A Case Study of Integrating 3D High Definition Laser Scanning Technology and BIM into Drywall Installation

Caitlin T. Clark
Auburn University
Auburn, Alabama, USA

Junshan Liu
Auburn University
Auburn, Alabama, USA

The requirements of planning and executing design and construction projects are intensive and meticulous; this process will only become more complex as projects become more complex and have shorter durations. Although the construction industry has experienced a significant shift forward in technological and process innovations in recent years, the installation of drywall has remained unchanged. Of all the activities on a construction project, the installation of drywall is one of the industry's most wasteful and time-consuming schedule items. This paper demonstrates usage of LiDAR in construction, and presents a case study of integrating three-dimensional high definition laser scanning and building information modeling (BIM) technology into the drywall installation, with an intention to create a more efficient drywall installation process.

Keywords: Light Detection And Ranging (LiDAR), Three-dimensional High Definition Laser Scanning; Building Information Modeling (BIM); Drywall Installation, Construction Productivity

Introduction

LiDAR Technology in Construction

Terrestrial Laser Scanning (TLS) – also called LiDAR (Light Detection And Ranging) technology – once a high-tech, experimental and expensive technology, is now being steadily adopted on building sites (Baltsavias, 1998). It has been reported that the TLS hardware, software and service market has experienced an substantial growth in revenues in the last decade, with the architectural, engineering, construction and facility management (AEC/FM) industry being one of its major customers. Large-size contractors have identified laser scanning as a technology that enables them to perform critical dimensional quality control accurately, comprehensively and rapidly. Established usages of TLS on construction include surveying, earth moving, as-built dimensions control, work progress measurement, structural health monitoring, and as-built project documentation.

Over the last twenty years, laser-scanning technology has seen a significant shift in applications across multiple disciplines. The use and application of three-dimensional high definition laser scanning within the disciplines of architecture and building are continuing to grow daily mainly within the realm of surveying while other uses such as fabrication, structural monitoring and CAD continue to emerge. For the sake of this discussion, the applications listed below will remain specific to uses within the construction industry:

The revolution in technology and software has brought building modifications, renovations, and additions to the forefront of laser-scanning applications worldwide. Since most of these types of projects involve old buildings, new additions must be designed around existing key elements. The use of laser-scanning to model existing structures for renovations is being frequently used in urban areas in Europe and Asia with still limited use in the United States (Jacobs, 2012). When paired with existing CAD and BIM tools, laser-scanning can provide an integrated view of existing and proposed structures allowing owners to make more informed decisions and giving construction managers better estimates of feasibility of projects.

Property surveying is the main application of laser scanning within the United States. This application is mainly used for determining property lines, encroachments, and offsets. This use can also apply the technology to determine point locations for precise erection of cladding, window casings, and other related exterior elements. The reason laser-scanning technology is being used for these purposes is to eliminate the need for other costly and laborious resources to reach desired structures (Jacobs, 2012).

The most promising application of laser-scanning technology for building construction is in construction planning. Over the coming years, manufacturers foresee this technology will be an essential tool for construction managers as they plan around existing structures, populated areas and living campuses. With current and accurate mapping of existing site conditions, managers can more efficiently utilize construction sites for cranes, laydown areas, labor and material movements (Jacobs, 2012).

Taking the application of laser-scanning technology within construction management to the next level, the last application for laser-scanning technology that will be discussed is structural health monitoring. This application is a relatively new concept and is seeing almost no usage worldwide. Theory states that by systematically capturing scans of existing structures at regular intervals, facility managers can more accurately predict the overall health of structures and buildings by overlapping a previous point cloud with the current. The main health factors of buildings captured with this application is structural shifts in steel and concrete through visual deflections of elements captured in the point clouds. This revolutionary application can easily help owners find structural deflections before they become a problem and allow for less costly fixes (Park et al., 2007).

Despite these many works and the industry-wide acknowledgement of the accuracy and versatility of the LiDAR technology, the use of laser scanning on construction sites remains limited. Some of the reasons are believed to be: 1) high equipment cost, 2) high operating and maintenance cost, 3) low levels of automation and/or poor efficiency of the current systems. However, it is also believed that with a rapid decrease in the equipment cost and more practical procedures, laser scanning may become another evolutionary factor in the construction industry in the near future.

