*Cost and Efficiency*

# Quantifying MEPFP Mass-Timber Trade Efficiency Through Vertical Mechanical Fastener Analysis

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*Touted attributes of mass-timber structures include its efficiency in both erection and labor productivity. These efficiencies are a result of differing methods, induced by varying contractors, and are impacted by site specific variables. This study explores efficiency related to overhead fastener applications installed by MEPFP trades in a mass timber frame vs. reinforced concrete. Fastener installation time in an overhead rebar reinforced concrete beam is compared to that installed in a mass-timber structural beam to determine efficiency disparities (if any). Two standard sets of fasteners are compared in the differing materials: one for heavy (SAMMYS) and the other for light duty applications (FNL sharp point screws for CLT and ITW Read Head Tapcon for concrete). A total of sixty fasteners were installed, consisting of two sets of fasteners, installed in both concrete and mass-timber. Results were analyzed with two independent t-tests to determine statistical significance and mean difference in time taken for fixing between fastener and material type. The study found that heavy-duty conventional overhead concrete fastener installation takes significantly longer (Fastener A-Conc. M=12.82 seconds) than mass-timber fastener installation (Fastener A-MT. M=1.01 seconds), $t(26)=38.72$, $p=<.001$. Additionally, light-duty fasteners share similar results in concrete (Fastener B-Conc. M=12.18 seconds) compared to mass-timber (Fastener B-MT M=2.32 seconds) conditions; $t(23)=33.56$, $p=<.001$. This study provides evidence that fastener types affixed to the mass-timber superstructure offer significant time savings per overhead fastener installation, when compared to traditional concrete structures. These results can be used for construction planning, productivity rates databases, and cost analysis.*

Keywords: *mass timber, MEPFP, labor productivity, fastener*

## 1 Introduction

Commercial mass timber (MT) structures are proliferating in every corner of the United States. By September 2023, there were 1.934 multi-family, commercial, or institutional mass timber projects in progress, or constructed (WoodWorks, 2023). The spread of this material and methodology is attributed to several factors including the rising demand for more sustainable materials and the continual pursuit for increasing efficiency in the construction industry, which culminates in the reduction of embodied carbon. Mass timber proponents have argued that this methodology increases efficiency, it is a faster construction method, and it is a more sustainable alternative to the other traditional materials (concrete and steel) (Mirando & Onsarigo, 2022; Harte, 2017; Kremer & Symmons, 2015). These authors have argued that MT is not only faster to erect, but also beneficial to subsequent trades. For example, CLT panels can be pre-engineered, fabricated and delivered with mechanical, electrical, plumbing and fire protection (MEPFP) penetrations (see Figure 1) eradicating the need for on-site drilling. It is also faster and easier to install MEPFP fasteners in wood than other alternative materials. While this argument has been made in literature, there is no scientific study conducted to test that claim and give a proven and reliable estimate of the efficiency improvements that MT affords. This study compares the production rates for installing MEPFP fasteners for threaded rod hangers in mass timber and reinforced concrete.

**Figure 1:** CLT Ceiling panel with pre-drilled penetrations

## 2. Overview of Mass Timber

A solid piece of lumber typically has critical strength-limiting defects such as knots, grain deviations, splits, checks, or decay, which tend to concentrate in a single area of the lumber, making that part of the lumber the weak spot and where the wood is most likely to fail. These defects make lumber structurally unpredictable and, consequently, difficult to design with, especially when high loads are involved. Engineered wood products are designed to distribute these weak spots across the entire wood, resulting in a stronger product with predictable strength characteristics.

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Engineered Wood Products include structural building materials such as plywood, oriented strand board (OSB), laminated veneer lumber (LVL), wooden I-joists, and mass timber. Massive or "mass" timber is a category of framing styles typically characterized using large solid engineered wood panels for wall, floor, and roof construction. Mass timber consists of multiple solid wood panels nailed or glued together, providing exceptional strength and stability. There are various types of mass timber including cross-laminated timber (CLT), nail-laminated timber (NLT), glued-laminated timber (GLT), dowel-laminated timber (DLT) and structural composite lumber (SCL). The ability of these engineered lumber to carry large loads has made it possible to use mass timber for construction of larger and more complex structures, including high-rise buildings. Figure 2 is a picture from a project that utilized glued-laminated timber for its beams and columns, and cross-laminated timber for its floor panels.

**Figure 2:** INTRO Cleveland

**3. MEPFP Trades**

It is common construction knowledge that the critical path in construction projects always includes mechanical, electrical, plumbing, and fire protection contractors (MEPFP) (when they are specified to be included), or some element of those combined trades. These special sets of trades install critical systems in the structure that have a big impact on peripheral trades as well. Subsequent drywall and other finish contractors require the timely completion of these systems before they begin their work. This highlights the importance and impact these trades have on successful completion of commercial construction projects and provides the perfect place to start analyzing efficiency. This study focuses on these critical systems trades that require the installation of overhead support systems. Examples include ductwork strapping, fire protection line hangers, electrical/fire alarm conduits, cable harnesses, plumbing waste and supply lines, cable trays, and more. Consider (Figure 3), taken from the test area, which shows how elaborate and numerous overhead systems can be. The trades that install these systems have critical importance to driving efficiency on the project.

