA) and quality control (QC). A lot of effort is expended during the BIM process to coordinate building systems to avoid clashes and ensure constructability. However, if the systems are not installed accurately in the field, than all of the planning goes to waste. Depending on the type of construction, rework can account for up to 12% of the construction costs (Hwang et al. 2009), and with the construction industry in the U.S. reaching the trillion dollar mark, there is the opportunity for great savings. By superimposing laser scanned point cloud images over building information models, contractors are able to almost instantaneously catch deviations from the design and reduce their rework costs by making adjustments to the remaining project, avoiding the perils of error propagation. For example, if a plumbing riser deviates from the designed location the team can adjust it to its as-built location in the model and asses its impacts on the floor above, making adjustments where necessary. Additionally, if the problem is caught early enough, the installer can move the element into compliance with the designed location before too much additional work has been completed. This process can reduce rework by allowing the team to accurately plan, which results in considerable cost savings and can also help keep the project on schedule.

As the construction industry evolves, the utilization of laser scanning will continue to grow as construction professionals seek more effective means of project documentation and control. With the adoption and expansion of this technology there is a parallel need for professionals who can conduct and manage laser scanning processes. The implications of this are that new hires in the construction industry, will be held to increased expectations regarding their proficiency with laser scanning and similar reality computing techniques. Construction management education will have to adapt to the new expectations placed on graduating students and consider including laser scanning as part of the curriculum for students. Current BIM courses can be adapted to include laser scanning, if proper considerations are made for the level of knowledge required by the students, as well as the required access to scanning equipment. Technology is ever evolving, however an understanding of the concepts and principles of laser scanning will provide students and professionals an appreciation for the capabilities of the technology throughout their careers.

3. INTEGRATION OF LASER SCANNING INTO BIM EDUCATION

In order to increase efficiency, many construction companies are requiring and training all employees to have at least the minimum skills and theoretical understanding necessary to open and navigate BIM models. Even if an employee is not responsible for modeling directly they need to be able to manage and work with those employees who are. Through the development of an appreciation for the technology, industry professionals will be better equipped to manage their projects and leverage such technology to gain an advantage in their work. Fortunately, students studying construction management have the opportunity to gain this knowledge before they enter the industry and position themselves ahead in the job market. This education is not just the responsibility of the students, but also of the educational institutions that they attend, and that can provide them both with a tangible market advantage..

As the use of BIM in the construction industry becomes the standard for project management, construction management departments need to expose their students to the expanding realm of this new technology. Having the required BIM knowledge and skills will give graduates of those educational institutions an edge as they seek employment opportunities and begin their professional careers in the industry. In addition to knowledge of the newest technology it is crucial for students to gain a theoretical appreciation for what such technology is capable of. The software itself changes year to year, but the overarching concepts remain true and if these are understood then students will have an easier time navigating the unsettled waters of technological advancement in the industry. The conceptual and theoretical understanding of BIM practices and technology is something that many companies are looking for when hiring new employees, and educational institutions would be doing students a disservice if they did not prepare them for these new expectations. The technology students should be exposed to extends beyond modeling software and includes the need for laser scanning education, in order to make BIM education more holistic. The ability to understand laser scanning and similar reality computing technology is crucial as it is how projects are being documented and project managers are using it to improve their project control methods.

As the general knowledge of BIM and related technology, such as laser scanning, continues to expand the need for a dedicated, company-wide BIM department may disappear. The increased efficiency found by having entire project teams knowledgeable in these areas would exist due to two key factors. The first factor would be a reduction in modeling time, since modelers would have the help of the project teams in managing the BIM process and would be able to focus their efforts on the modeling. Laser scanning is a time consuming endeavor and if the on-site project team can effectively complete this work the modelers can focus on using the data to develop the models and have limited lost time conducting scans. Furthermore, if each department or project group has one or more employees with enough modeling skills, the modeling can be done within that department or unit without having to rely on a dedicated modeling department at a company headquarters. The second approach construction companies can use to increase BIM efficiency is through the reduction of communication issues. Re-modeling is a source of wasted time and the main cause for that is miscommunication. When dedicated modeling personal are isolated from the jobsite they often have a lag in receiving information which helps them develop an understanding of the intricacies that exist in the flexible construction process and require their attention. The most effective approach to resolving these issues is through the education of professionals, and most importantly students who are beginning their careers in the industry in order to help bridge the gap between these groups of professionals.