Laser Scanning and BIM for Drywall Installation

Drywall installation is one of the most labor-intensive activities for construction workers. Hanging drywall involves multiple steps, including layout, measuring, cutting, delivering, and installing. Major problems with the conventional drying installation method in the trade are,

- Low labor productivity rate. One key factor affecting the productivity is that the process requires workers cut the gypsum boards to fit the dimensions or for small features such as holes for pipes, outlets and light switches on the wall, which takes significant amount of time and breaks the work flow.
- High labor and material waste ratio due to poor accuracy. The conventional method needs workers to take measurements and cut the boards while installing them. Very often the measurements taken are inaccurate, causing repetitive work and waste of gypsum boards.
- Work-related injuries in drywall installation, such as back injuries, due to drywallers' frequent bending, twisting and lifting for cutting, measuring and installing the drywalls.

This paper present a case study of the uses of three-dimensional high definition laser scanning technology and BIM in the construction industry and how these tools can be applied to the fabrication and installation of conventional drywall. There are several positive impacts that the technology brings to the industry including better end products, educated owners, innovative renovation solutions and a new era in as-built drawings. Understanding the overall impact of this technology and proposing the application of it for drywall fabrication and installation is the main purpose of this research paper.

The objective of this study is to design, test and evaluate a new procedure for commercial drywall installation that involves high definition laser scanning technology and BIM. This new procedure is expected to increase the productivity of drywall installation through the aspects of accuracy, efficiency and an automated procedure.

Methodology

Over the past 20 years, there has been an evolution of laser technology and its application. Although there is still limited research and application of this technology, the world is seeing a much broader spectrum of uses of three-dimensional high definition laser scanning technology. One of the key areas of application for this technology in the construction industry is fabrication. Since the installation of drywall is the construction industry's most time consuming and wasteful process, this research aims to establish a method for using 3D high definition laser scanning to prefabricate drywall in order to reduce the time associated with hanging drywall and significantly reduce the

waste it produces. To conduct this research, the researchers have reviewed the current three-dimensional high definition laser scanning technology and its applications in construction, and conducted a field test to integrate this technology into the installation of conventional commercial-grade drywall in a construction site.

3D HD Laser Scanning Technology Used in This Study

The Scanner and Its Specifications

The laser scanner used in this research is a Leica C10 ScanStation. The Leica C10 ScanStation is considered a light detecting and ranging (LiDAR) product within the realm of terrestrial laser scanning (TLS). There are several key components that all TLS equipment have: laser range finder, computer powered operating system, storage, scanner, geographic positioning system (GPS), and software (Baltsavias, 1998). These components can vary greatly in performance and size depending on manufacturers. The Leica C10 is considered an all-in-one product and can be seen in Figure 1. The C10 provides the laser range finder a 360° by 270° field of view with a reflectivity of 90% accuracy at 300 meters. It can capture 50,000 points per second at peak. Its on-board computer with touch screen operations provides an easy-to-use interface allowing users to easily navigate settings and operations. The C10 houses physical and digital leveling tools for precision scanning. Integrated with a video camera able to produce real-time streaming and zoom, points captured during scans can be textured to produce informative point clouds for end users. The Leica C10 ScanStation is considered one of the most versatile laser scanners on the market today. (Leica Geosystems, 2012)

Figure 1: Leica Geosystems C10 ScanStation (Leica Geosystems)

The Leica C10 ScanStation's output is a data set of points called a point cloud and each scan produces its own cloud. Each point is a reflection of the laser range finder off the chosen object scanned. The point clouds produced are imported, viewed, and manipulated using complimentary software provided by Leica Geosystems called Cyclone that will be discussed in later paragraphs. As seen in Figure 2 for a sample screen shot of laser scanning point clouds, multiple scans can be combined in to a single point cloud to produce a functional map of any given subject. As discussed in the previous paragraph, the density of points is varied depending on resolution settings chosen for the scan and each point can be textured to produce a truly functional point cloud. (Leica Geosystems, 2012)

A key accessory for Leica C10 scanner is the dual-head targets, which are used during scanning to provide concrete points of reference for combining multiple scans of a given object. These targets can be viewed, named, and stored within each scan allowing for easy registering within the Leica point cloud software.

