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Reality Capture (RC) Technology for Drywall Installation: A Scan-to-Prefab Approach

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Abstract. *Drywall, also known as gypsum board, sheetrock, or plasterboard, is a widely used building sheathing material in the US and Canada to create interior walls and ceilings. Typically, the design and construction documents of a project exclude detailed information about the layout of drywall sheets on interior surfaces. Such information is left to the drywall installation crews to determine solely based on their experience. This inconsistent approach often results in substantial rework and waste of material in the field. The construction industry has seen a significant increase in the adoption of Reality Capture (RC) technology in recent years, with the goal of improving the quality and productivity of various construction activities. This research aims to investigate the implementation of RC technology, explicitly Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM, also referred to as photogrammetry), in drywall installation. The research team has developed a framework that utilizes RC tools to capture the as-built information of the framing members of interior walls and penetrations of the MEP systems and uses these RC data to develop prefabricating shop drawings in a Building Information Modeling (BIM) platform for drywall cutting and installation. This framework has been tested and studied on active construction project sites. The preliminary findings indicate that this framework has the potential to lead to a more precise and efficient drywall installation process. This paper also proposes a process model for the execution of the proposed framework for improving drywall installation.*

Keywords: *Building Information Modeling (BIM); LiDAR; Photogrammetry; Prefabrication; TLS*

1 Introduction

Drywall, also known as gypsum panel, gypsum board, sheetrock, or plasterboard, is a widely used building sheathing material in the US and Canada to create interior walls and ceilings. This material is favored for its durability, non-combustibility, lightweight properties, cost-effectiveness, and ease of installation and repair. A recent report reveals that over 20 billion square feet (1.9 billion m^2) of drywall are manufactured annually in North America for residential and commercial buildings (*Just How Much Drywall Is Used in the United States?*, 2022).

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 for installation, as shown in Figure 1, 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 reported that constructing a typical 2,000 ft^2 (186 m^2) residential house can generate as much as 8,000 pounds (3,629 kg) of solid waste, with approximately 2,000 pounds (907 kg) comprising drywall (*Construction Waste*, 2021). One approach to address this issue requires a methodology that effectively enables proactive design and planning for drywall sheet layout and cutting. This study focuses on the implementation of Reality Capture (RC) techniques, specifically Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM), also is referred to as photogrammetry, to optimize drywall installation by capturing as-built data of wall framing members and installed mechanical, electrical, and plumbing (MEP) systems. By integrating this data into a Building Information Modeling (BIM) platform, the research aims to generate precise prefabrication shop drawings for drywall cutting and installation, enhancing the accuracy, efficiency, and overall quality of the process while reducing material waste and rework.

(a) A two-man crew measuring, cutting, and installing drywall boards on a construction site

(b) Installed drywall boards with MEP elements penetrating through them

Figure 1. Drywall installation. (authors' photo)

The significance of this research lies in its potential to revolutionize the drywall installation process by leveraging state-of-the-art RC techniques to capture comprehensive and accurate data of the installed building elements on a jobsite. As the research is ongoing, this paper presents the design and development of the framework for creating cut-sheets, along with a field testing of the process. Study of the productivity and efficiency of the proposed framework will be published in future research. The detailed methodology and experimental approaches are described in the subsequent sections.

2 Literature Review

This chapter provides an overview of drywall systems and prefabrication, proactive design and planning for sheathing materials, Reality Capture (RC) techniques in construction, and early attempts of prefabricating drywall sheets using RC and BIM techniques.

2.1 Drywall Systems and Prefabrication

The gypsum panel industry is extensive, with over 70 manufacturing plants in the United States. Gypsum panels are manufactured in standard sizes at factories and then transported to construction sites for installation. These panels often need to be measured and cut into smaller pieces to fit the required dimensions for installation, which can be time-consuming and impact project schedules (Cuellar Lobo et al., 2021). Prefabrication in construction has gained popularity due to its ability to improve product quality in a controlled environment, minimize waste, and increase sustainability. The use of shop drawings in the prefabrication design process is essential for ensuring accurate component production based on construction documents and actual on-site measurements. This can significantly reduce installation time and provide a higher degree of accuracy compared to traditional stick-built construction methods.