3.1 Course Curriculum and Structure

Introducing the concept of BIM is becoming commonplace in construction management education, however technologies such as laser scanning often are not included or are simply mentioned as an existing technology. Students need to understand how to approach a range of workflows, which increasingly include such technology, as well as develop a working understanding of how laser scanning can be integrated into BIM and construction process. In construction management education the content and teaching methods for BIM courses can vary widely among educational institutions. There are however two key components which all BIM courses should have. The first is the development of a conceptual understanding for how BIM, and its associated technologies, can help optimize the construction process and improve efficiency. The second part, is the fostering of the technical skills required to operate and leverage the technology for optimal results. Failing to introduce both the conceptual and theoretical components would result in a partial understanding, hindering the student's ability to use their knowledge to its full potential as they enter the industry and begin their careers as construction professionals. The development of technology is a fluid process, which makes the overarching concepts even more important for students who intend to manage projects and employees which utilize constantly changing BIM and laser scanning technology.

The development of conceptual background knowledge, even if brief, will help the students better understand the big picture when it comes to the implementation of the software and technology. Next, students should receive introductory lessons aimed at introducing the software user interface (UI) and allowing hands on experience in operating the software. It is very important to make the students familiar with the UI since it is the first line of communication within the software, and although it may change slightly over the years, generally uses similar navigation concepts which can help them communicate with the project team. After the students become comfortable using the various basic commands in the software, more advanced modeling techniques and commands should be presented. Every time the students get introduced to a new set of commands, an assignment should be handed out to enforce it and provide them encouragement to use the software outside of class. The more the students use these techniques and commands, the more familiar and comfortable they will become with them. That also makes it easier to introduce higher level commands that build on the basic ones. Finally, a course project should require use of all the learned commands and encourage collaboration with classmates, simulating how such technology would be used by a project team in the industry. Crucially, the final project introduces students to the variable of team work and communication in the BIM process.

3.2 Construction Information Systems

Construction information systems is a graduate level course at the University of Florida that introduces students to the expanding world of BIM. Students starting the course are expected to know how to read and interpret construction documents and have holistic knowledge of the construction process. The course starts with an introduction about the theory and application of BIM processes to familiarize students with its application in industry. The students then perform hands-on lab exercises in several software packages including Autodesk Revit®, BIM 360 Glue® and Navisworks®. After that, students are provided construction documents for an existing building from which they are required to develop a model in Revit® and complete basic coordination efforts for the building systems using Navisworks® and BIM 360 Glue®. These individual assignments are designed to enforce the material learned through modeling each building discipline, including architectural, structural and MEP systems. The course also introduces students to other BIM related software including Vico Office® and Synchro Professional® providing a breadth of understanding.

The next part of the course exposes the students to the collaboration aspect of BIM. This collaboration presents students with the social factors of project development that can make or break the BIM approach for a project. Students were divided into groups based on prior experiences and backgrounds. Each group was then assigned a campus building to model as accurately as possible using the techniques and skills learned in class. However, unlike previous assignments, none of the groups received as-built drawings to base their models on. Instead, each group helped plan and set-up the laser scanning activities necessary to collect data for their assigned building. Students were provided with basic floor plans as reference for their buildings, however the lack of an as-built drawing set made laser scanning and field measurements their only data sources for modeling. Following the scanning of the buildings, and subsequent point cloud development, the different groups received the federated point cloud for their assigned building and used it in the modeling process. In addition, groups received schematic floor plans for their assigned buildings. The lack of dimensions and elevation views forced the students to utilize the point cloud for measurements of façade elements and overall building details. Moreover, every group was required to deliver a BIM execution plan that stated members' roles and responsibilities throughout the project. The project duration was approximately six weeks and groups had to complete models of the different disciplines, e.g. architectural, structural, MEP. The groups were then asked to submit a federated model that merged the models together into one complete building model. The project was graded on the accuracy of modeling, in terms of dimensions, imbedded information and process.

Lastly, the final test of the course examines the students' performance on the taught software under a time constraint. Students are allotted three hours to complete various modeling parts based on provided construction drawings. Students model specific parts of a building, identify modelling errors and complete basic construction sequencing animations using provided models. These deliverables provide the students the opportunity to demonstrate their mastery of the technology, as well as their understanding of how the various technologies can be leveraged during a project. At the conclusion of the course students were expected to have a conceptual understanding of a range of BIM processes, including laser scanning, as well as hands on experience which provides confidence and capability for using such technology when they enter the construction industry.