The Scanning Process

During field scanning, the C10 scanner itself is attached to a tripod, and positioned and leveled within the 300-meter range of the given object. The dual-head targets are then arranged within the scanner's field of view. Once all equipment is set-up and placed in the desired location, the scanning process can be limited to the on-board touch screen. Once the C10 ScanStation is powered, the Leica software will immediately begin to run on the operating system.
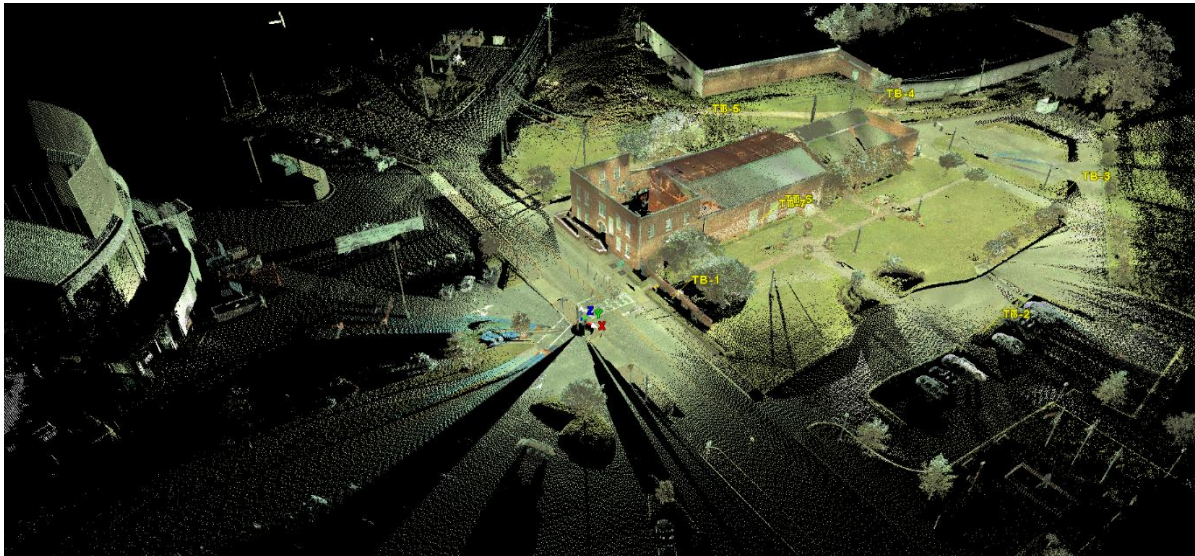
Figure 2: A sample point clouds

The key factors that allow the scanning process to move quickly are the speed of the laser range finder, resolution selected by user, and the ability to keep the C10 running while moving to the next location. A typical scan of medium resolution (3 million points produced) from set-up to storage of data takes a maximum of 30 minutes allowing users to make multiple scans per hour. The intentional placement of C10 equipment and targets can also play a large role in the speed and accuracy of scans.

The Point Cloud Software

The Leica C10 ScanStation comes with proprietary software, Cyclone. Cyclone is the version of Leica's solution to point cloud importing, exporting, registering, viewing and manipulating. Cyclone provides users with essential tools for gaining information from a given point cloud. There are several key functions that are being used with the Cyclone software once a project is imported from the Leica C10. The first is simple viewing and cropping a given point cloud. Next is combing several scans into a single point cloud. Third, users can acquire a large variety of information including measurements, angles, and elevations of selected points. Lastly, point clouds can be exported to multiple computer aided design (CAD) tools for the next step in building information modeling (BIM). (Leica Cyclone, 2012)

Selection of the Project Site for the Case Study

Project Selection Criteria

The first step of this research process was to select a construction project and industry partners to test solutions aimed at improving the drywall installation process using 3D laser scanning. Below are the criteria set by the researchers for selecting a construction project for the case study:
- A building project must be in the stage of construction after finished framing and MEP rough-in and before drywall installation
- The building has repetitive rooms with similar layout and size or long corridors, to conduct and compare the new drywall process with the conventional process.
- The construction site is located in an easily accessible area and within driving distance for the researchers.
- The onsite project management team and drywall subcontractor are willing to collaborate and invest in this research.

The Building

After a series of emails to professionals working on construction projects around the Southeast of the U.S, the Auburn University Small Animal Teaching Hospital building (SATH) was selected as the project for this research. This project was located on Auburn University's campus and provided a project team that was ready and willing to partner in this research after previous academic partnerships with the researchers. SATH is a 208,000 square foot new construction medical facility built to accommodate larger class sizes for the University's School of Veterinary Medicine. It's budgeted for $74 million. Upon completion, the new SATH building will become one of the nation's largest small animal hospitals. This facility will house faculty and staff offices, exam rooms, research facilities, and surgical rooms in a three story, steel-frame building. The SATH is in phase two of the overall project which included a new classroom building which houses the auditoriums and classrooms to accommodate increased class sizes. The second floor of SATH has a series of faculty offices which were laid out in mirrored pairs along a long corridor providing this research with both the stipulated floor plan criteria. Also, the project's second floor schedule fell within the window for the research study.

