

Integrating Laser-scanning Technology into a Construction Engineering and Management Curriculum

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Evaluating the feasibility of integrating laser scanning technology in the construction engineering management curriculum

Abstract

Laser scanning technology has emerged as an essential tool in measuring and documenting existing conditions of buildings and infrastructures. It has been widely used in surveying, recording existing structures, calculating quantity, monitoring construction progress, understanding the general topography of a site, capturing the complicated geometries seen in manufacturing facilities, and supporting Building Information Modeling (BIM) and Virtual Design and Construction (VDC). While it has become popular for construction engineering and management programs to include Building Information Modeling in their curricula, very few construction programs have introduced laser scanning technology to their students. The high cost of the laser scanner and the associated software, the lack of qualified instructors, and the lack of an accreditation requirement are the primary reasons for this situation. However, recently, the construction industry has adopted many technological innovations, and the cost of laser scanners has been going down. Educators need to look into the potential of adopting laser scanning in their curricula. This research aims to assess the need for and evaluate the feasibility of incorporating laser scanning technology into the construction engineering and management curriculum. The study conducted a thorough literature review to assess how laser scanning technology can improve Student Learning Outcomes (SLOs), which are required by the American Council of Construction Education (ACCE). The contributions of the study involve (1) helping educators in construction engineering and management programs to understand the importance of laser scanning technology in the construction industry, (2) improving current Student Learning Outcomes by using laser scanning technology.

Key words: Laser scanning technology, student learning outcomes, construction engineering and management, curriculum development.

Introduction

Terrestrial 3D laser scanning has gained acceptance in the construction engineering field in the last twenty years. It is an effective and efficient method to generate as-built documentation [1-3], to measure construction activities accurately, to improve topographic surveys, to reconstruct 3D models for buildings and civil infrastructures [4] to track construction progress [5], to conduct building performance analysis, to manage construction safety, to maintain construction quality control, to improve the design with Building Information Modeling, and to preserve heritage buildings and sites [6]. As the terrestrial laser scanning technology is adopted and applied to construction engineering and management,

researchers in higher education also carried out many projects and innovations. Zhang [7] developed an automated process control function in construction activities, which reduces the workforce, the cost and the time used, and improved the overall efficiency. Min-Koo [8] presented a new framework that can automatically perform a dimensional and surface quality assessment of precast concrete elements; this approach combined BIM and laser scanning technology. Chai [9] developed a new as-built modeling process for industrial components based on laser scanning; the result showed that this method could improve the recognition rate and shorten the manufacturing time.

One challenge of introducing laser scanning technology to construction engineering students is the high cost of the hardware and software. However, as the cost gradually went down through continuous innovation, this relatively new technology gradually attracted instructors' attention who eventually attempted to introduce laser scanning to their coursework [7]. Practitioners also began to recruit competent professionals who can master this new technology. It is beneficial to create a rich visual learning environment that allows students to master the laser scanning technology for. For example, an instructor at the construction management program at Southern Polytechnic State University has taught students how to perform structural analysis and geometric modeling using laser scanning technology. The instructor used a FARO laser scanner to record a wall's displacement for out-of-plan loads and a destructive test to clearly explain the mechanical behavior of the rubble walls of the target house for students [8].

The American Council for Construction Education (ACCE) is a private non-profit corporation, which accredits construction education programs in colleges and universities that request its evaluation and meet its standards and criteria. The primary goal of ACCE is to promote and improve construction education in colleges and universities. By working together through ACCE, stakeholders representing the construction community and the public at large, construction educators, and constructors establish and maintain standards and criteria for accreditation, provide guidance to those programs seeking accredited status, and carry out the accreditation process [9].

The latest Outcome-Based Standards were approved by ACCE in 2016 which required all construction management programs accredited by ACCE to measure and evaluate the following 20 Student Learning Outcomes (SLO) [10]:

1. Create written communications appropriate to the construction discipline.
2. Create oral presentations appropriate to the construction discipline.
3. Create a construction project safety plan.
4. Create construction project cost estimates.
5. Create construction project schedules.
6. Analyze professional decisions based on ethical principles.
7. Analyze construction documents for planning and management of construction processes.
8. Analyze methods, materials, and equipment used to construct projects.