3.3 Limitations of such courses

The primary limitation of most BIM courses is the abundance of technical software used in the industry. It takes almost an entire semester to cover one software package at a level where students would feel comfortable using it. This competence is crucial and the introduction of every available software package cannot be completed in a semester in enough detail to be valuable. The construction industry is fragmented and uses a range of software packages, making it difficult to prepare students for every situation they may experience. This is why the focus on the conceptual understanding is crucial throughout the course. Learning new software is something that never ends and if students understand the conceptual basis for what they are doing, learning a different software platform becomes much easier.

Another limitation of such courses is, in some cases, the lack of availability of educational versions of many BIM software packages. Many of these software packages are marketed towards construction companies and are extremely expensive especially for college students. The students, and often the educational institutions they attend, can simply not support the cost of such software. This eliminates the possibility for students to experience those software packages hands-on and therefore limits the breadth of their exposure. Despite these limitations, BIM courses offer students' knowledge that would otherwise not be available and utilizes the skills and expertise that they have developed during their education. BIM does not exist in isolation and requires a holistic understanding of construction processes, materials and methods, scheduling and estimating to take full advantage of its capabilities. This is one of the many factors that continues to drive the proliferation of BIM education despite some of the limitations which will hopefully be overcome in the future.

3.4 Incorporating Laser Scanning in BIM course

Laser scanning is one of the latest technologies that can aid the BIM approach and students gaining a construction management education should be exposed to it, giving them the opportunity to further enhance their skillset. This would ensure that graduates of a given program are equipped with cutting-edge skills making them more valuable to the industry and better prepared for their careers. Laser scanning continues to evolve year after year and as such the curriculum for the BIM course should be revised on a yearly basis to ensure the instruction of the latest technologies, while avoiding obsolete or superseded ones. Additionally, introduction to laser scanning in the course must work in parallel with the existing curriculum demonstrating how laser scanning can be part of the BIM process, and is not just a standalone technology. That means that new material is needed to compliment and add to the existing assignments enabling the inclusion of laser scanning into the existing project and assignment structure. It was discovered that the best way to approach this was to treat the final project in the course as an as-built documentation or historic preservation style project. This ensured that students learned the implementation and use of BIM software in a real world application, while incorporating the laser scanning technology to allow for more accurate modeling and documentation of as-built conditions. Furthermore, selecting projects accessible to the students allowed them to visit the building and complete hands on exercises which enforce the learning done in the classroom.

3.4.1 Working with a laser scanner

When incorporating laser scanning in construction management education, the first thing students need to be exposed to is the scanner itself and how it operates. The various operating principles and scan settings were explained in detail to develop and understanding of how the device works. The scanner, in the case of this study a Faro Focus3D®, was introduced to the students providing them the opportunity to see the device and manipulate the operating interface. The menus and settings on the touch-screen style user interface were displayed in order for the students to become comfortable with operating the laser scanner and identifying what settings needed to be considered. During this process, each of the settings were elaborated on so that the students had an understanding of why certain settings may need to be altered prior to a scan. For example, scan resolution and quality settings must be adjusted based on the location of the scan (i.e. indoor or outdoor), the lighting conditions present during the scan, size of the target building or area and the desired point cloud density. Although students would not actually get to see the scanner work until later on, this initial tutorial made the students comfortable with the scanner and introduced them to the basic concepts required when operating it in the field.

The introduction session, in addition to scan planning lesson discussed in the next section, helped reduce scanning times and increase efficiency in the field. The increase in efficiency was mainly due to the students' understanding of the scanning process beforehand and knowledge of the basic operating principles which allow the scanner to work. It also reduced the questions asked during the scanning sessions, making it possible for the process to proceed in a smoother manner. Moreover, students had a better understanding of how the different modes of scanning would affect the final output especially when it comes to merging, or stitching, the different scans together. This knowledge was crucial in the field but was even more crucial during the planning stage where students were asked to plan the scanning activities required to capture the exterior façade of their assigned buildings.

3.4.2 Planning the scan

Planning is a crucial component of every construction project and laser scanning activities are not exempt from the need for thorough planning. Scan planning is an extremely important step in the scanning process that helps achieve efficient and effectively executed scanning activities. In the BIM course used for this study, students were first introduced to the concepts of laser scan planning as they were introduced to the fundamentals of laser scanning itself. Laser scan planning is a multi-faceted process which includes considerations for the locations of the scans, identification of possible occlusions, review of weather conditions and a rough calculation of the anticipated time it will take to complete the scans. Students were asked to plan the laser scanning job by first thinking about the desired result, or area to be captured, and then working backwards to determine the best way to achieve that result. Providing examples of multiple point-clouds produced of the same building, generated from different scanning locations around the building, can help students comprehend how the selected scan locations can impact the final product. This further clarifies and emphasizes the importance of effectively planning the scan locations, especially in terms of stitching the point-clouds together.