2.2 Reality Capture in Construction

Reality Capture (RC) technology is gradually being adopted in the construction sector. However, there is a growing demand for innovative approaches to process RC raw data and integrate it with technologies like Building Information Modeling (BIM) for practical applications (Almukhtar et al., 2021). Two of the techniques used for RC data collection in construction are LiDAR scanning and 360-degree panoramic photogrammetry (Subramanian & Gheisari, 2019).

2.2.1 Terrestrial Laser Scanning (TLS)

TLS is an RC technique that uses LiDAR scanners to create highly accurate Point Clouds (PCs), representing the existing condition of scanned objects. The level of accuracy of the captured data and time savings are difficult to achieve using traditional manual measurement techniques (Fobiri et al., 2022). TLS has been used in various applications within the built environment, such as as-built documentation, quality assessment and quality control (QAQC), structural health monitoring, generating as-built drawings, and tracking work progress (Liu et al., 2022).

2.2.2 Matterport Technology

Matterport is a RC technique that combines a 360-degree camera with LiDAR scanning to provide advanced photogrammetry data (Matterport, 2022). This technology integrates visual information from 360-degree photos with the depth and accuracy of LiDAR technology, offering a comprehensive representation of built environments. Matterport has been utilized in applications such as as-built documentation, facility management, virtual tours, and documentation of historical sites (Liu et al., 2022).

2.3 Proactive Design and Planning for Sheathing Materials

Current practices in drywall installation often overlook proactive design and planning, leading to material waste and inefficiencies (Cuellar Lobo et al., 2021). Research studies have proposed rule-based automated BIM approaches for optimizing drywall layout and cutting plans, aiming to minimize material waste and improve installation efficiency. For instance, Lodo et al. (2021) presented a BIM-based generative design approach using fuzzy analytical hierarchy process (AHP) for prioritizing management criteria and selecting the best layout option. Liu et al. (2018) developed a rule-based automated BIM approach integrated with mathematical algorithms for generating design and planning alternatives.

2.4 Early Attempts of Integrating RC and BIM to Develop Drywall Cut-Sheets

The integration of RC technology and BIM has shown potential in creating of drywall shop drawings (Clark & Liu, 2014; Holley & Mancill, 2014). These early attempts demonstrated the potentials and identified limitations of using LiDAR scanners and BIM to create shop drawings without manual on-site measurements. However, RC and BIM have evolved rapidly, further research and development are needed to establish a comprehensive framework that leverages the full potential of these technologies, incorporating their recent advancements, such as Scan-to-BIM techniques and Matterport technology, to enhance data accuracy and processing times.

3 Methodology

This chapter outlines the proposed framework that was implemented in a case study, including steps for acquisition of RC data, comparison of the two PCs captured by TLS and Matterport, and development of the drywall cut-sheets from the PC data. The proposed framework of creating drywall cut-sheets is illustrated in Figure 2.

3.1 Case Study and RC Instruments

A case study was conducted at a construction site of a middle school building during the pre-drywall phase, following the completion and inspection of the rough-in work. The selected area, covering approximately 1,140 square feet (106 m^2), consists of seven interconnected rooms and a central hall. One of the aims of this study was to compare the quality and accuracy of point clouds captured by the two state-of-the-art RC instruments: the FARO Focus S-350 3D laser scanner and the Matterport Pro3 camera. Two separate sets of data were collected for the interior wall framing system and installed MEP components within the walls using these devices. The LiDAR point cloud, captured by the FARO Focus S-350, served as the baseline for the comparison study to assess the accuracy and reliability of the PC data acquired by both techniques. Figure 3 shows the floor plan of the scanned area and RC devices.