9. Apply construction management skills as a member of a multidisciplinary team.
10. Apply electronic-based technology to manage the construction process.
11. Apply basic surveying techniques for construction layout and control.
12. Understand different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.
13. Understand construction risk management.
14. Understand construction accounting and cost control.
15. Understand construction quality assurance and control.
16. Understand construction project control processes.
17. Understand the legal implications of contract, common, and regulatory law to manage a construction project.
18. Understand the basic principles of sustainable construction.
19. Understand the basic principles of structural behavior.
20. Understand the basic principles of mechanical, electrical, and piping systems.

Since laser scanning technology was not considered a measurable SLO by ACCE explicitly, most construction engineering programs do not focus on teaching laser scanning applications. Students have only few opportunities to access and take advantage of this new technology. Affordable 3D laser scanners and software can improve the construction education in five major areas : (1) accelerating three-dimensional learning on building and civil structures [1, 11, 12]; (2) increasing engagement with core topics by moving from abstract to interactive learning [7, 11, 13]; (3) introducing the engineering design process in a quick, easy, and visible way [14, 15]; (4) bridging the physical and digital model within the classroom [7]; (5) integrating hands-on experience with digital work in a creative capstone project [7]. This paper aims to evaluate the feasibility of integrating laser scanning technology in the construction engineering management curriculum. The study conducted a thorough literature review to assess how laser scanning technology can improve SLOs required by ACCE. The contributions of the study involve (1) helping educators in construction engineering and management programs to understand the importance of laser scanning technology in the construction industry, (2) improving current Student Learning Outcomes by using laser scanning technology.

Laser Scanning Technology

3D laser scanning is a technology that employs lasers to measure an object's geometry to create a digital 3D model. Laser scanners measure fine details and capture free-form shapes to quickly generate highly accurate point clouds. 3D Laser scanning technology was developed in the early 1960s. Equipment such as lights, cameras and projectors were used at that time to capture the surfaces of a real-world object or environment. Due to the limitations of the equipment, it was hard to reach high accuracy, and it usually took a long time to perform the process of recording. The industry did not widely recognize this type of technology. After 1985, the equipment was upgraded by adding white light, lasers and shadowing. Nowadays, with one single setup, laser scanning generates millions of measurements called point clouds in a few minutes. Each point of this cloud has three-

dimensional coordinates with accuracies of up to a few millimeters [16]. 3D laser scanning technology is suited to the measurement and inspection of contoured surfaces and complex geometries which require massive amounts of data for their accurate description and where doing this is impractical with the use of traditional measurement methods.

There are mainly three types of laser scanning technology, namely stationary terrestrial laser scanning, mobile laser scanning technology, and airborne laser scanning. Stationary terrestrial laser scanning (STLS) technology refers to laser scanning applications that are performed from a static point on the surface of the earth [17]. It can be described as a motorized total station, which automatically measures all the points in its horizontal and vertical fields. Terrestrial laser scanners, as shown in Figure 1, scan the surface of an object by obtaining X, Y, Z coordinates within seconds, possibly with color information, i.e., RGB (Red, Green, and Blue) depending on the function of the scanner and the distance between the scanner and the object.



Figure 1 Terrestrial laser scanner

Mobile laser scanning (MLS) technology has been actively researched and developed over many years [18]. It uses laser scanner technology in combination with Global Navigation Satellite Systems (GNSS) and other sensors to produce accurate and precise geospatial data from a moving vehicle [17], such as the 4 × 4 all-terrain vehicle shown in Figure 2.

