Defining an existing prefabrication workflow to identify measures for increased labour time utilization rates

J Cribbs¹, S Root²
¹ Department of Construction Management, Wentworth Institute of Technology, 550 Huntington Avenue, Boston, MA 02115; PH (617) 989-4909, USA
² School of Sustainable Energy and the Built Environment, Arizona State University, 660 S. College Avenue, Tempe, AZ 85281; PH (480) 965-3589, USA
E-mail: cribbj@wit.edu

Abstract. This paper analyses the current operations and labour utilization rates for a project team engaged in the prefabrication of exterior wall panels, in an existing manufacturing facility in Tempe, Arizona. A current state process is defined for the BIM-to-install process of each exterior insulation and finish system (EIFS) wall panel. Through analysis of the current state, it is found that only 17% of time was spent directly modelling components meant for prefabrication. The remaining 83% of time engaged in modelling is subject to optimization. Based on these findings, a discussion is presented regarding in place scheduling procedures, model and data management protocols, and field to shop verification/validation measures impacting modelling activities. Finally, a presentation of a series of future workflow interventions intended to improve labour utilization rates for modelling and shop personnel while enabling the internal shop ideal for “mass customization through prefabrication” is provided.

1. Introduction

1.1. Research Question and Definition
The construction industry is undergoing a paradigm shift from traditional, on-site methods of assembly to more of a focus on engagement of technology enabled assembly methods and related offsite construction techniques such as prefabrication, preassembly, modularization and off-site fabrication [1]. Much of the offsite construction techniques currently deployed by industry leaders are driven through the use of Building Information Modelling tools and workflows [2]. These techniques seek to address issues related to skilled labour shortages, schedule compression and demands, jobsite constraints and logistical issues, safety concerns and minimal access to construction work areas [3]. According to surveys undertaken by the BIMForum organization, prefabrication has seen a major growth since 2016 in response to anecdotal project efficiency gains. However, direct quantification of labour time spent on 3d modelling in support of prefabrication efforts is not well understood or defined.

This research sets out to understand the current state workflow of an existing manufacturing facility for prefabricated wall panels. More specifically, the research seeks to quantify labour time utilization rates of the building information modelling team engaged in the prefabrication process. The facility under study is located in Tempe, Arizona and the focus of operations within this facility is to prefabricate exterior insulation and finish system (EIFS) wall panels for just-in-time (JIT) [4], [5] delivery to various construction sites in the southwest region. Currently, the facility engages internal building information modelling (BIM) processes to create shop drawings which are utilized in the manufacturing process. This research seeks to understand the amount of time utilized in creating accurate and usable BIM’s for this manufacturing undertaking. The initial driving question for the research team is as follows:
“What is the ideal modelling workflow to enable mass customization through the engagement of offsite prefabrication?”

This question seeks to provide insight into how a modelling process can allow for design freedom when prefabricating, as well as how to close the loop on ever-changing site conditions once the panels have been installed. The remainder of this paper outlines the current state of operations for the location under study and identifies data collection processes deployed to quantify the amount of time spent in the building information modelling phase of prefabrication.

1.2. Current State Panel Manufacturing Process

1.2.1. Physical EIFS (Exterior Insulation and Finish System) Manufacturing Process

The manufacturing facility at the focus of the case study is located in Tempe, Arizona. It contains 105,000 square feet of production space and 5,000 square feet of office space. The manufacturing floor is separated into the following six (6) sections: sub assembly area, production line 1, production line 2, production line 3, material storage area (i.e. Grocery Store) and panel storage and truck loading area [6]. The overall facility layout is shown below in Figure 1.

![Manufacturing Facility Layout](image)

**Figure 1.** Manufacturing Facility Layout [3] – (Included w/ Authors Permission)

Production line 2 is the main EIFS panel assembly line of focus for this research and it is split into a total of 24 distinct process stations as follows [6]:
- Station 1 – Framing
- Station 2 – Waterproofing
- Stations 3 through 6 – Drying stations for applied waterproofing
- Station 7 – EPS foam application
- Station 8 – Architectural detailing
- Station 9 – Foam rasping and levelling
- Station 10 – Basecoat and fiber mesh application
- Station 11 through 13 – Drying stations for cementitious basecoat
- Station 14 – Sanding and skim coating
Station 15 through 17 – Drying stations for skim coat
Stations 18 through 20 – Finishing
Stations 21 through 22 – Drying stations for finish coat
Station 23 – Stacking and staging of finished panels
Station 24 – Loading of finished panels for delivery

