

Applied Laser Scanning for the Construction Classroom: Instructional Design and Best Practices

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Laser scanning is a powerful tool that is being deployed throughout the construction industry. In order to enjoy its benefits, users must first be instructed in the proper use of the hardware and software necessary to capture and employ the scan data. The purpose of this paper is to present a pedagogical approach to delivering a laser scanning learning module and assessing student performance. The methods are designed for undergraduate construction management programs. The paper concludes with findings and best practices based on student feedback and instructor reflection.

Key Words: Laser Scanning, As-Built Drawings, Integrated learning module, BIM Integration

Introduction

Laser scanning is a powerful technology that allows users to capture highly accurate dimensional data. It has been accepted and is being applied in many fields including science, medicine, and manufacturing. The construction industry is also leveraging the power of laser scanning for multiple applications that are providing tangible benefits for owners, designers, and constructors.

In response to the industry adoption of laser scanning, the faculty at Missouri State University (MSU) have prepared a comprehensive learning module designed to prepare students to address the challenges and embrace the opportunities presented by laser scanning. The purpose of this study is to document the instructional design and best practices gathered from applying the learning module in the classroom. The authors present pedagogical components including student outcomes, tools required, content delivery, and student assessment measures along with preliminary student feedback and a reflection on findings and recommended best practices.

Literature Review

Laser scanning was implemented in the fields of engineering and medical sciences almost three decades ago. Since that time laser scanning has also been introduced into multiple industries including robotics (eye control), construction (as-built drawings, site layout and modeling, surveying, geomatics and forensic documentation), automotive manufacturing, entertainment (movies and video games), photography, reverse engineering, virtual reality, medical applications and industrial quality assurance (Brenner, 2005; Davidovits & Egger, 1971; Heritage, 2007; Pfeifer & Briese, 2007). The reason for the abundant growth in the application of laser scanning technology is its capacity to capture highly accurate spatial data in three dimensions (Kukko, Kaartinen, Hyyppä, & Chen, 2012).

3D scanning and processing technologies have earned significant attention in the construction industry for close to a decade. Laser scanning is widely utilized in the integration of laser scans to BIM, combining 3D scanning with total stations, creating highly accurate as-built drawings, sustainable performance evaluation, energy rehabilitation of structures, retrofitting old structures, dimensional assessment of precast concrete elements, pipe leak detection, and analyzing the deformation of large-scale infrastructures (Clark & Liu, 2014; Reginato, Ph, & Assoc, 2014). Similarly, Golparvar-Fard et al. (2011) used laser scanning to evaluate the accuracy of the structural deformation. Walters et al. (2005) utilized the same technology to determine and adjust pavement thickness in real time.

Alizadehsalehi, S., Koseoglu, O., & Celikag, M. (2015) also reported on the integration of laser scanning and BIM technology in the construction industry.

Though there are numerous established applications in the industry, laser scanning technologies have not been widely adopted in the construction management curriculum by schools in the United States for various reasons (Martin & Plugge, 2015; Reginato et al., 2014). The primary reason being the hardware requirements and the cost of the laser scanning equipment (Meadati et al., 2013). With technological advancements like infographic models and 3D visualization tools, CM students need more hands-on experience to handle enhanced challenges of capturing and registering scans using lasers. Registering the scans refers to the process of matching up multiple scans taken from different locations to create a comprehensive 3D image. Also, it is essential for students to understand the integration of BIM with laser scans to create useful as-built drawings. Meadati et al. (2013) suggested that 3D scans have the potential to enhance students' skills greatly and will also assist the faculty in elevating the quality of the curriculum.

With motivation from multiple sources addressing the need to implement laser scanning (which is highly used in the construction industry) into the construction curriculum, this paper presents the pedagogical design applied by the faculty at MSU to prepare students to leverage laser scanning in their career. The following section includes the pedagogical components of the laser scanning learning module and the paper concludes with findings and best practices based on student feedback and instructor reflection.