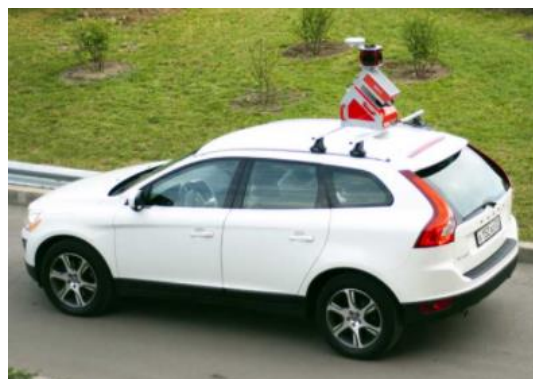


Figure 2 Mobile laser scanning technology

Airborne laser scanning is a rapid, highly accurate, and efficient method of capturing 3D data of large areas, such as agricultural or forestry sites, urban areas, industrial plants, etc. [19].

The term LIDAR is sometimes used interchangeably with laser scanning but is often associated with the airborne method, performed from an airplane, helicopter, or drone, as shown in Figure 3. The general principles of operation for airborne and ground-based mobile laser scanning are very similar. Airborne laser scanning systems use almost solely the pulse time of flight measurement principle for ranging [19, 20]. With pulsed lasers and integrated GPS and inertial measurement unit technology, airborne LIDAR has emerged in recent years as a competitive, low-cost, and efficient alternative for topographic surveys and terrain mapping projects [21].

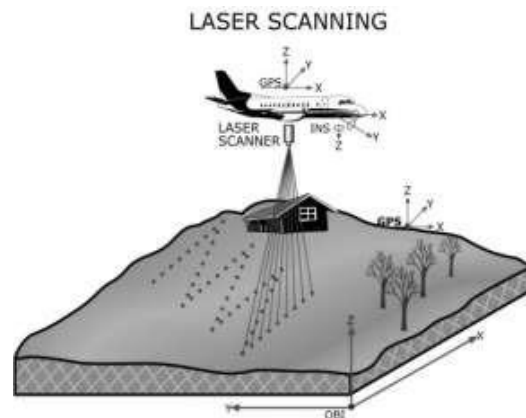


Figure 3. Airborne laser scanning

Improving Student Learning Outcomes with laser scanning technology

By creating a comfortable visual and kinesthetic learning environment, laser scanning technology has the potential to significantly enhance the educational experience of CM students in acquiring skills related to different areas and to provide faculty with a tool that can improve teaching different courses in a more visual and interactive way. These environments allow students to discover the strengths and weaknesses of their learning practices and facilitate self-improvement [13]. This section discusses the feasibility of using laser scanning technology to improve certain student learning outcomes required by ACCE, as shown in figure 4.