3.2 On-Site RC Data Acquisition

The scanning resolution for the FARO Focus S-350 was predefined (as shown in Table 1), ensuring precision and accuracy, while the scanning settings for the Matterport Pro3 were fixed, with registration and processing conducted automatically on Matterport's cloud platform. Both devices were set up on-site, and the scanning process was completed within a specific time frame. A total of 11 scans were taken using the FARO scanner in 62 minutes, and 34 Matterport scans were performed in 24 minutes. To ensure accurate and complete coverage of the objects on site, several factors were considered in determining scan locations. These include the location of above-ceiling rough-ins, room dimensions, and corners and frames of doors and windows. Pre-planning the space scan is crucial for capturing all the required objects in the shortest time with the least amount of scans.

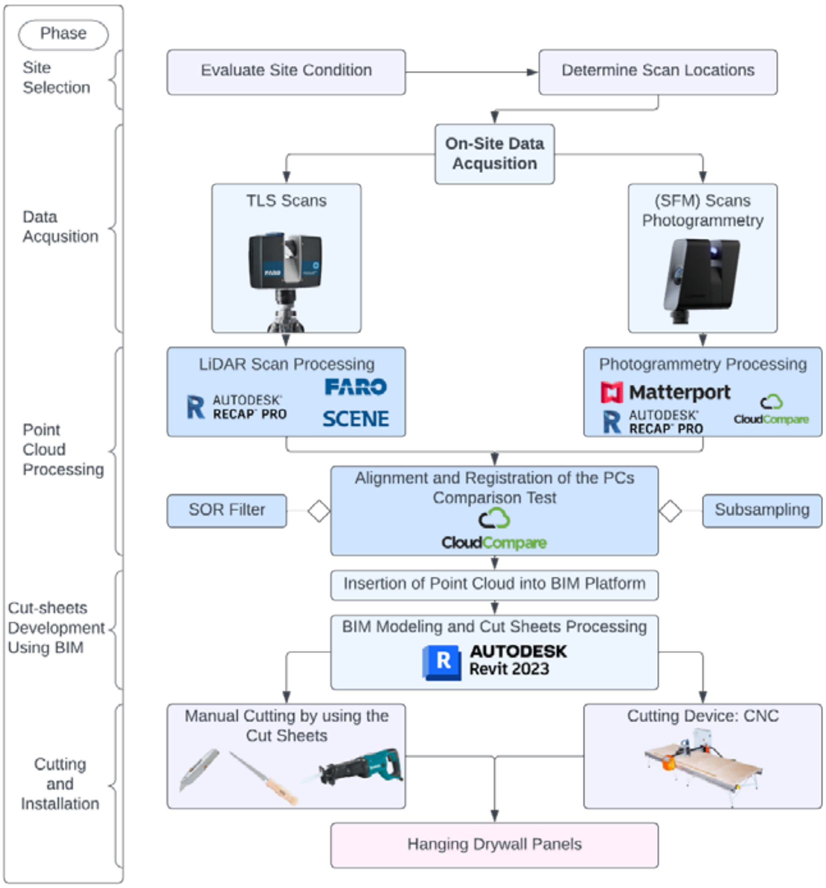
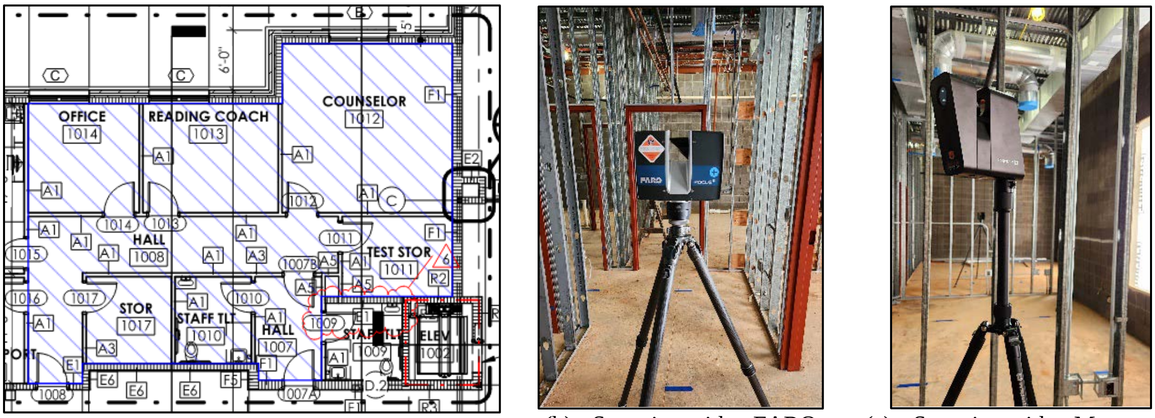