Field Scanning

Scans

Three different field scans using Leica C10 ScanStation were performed for this case study in SATH in June and July 2013. The first scans were to test the documentation of a four walled room with several in wall protrusions by scanning a set of bathrooms on the second floor. The second set of scans documented two of the second floor faculty offices on the SATH project. The last set of scans ran the length of the second floor south corridor that lined the faculty offices scanned in the previous scan.

The scan of the four faculty offices located on the second floor involved just one scan of each office. The center most spot in the room was selected as the placement of the Leica scanner. The first scan was set up as a medium resolution scan with image capture and no limit on the laser range. This produced a point cloud that picked up elements far outside the scanned office. The second scan was also set up in the center most point of the room with medium resolution, image capture, and a laser range of 100 feet. This produced a cleaner scan with fewer elements documented outside the scanned office. Since this was a single scan of a single room with no need to register several point clouds, no reference targets were needed.

The last scan of the second floor south corridor was accomplished with multiple scans per station in increments of twenty feet. At each station, a three-inch target was placed on the corridor wall. This provided the first and last scan with two reference targets and scans in between with three reference targets. At each station, an initial low resolution scan without image capture was taken. This scan was taken to document the entire corridor area. A second medium resolution scan with image capture was taken to document just the south side of the corridor. These two scans were executed at twenty-foot increment for 100 feet of the corridor for a total of five stations.

Each scan required the initial clearing of the area on the construction site and the setup of the scanning equipment and targets. The longest time required for a scan station set up was no more than twenty-five minutes which including the set up and take down of the equipment and the scanning of the area. Once field scanning was complete, the data was removed from the Leica C10 and transferred to the Cyclone computer software for editing and registering.

### *Point Cloud and BIM Modeling for Drywall "Cut Sheet"*

After the field scan, Cyclone and Autodesk Revit were used to edit and manipulate the point clouds in order to produce cut sheets for field trades to use during the installation of drywall in the scanned areas. The following paragraphs explain the process used to produce the cut sheets for the scanned offices with the integration of Cyclone and Revit.

The data collected in the field scanning was imported to Cyclone. Since there were elements well outside the targeted area documented in each scan, the point clouds were edited and trimmed to reflect just the scanned area and eliminate unnecessary data. The four walls of the offices were directionally named north, south, east and west and each wall was trimmed from the edited point cloud. These separate wall point clouds were then imported in to Revit for modeling

Once the wall point clouds were imported in to Revit, the drywall was modeled by tracing the points of each wall along with appropriate protrusions for electrical outlets, doors and windows. See Figure 3 for the point cloud of the north wall of faculty office and its drywall BIM model in Revit. As seen in Figure 4, each piece of drywall was sectioned and dimensions of the protrusions and their location from the closest edge were marked. Each modeled wall was placed on a sheet and labeled according to location. These cut sheets were then printed for field-testing.
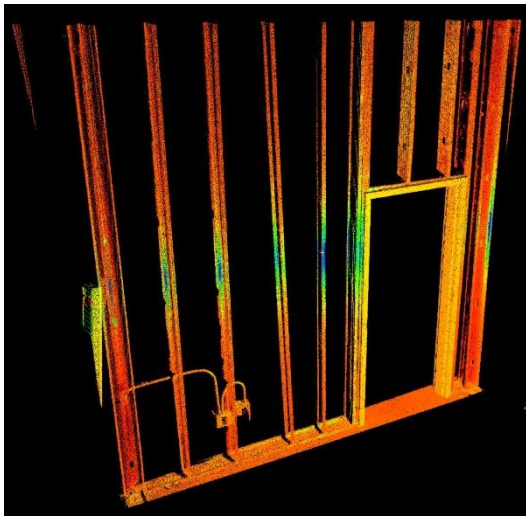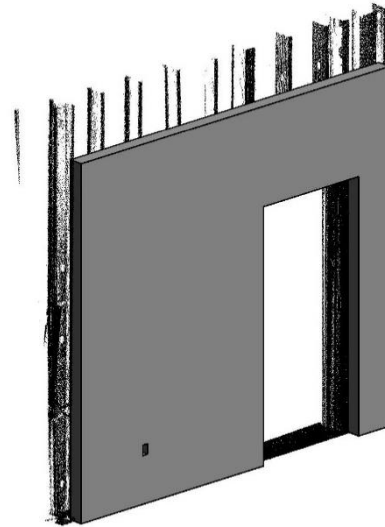
a.   Point cloud   *b.   Revit model*