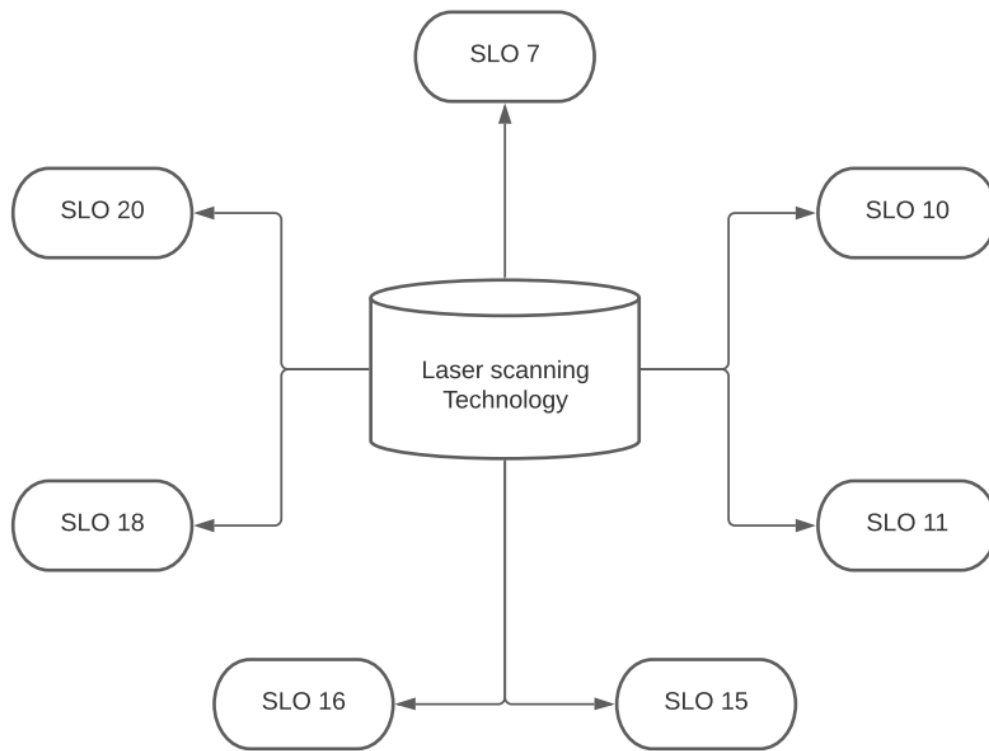


Figure 4 Laser scanning technology help improve SLOs

SLO7 - Analyze construction documents for planning and management of construction processes.

Construction as-builts are typically envisioned in a 2D format depicted by the location of stations and offsets along the project alignment [22]. This format is difficult for the layman to interpret. Additionally, large amounts of individual records are often produced, which may end up stored in an archival room and forgotten [23]. Today, greater transparency is necessary to make project information available to construction owners, government decision makers, and the general public. 3D laser scanning technology can be utilized to provide a 3D visual representation of the as-built condition with high accuracy, hence helping students learn how to analyze construction documents for planning and managing construction processes, A project can be digitized in 3D using X- Y-Z coordinates and high-resolution images that are transformed into a global coordinate system by a control survey and referenced to a web mapping service [24]. Students will benefit from a 3D “picture,” which is easier to comprehend than a 2D environment. 3D laser scanning is increasingly utilized in forensic analysis of collapsed and overturned buildings or structures, where a model is required to reconstruct the accident [25].

Digital technologies are utilized in the conservation of cultural heritage sites, as well. Conservation plans require understanding the object and gathering data about its physical condition prior to any action and intervention that might change the object [23]. Cultural heritage is threatened by various factors such as natural hazards, vandalism, development of

cities, and aging. In a pragmatic view, one cannot guarantee their eternity, and each moment there is the possibility of their loss. By using laser scanning, students can learn an innovative way to document the as-built condition of historic structures. In case of their loss, documented laser scans, and archives of recorded information can be passed to future generations or, if needed, used for reconstruction purposes [23].

SLO 10 - Apply electronic-based technology to manage the construction process.

There are many ways for students to apply electronic-based technology to manage the construction process. Adopting a Building Information Modeling (BIM) model and 3D laser scanning will provide them with a platform to improve the quantity management process' efficiency by enhancing the design plan, mitigating conflicts, and minimizing risks during a project. BIM proposed a relatively new and collaborative environment in which the project team can work. It is a process that is supported by various tools and technologies and has been used to manage the design and construction processes [26]. BIM uses a computer-generated model to simulate the planning, design, construction, and operation of a building [27]. The BIM model can be utilized to extract exact volume schedules via 3D laser scanning technology to approve the volume at different points in various construction phases and to determine the amount of work done [28]. Adjusted schedules, the volume of required material for the remaining tasks can also be planned.

In addition to the design and construction of new buildings, laser scanning can be utilized along with BIM in the management of existing ones. Modeling the physical and functional characteristics, geometry, and inner spatial relationships of a building ensures proper functioning of building systems and ensures occupant and visitor safety and security, and structure and cultural heritage preservation and protection [11, 27].

SLO 11- Apply basic surveying techniques for construction layout and control.

As the 3D laser scanning industry grew in recent years, advances in point cloud processing software and office workflow options have made laser scanning more useful than before for many common surveying applications. It is frustrating to make complex design decisions with 2D information produced by manual surveying. Unlike manual surveying and other surveying methods, 3D laser scanning provides the surveyor with an accurate and efficient way to collect and present the physical data of space, environment, or object. Yu [29] developed a curriculum for implementing laser scanning technology in a land surveying program. The end-of-semester student survey showed a positive result of evaluating the learning outcomes. The student can benefit from laser scanning technology by extracting survey features from the point cloud, calculating volumes or surface areas, creating a TIN (triangulated irregular network) model, and generating contours. Although the benefits may vary based on the discipline, the point cloud is an up-to date, accurate, and unambiguous measurement of what exists in the real world.