Selecting scan locations is not something that can be done haphazardly and requires an understanding of how the laser scanner operates. In this regard, students were first introduced to the fundamentals of laser scanner so that they have an appreciation for how the range of the scanner, impacted by the operating principle and selected scan quality, can influence the number of scans required for a given building or space. As the desired quality increases there will be a parallel increase of either the quantity of scans or the overall scanning duration. Once the range of the scanner is determined and preliminary scan locations are selected for the target building or space, students must then consider any occlusions which are present in the scans.

Occlusions can range from furniture or clutter to large hanging light fixtures in a space. Since scanners cannot see through these objects, it may be necessary to move objects or possibly complete additional scans to capture the area blocked by the object. To demonstrate how occlusions can create “shadows”, or areas not captured by the scanner, students were shown different point-clouds which were impacted by objects and equipment within the scan. The “shadows” were explained to the students as objects on the scene that obstructed the scanner from capturing the space and other objects behind them. Fig. 3 shows a completed laser scan with a “shadow” from a light pole extending all the way to the surface of the building.

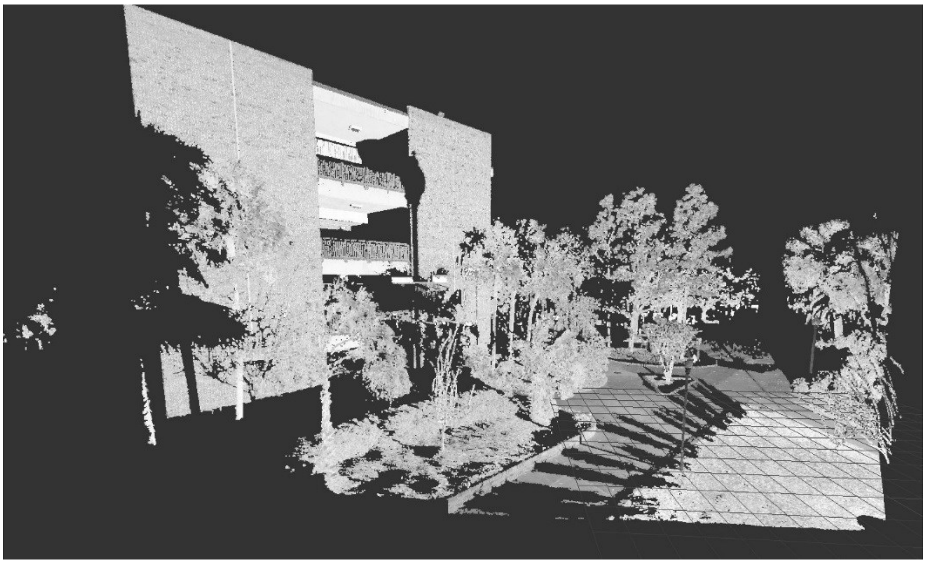

FIG. 3: Completed scan of a building demonstrating a scan “Shadow” created by a light pole.

The scan location is in the bottom right corner of Fig. 3 and the light pole is between the scan location and the building creating the “shadow”. These “shadows” lead to missing data in point clouds and need to be carefully considered. The best way to describe this issue in laser scanning is to compare the laser scanner to shining a flashlight in a dark room. Anywhere that the light would be blocked, and thus in shadow, is not visible to the scanner in will result in a similar scan “shadow”. Planning for such obstacles is extremely important in order to have a complete scan that captures all main elements of a building. Many times obstacles are unavoidable and additional scans will be necessary to fill in the missing data. In the BIM course, the students were asked to plan laser scanning operations for buildings on campus which allowed them to walk around the building and visually inspect the scan area for possible obstructions. This was also an effective way to bring the students into the real world and provide hands on learning to tie the concepts discussed in the classroom to real examples. The combination of lecture with floor plans and site trips to the target buildings provided a holistic understanding of occlusions and led to the development of more effective plans.