Figure 2. Process of the proposed framework for creating drywall cut-sheets using RC techniques.



(a) Floor plan of the captured space, highlighted in Blue

(b) Scanning with a FARO Focus S-350

(c) Scanning with a Matterport Pro3

Figure 3. Acquisition of RC data for the case study.

Table 1 Settings of FARO Focus S-350 scanner for the case study.

Parameter	Value
Quality	3X
Resolution	1/8
Scan Duration	04:08 (min:sec)
Scan Size	5120 X 2133 pt
MPts	10.9
Point Distance	0.442 in/30 ft (11.2mm/9.14m)
Unambiguity Interval	2014.354
Scan with color	Yes

3.3 RC Data Processing

The data processing stage involved the point clouds acquired by both devices. For the FARO S-350 scans, they were first imported into the FARO SCENE software for initial processing, colorizing, and registration. The resultant PC from this step was then exported to Autodesk ReCap Pro (ReCap Pro) software for cleaning and subsampling. The purpose of subsampling was to reduce the density and the total number of points in the PC to under 10 million for the next step of data comparison. On the other hand, the Matterport point cloud data was automatically processed on Matterport's cloud server. The data became available to download as an E57 file a few hours after uploading the scans. This data was also imported into Autodesk ReCap Pro for cleaning and subsampling to reduce the total number of points. Table 2 shows the time spent for RC data acquisition and data processing for both techniques.

3.4 Comparison of Two Point Clouds (FARO and Matterport)

In this stage, the point clouds captured by the FARO Focus S-350 and Matterport Pro3 were compared and analyzed quantitively using CloudCompare software. The FARO PC served as the baseline for the comparison study. The purpose of this comparison was to evaluate the quality, accuracy, and suitability of both point clouds for the development of cut-sheets.

First, the two PCs were imported into CloudCompare, before they were aligned and registered to each other to ensure a proper comparison of their spatial properties. Once the PCs were aligned, various analytical tools in CloudCompare were employed to assess the differences between the two datasets, including calculating point-to-point distances, examining the distribution of these distances, and generating heatmaps to visualize the deviations between the two PCs. Additionally, CloudCompare was used to study the point density, noise levels, and overall completeness of the data.

Table 2 Scanning and processing time for both FARO Focus S-350 and Matterport Pro3.

Description	FARO S-350 (min:sec)	Matterport PRO3 (min:sec)
On-site equipment setup	05:00	03:00
Setup equipment time / 1 scan	00:30	00:30
Scanning time / 1 scan	04:08	00:20
Scans Number	11 EA	34 EA
Pack up the equipment	05:00	03:00
Total Scanning time	**61:58**	**24:20**
Off-site registration and processing	30:00	00:00 (Automatic)
Clean and subsampling in ReCap Pro	10:00	10:00
Overall time to acquire PC data	**101:58**	**34:20**

3.5 Development of Drywall Cut-Sheets

Utilizing the RC data, drywall cut-sheets were developed. This process involved inserting the PC into Autodesk Revit, modeling walls and penetrations in Revit according to the point cloud, creating wall layout plans from the Revit model, and annotating the layout plans. The resulting cut-sheets provide a valuable resource for construction and planning purposes, facilitating more accurate and efficient drywall installation.

