Innovations In Drywall Installation Through Integrating Terrestrial Laser Scanning (TLS) And Building Information Modeling (BIM)

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Abstract

The installation phase of drywall presents significant challenges within the construction industry, including issues such as low productivity, material waste, and shortages of skilled labor. This study investigates the application of reality capture technology, specifically Terrestrial Laser Scanning (TLS), in conjunction with Building Information Modeling (BIM), to enhance the efficiency and precision of drywall installation processes. Employing a mixed-methods approach, the research integrates TLS and BIM to capture real-time data and create accurate drywall panel shop drawings to replace manual measurements at construction sites. This approach was implemented and evaluated through an experiment conducted on an active construction site, demonstrating potential improvements in accuracy and waste reduction. The experiment results using a full-scale framework demonstrate high accuracy in the cut sheets for certain wall components. TLS was found to be adequate for capturing the geometry of metal studs, penetrations, and MEP components, and it could be utilized to replace manual measurement of drywall sheets. However, further improvements to the framework are required to enhance productivity, such as automating the process of drafting the cut sheets from the raw scan data. By introducing this innovative approach, the study contributes to the construction management field by establishing a new standard for drywall installation practices.

Keywords

Construction Productivity, Drywall Installation, LiDAR, Reality Capture, Skilled Labor Shortage.

1. Introduction

The construction industry continually seeks improvement in digital transformation to overcome the labour shortage and meet the complex demands of contemporary projects (Kim et al., 2020; Olsen et al., 2012). However, compared to other disciplines, slow adoption of new technologies in construction is evident, partially due to factors such as a weak connection between technologies and construction applications and an absence of best practices, methods, and techniques (Almukhtar et al., 2021; B. Liu et al., 2022). Quality, safety, and productivity are three key criteria in construction that benefit greatly from technological improvements. Challenges such as a shortage of skilled labour heighten the potential for automating tasks through technology to enhance productivity (Acemoglu & Restrepo, 2018, 2019; Autor, 2015; Fobiri et al., 2022).

The integration of Reality Capture (RC) technology, especially LiDAR (Light Detection and Ranging) technology (National Oceanic and Atmosphere Administration, 2021), also recognized as laser scanning, holds the promise to enhance the construction process, although its application remains limited (B. Liu et al., 2022; Oh et al., 2019; Sepasgozar et al., 2014). This study explores the implementation of Terrestrial Laser Scanning (TLS) in drywall installation to create drywall panel cut sheets in the Building Information Modelling (BIM) platform. The goal is to investigate current practices, devise a new drywall installation framework, and assess the accuracy and efficiency of this framework on active construction sites. By fostering innovation in technology application, this research aspires to revolutionize drywall installation, thereby increasing efficiency, minimizing waste, and laying the groundwork for future technological advancements in construction management and architecture.

1.1 Reality Capture in Construction

Reality Capture (RC) is a transformative technology that plays a pivotal role in accurately collecting data from the actual environment (J. Liu et al., 2016). The key types of RC technologies used in construction include Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM) or photogrammetry (Elliott & Olbina, 2023; Gordon et al., 2003; Hamledari & Fischer, 2021). Recently, these technologies have become versatile tools to enhance productivity and create highly efficient methods for various tasks within the field (Fobiri et al., 2022). From renovations and work progress tracking to structural health monitoring and as-built project documentation, the applications of RC in construction are both broad and critical (J. Liu et al., 2022, 2023; Wetzel et al., 2022).

While the benefits are clear, the construction sector's adaptation of RC technology has been gradual. This is partly due to a lack of established strategies for analyzing and utilizing the raw data generated by RC instruments (Almukhtar et al., 2021). There's a growing demand for information on how RC can process raw data from construction projects and how this data might be integrated with other technologies, such as BIM, to enhance professional practices (Antova et al., 2016; Rodríguez-Moreno et al., 2018).

1.2 Drywall as Building Sheathing Material

Drywall is a widely used building sheathing material in North America to create interior walls and ceilings. Standard drywall sheets are available in various standardized sizes, such as 4ft×8ft, 4ft×10ft, and 4ft×12ft. In the construction industry, field crew members, also known as drywallers or hangers, typically make ad hoc decisions regarding drywall sheet layout and cutting plans, relying solely on their experience and rules of thumb (Liu et al., 2018)This approach often results in considerable material waste and rework in the field. For example, the National Association of Home Builders reports that constructing a typical 2,000 ft2 residential house can generate as much as 8,000 pounds of solid waste, of which approximately 2,000 pounds comprise drywall.