1.2.2. Current State Digital Manufacturing Preparation Process

The manufacturing process for EIFS panels begins with preparation of panel shop drawings using a Building Information Modelling (BIM) interface. The digital process engages parametric attributes of model authoring software (ie. Revit) to generate geometry and an external software application plug-in (Structsoft Metal Wood Framing) to read the model data and populate sheet sets with standardized framing sizes, spacing and connection details. While this plug-in allowed for initial automation of manufacturing standards to be overlayed onto the model, the final detailing process to generate fabrication sheets requires heavy manual coordination between the modelling team and structural engineer [6]. The physical result of the BIM process is a dual sided shop drawing that fits the constraints of a standard 11” x 17” printout sheet. The front side of the sheet contains panel elevations which are structurally dimensioned for framing fabrication requirements. The backside of the sheet contains EIFS elevations and focusses on laying out finish panel dimensions and architectural finish details such as reveals, reliefs and colour schemes.

2. Defining Current State labour Time Utilization Regarding BIM efforts

It is important to understand the current state labour time utilization rate for modelers engaged in the shop drawing process. The purpose of measuring this rate is threefold. First, to gain insight into the allocation of time dedicated to coordination between stakeholders to identify any areas where process changes could enhance the initial modelling process and streamline the panel/shop drawing model output as a result. Second, is to identify areas where manual processes are heavy time constraints in upfront modelling, in order to streamline, engineer out or automate these activities to increase overall productivity within the panel delivery system. Lastly, to begin understanding where time is spent in making an accurate, constructible model for panel fabrication, delivery and installation. From this final piece of insight, it will be possible to identify how best to close the data loop against changing site/field conditions.

This research was embedded in a case-study environment and utilized a mixed methodology for data collection and analysis. The research team engaged in participant observation to gain insight into daily operations of project team members and modelers. A series of unstructured interviews and informal discussions were also engaged to provide more focus to the areas of observation. The structure of these participant observations was borrowed from techniques deployed in “Workflow Management Using Building Information Modelling (BIM) for Prefabrication in a Construction Retrofit Environment” [7]. These unstructured interviews and informal discussions provided researchers with an understanding of how team members perceived the prefabrication process and their role within daily operations. With this knowledge, the research team could identify any deviations in working processes being practiced and those which were formally documented. Ultimately, these findings are out of the scope of this paper, as they are more closely related to fabrication line construction and not building information modelling efforts.

Following participant observation, a series of direct observations took place with the building information modelling team. These direct observations were specifically focused on tasks undertaken to model components which would ultimately be prefabricated within the facility. Again, techniques presented by Cribbs [7] were utilized for data collection throughout the direct observation period. The basis of the applied techniques was focused on the utilization of a pre-designed, categorical observation matrix, which separates physically observed modelling processes into three specific categories: direct modelling work (value added time spent modelling), support modelling work (necessary non-value-added time spent modelling) and any delays (non-value-added time spent...
modelling or waste). These categories are further broken down into 15 sub-categories to define typical activities engaged by modelers. All typical activities were pre-defined by the research team through an understanding of required tasks undertaken by modelers and these tasks were verified by modelers during an initial observation period which was not counted towards data collection efforts. Ultimately, the final observation matrix was utilized by researchers when physically sitting next to modelers and watching their workflow, over a specific randomized period of time. Every minute that was observed was categorized and tallied within the observation matrix as a single data point. Overall, the research team collected 367 data points in aggregate. Each data point is related to a 1-minute direct observation period which is summarized, notated and placed into a specific category within the observation matrix. Table 1 below depicts the adapted observation matrix used during observations.

Table 1. Table 1: Direct Observation Matrix (adapted from [7]).

| Direct Modelling                      | Support                                           | Delays                          |
|--------------------------------------|---------------------------------------------------|---------------------------------|
| Framing                              | Preparatory Work and (Drawing) / Model Set-Up     | Field Re-Verification / Shop Revisions |
| EIFS panel tickets                   | Design Package Review / Specification Review      | Re-Setup / Re-Drawing / Re-Modelling / Redlines |
| Dimensioning                         | Existing Conditions Coordinate Verification / Coordination | Inaccurate Existing Conditions |
| Sheathing, finishes, details         | Field Walk Verification / Field Modelling         | Waiting / Correspondence Needed |
|                                      | Internal / External Trade Coordination             | Personal                        |
|                                      | File Searching / Model Load/Download / File Sharing|                                 |

3. Measuring BIM use for panelization

3.1. Results of Data Analysis

3.1.1. Aggregate Modelling Time Utilization Rates

In analysing the initial data set, as expected, a substantial amount of time is spent engaged in support work for the modelling process. Figure 2 breaks out the aggregate time utilization rates across the highest tiers of categorization within the observation matrix: direct modelling, support modelling and delays (waste) in the process. Overall, 17% of total modelling time is spent directly modelling a component of the panel which will result in prefabrication. Delays were seen across the random sampling data collection process at a rate of 19% in aggregate. Support work becomes the largest component at a total of 64%-time utilization rate.
3.1.2. Aggregate Time Utilization Rates for Direct Modelling Activities