The final factor to consider when planning laser scanning activities is how different weather conditions can impact the scan. Laser scans cannot be conducted outside in adverse weather, including precipitation or high winds that may cause the scanner to tip over. More importantly, intense light and glare can restrict the ability of the scanner to capture the desired target. In this regard, scanning is best conducted early or late in the day when the sun is not directly overhead, or ideally on days that are overcast. Weather is something that cannot be controlled but needs to be considered when planning. This is especially true if the scans are being conducted on a remote site which must be traveled to. All of the considerations discussed here regarding laser scanning factor into the amount of time it will take to complete a given laser scanning job, which is crucial information when trying to complete scans in active buildings or jobsites. Knowing the time of operation for the target building as well as the frequency or rate of occupancy in the building allows the scanner operator to select the best time to complete the scans. People moving around the building can act as temporary occlusions that cannot be easily controlled. This is a factor which can be easily worked with once the total anticipated duration of the laser scanning job is known. The students took all of the considerations outlined here into account and were able to plan for people walking around the building. They were able to time their scans to avoid times of high volume pedestrian traffic and times of intense sunlight on the various sides of the building. Some campus buildings were harder to scan than others due to size, shape and location. However, using the knowledge gained and through the developed holistic understanding of laser scanning all groups were able to successfully plan and complete scans for their assigned buildings.

3.4.3 Modeling based on the produced point-cloud

Following the completion of laser scanning for a project, the generated point-clouds for each building were processed, or stitched together, and access to the completed federated point cloud was given to the respective groups. During the stitching process students were able to assess the effectiveness of their selected scan locations and see how the locations they chose impacted the point cloud development process. Due to the preplanning all of the buildings, scans were able to be easily federated into complete point clouds ready for use in modeling software. Students used the point clouds along with the provided floor plans to model their buildings. The information in the point cloud was crucial for the successful modelling of the building facades as there were no elevations provided and the collection of measurements was not possible for many of the façade elements. The produced point clouds were a source of information during the modeling process, however some students had problems using them on their personal computers. Fig. 4 shows a rendering of the completed model for one of the groups in the class. The model was checked several times against the point cloud to ensure accuracy and detail level.

FIG. 4: Completed model that was based on the laser scanner generated point cloud

Due to the large size of the point-cloud files, some students found it difficult to use them within Autodesk Revit, especially on their personal laptops. Point clouds have millions of points and using them is very processor and graphics intensive. Instead of using Autodesk Revit, the students were instructed to use Autodesk Recap to view the point-cloud and take measurements for reference while modeling. The point clouds helped students better visualize the spatial environment of the buildings and ensure accuracy of the exterior façade of the building. In addition, the point-cloud made it easier and more convenient to collect countless accurate measurements of the building, which would have been otherwise unobtainable. In this case, students were using the point-clouds as a reference tool and a supplemental source of data during the modeling process. With more powerful computing capabilities it is possible to overlay the point clouds directly in the modeling environment which can further improve the accuracy of the final model. With the combination of the point clouds, schematic floor plans and site pictures, students were able to complete reasonably accurate as-built models of their assigned building during their enrollment in the BIM course. Laser scanning enabled students to not only complete their projects, but also provided proficiency with new technology and workflows which are gaining popularity throughout the construction industry.

4. BENEFITS AND RESULTS

During their enrollment in the BIM course, all five teams managed to successfully complete their projects using point clouds derived from laser scans on time and with more than acceptable results. Students leveraged the data in the point clouds to measure features on the building facades which were otherwise unobtainable through field measurements. Initially there was some skepticism regarding the accuracy of the developed point clouds and the measurements which would be taken. The students were instructed to take a few measurements of accessible façade elements on site, and to use those measurements to verify the ones taken from the point-cloud. Upon verifying several measurements, students' confidence in the point-clouds' accuracy increased and they were more comfortable using the available scans. This simple exercise completed the appreciation the students had for laser scanning technology and aided in the acceptance of its usefulness. All measurements for the building facades used for the model process were taken from the point clouds following the verification process. The models produced during the course were accurate within ½" (12.7 mm) of verified actual dimensions.

Although a certain degree of accuracy for the completed models could be achieved without the aid of the laser scan generated point-clouds, it would have taken students a large amount of additional effort and time to do so. Furthermore certain parts of the building's exterior would not have been accessible without lifts or ladders making the collection of measurements unreasonable. The generated point-clouds made it easier for students to look at the building from various angles and collect accurate measurements instantaneously. Furthermore, it eliminated the need for additional site visits while keeping everyone safely on the ground, with no need for ladders or lifts. In addition to the safety benefits, there were also time savings realized through the use of laser scanning. These savings allowed for more time to be spent on the modeling and information management itself. The generated point clouds enabled the creation of models at a much higher quality than would have been possible with the limited floor plans available for the buildings.