The construction industry has been upgrading its techniques and procedures across a variety of fields in an effort to apply new technology and equipment to increase production quality, create a safer working environment, and improve productivity. However, the methods for installing drywall panels essentially stay the same. Since there is a lack of established methods of drywall installations and their development, it’s necessary to create innovative installation techniques that will speed up projects, cut costs, and improve quality and safety while installing drywall (Clark & Liu, 2014). Research studies have directed attention to this area, particularly in the context of drywall planning, cutting, and installation (Cuellar Lobo et al., 2021; Williams & Anderson, 2016). Within this framework, existing research has showcased the potential of integration of BIM and TLS technology. For instance, Almukhtar et al. (2021) Emphasized the use of BIM to optimize the layout and create accurate shop drawings for prefabrication usage, and the LiDAR scanner has been found effective in creating drywall shop drawings for the fabrication and installation of drywall sheets without on-site measurements (Alathamneh et al., 2023; Clark & Liu, 2014). However, this study aims to test a new drywall installation framework on an active construction site. The process will involve TLS data acquisition, data processing, generating drywall shop drawings, and then cutting and installing the drywall panels to measure the accuracy of the cut sheets.

2. Methods

In the complex and demanding environment of construction management, the research employed one of the most advanced and widely used pieces of laser scanning equipment: the FARO Focus S-350 scanner. The FARO S-350 Scanner is renowned for its high precision, boasting an accuracy level of up to 2mm (approximately 1/12 inch). Its capabilities extend to high-speed data capture of up to 976,000 points per second with a 360° continuous rotation and a significant scanning range of up to 350 meters (approximately 1,148 feet) (*FARO Focus Laser Scanner | FARO*, 2023). In the realm of construction management, it's often utilized for as-built documentation, structural monitoring, renovation design, and clash detection (J. Liu, Bugg, et al., 2023). Its detailed scans are instrumental in virtual simulation, reducing errors and enhancing coordination among various construction stages. However, challenges may arise with highly reflective or absorptive surfaces, and it depends on line-of-sight, leading to potential blind spots (J. Liu, Azhar, et al., 2023).

This research is aimed at conducting a comprehensive full-scale field test for the proposed framework. As a commercial construction project, the 5,685 square-foot (or 528 square-meter) office building was chosen during the hanging drywall panel phase when the wall framings were inspected and ready to be covered. The objective encompassed all aspects of the proposed framework, from scanning to drywall panel installation using provided cut sheets. The field test also included a comparative study of the accuracy and productivity of traditional drywall installation techniques versus the method of using cut sheets created with the proposed framework. A survey of the drywall professionals participating in this experimentation was also carried out at the end of this project. The methodology implemented in this research is systematically organized into five distinct stages as a framework for the Integration of TLS Technology with Drywall Installation:

1. **Data Acquisition:** Use TLS to capture the as-built conditions of the metal studs and penetrations in the wall.
2. **Point Cloud Data Processing:** The captured TLS scans are registered and processed into a single PC. The PC goes through noise reduction (to remove unwanted points) and subsampling (to reduce the number of points). The file is downloaded.
3. **Cut Sheets Creation in Revit:** The PC is imported into Revit and is used to create drywall panel cut sheets.
4. Dimensioning and Sheet Sizing: The cut sheets are carefully dimensioned and conformed to standard sheet sizes for printing.
5. **Cutting and Hanging Drywall Panels Using Cut Sheets:** The drywallers use the cut sheets to make cuts without taking on-site measurements and hang the cut panels on metal studs.

Three walls were ready-for-coverage on the Conference Room area chosen for this study due to their similarity, highlighted in Figure 1. Because the space to capture was a single room, only 6 FARO scans were needed to cover the area. Afterward, drywall cut sheets were created following the designed framework. Each wall was viewed individually with detailed dimensions and narratives for the drywallers to follow, as shown in Figure 2. Table 1 summarizes the time spent to develop the cut sheets for the three walls (East, West, and South) in the study.