Further analysing the direct modelling time highlights that a large portion of tasks (51%) is focused on the generation of sheathing, finishes and final panel details for prefabrication. This large portion of the direct modelling process can be attributed to the highly manual process of inputting the model data. This is juxtaposed against the initially automated process of standardized framing details via the model authoring tool plug-in at 11% overall time. Finally, the generation of the actual EIFS panel ticket which will be sent out for fabrication takes the remaining 38% of overall direct modelling time. This breakdown can be seen in detail in Figure 3.

The most interesting area to focus on in analysing data is the support modelling category. 63% of total support modelling time is spent in the realm of internal/external coordination to verify model requirements. Again, this is a highly manual process of creating and verifying data from a 2d to 3d format and one which could be the focus for future streamlining of workflows through a model-based, project delivery system. The next area of focus is the verification of existing field conditions throughout the modelling process. In total, verification of existing conditions and then coordinating upcoming models to match these conditions requires the second largest chunk of support work time at 17%. Figure 4 provides a full breakdown of all support work modelling time utilization rates.
Finally, a review of delays in the system provides insight into areas of wasted time which should be reallocated to support work and/or direct modelling. Overall, 80% of wasted time is spent either revising shop drawings to match verified field conditions (after the initial process of modelling to match existing conditions, as stated above in the support work section), or re-modelling due to errors, omissions or issues identified during the manufacturing process. Figure 5 provides an overall breakdown of all delays in modelling.

4. A discussion: conclusions & future research direction
Findings from this research show that a significant amount of time is spent in augmenting automated model geometry to meet specific fabrication detail requirements. This signals the need for additional standardized geometric rules to be developed by the plug-in software manufacturer or prefabrication team which could be automatically applied to future models. Additionally, the coordination process related to matching field conditions with design conditions is seen to cause wasted time and effort which can ultimately be streamlined out of the process through revised workflows which close the construction loop. In short, it is recommended that the modelling team utilize a centralized, construction model that is constantly validated for on-site installation accuracy through the engagement of continuous LiDar scans. Upon successful installation of completed prefabrication panels, a LiDar scan should take place to push 3-dimensional, digital data representative of physical site conditions, back to the construction prefabrication team’s centralized model for use in continuous panel design and detailing. This process will enable up-front response to changing site conditions rather than downstream reaction via field modifications for completed panels.
While this research is focused on new construction processes, the methodologies for measuring labour time utilization rates are borrowed from a retrofit case study. This can be attributed to the changing conditions on site once the first panel is installed and the project continues in sequence. A retrofit environment is effectively created within this case study environment when attempting to close the modelling data loop and understand the implications of final field install of each panel against the perfect accuracy of an original, digital model. Therefore, the research draws upon the idea that the planning efforts for accurate geometry becomes the critical factor in success when dealing with a BIM for prefabrication workflow in any environment [7].

This research presents the beginning of case study efforts to optimize prefabrication workflows. The focus on upfront modelling seeks to understand where manual activities over-burden the workforce and create bottlenecks for manufacturing personnel downstream. This becomes extremely critical when looking into issues directly related to panel detailing and standardized framing techniques. If these areas require revisions after the initial panel drawing has been sent to the shop floor due to updated site conditions, the amount of time spent revising the model to react to these changes becomes critical in shop flow and output. Ultimately, these areas of modelling can cause a delay in manufacturing which will transpose to the project site.

The next steps in this research are to intervene where the manual modelling activities are heaviest and undertake a second round of observations. The research team intends to engage a similar workflow to that of “prefaBIM” [7] and adapt the overall ideal state to meet the requirements of this manufacturing facility.

Following this adaptation and validation process, the direct observations will follow individual panel drawings through the shop floor to begin defining the critical data involved with the manufacturing process. With the help of shop floor cameras utilizing artificial intelligence software, data collection related to individual panel flow along the assembly line floor can be semi-automated to allow for a more robust data set for review, intervention and optimization.

4.1. Final notes: research limitations
This research is limited to the requirements of this specific case study environment and the current personnel involved with the modelling and manufacturing process. Currently, there are two dedicated modelers involved with EIFS panel shop drawings. Both modelers were observed throughout the data collection process and all results were aggregated for an overall look at process requirements. It is noted that the study of a single factory is a limitation, this prefabrication facility is on the cutting-edge of this construction technique and serves as a suitable baseline for future comparison and scalability of best practices. Future research seeks to identify similar prefabrication facilities for identical study and comparison.

5. References
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