4 Results and Discussion

The two PCs captured in the case study are shown in Figure 4. Visually, the FARO PC appears to have more uniform density and fewer artifacts, while the Matterport PC exhibits more noise and artifacts in the areas where the scans overlap. The field testing demonstrated that the time required to acquire point cloud data using the Matterport device is significantly shorter compared to the LiDAR scanner.

4.1 Acquired Point Clouds

Before comparing the two PCs quantitively in CloudCompare, it is essential to process each of them independently to eliminate any outliers that may affect the results. This process applied the Statistical Outlier Removal (SOR) filter to each cloud, using a mean distance estimation of 6 neighboring points and a standard deviation multiplier threshold of 1.00. This removed any outliers or irrelevant points. Next, random subsampling was applied to both PCs to achieve a similar density of 10 million points each, eliminating insignificant differences and facilitating transfer to the BIM environment. Finally, the PCs were aligned using CloudCompare's registration command with specific parameters: a fixed scale of 1.0, a random sampling limit of 50,000 points, and enabling farthest point removal for a 100% theoretical overlap. The resulting Root Mean Square (RMS) error was minimal, at 0.0557 on 43,383 computed points, ensuring an accurate comparison between the two datasets. Table 3 shows the results of this process.

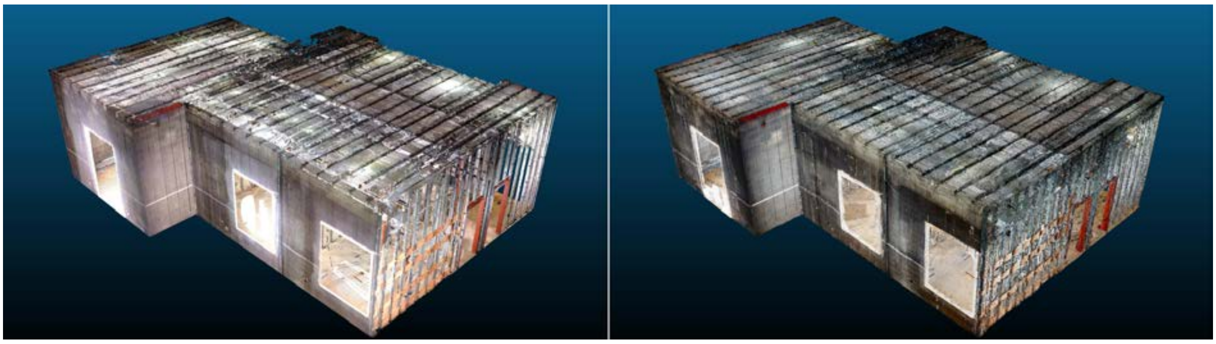


Figure 4. The two point clouds captured during the case study: FARO (Left) and Matterport (Right).

Table 3 Point Cloud data comparison.

Point Cloud	FARO S-350	Matterport Pro3
Total points count in the “raw” PC	103,731,398	157,385,182
Points count per sf	90,992	138,057
Total points count after SOR	93,723,155	142,370,234
SOR Cleaning Ratio	9.6%	9.5%
Total points count after subsampling	10,000,000	10,000,000
Subsampling ratio	89.3%	93.0%

4.2 Comparison of Point Clouds

To assess the accuracy of the Matterport PC, a comparison was conducted with the FARO PC in CloudCompare at an Octree level of 8, considering a maximum distance of 0.01m. The results showed that most points in both clouds were within a distance of 0.0085m or less, with a mean range of 0.006m and a standard deviation of 0.007m. Figure 4 presents the heatmap of the test results and a histogram of distance measurements (m) for the case study.

To further evaluate the precision of the Matterport PC relative to the FARO PC, a specific section of the building, including metal stud frames and duct work, was chosen. This section is shown in Figure 6. An Octree level 8 was used to calculate the distances between corresponding points on the two clouds, and the heatmap demonstrates the deviation between the points. These results indicate that the Matterport PC provides a satisfactory level of accuracy when compared to the FARO PC. The small deviation between the two datasets demonstrates the potential for using Matterport Pro3 camera as a reliable method for capturing RC data.