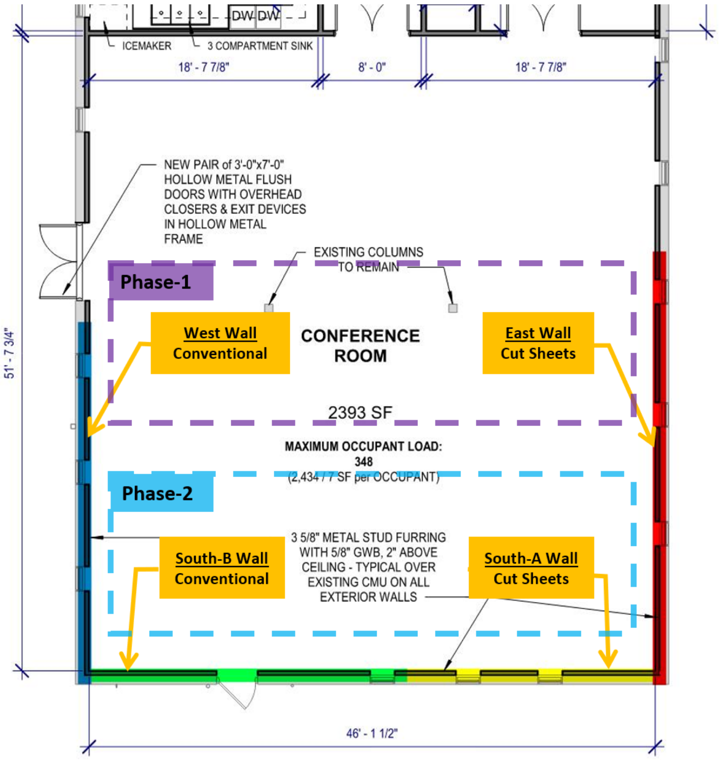

Figure 1: Walls in the Conference Room selected for the study, being highlighted in colors: West wall, blue; East wall, red; South-A, yellow; and South-B, green.

Table 1 Time for creating the three drywall cut sheets for Project-4.

Description	Time (hr:min)	Notes
On-site TLS Scanning	00:38	Equipment setting up and scanning
PC processing in FARO SCENE	00:30	Registration, cleaning noise, exporting
Modeling in Revit	02:00	Layout panels, studs, penetrations
Adding Narratives in Revit	02:00	Dimensions and labels
Creating cut sheets and printing	00:40	Hard copies in 35”x45”
Total Time:	**5 hours and 48 minutes**	**98.5 m^2 (1,060 ft^2) of wall area**

One critical aspect of this process is the need for a skilled individual proficient in various technical areas. These include operating the FARO scanner, understanding Point Cloud (PC) software, being skilled with Revit, and knowing the drywall installation process, layout standards, parameters, algorithms, and building codes. The precise identification of building materials such as metal studs and rough-in components depends heavily on human visual analysis, requiring experienced individuals to examine the PC data for accurate identification.