Figure 3: Point cloud of a wall and its drywall BIM model developed in Revit using point cloud.
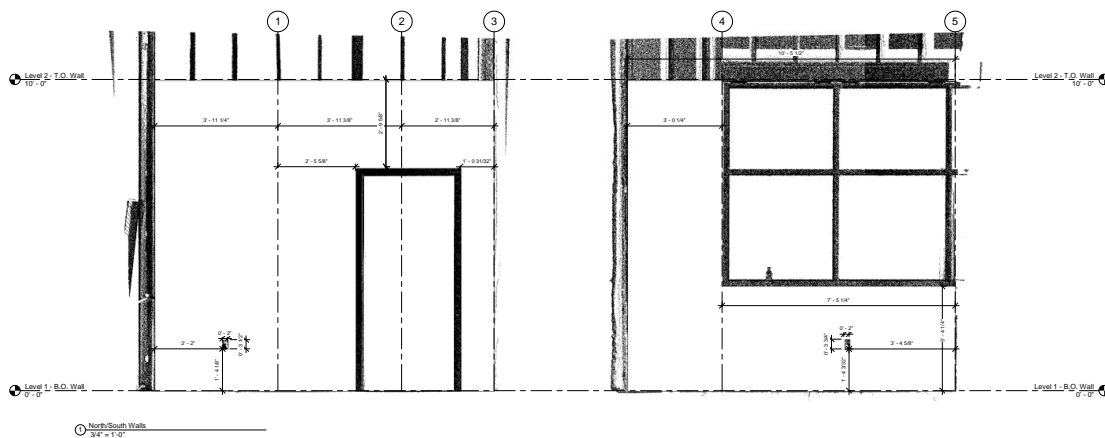

Figure 4: A sample drywall "cut sheet" developed in Autodesk Revit using point clouds.

Field Drywall Installation Testing

In the traditional method of hanging drywall, for a small office used for this research, it generally involves a crew of two or three tradesmen to install the drywall. As shown in the series of photos in Figure 5, the tradesmen first collect enough sheets of drywall for one area, then trim to the appropriate length and mark stud placement. The placements of protrusions are then marked on the floor with the measurement of elevation to the edge of the protrusion. The drywall is then hung on the wall ¾" above the finish floor with screws and the protrusions are cut using a router.

a. Measure	b. Trim	c. Install	d. Cut a hole

Figure 5: Conventional drywall installation procedure.

The drywall installation method proposed by the research team was to use the cut sheet provided to trim and cut each piece of drywall to length and associated protrusions using the dimensions given before entering the room, and then placing each piece according to the cut sheets on the wall, and then tying the drywall sheets to the metal studs using screws. See Figure 6 for a series of photos taken during this process.
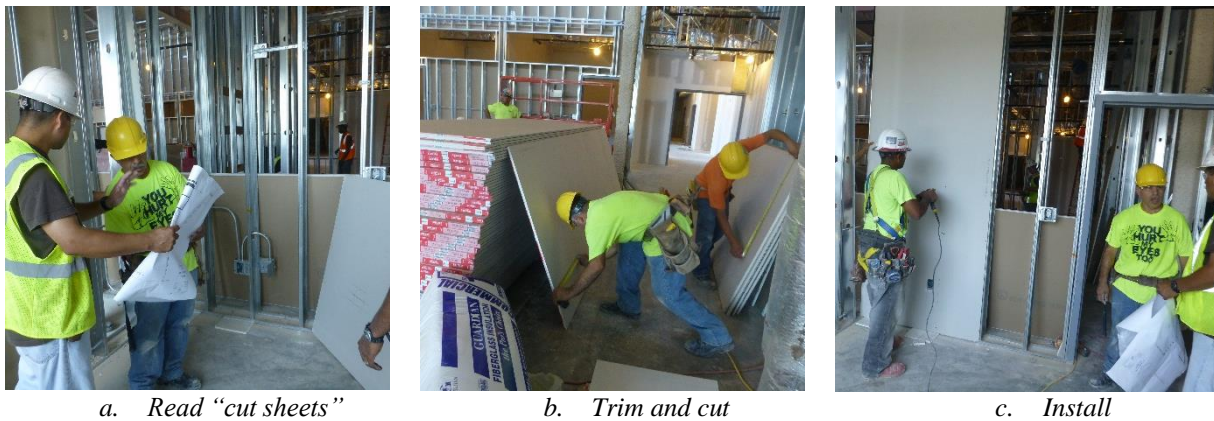

a. Read "cut sheets"	b. Trim and cut	c. Install

Figure 6: Integrated drywall installation procedure using "cut sheets".