On the other hand, the information embedded in the models was not as accurate as the dimensional characteristics. This was because the information about the existing building components was not available or provided to the students, i.e. the building specifications and contract documents. Laser scanning the building provided students with geometrical and spatial information only and provided no insight into the materiality of the building. In order to discern the composition and materiality of the different building components, students had to visit the site and rely on their knowledge of construction to make informed decisions. As for the hidden building components, such as foundations, structural columns and beams, students had to make educated guesses as to their composition based on the style of building and elements which were visible throughout the building. Such information can only be found in as-built drawings and specifications that were generated by the contractor at the time of construction and were unavailable at the time of the BIM course. In order for laser scanning to be conducted of these elements parts of the buildings would have to be removed, which was not an option. The ability for students to learn how to model and use new technology was not hampered by this missing information but it did provide an added layer of overall difficulty to the project.

Upon completing the BIM course, students conveyed positive feedback about their experience regarding the inclusion of laser scanning. The general consensus was that knowing more about this new technology gave them added confidence in their BIM abilities and with new technology in the industry as a whole. In addition, students indicated that they were excited to take their experience with laser scanning into the professional environment.

The negative feedback regarding laser scanning all focused on the lack of computing power found on the students' personal computers. Some students had older or less equipped computers that were not able to handle the large point-cloud files. Those students reported that the process was cumbersome and that they had to count on their group to supply the information they needed from the point clouds. In this regard, it is important to consider the access students have to computers which are capable of running the necessary software for the effective use of point clouds. Overall, laser scanning can provide unprecedented amounts of data to inform the construction and BIM process. The effectiveness of this data is directly related to the education and practice that those using it have received. Through the inclusion of laser scanning as part of construction management education students get a head start in developing the technological knowledge and skills which are becoming prized in the construction industry.

5. CONCLUSION

Laser scanning is becoming part of the workflow for construction professionals who use BIM and VDC processes industry wide. As is the case with any tool, project teams need to ensure that it is being employed where it is most advantageous and can provide information to aid the construction process. The success of this and similar technologies relies on the continued education of professionals and students studying for careers in the construction industry. In addition to including education about the new technology and hardware itself, course work should be developed which outlines best practices, as well as the means and methods for using laser scan data within existing workflows. This kind of information should be a part of both undergraduate and graduate student's education in construction management, architecture and related engineering programs alike. Providing students with experience regarding the implementation of such technologies not only enriches the experience of the students, but as they enter the industry it serves to aid in the improvement of existing workflows through the integration of such technology.

In order to keep up with the ever evolving technologies in construction, educational institutions need to continue integrating and updating the technologies included in their courses. The implementation of laser scanning technology in a graduate BIM course at the University of Florida has garnered positive feedback, demonstrating desirable outcomes for students. An appreciation and understanding of laser scanning technology was developed holistically, including the operating principles of the technology as well as how it can be implemented within the BIM process. Most importantly, students learned the best methods for planning and executing scanning activities for existing buildings, with the goal of using the collected data for modeling and documentation purposes. The information that was obtained from the generated point-clouds helped the students successfully model the existing buildings despite the lack of as-built documentation available to them. In addition to increasing the students' enthusiasm for modeling, the knowledge gained in the course gave students an advantage as they applied for jobs and sought to begin their careers in the construction industry. An appreciation was gained for the time and considerations which must be made when including laser scanning as part of a job, enabling students to make better and more informed decisions regarding its use during their careers.

The full potential for laser scanning has not yet been realized and as its use continues to expand within the industry it is crucial to expose students to its capabilities. Students should be provided with the opportunity to be as prepared as possible entering the workforce as the new generation of construction professionals. The need for education goes beyond students and extends to the industry as well. We can all learn from each other every day and through the education of students, professionals and companies alike can be spurred to seek additional knowledge to improve their efficiency. Laser scanning has a wide range of uses, which extend beyond what can be taught in a single semester, and hands on experience with laser scanners and the data they produce proved to be invaluable. Students with little to no knowledge or experience with laser scanning and BIM were able to not only comprehend but successfully use laser scanning for the development of an as-built model. During one semester students gained proficiency and knowledge for a variety of technologies which exceeded what many of them thought they were capable of. Including laser scanning in construction management education, when thoughtfully considered and executed, can not only better prepare students for their careers but also further encourage progressive thinking aimed at leveraging new technologies to improve the construction industry as a whole.

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