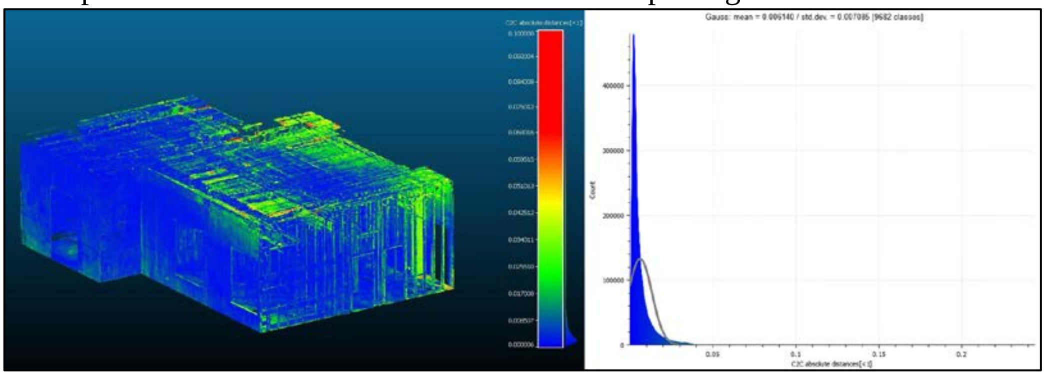


Figure 5. The comparison heatmap and histogram of distance measurements of the 2 PCS in ClouodCompare.

4.3 Drywall Cut-Sheets Development

Figure 7 shows a cut-sheet that was produced in Autodesk Revit from the Matterport PC. The process of modeling the drywall panels and openings for the penetrations is carried out manually by tracing the point cloud in Revit. Each wall is sectioned and dimensioned, resulting in a useful construction shop drawing that can be used by drywallers to make drywall cuts without having to take on-site measurements manually. The cut-sheets can also serve as a helpful guide during the installation of drywall panels. In addition, this data can be exported as CAD files that can be sent to a CNC machine to automate the cutting process.

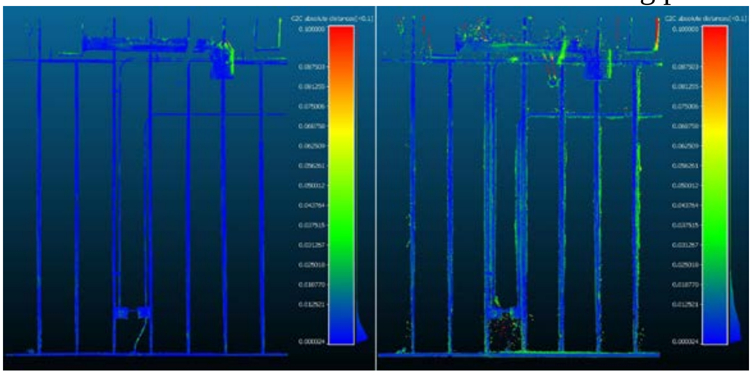


Figure 6. Comparison of a small section of PC of the wall framing: FARO (left) and Matterport (right).

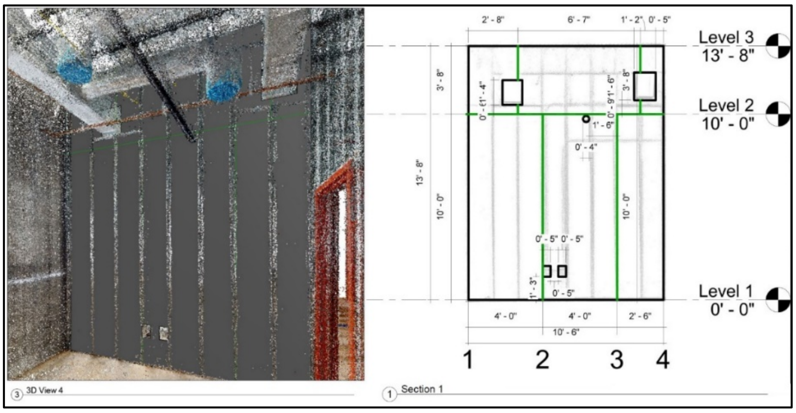


Figure 7. A drywall cut-sheet developed in Revit from the Matterport point cloud data.