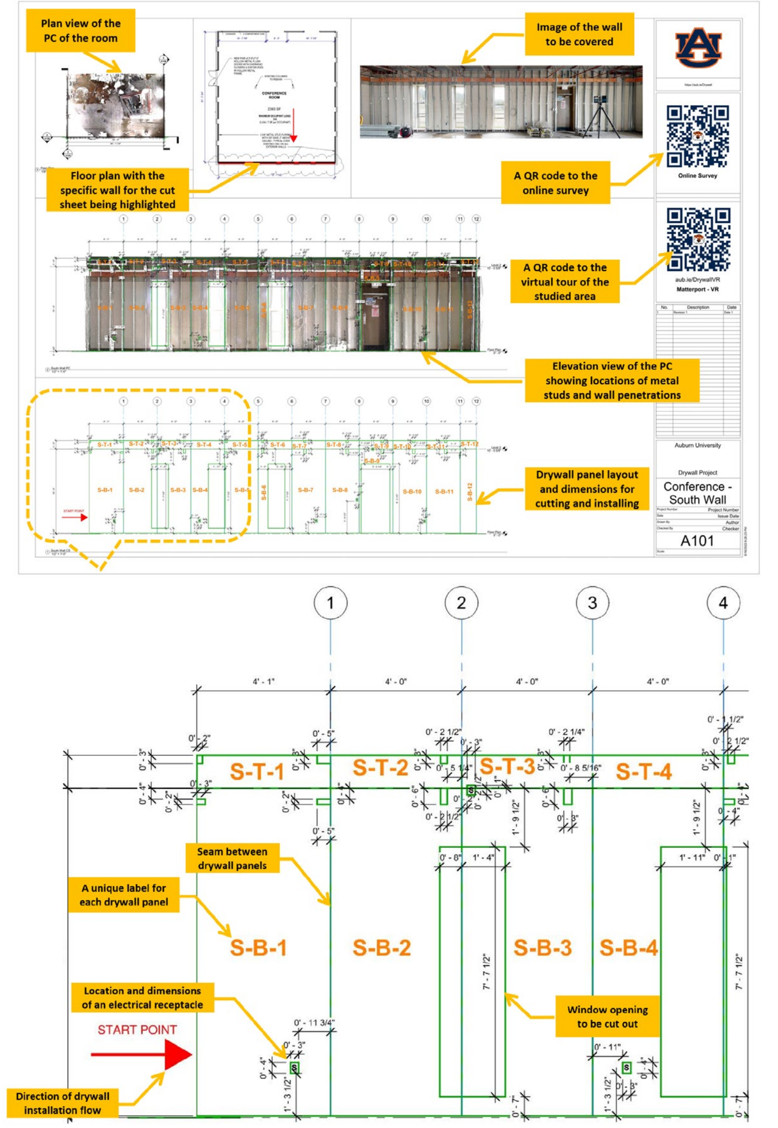

Figure 2: A cut sheet created for Project-4 using point cloud captured by FARO S-350 scanner.

3. Results

Once the cut sheets were prepared, the research team conducted a full-scale on-site experiment with drywall mechanics to cut and hang drywall panels. The primary goals of the experiment were to assess the cut sheets' accuracy and compare the new framework's productivity against the conventional method. To evaluate the cut sheets' accuracy, the team compared the dimensions on the cut sheets to actual measurements taken with a tape measure during the drywall panel installation. This comparison helped determine how well the cut sheets matched the real-world dimensions. To compare productivity, the research team recorded the entire process of installing the drywall panels using both the cut sheets approach and the traditional technique with two GoPro cameras. This documentation allowed for a time analysis and comparison of productivity between the two methods.

Anticipating that the drywall mechanics might need time to adapt to the new approach, the research team divided the experiment into two phases to help them overcome the "learning curve." In Phase 1, the drywallers used cut sheets for the East (red) wall, followed by their usual method of manual measuring for the West (blue) wall. Since these two walls had similar complexity in penetration and wall area, this provided a consistent basis for comparison, ensuring more reliable results. In Phase 2, the focus shifted to the conference room's south wall, which was split into two sections: South-A (yellow) and South-B (green). Both parts had similar workloads and penetration requirements. The team used cut sheets for South-A and the conventional method for South-B, allowing for a direct comparison between the two approaches. Details of penetration cuts for each wall were documented, as shown in Table 2.

Table 2 Details of wall penetrations in the drywall panels.

Wall	Phase	Method	# of Panels	Penetration Type	# of Penetration Cuts	Total Penetration Area (ft² / m²)	Length of Penetration Perimeter (ft/m)
East	1	Cut Sheets	7	Windows/Doors	2	25.3 (2.35)	35.1 (10.70)
				Small Penetrations	5	0.37 (0.03)	5.45 (1.66)
West	1	Conventional	7	Windows/Doors	3	38.31 (3.56)	52.81 (16.10)
				Small Penetrations	4	0.23 (0.02)	3.86 (1.18)
S-A	2	Cut Sheets	6	Windows/Doors	3	36.83 (3.42)	52.51 (16.01)
				Small Penetrations	2	0.14 (0.01)	2.12 (0.65)
S-B	2	Conventional	5.5	Windows/Doors	1	23.19 (2.15)	21.14 (6.44)
				Small Penetrations	3	0.21 (0.02)	3.18 (0.97)

The procedures for each phase were videotaped for time study, and the detailed time recordings are presented in Table 3. This analysis allowed the research team to effectively assess the cut sheets' accuracy and compare the new framework's efficiency with traditional drywall installation techniques. These results demonstrate the potential benefits and challenges of implementing cut sheets in drywall installation, providing valuable insights for further refinement and adoption in construction practices.

Table 3. Time analysis of the experimentation and comparison.

