Employing LiDAR Scanning for Drywall Prefabrication: A Qualitative Pilot Proof of Concept Study

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ABSTRACT
The construction industry has sought many forms of improvements to materials and methods to increase productivity. Prefabrication in products, components and systems has made some headway in this arena, but overall productivity still remains largely flat as measured against all other non-farm industries in the U.S. One new technology that is starting to garner interest in the vertical construction industry is the use of LiDAR scanning, currently used primarily for large scale geospatial measuring, data capturing, and modeling. This paper explores the potential for using this technology on smaller interior components, namely gypsum panel installation, and presents a qualitative pilot proof of concept study to compel further quantitative research. As a method, LiDAR was used to produce a dense registered point cloud from which ‘slices’ were extracted from a VDC model; which were then used to produce prefabrication drawings for gypsum panels and measured against actual conditions. As a large scale ubiquitous material, incremental improvements to gypsum installation could have a significant impact on overall productivity in vertical construction.

INTRODUCTION AND LITERATURE REVIEW

Productivity

Productivity in construction is of great importance in professional practice, but is often debated as to how to measure or improve it. Several researchers as well as the U.S. Department of Labor report that productivity in non-farming disciplines has seen much more improvement over that measured as relatively stagnant in construction (Goodrum, et al., 2009; Hewage and Ruwanpura, 2006; Koningsveld and Henk, 1997, Chapman et al., 2012.) The U.S. Department of Labor, Bureau of Labor Statistics’ data concurs with these findings, noting that over the past forty years, construction productivity has remained relatively flat (Figure 1.)
One broad endeavor in the industry to improve this disparity is through prefabrication of components, systems, structural members, and in some cases interior finishes. Components and combinations of them which can be fabricated in a controlled shop environment often result in better productivity. Common examples include precast concrete, structural wood panels, duct bank, medical gas zone valve assemblies, patient room headwalls, and HVAC piping.

LiDAR

Another current shift in the industry is through the use of Light Detection and Ranging (LiDAR) systems, and the use of their point cloud output in three dimensional modeling. LiDAR produces copious amounts of data in ‘point’ format, typically within a geospatial tolerance of 2mm each. Akca et al (2010) note that this type of unstructured data can be very useful in developing accurate 3D models, although there are some issues with errors and omissions based on range and line of sight. Generally, this type of technology is being utilized in the vertical construction industry on large scale geospatial measuring, such as excavation, structural frames, and dense mechanical spaces.

Drywall Systems

Drywall installation represents a significant portion of most vertical construction projects. Everett and Kelly (1998) note that Today, gypsum panels are
used extensively for wall cladding and structural fireproofing. Also known as drywall, gypsum wall board, plaster board, or by the registered U.S. Gypsum brand name SHEETROCK®, gypsum panels are common wall cladding materials in both residential and commercial construction. They go on to state that Annual gypsum panel fabrication in the United States since 1987 has been nearly 19 billion square feet of regular and type X gypsum panels. While their research focused on productivity in the ‘finishing’ of drywall panels, published literature related to the productivity of actual panel installation is relatively non-existent.

**Purpose**

Given the magnitude and scale of this particular component of vertical construction, improvements to productivity in drywall installation could be a meaningful vehicle of study. This paper presents a qualitative case study of a pilot proof of concept effort to measure the effectiveness and accuracy of LiDAR-produced data used to produce shop drawings for panel prefabrication in an effort to improve productivity.

**METHODOLOGY AND RESULTS**

For this initial pilot, the authors employed a multi-stage qualitative process in an effort to make iterative improvements to determine if the concept could be proven. Given the nature of the work, a quantitative approach was determined to be unrealistic. All of the test phases described herein were undertaken on actual project sites, and using the same LiDAR instruments for each, a Leica C10 high definition scanner.

**Test 1**

This test was initiated based on a preliminary site visit at a significant urban commercial project during the ‘finishes’ stage, hosted by a large ($1BB) general contractor. The scanning was performed of a small room and was not structured in its approach. Three separate scans were performed of a service space that contained multiple plumbing and HVAC penetrations through the ‘above ceiling’ portion of the partitions. The spacing of the scans was only approximated. Two scans were performed near the plane of the wall partition and one scan was performed with the scanner approximately three feet away from the partition. Targets were used in the process in order to register the scans together and gain accurate data of the entire space. For ‘pilot’ analysis purposes, the area for a single piece of sheetrock to be hung was identified for testing purposes (Figure 2.)
After scanning, the data was taken from the scanner and into Leica’s Proprietary ‘Cyclone’ software for analysis. The scan data was registered together into one point cloud and then analyzed in a one foot thick ‘slice’ to represent only the data necessary for the initial study. The data was then taken to two different modeling programs: AutoCAD® and Revit Architecture®, for shop drawing development. Figures 2 and 3 show the data as imported and ‘sliced’ within Revit.
From this data, ‘shop drawings’ for the board identified were produced in both Autocad and Revit, including the board, all penetrations, and appropriate dimensions. The drawing produced in Revit is shown in Figure 5.

Figure 5: Shop drawing produced in pilot phase

The drawings produced in Revit with the point cloud imported, versus the drawing produced in AutoCAD with data directly from Cyclone, were compared. After discussion and analysis, the authors elected to utilize it the Revit-produced data via imported cloud.