Pedagogical Content

The following paragraphs will present the pedagogical content associated with the laser scanning learning module. It will include student learning outcomes, tools required, content delivery and student assessment methods. The laser scanning learning module is designed around three primary learning objectives. These objectives are designed to replicate the steps required to collect laser scan data and generate a functional project deliverable. Upon completion of the module, students should be able to 1) accurately setup the laser scanner and produce a scan, 2) register multiple scans into a single document using Scene® software, and 3) introduce the registered master scan into Revit® and produce an accurate as-built drawing. Figure 1 shows the various pedagogical components of the learning module and their learning outcomes.

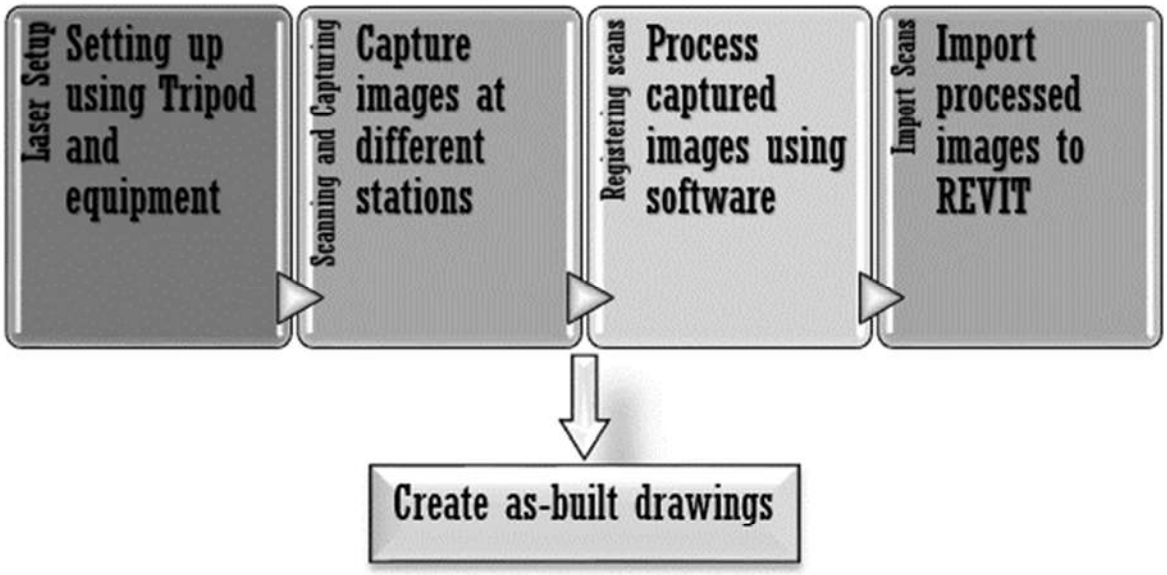

Figure 1 Step by step process of the lab activity

Several tools including hardware and software are needed to deliver the learning module. At the core of the exercise is the laser scanning device itself. For this learning module, the researchers chose to use the FARO® Focus X 130

laser scanner. From a cost perspective, the Focus X 130 ranks at a median price point and has proven to be user-friendly and adequately durable with the excellent scan quality. Along with the scanner, users must also have access to a robust computing system. The primary considerations for the computing system are the speed of the processor, the memory, and the video card. For the learning module students had access to Dell desktop computers with Intel® Core I5 - 64-bit core processors, 8 GB RAM, and an Intel® HD graphics 4600 card. The computers were using the Windows® 10 operating system.

The software requirements include a program to register the scans and finally a design program to accept the registered scans and produce the as-built drawings. Registering the scan refers to the process of matching up the point clouds collected from multiple scans to create a comprehensive 3D Image. As was noted in the student learning outcomes, the researchers used Scene version 5.4 for registering scans. Within Scene, users manually select planes (such as walls and floors) and points (such as a stain on the floor or a sprinkler head) to align images from multiple scans. Scene software is designed to work with the FARO® focus X130 scanner and was purchased with the scanner. Autodesk® Revit 2017 was the design software used to create the as-built final drawings. With the required hardware and software identified, the following paragraphs will explain the content delivery for the learning module.