SLO 15: Understanding construction quality insurance and control

Quality inspection is primarily manually performed and is a labor-intensive approach prone to error [30]. To increase productivity and efficiency, the construction industry has embraced prefabrication [31]. Prefabricated, precast, and modular building construction can improve project quality by overcoming poor construction site conditions [32]. It also decreases field installation time, increases quality and safety, and reduces wasted materials [31]. Quality control of the prefabricated modular construction projects can be improved by integrating building information modeling (BIM) with 3D laser scanning technology [31]. Min-Koo [31] developed a quality inspection technique for full-scale precast concrete elements, which was based on laser scanning and BIM. To collect and process the real-time onsite quality information for construction quality control, Wang [32] presented an integrated system based on BIM and laser scanning. Wang [32] used different methods to control the operation's dimensional quality in the various stages of precast construction. Li [33] improved the quality control of the prefabricated modular construction projects by integrating building information modeling (BIM) with three-dimensional (3D) laser scanning technology. Bosché and Haas [14] developed an approach that uses the Scan-vs-BIM principle to segment point clouds acquired onsite by matching each point to the corresponding object in the BIM model. Then two different standard flatness control techniques, namely “straightedge” and “F-numbers”, are applied to the point clouds associated with each floor to ensure compliance with given tolerances [34].

SLO 16: Understand construction project control process.

Construction progress tracking is an important management function for the successful delivery of construction projects with minimum delay. By reducing errors and rework and improving responsiveness to project changes, laser scanning technology can benefit project costs and schedule. The project control process traditionally utilizes visual inspections and written reports. It is an extensive manual operation, which requires intense labor relying on personal judgment with a high probability of incomplete and inaccurate reports [35]. 3D laser scanning technology leads to an automated process for identifying and localizing engineered components on a construction site by creating a 3D as-built point cloud of a site and comparing with 3D-designed data (Scan-versus-BIM) for quick and accurate project progress assessment and monitoring [35]. Hashash [15] used 3D laser scanning technology to monitor construction progress for deep supported urban excavations. Samir [36] adopted 3D laser scanning and photogrammetry to collect data from construction sites. These data were used to measure and control project progress. Zhang [37] presented a practical automated method based on laser scanning technology, which could record the project's progress in some actual buildings with less labor. 3D scanning and photogrammetry are also combined to enhance the 3D modeling process comparing actual work performed to that planned [12]. In photogrammetry, the geometrical properties of an object on site are generated from its photo image. In 3D laser scanning, the construction site is scanned at different times to generate data, which can then be used to estimate the quantities of work performed within the time interval considered between two successive scans [12]. These methods can be combined with

RFID (Radio Frequency Identification) or barcodes to automate the process of data collection from construction sites for reporting progress on site [12].

SLO 18- Understand the basic principles of sustainable construction.

Buildings account for about 42% of the primary energy usage and 71% of the United States' electricity usage [38]. From the life-cycle viewpoint, the thermal performance during the installation, maintenance, and operation phases usually differs from what was planned at the design phase due to deviation, thermal bridge, insulation aging, etc. [38]. Building performance analysis of existing structures is used to quickly visualize a building's performance to determine how to improve building energy efficiency and reduce environmental impacts [38]. 3D laser scanning technology can be used to create an as-built BIM model for simulating the energy retrofit of an existing building. Energy audits require the collection of as-built building geometry and the thermal resistance value of the envelope. These audits can utilize a non-invasive 3D thermal modeling methodology (hybrid 3D LIDAR scanner) that rapidly and accurately measures the 3D geometry with the thermal data of a building envelope automatically creating an as-built BIM model of existing residential buildings for building energy simulation [38]. The as-built BIM is imported into energy analysis software to conduct building performance analysis [38].

SLO 20- Understand the basic principles of mechanical, electrical and plumbing systems.