Wall	Phase	Method	Total Time (mm:ss)	Break Time (mm:ss)	Total Area (ft2)
East	1	Cut Sheets	36:00	2:00	280
West	1	Conventional	31:25	0:00	280
South-A	2	Cut Sheets	25:40	0:00	240
South-B	2	Conventional	20:20	3:00	220

Figure 3 illustrates the cut sheets utilized by drywallers to complete the coverage of the east wall in the conference room. The figure also shows sample dimensions that were essential for guiding the drywallers in accurately cutting the sheets and ensuring proper penetrations for windows and power outlets. To validate these dimensions, tape measurements were employed on-site, confirming the precision of the cut sheets.

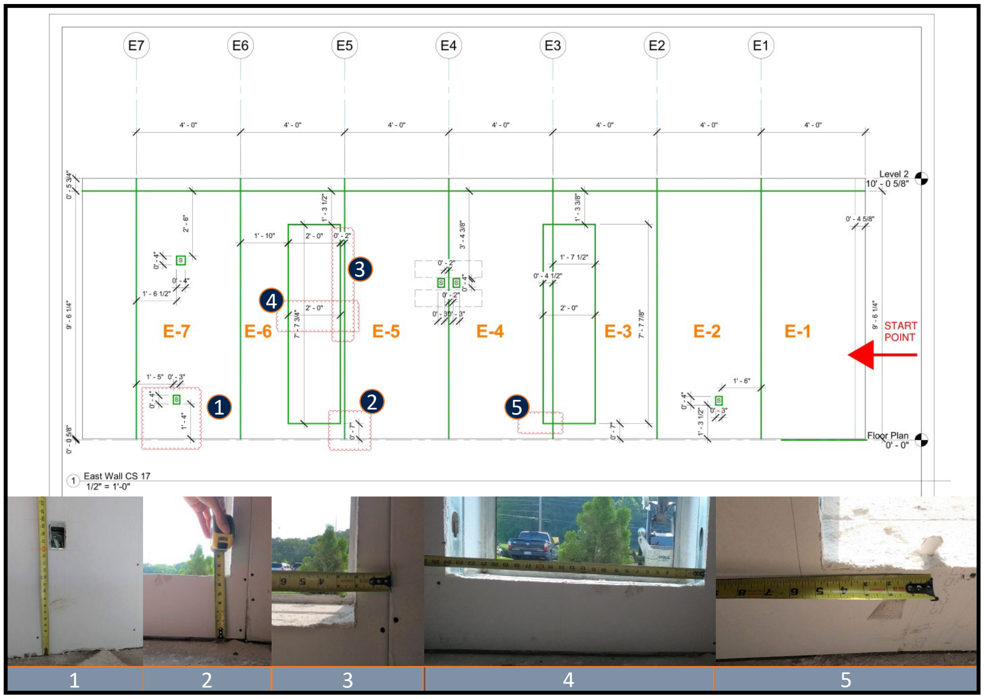

Figure 3: Dimensional Verification of East Wall Cut Sheets for Drywall Installation

Specifically, five dimensions were inspected for accuracy, with corresponding images that show the tape measurements. The results indicate that the dimensions provided in the cut sheets were highly accurate, facilitating the necessary penetrations for windows and power outlets. This accuracy ensured seamless installation of the drywall around the structural components. These findings underscore the effectiveness of the cut sheets in providing precise guidelines for drywall installation, thereby minimizing errors and enhancing the quality of the finished construction.

4. Discussion

The evaluation of cut sheets for drywall installation revealed significant insights into both accuracy and productivity. The results indicate that while cut sheets offer precision, especially near the starting point, they also present challenges, particularly related to slab levelness. During the installation phase, discrepancies in the slab's height, such as deviations within 12.7 mm (1/2"), emerged as critical issues. These challenges underscore the importance of considering slab levelness when preparing cut sheets to avoid height-related problems during drywall panel installation.

In terms of productivity, a detailed time analysis highlighted notable differences between the conventional and cut-sheet approaches. The conventional method demonstrated superior productivity, with rates of 8.75 sf/minute (0.81 m^2/minute) and 10.48 sf/minute (0.97 m^2/minute) for the West and South-B walls, respectively. Conversely, the cut sheets method resulted in lower productivity rates of 7.78 sf/minute (0.72 m^2/minute) and 9.23 sf/minute (0.84 m^2/minute) for the East and South A walls, respectively. This reduced productivity may be attributed to the steep learning curve associated with the cut sheets method for drywall mechanics. Although the cut sheets approach appears more time-consuming, it potentially offers greater precision and thoroughness, particularly when dealing with complex penetrations. In contrast, the conventional method, while quicker, may be better suited for simpler or more familiar installations.