A comparison of the Revit shop drawing to actual field conditions showed there were measurable discrepancies of between 1/8” and 3” for the range of penetrations. This was felt to be due to two primary factors: too large of a slice-depth taken in the modeling software, as well as the random nature of the scanner locations in the initial scans. Because the stations were spread apart and not consistently placed, the data was not as accurate as needed for this process.
A discussion between the parties illuminated that a more shallow depth of ‘slice’ would illuminate the penetrations more clearly, as shown in Figures 6 and 7.

![Figure 6: Slice ‘thinned’ to 1”](image1)
![Figure 7: Same slice with factory joints and penetrations overlaid](image2)

Test 2

In order to correct the inaccuracies in Test 1 (DT1), changes were made to the scanning process. A series of four scans were taken on a different project site, with distance from the plane of the partition and distance between scans controlled. A 2x2 matrix was used to define simple variable control, in hopes to illuminate tendencies toward more accurate data collection. The diagram in Figure 8 shows the nomenclature for scan spacing on the x axis of 4 feet and 10 feet, and the y axis shows distance from the plane of the slice at (nearly) 0’ and 4’. Four feet was chosen for control of distance from the slice plane in that most commercial corridors are 8 feet wide, speculating that if this distance proved accurate, then a single set of scans could capture both sides of the corridor. Four feet on center scan spading was chosen based on typical drywall sheet widths, and ten feet on center scan spacing was chosen to push the limits of the scan resolution. By way of example, the set of scans taken at four feet from the slice plane and ten feet on center were named “04_10.”
Each of the scans was taken with the same ‘medium’ resolution settings, and all but the last included the capture of photographic images. The last session removed the images to test the speed differential in the scanning process. Removing the images yielded a 10 minute decrease in time taken to perform the scan set.

After scanning and collecting the data, the same process of extraction and registering the data was taken. Once the data had been registered and processed, the data was imported into Revit Architecture. This was done because the shop drawings can be created quicker and more effectively than in Cyclone. In processing the data, only one board was processed from each scan (Figure 9.) For comparison, the same board was used in each of the four target datasets. The comparison yielded predictable results. It was anticipated that the 00_04 and the 04_04 scan would prove to be the most accurate of the scans, which was indeed the case. As the spacing progressed to the ten foot spacing, the accuracy and the detail dropped drastically to the point that the data was not effective in relaying the information needed to create the shop drawings.
Focusing on the 00_04 and the 04_04 scans, a comparison was made between them and the actual field measurements in the horizontal dimension to the penetrations, shown in Figure 10. The table shows the comparison of scan-produced dimensions versus the actual field dimensions, their delta and average discrepancy.

<table>
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<th>Penetration #</th>
<th>Drywall Test</th>
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<th>2</th>
<th>3</th>
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**Figure 10: Comparison of shop drawing and field condition penetration layout**

**Test 3**

Following this comparison, a third set of scans was performed on an eight foot section of wall on the same project site as the second test, and that had multiple penetrations in the ‘top out’ drywall. To expand the pilot scope, this scan sought to confirm the results in Test 2 as well as to expand the vertical scope all the way to the structural floor deck to include finished penetrations as well as door openings. Based on the results from Test 2, the 00_04 spacing was chosen to be the scan set for the operation.

Test 3 was performed with the intention of producing shop drawings that would be used the drywall subcontractor to cut the drywall based solely on the drawing produced by the scan. This process was conducted in the same way as described in drywall test 2. The 00_04 method was used on an eight foot section of wall that contained an HVAC penetration, multiple plumbing penetrations, and a door frame. This test was also set up to capture the entire height of the wall from floor to metal deck, to also evaluate whether the process could be used to for fabrication below the ceiling plane. The shop drawing was also developed in Revit Architecture, similar to those in Test 2.
Compared against field conditions, the results from test 3 were quantitatively similar to those from test 2, suggesting that the concept was indeed viable.

CONCLUSIONS

This study has presented many unique issues from which several observations can be made. As for nuances, the determination that a 00_04 scan is the most accurate model as tested is significant as it relates to projecting labor efficiency of the concept. The scanner is rated to be accurate to 3mm at 900 meters. This accuracy is not ‘linear,’ and in fact in some cases even grew at short ranges. From the test 2 iterations, however, it appears that shorter spacing and close proximity to the wall is necessary to obtaining quality data that is useable.

In terms of the scanning process, it should be noted that the 00_04 configuration is not the most effective method for full height scans. One problem that was encountered is the loss of data on the door frames for Test 3. The proximity of the scanner to the wall cuts off data that is essential to the shop drawing collection. A recommendation would be to use a hybrid system, using the zero spacing whenever it is felt that no data will be lost. It is better to use the four foot spacing when objects like door frames are encountered so that the door frame can be captured and no data is lost.

The shop drawing development process is not for an inexperienced user of scanning, or one who is unfamiliar with the construction process in context. The user must setup the Revit file prior to the development of the drawing. This included importing the scan data into the project. The user must then analyze the data based on orientation within the Revit file. Sections or elevations must then be created and adjusted based on the desired cut of the wall, and requires interpolation based on the type of penetration, e.g. duct, pipe, conduit. At the moment, this is a time intensive process. After the section or elevation is created, the user must use detail lines to create the shop drawing. After the drawing is completed the user must then dimension the drawing.

In general, the researchers believe that the concept is indeed viable, and that with technological improvements to the scanning process and the shop drawing development process, short range interior scanning could be viable, and have dramatic impact on some of the most repetitive processes in commercial construction. This pilot provides credible data to compel further exploration of the technique.
REFERENCES

Akca, D; Freeman, M; Sargent, I; Gruen, A (2010). “Quality Assessment of 3D building Data”, The Photogrammetric Record. December 25(132), 339-355