4.4 Implementation of the New Framework

The implementation of the proposed framework necessitates modifications to the conventional drywall installation process. The research team devised a process model, depicted in Figure 8, which outlines the tasks and responsibilities for the three primary stakeholders involved in the execution of the proposed framework , as well as the data to be exchanged. These stakeholders include the Virtual Design and Construction (VDC) engineer, the drywall crew leader, and the drywall crew member. The VDC engineer employs the RC technology to generate precise drywall cut-sheets. Meanwhile, the crew leader oversees daily tasks and ensures quality control of drywall installation, and the drywall crew members use the cut-sheets to guide efficient installation. This collaborative approach optimizes the workflow, minimizes material waste, and enhances the overall quality of drywall installation on construction sites.

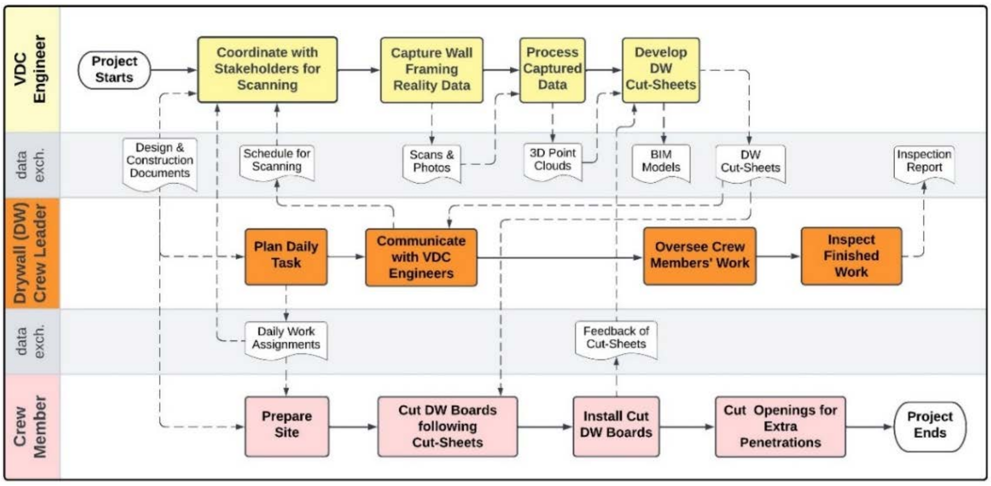


Figure 7. A process model for the implementation of the new framework on a construction project.

5 Conclusions

This research developed an innovative framework for optimizing drywall fabrication and installation using Reality Capture (RC) and BIM technologies. By employing LiDAR and Matterport techniques to capture interior framing and penetrations, and creating detailed shop drawings on a BIM platform, this framework can provide a more accurate and efficient approach for drywall installation. This paper aimed to investigate the required data acquisition techniques and compare the quality and accuracy of data obtained from different methods. The results demonstrated that the Matterport point cloud provides sufficient quality and accuracy for developing drywall cut-sheets, which is crucial for the success of the proposed framework in enhancing drywall installation efficiency. Additionally, the paper presented a novel process model emphasizing the collaboration between key stakeholders to effectively implement the proposed framework for drywall installation on construction project sites.

As the next phase of this research project, timed studies will be carried out to assess the actual productivity and efficiency of using cut-sheets by construction workers for drywall installation. These studies will provide valuable insights into the real-world impact of implementing this innovative approach.

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