It is important to consider where laser scanning instruction fits into the overall curriculum at each institution. At MSU, the laser scanning module was presented in TCM 313 Facility Design. TCM 313 is a course where students are exposed to 3D design and Building Information Modeling tools and techniques. Autodesk® Revit is introduced early in the semester and used extensively throughout the course. The laser scanning learning module is introduced at near the midpoint of the semester after students have a functional knowledge of Revit.

The laser scanning module is delivered over two days. On the first day, students are broken into small groups of about seven students, and each group is instructed on scanner setup and the commands necessary to execute the scan. This step works best in conjunction with a lab session where the majority of the class is working on assignments while the instructor can provide dedicated instruction to each small group. Faculty should allow approximately ten minutes to complete each scan. For this module, the faculty scanned a computer lab and several adjoining rooms. Approximately seven scans are collected. It is crucial that the instructor establish a placement plan for where to set up the scanner to collect the necessary data to allow the scans to be fitted together with common reference points in the registration process.

Figure 2 Plan view of the as-built drawing

The actual setup of the scanner is similar to other types of surveying equipment on a tripod except that it is not necessary to level the scanner head because the orientation of the scan can be manipulated in the design software.

While commands will differ between manufacturers, the FARO® scanner requires users to indicate the scanned title, operator name, resolution, and if color or black and white photos will be collected. Students have shown a preference for the color photos as it can aid in matching reference points in the registration process. During the scan, the area should be vacated to allow the scanner an unobstructed view of all surfaces.

On the second day of the learning module students are instructed in registering the scans and importing the registered scans into Revit. It should be conducted in a computer lab where the instructor can demonstrate each step while students follow on their computer. Scans are imported into the Scene software where scans are registered in pairs by matching reference points which are identified as planes (a common wall) or points (doorknob or blemish in the carpet). Once all of the scans are registered with common points, the software will process the scans into a single document. The final file is then exported in Autodesk® Recap with the file extension (. rcp). Within Revit, students are then able to cut sections through the laser scan image and create an as-built drawing by overlaying objects (walls, doors, etc.) on the point cloud data.

The primary assessment for the learning module is a lab assignment that is completed from the laser scans collected by the small groups. To complete this assignment, students are allowed to work individually or in pairs. The assignment requires students to register multiple scans, import the registered file into Revit and complete an as-built drawing (see Attachment A). Students are also instructed in the formatting requirements for the assignment; select sheet size, identify sheet name, identify room numbers and names, show desks and chairs, indicate North, and scale images to fit on the sheet. The as-built drawing is presented in a plan view (figure 2), a cross-section (figure 3) and a 3D view (figure 4). All figures are examples of student work.

Figure 3 Cross sectional view of the captured scan

Figure 4 3D view of the captured scan

As a primer to the lab assignment, faculty may consider making a writing assignment where students are required to research applications of laser scanning for the construction industry or in other fields. Also, for most courses, it will be impractical to administer a summative assessment where students are individually assessed on their ability to collect and register scans and create final as-built drawings. However, the authors propose that an essay question is used as part of a summative assessment that requires students to explain the steps necessary to complete the process.

Findings and Best Practices

The laser scanning learning module was first delivered in the fall of 2016. Following the module, student feedback was collected in the form of a brief survey to improve the instructional delivery and assessment measure. A complete copy of the survey instrument is included as Appendix B. A total of 27 students completed the learning module and 15 students completed the optional survey. The following findings are based on student performance and student feedback from the survey instrument.

Figure 5 shows the distribution of scores for all students that completed the learning module. The average score on the assignment was 45.6 out of 50 possible points. From figure 5, it is evident that six students scored full score on their lab, 11 students scored more than 45, and only two scored between 30 and 39.5.