3D laser scanning is applicable to tracking structural works and mechanical, electrical, and plumbing systems (MEP), which constitute a large portion of construction costs. An MEP module typically includes pipes, cable trays, and ventilation ducts, contributing to 40% to 60% of the total construction cost of a building [39]. Understanding the basic principles of mechanical, electrical, and plumbing systems is critical for control, tracking, and management [35]. Laser scanned data and the data in the as-designed BIM model of the MEP modules can be compared to detect the discrepancies (if any) between the laser scanned data and the as-designed BIM model by using an automated geometric quality inspection technique [39, 40]. Tracking these systems is especially important since the installation of MEP pipes and ducts in traditional ways is not as constrained as structural works, so that elements may be installed in positions that differ, sometimes significantly, from the positions defined by the engineer in the design.

Conclusion

Laser scanning technology has been used in various engineering fields. However, this technology is not widely used in education due to the high cost of the hardware and the high technical expertise required for data processing. The continuous evolution of this technology over the years made it more affordable for use in the classroom. Laser scanning provides excellent opportunities to enhance the construction engineering management curriculum. This paper presents an extensive literature review on laser scanning technology applications and

evaluates the feasibility of integrating it in the construction engineering management curriculum. It was found that seven out of the 20 student learning outcomes required by ACCE can be improved if laser scanning technology is used in the curriculum. Laser scanning is a useful tool that not only enhances the 3D environment, but also may significantly improve the learning process in building and civil structure construction and management. In addition, this technology can improve students' engagement with construction topics by moving the learning style from abstract to more interactive learning. Combined with BIM, laser scanning can introduce the construction engineering design process more quickly and easily and increase students' visualization capabilities. This paper concludes that accreditation agencies, administrators in charge of construction engineering management programs, instructors, and students should acknowledge the existence and practical implications of laser scanning technology, and should seriously consider the advantages of incorporating this technology into their curricula. The fact that laser scanning technology satisfies many ACCE SLO requirements should be an important motivation to do so. The cost of hardware and software has come down significantly and instructors' lack of familiarity with this technology can be overcome given that laser scanning provides instructors with a tool that bridges the physical and digital models, integrates hands-on experience with digital work, and improves teaching by using a more visual and interactive approach.

References

- [1] E. J. Jaselskis, Z. Gao, and R. C. Walters, "Improving Transportation Projects Using Laser Scanning," *Journal of Construction Engineering & Management*, vol. 131, no. 3, pp. 377-384, 2005.
- [2] M. J. Olsen, F. Kuester, B. J. Chang, and T. C. Hutchinson, "Terrestrial Laser Scanning-Based Structural Damage Assessment," *Journal of Computing in Civil Engineering*, vol. 24, no. 3, pp. 264-272, 2010.
- [3] N. J. Shih and P. H. Wang, "Point-Cloud-Based Comparison between Construction Schedule and As-Built Progress: Long-Range Three-Dimensional Laser Scanner's Approach," *Journal of Architectural Engineering*, vol. 10, no. 3, pp. 98-102, 2004.
- [4] A. Holgado-Barco, D. Gonzalez-Aguilera, P. Arias-Sanchez, and J. Martinez-Sanchez, "An automated approach to vertical road characterisation using mobile LiDAR systems: Longitudinal profiles and cross-sections," *Isprs Journal of Photogrammetry & Remote Sensing*, vol. 96, pp. 28-37, 2014.
- [5] C. Zhang, D. Arditi, and Z. Chen, "Using terrestrial laser scanners to calculate and map vertical bridge clearance," *Isprs International Archives of the Photogrammetry Remote Sensing & Spatial Information Sciences*, 2013.
- [6] L. J. Sánchez-Aparicio, M. G. Masciotta, J. G. Alvarez, L. F. Ramos, and P. Monteiro, "Web-GIS approach to preventive conservation of heritage buildings," *Automation in Construction*, vol. 118, p. 103304, 2020.
- [7] P. Meadati, J. Irizarry, and F.-s. Liou, "Teaching Using 3D Laser Scans," in *49th ASC Annual International Conference Proceedings*, San Luis Obispo, California, 2013.