The survey conducted after the full-scale field test involved five drywall professionals, including three project managers and two superintendents, who either participated in or observed the test. The survey results revealed a unanimous agreement on the most time-consuming aspect of drywall installation: the process of installing "above the ceiling (top out)." This was attributed to measurement difficulties, complex procedures, and numerous MEP penetrations. The survey also highlighted the varying challenges associated with different types of drywalls and the productivity disparities between different parts of the wall, noting that below-ceiling drywall was generally easier to hang. The survey revealed mixed satisfaction among the respondents regarding the effectiveness of using cut sheets to cut and hang drywall panels. While most professionals viewed the method positively, they identified areas for improvement, such as addressing floor levelness and enhancing measurement accuracy. Suggestions for enhancing the framework included better coordination with other trades to ensure readiness for scanning, improving precision, and refining penetration cuts.

6. Conclusions

This research was initiated to address significant challenges in conventional drywall installation methods, specifically targeting issues of inaccuracy, low productivity, and high material waste. The study examined traditional and new drywall installation techniques on an active construction site by employing a mixed-methods approach that combined qualitative and quantitative analyses. The aim of this research was to propose a framework for integrating TLS point cloud data into drywall installation to create precise drywall panel shop drawings, also known as cut sheets. The findings demonstrate that TLS is highly effective for capturing the geometry of metal studs, penetrations, and MEP components in wall frames, potentially replacing manual measurements. The full-scale experiment validated the framework's ability to produce accurate cut sheets for specific wall parts. However, the field testing indicated that drywall mechanics took longer to utilize the cut sheets compared to conventional methods, likely due to the steep learning curve associated with understanding and using the new technology. Moreover, the observed behavior of the mechanics might have been influenced by the Hawthorne Effect, where individuals alter their behavior because they know they are being observed, potentially skewing the results.

Integrating TLS technology into drywall installation offers valuable insights and several key recommendations for future research and practical application. Firstly, identifying the required skills for drywall installation, including the technical aspects of operating various equipment, is essential. Developing targeted training programs can bridge knowledge gaps and facilitate the adoption of advanced technologies in the construction industry. Secondly, exploring the integration of TLS with other innovative technologies, such as Radio-Frequency Identification (RFID) tags and QR codes, can enhance tracking and identification processes in drywall installation. Comparing on-site and off-site cutting methods, like Computer Numerical Control (CNC) machines and robotics, can provide a comprehensive understanding of their effectiveness and practicality. Lastly, automating drywall layout optimization should be a focus. Developing algorithms that automatically detect metal studs from point cloud data, integrate material and object classification, and adjust drywall size, type, and other parameters can potentially reduce material waste and promote more sustainable construction practices.

References

Acemoglu, D., & Restrepo, P. (2018). Artificial intelligence, automation, and work. In *The economics of artificial intelligence: An agenda* (pp. 197–236). University of Chicago Press.

Acemoglu, D., & Restrepo, P. (2019). Automation and new tasks: How technology displaces and reinstates labor. *Journal of Economic Perspectives*, *33*(2), 3–30.

Alathamneh, S. A., Liu, J. L., Azhar, S. A., & Burt, R. B. (2023, October 3). Reality Capture (RC) Technology for Drywall Installation: A Scan-toPrefab Approach. *16th International Conference on Durability of Building Materials and Components (XVI DBMC)*. https://doi.org/10.23967/c.dbmc.2023.088

Almukhtar, A., Saeed, Z. O., Abanda, H., & Tah, J. H. M. (2021). Reality Capture of Buildings Using 3D Laser Scanners. *CivilEng*, *2*(1), Article 1. https://doi.org/10.3390/civileng2010012

Antova, G., Kunchev, I., & Mickrenska-Cherneva, C. (2016). *Point clouds in BIM*. *44*, 42034. https://doi.org/10.1088/1755-1315/44/4/042034

Autor, D. H. (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*, *29*(3), 3–30.

Clark, C. T., & Liu, J. (2014). A case study of integrating 3D high definition laser scanning technology and BIM into drywall installation. *50th ASC Annual International Conference Proceedings*.