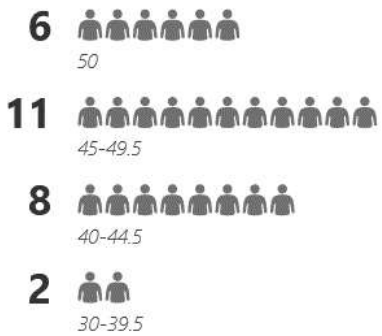

Figure 5 Distribution of students' scores

The survey instrument collected data on student perceptions of the difficulty of each step/procedure and their confidence in applying laser scanning techniques in the industry in the future.

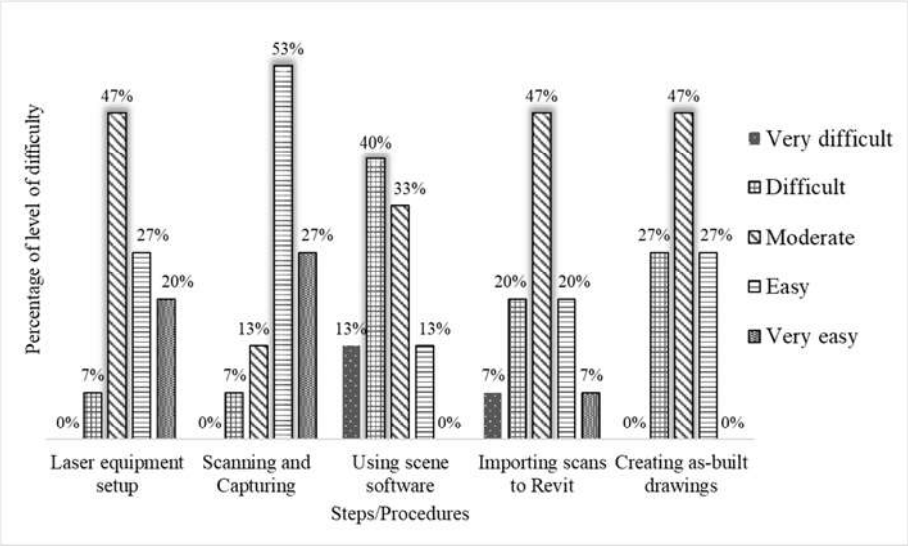

Figure 6 Survey responses from the students

The first step in the process was to setup the laser equipment and station it with a leveled tripod stand. Survey results indicate the majority (47%) of the students felt that the laser setup was moderately difficult. Only seven percent of respondents felt the activity was difficult. The second step of the lab was to scan and capture the images using laser scanning equipment. The results from the survey indicate that the majority (53%) of student reported this as easy. Again, only seven percent of respondents felt the activity was difficult. The majority of students (40%) felt that using the Scene software was difficult along with 13% reporting that this step was very difficult. For importing the scans into Revit, the majority of students (46%) reported moderate difficulty with 27% of students reporting difficulty or extreme difficulty. For the final step which was creating as-built drawings, 46% of students felt it was moderately difficult, and 27% of students reported the step as difficult. From the previous charts, the instructors were able to identify that registering the scans within Scene software was the most difficult part of the lab activity as reported by the students. Instructors wishing to initiate a laser scanning learning module in their classroom should be prepared to provide additional support and instruction for students who struggle with this outcome.

The survey instrument also asked students to report on their confidence in being able to perform a laser scan and create an as-built drawing in the industry. The following figure shows the distribution of responses. The instructors were encouraged that the majority of students felt that with more practice they could use the laser scanning technology in the field.

Figure 7 Level of confidence in applying to the construction industry

The survey included a qualitative component were students were encouraged to provide feedback to improve the learning module. Nine students responded that they would have liked more practice with the scanner and software. Two students suggested that the program should add another scanner and two students reported technical issues due to the available computing systems.