- [8] Monique, Johnson, Eugene, and Liscio, "Suspect Height Estimation Using the Faro Focus3DLaser Scanner," *Journal of Forensic Sciences*, 2015.
- [9] J. Strijbos, N. Engels, and K. Struyven, "Criteria and standards of generic competences at bachelor degree level: A review study," *Educational Research Review*, vol. 14, pp. 18-32, 2015.
- [10] ACCE, "ACCE (2015) Document 103 Standard and Criteria for Accreditation of Postsecondary Construction Education Degree Programs," in *ACCE (2015) Document 103*, 2015.
- [11] M. G. Angelini, V. Baiocchi, D. Costantino, and F. Garzia, "Scan to Bim for 3d Reconstruction of the Papal Basilica of Saint Francis in Assisi in Italy," *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-5/W1, no. W1, pp. 47-54, 2017.
- [12] S. El-Omari and O. Moselhi, "Integrating 3D laser scanning and photogrammetry for progress measurement of construction work," *Automation in construction*, vol. 18, no. 1, pp. 1-9, 2008.
- [13] P. Meadati and J. Irizarry, "BIM-A New Teaching Tool," in *Proceedings of the ASEE Southeast Section Conference, American Society for Engineering Education*, 2011, pp. 1-9.
- [14] F. Bosché and E. Guenet, "Automating surface flatness control using terrestrial laser scanning and building information models," *Automation in Construction*, vol. 44, no. aug., pp. 212-226, 2014.
- [15] Y. Su, Y. Hashash, and L. Liu, "Integration of construction as-built data via laser scanning with geotechnical monitoring of urban excavation," *Journal of construction engineering and management*, vol. 132, no. 12, pp. 1234-1241, 2006.
- [16] G. Guide, "GSA Building Information Modeling Guide Series: 03," ed: US General Services Administration: Washington, DC, USA, 2009.
- [17] P. Galvez, J.-P. Ampuero, L. A. Dalguer, S. N. Somala, and T. Nissen-Meyer, "Dynamic earthquake rupture modelled with an unstructured 3-D spectral element method applied to the 2011 M 9 Tohoku earthquake," *Geophysical Journal International*, vol. 198, no. 2, pp. 1222-1240, 2014.
- [18] C.M., Ellum, N., and El-Sheimy, "land-based integrated systems for mapping and gis applications," *Survey Review*, vol. 36, no. 283, pp. 323-339, 2013.
- [19] Y. Wang, Q. Chen, Q. Zhu, L. Liu, C. Li, and D. Zheng, "A survey of mobile laser scanning applications and key techniques over urban areas," *Remote Sensing*, vol. 11, no. 13, p. 1540, 2019.
- [20] P. Rieger, N. Studnicka, and M. Pfennigbauer, "RIEGL Laser Measurement Systems GmbH," *Geoinformatics*, 2014.
- [21] W. Uddin, "Airborne Laser Terrain Mapping for Expediting Highway Projects: Evaluation of Accuracy and Cost," *Journal of Construction Engineering & Management*, vol. 134, no. 6, pp. 411-420, 2008.
- [22] C. Y. Zhang, D. Arditi, and Z. Chen, "DOCUMENTATION AND VISUALIZATION OF AN AS-BUILT TUNNEL BY COMBINING 3D LASER SCANNING AND WEB MAPPING," *Isprs 8th 3d Geoinfo Conference & Wg Ii/2 Workshop*, vol. 40-2-W2, pp. 139-144, 2013.