Field-testing was only performed on the four pre-scanned faculty offices on the second floor. Before the actual testing, this research team met with drywall foreman to discuss the purpose of the field-testing and to review the instructions. During this pre-testing meeting, the research team learned several considerations and improvements for this research process:

1. The most wasteful and time consuming part of installing drywall is the "top out" process in which tradesmen are installing drywall around ceiling joists and overhead MEP and under roof decking. This is where the largest contribution to schedule and cost can be made with prefabrication.
2. In order to prefabricate drywall using laser scanning technology and BIM, a fast process must be developed since the time window between finished rough in and drywall installation is usually just a few days.
3. In order to correctly install fabricated drywall, each piece needs to be marked and ordered according to a set of cut sheets for each room.
4. A third technology needs to be integrated in to this process to allow foremen and tradesmen to easily locate the fabricated drywall associated with each room such as RFID tags. Time spent locating the correct pallet of drywall should be minimized.

The research team documented the field-testing through photos and videos of the process for installing drywall in the traditional method and installing drywall in the proposed method of using cut sheets. This first field-testing was to observe the traditional and new method of installing drywall. The ultimate goal of this testing was to document the accuracy of installing drywall from the produced cut sheets. The research team also learned several improvements for the cut sheet process:

1. Drywall is often hung around ¾" off the finished floor to prevent water damage.
2. Drywall must be continuous along exterior walls and fire rated corridors including around fire protected steel members and behind wall framing.

3. Drywall is hung horizontally above doorframes with separate pieces hung vertically on either side of the door frame to prevent cracking.
4. Corners of drywall in rooms and around windows are installed with one edge butted up against the other.

The cut sheets produced for the first round of testing did not take in to consideration all the suggestions made by tradesmen above. However, these suggestions did not compromise the accuracy of the cut sheets. While it took the tradesmen longer to install the drywall using the new method versus the traditional method, the holes for electrical protrusions and placement and dimensions of each sheet of drywall were 100% accurate.

Conclusion and Recommendations for Future Research

Several conclusions were made during and after the field testing drywall installation using laser scanning and BIM. Finding the right construction project and team is crucial to the success of time sensitive and complex research such as this. The field scanning requirements for simple rooms such as offices are minimal requiring only one medium resolution scan with image capture for reference; a twenty minute investment for each office. The accuracy of the holes cut from the cut sheets proved that the integration of laser scanning and BIM technology can be used to document and fabricate drywall for a specified area without having to make any field measurements. This is the first substantial step towards prefabricating drywall using these technologies; however, several considerations should be made in the next steps of this research.

There are many adjustments that need to be made to the process before attempting to prefabricate drywall using laser scanning technology. As stated above, one of the largest concerns for prefabricating drywall expressed by the drywall foremen is the small time window between finished rough in and drywall installation. On most construction projects, this window can be as little as a few days. Finding a fast process for scanning an area, importing the data and producing cut sheets for fabrication should be the next step in this research process.

While it was proven in this research that the traditional method for installing drywall below the ceiling is faster than the method proposed, there is an extreme need to produce a method that mitigates the time and waste associated with installing drywall above the ceiling. Once a process has been developed to turn the digital data in to cut sheets, this method should be applied to the installation of drywall above ceiling or "top out". As observed on site and according to interviews with the drywall foreman, any improvements in speed and waste reduction to the top out process would produce large benefits to any construction project.

After a process has been developed for prefabricating (above ceiling) drywall, finding a technology such as RFID tags to allow drywall tradesmen to easily locate the fabricated drywall and its associated installation area should be researched. While technologies such as RFID tags have been used in steel fabrication for many years, it has been just recently that construction managers are using it to track materials, tools and employees on construction sites. It is this research's goal to mitigate time and waste associated with the installation of drywall which should include the time spent on locating the correct fabricated drywall and reducing the chances of incorrect installation.

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