Based on the initial delivery of the laser scanning learning module the researchers have identified the following best practices that will assist others who choose to deliver a similar exercise. The first suggested best practices deals with the in-class collection of the scan data. Due to the high cost of the scanner itself, it is reasonable to assume that instructors will have access to only one scanning unit that must be shared by all students. A limited number of scanners coupled with the time required to setup and complete each scan (about 8 to 10 minutes) presents time and usage constraints for a typically sized class. For this exercise, it is recommended that each small group be allowed to execute one or two scans based on the time allowed so that all data can be collected within one class period. Collecting the scans in small groups allows students to work hands-on with the scanner and encourages participation. A benefit of requiring all students to complete the assignment based on a common set of scans is easier and more consistent grading of the final deliverable

As was previously stated, it is important that the instructor has a pre-scan plan in place to collect the necessary data. This plan should consider the distance between scans and the access to common reference points to use in the registration process. While possible, it is not practical to come back at a later date to collect additional scans for use with the assessment. Since most laser scanners are battery operated, it is also critical that the unit is fully charged before the start of the activity to be able to collect all scans at one time.

Another issue that instructors should be prepared to address deals with limitations of the available computer systems. The completion of the learning module requires the use of powerful software and the rendering of large data files. The computers listed previously were adequate to complete the learning module but were operating at the limit of their capability. Instructors should experiment with their available computing equipment and understand its capabilities before determining the number of scans that will be collected for the learning module. Using lower resolution scans and fewer total scans will reduce the computing power necessary to complete the assignment.

Instructors should also recognize that the completion of the learning module will be challenging for some students and easier for others. Creating as-built drawings from laser scans requires students to synthesize multiple tools including advanced hardware and software. Students with interest in computers and technology will be more inclined to embrace the experience than those who struggle in those areas.

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Appendix A

Sample Assessment

3D Laser scanning module (50 points)

Work in groups of two or individually. Please list all of your group members below. Submit homework sheet for grading. (3-points) Upload Arch D sheet A100 on the blackboard for grading.

Member 1 - _____ Member 2 - _____

1. Using Scene software, match the seven scans taking during class on XX-XX-XX and import the point clouds into Revit. (5-points)
2. Recreate rooms 205, 207, the hallway to the rooms, and the second-floor atrium in Revit using the scans. (10-points)
3. Add room names and number (3-points)
4. Uploaded sheet A100 shall have the following:
   - Name the sheet "XXXXXXXXX." (2-points)
   - Detail 1 – Second Floor Plan. (2-points)
   - Detail 2 – North-South Section through 205 and 207. (2-points)
   - Detail 3 – 3D View (2-points)
5. Show desk, chairs, and computers in 205 and 207 to match scans. (8-points)
6. Show point cloud in North-South Section. (3-points)
7. Show point cloud in 3D view. (3-points)
8. Provide a north arrow on detail 1. (2-points)
9. Scale drawing, section, and 3d view to maximizing space on the sheet. (5-points)

Comments by Instructor:

Appendix B

Survey Questionnaire

1. The laser scanning laboratory was comprised of five steps/procedures that included laser equipment setup, scanning and capturing of the site, using scene software to process the images captured, importing the processed images into the Revit software, and finally creating the as-built drawings. Please rate the level of difficulty on all five steps mentioned below.

Steps/Procedures	Level of difficulty				
	Very difficult	Difficult	Moderate	Easy	Very Easy
Laser equipment set up	☐	☐	☐	☐	☐
Scanning and capturing	☐	☐	☐	☐	☐
Using Scene software	☐	☐	☐	☐	☐
Importing scans to Revit	☐	☐	☐	☐	☐
Creating as-built drawings	☐	☐	☐	☐	☐

2. Following the completion of the laser scanning lab, please rate your confidence in the ability to apply this technology in the industry to produce accurate as build documents.

- ☐ Not at all confident
- ☐ Not very confident
- ☐ Confident with more practice
- ☐ Very Confident

3. Please provide any feedback which can help improve the laser scanning laboratory experiment in the upcoming semesters.