- [23] M. Lezzerini *et al.*, "Cultural Heritage Documentation and Conservation: Three-Dimensional (3D) Laser Scanning and Geographical Information System (GIS) Techniques for Thematic Mapping of Facade Stonework of St. Nicholas Church (Pisa, Italy)," *International Journal of Architectural Heritage*, vol. 10, no. 1, pp. 9-19, 2014.
- [24] Q. Feng. (2012). *Practical application of 3d laser scanning techniques to underground projects*. Available: http://www.befoonline.org/UserFiles/Archive/250/Rapport_114_NY_G5.pdf
- [25] C. S. Park, H. P. Jeon, K. S. Choi, J. P. Kim, and N. K. Park, "Application of 3D Laser Scanner to Forensic Engineering," *J Forensic Sci*, vol. 63, no. 3, pp. 930-934, May 2018.
- [26] H. Li, C. Zhang, S. Song, S. D. Akr, and R. Chang, "Improving Tolerance Control on Modular Construction Project with 3D Laser Scanning and BIM: A Case Study of Removable Floodwall Project," *Applied Sciences*, vol. 10, no. 23, p. 8680, 2020.
- [27] T. Mill, A. Alt, and R. Liias, "Combined 3d Building Surveying Techniques – Terrestrial Laser Scanning (Tls) and Total Station Surveying for Bim Data Management Purposes," *Journal of Civil Engineering and Management*, vol. 19, no. Supplement_1, pp. S23-S32, 2013.
- [28] T. A. Nguyen, P. T. Nguyen, S. T. Do, and T. O. Olawumi, "Application of BIM and 3D Laser Scanning for Quantity Management in Construction Projects," *Advances in Civil Engineering*, vol. 2020, pp. 1-10, 2020/12/28 2020.
- [29] J. Yu *et al.*, "Development and Implementation of a 3D Laser Scanning Course for Land Surveying," *Surveying and Land Information Science*, vol. 70, pp. 23-28, 03/01 2010.
- [30] J. Liu, Q. Zhang, J. Wu, and Y. Zhao, "Dimensional accuracy and structural performance assessment of spatial structure components using 3D laser scanning," *Automation in Construction*, vol. 96, pp. 324-336, 2018/12/01/ 2018.
- [31] T. FISCHER. (2019). *Prefabrication & BIM: Creating more efficient projec*. Available: <https://www.bdcnetwork.com/blog/prefabrication-bim-creating-more-efficient-projects>
- [32] H. Li, C. Zhang, S. Song, S. Demirkesen, and R. Chang, "Improving Tolerance Control on Modular Construction Project with 3D Laser Scanning and BIM: A Case Study of Removable Floodwall Project," *Applied Sciences*, vol. 10, no. 23, Dec 2020, Art. no. 8680.
- [33] H. Li, C. Zhang, S. Song, S. Demirkesen, and R. Chang, "Improving Tolerance Control on Modular Construction Project with 3D Laser Scanning and BIM: A Case Study of Removable Floodwall Project," *Applied Sciences*, vol. 10, no. 23, p. 8680, 2020.
- [34] F. Bosché and E. Guenet, "Automating surface flatness control using terrestrial laser scanning and building information models," *Automation in Construction*, vol. 44, pp. 212-226, 2014/08/01/ 2014.
- [35] F. Bosche, A. Guillemet, Y. Turkan, C. T. Haas, and R. Haas, "Tracking the Built Status of MEP Works: Assessing the Value of a Scan-vs.-BIM System (vol 28, 05014004, 2014)," *Journal of Computing in Civil Engineering*, vol. 28, no. 4, Jul 2014.

- [36] S. El-Omari, "Automated data acquisition for tracking and control of construction projects," Concordia University, 2008.
- [37] C. Zhang and D. Arditi, "Automated progress control using laser scanning technology," *Automation in Construction*, vol. 36, no. dec., pp. 108-116, 2013.
- [38] C. Wang and Y. K. Cho, "Performance Evaluation of Automatically Generated BIM from Laser Scanner Data for Sustainability Analyses," *Procedia Engineering*, vol. 118, pp. 918-925, 2015.
- [39] J. Guo, Q. Wang, and J.-H. Park, "Geometric quality inspection of prefabricated MEP modules with 3D laser scanning," *Automation in Construction*, vol. 111, Mar 2020, Art. no. 103053.
- [40] J. J. Guo and Q. Wang, "Dimensional Quality Inspection of Prefabricated MEP Modules with 3D Laser Scanning," *Computing in Civil Engineering 2019: Data, Sensing, and Analytics*, pp. 171-177, 2019.