Cuellar Lobo, J. D., Lei, Z., Liu, H., Li, H. X., & Han, S. (2021). Building information modelling- (BIM-) based generative design for drywall installation planning in prefabricated construction. *Advances in Civil Engineering*, *2021*, e6638236. https://doi.org/10.1155/2021/6638236

Elliott, J. W., & Olbina, S. (2023). Benefits and Obstacles to the Adoption of Reality Capture Technologies in the US Commercial and Infrastructure Construction Sectors. *Buildings*, *13*(3), 576.

Fobiri, G., Musonda, I., & Muleya, F. (2022). Reality capture in construction project management: A review of opportunities and challenges. *Buildings*, *12*(9), Article 9. https://doi.org/10.3390/buildings12091381

Gordon, C., Boukamp, F., Huber, D., Latimer, E., Park, K., & Akinci, B. (2003). Combining reality capture technologies for construction defect detection: A case study. *EIA9: E-Activities and Intelligent Support in Design and the Built Environment, 9th EuropIA International Conference*, 99–108.

Hamledari, H., & Fischer, M. (2021). Construction payment automation using blockchain-enabled smart contracts and robotic reality capture technologies. *Automation in Construction*, *132*, 103926. https://doi.org/10.1016/j.autcon.2021.103926

Kim, S., Chang, S., & Castro-Lacouture, D. (2020). Dynamic modeling for analyzing impacts of skilled labor shortage on construction project management. *Journal of Management in Engineering*, *36*(1), 04019035.

Liu, B., Bi, X., & Gu, L. (2022). 3D Point Cloud Construction and Display Based on LiDAR. *2022 2nd International Conference on Computer, Control and Robotics (ICCCR)*, 268–272. https://doi.org/10.1109/ICCCR54399.2022.9790279

Liu, H., Singh, G., Lu, M., Bouferguene, A., & Al-Hussein, M. (2018). BIM-based automated design and planning for boarding of light-frame residential buildings. *Automation in Construction*, *89*, 235–249. https://doi.org/10.1016/j.autcon.2018.02.001

Liu, J., Bugg, R. A., & Fisher, C. W. (2023). Advancing Erosion Control Analysis: A Comparative Study of Terrestrial Laser Scanning (TLS) and Robotic Total Station Techniques for Sediment Barrier Retention Measurement. *Geomatics*, *3*(2), Article 2. https://doi.org/10.3390/geomatics3020019

Liu, J., Jennesse, M., & Holley, P. (2016). *Utilizing Light Unmanned Aerial Vehicles for the Inspection of Curtain Walls: A Case Study*. 2651–2659. https://doi.org/10.1061/9780784479827.264

Liu, J., Willkens, D. S., & Foreman, G. (2022). An introduction to technological tools and process of Heritage Building Information Modeling (HBIM). *EGE Revista de Expresión Gráfica en la Edificación*, *16*, 50–65. https://doi.org/10.4995/ege.2022.17723

National Oceanic and Atmosphere Administration. (2021). *What is lidar*.

Oh, B., Kim, M., Lee, C., Cho, H., & Kang, K. I. (2019). 3D modeling approach of building construction based on point cloud data using LiDAR. *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, *36*, 906–912.

Olsen, D., Tatum, M., & Defnall, C. (2012). How industrial contractors are handling skilled labor shortages in the United States. *48th ASC Annual International Conference Proceedings*, 11–14.

Rodríguez-Moreno, C., Reinoso-Gordo, J. F., Rivas-López, E., Gómez-Blanco, A., Ariza-López, F. J., & Ariza-López, I. (2018). From point cloud to BIM: An integrated workflow for documentation, research and modelling of architectural heritage. *Survey Review*, *50*(360), Article 360. https://doi.org/10.1080/00396265.2016.1259719

Sepasgozar, S. M., Lim, S., & Shirowzhan, S. (2014). Implementation of Rapid As-built Building Information Modeling Using Mobile LiDAR. *Construction Research Congress 2014: Construction in a Global Network*, 209–218.

Wetzel, E., Liu, J., Leathem, T., & Sattineni, A. (2022). *The Use of Boston Dynamics SPOT in Support of LiDAR Scanning on Active Construction Sites*. https://doi.org/10.22260/ISARC2022/0014

Williams, G. H., & Anderson, T. R. (2016). Impacts to productivity in metal stud Framing, and the hanging and Finishing of gypsum Drywall. *2016 Portland International Conference on Management of Engineering and Technology (PICMET)*, 2290–2299. https://doi.org/10.1109/PICMET.2016.7806805