Competent project teams look for ways to positively impact critical path line items on their projects. What makes critical path items so important is the effect they have on the overall project schedule. A reduction in the duration of a critical path activity often translates to a reduction in the overall duration of the project. As mentioned above, MEPFP trades are often of the critical path of construction schedules and are consistently involved throughout the construction phase. Additionally, due to the specialized nature of their work, these skilled craftsmen are some of the highest paid trades on construction jobsites. The unique makeup and specialized requirements of MEPFP contractors make them critical to project success. Efficiency at the MEPFP level can have major positive effects on commercial construction projects, hence the focus of this study.

**Figure 3:** Overhead MEPFP Systems

**4. Methodology**

The main purpose of this study was to determine the effect of mass timber construction on efficiency of MEPFP fasteners installations. To achieve this, the study compared productivity for the installation of fasteners for threaded rod hangers in both steel-reinforced concrete ceilings and cross-laminated timber (CLT) structure. This study utilized an observational and time-based quantification approach to gather field installation data on the job site. The team observed sixty successful installations of overhead fasteners in the two material types and recorded the time of each installation. This process is explained in detail in the data collection section. Once the data was collected through the observational approach, it was analyzed using SPSS as described in the data analysis section.

**4.1 Purpose and Research Design**

It should be noted that the research design was grounded in replicating field conditions as closely as possible. This involved installing the fasteners in an existing mass timber building at a location and height that other existing fasteners were installed, and using the equipment and skilled labor that would typically be used for these installations. The same was replicated for installation in reinforced concrete. Input from the union foreman installing the fasteners was integral in understanding their installation process, tools used, and typical issues. The team met prior to the installation to get an understanding of the industry's process, different tools that are utilized, fastener types, and processes that critical trades go through. Choosing validation methods in construction research can be challenging for several reasons, especially since humans are involved in every aspect of construction projects (Liu, Shahi, Haas, Goodrum, & Caldas, 2014). Using the union foreman's experience of over seven years, a typical overhead installation process was replicated.

The main purpose of this study was to determine the effect of mass timber construction on efficiency of MEP installations. To achieve this, the study utilized an observational case study approach and available statistical tools to compare productivity of installing threaded rod hanger fasteners in both reinforced concrete and cross-laminated timber ceilings. There are up to seven types of observational studies, which can be used independently, or in varying combinations. This study deployed (and aligned best with) a structured observational case study, involving a structured environment that was more controlled than the natural environment, but that closely mimicked actual field conditions. The study differs from an experimental study in the fact that the researchers did not want to influence or intervene with the installation process, simply observed, and recorded the process.

Two identical spaces in the same building, one with a concrete ceiling and the other with mass timber (cross-laminated timber) ceiling, were used to conduct the experiment. A total of 60 threaded rod hanger fasteners were installed:

1. Fifteen (15) heavy-duty fasteners were installed in both concrete and CLT ceilings.
2. Fifteen (15) light-duty fasteners were installed in both concrete and CLT ceilings.

Fasteners in concrete were installed using a dual-motion process: 1. pre-drilling and 2. installing the fastener, while those in mass timber utilized a single-motion process. Both processes were timed and tracked using video recording cameras and a stopwatch. Data collected is described in detail in the following subsection on data collection. Independent-samples t test was used to analyze the data to determine whether there is a statistically significant difference between installing fasteners in concrete and mass timber. The chosen t test is described in detail in the subsection on data analysis.

### 4.1 Data Collection

#### *4.2.1 Instrument*

Data for this study was collected through observation. Two video cameras with time and date stamps were used to capture the installation processes. In addition to this, two observers documented the times for each fastener installation using a stopwatch. In the first (Fastener A-Heavy-Duty) concrete application, two observers captured time data from the foreman installing the first fifteen (15) fasteners. The stopwatch was depressed when the pre-drilling started, and timing was concluded when the fastener was fully seated in the pre-drilled hole. Data for installation on the mass timber beam was collected in the same exact manner to maintain consistency (see Figure 4). This process was repeated for Fastener B-Light-Duty.

The data recorded on paper and video formats was harmonized and transferred to an excel spreadsheet and the variables were coded: material (Concrete - 0, MT - 1), Fastener type (Fastener A - 0, Fastener B - 1), and installation time (seconds). No outliers or missing/inaccurate data points were detected from visual inspection and the data was grouped and sorted for import into SPSS. See Appendix B for the raw data.

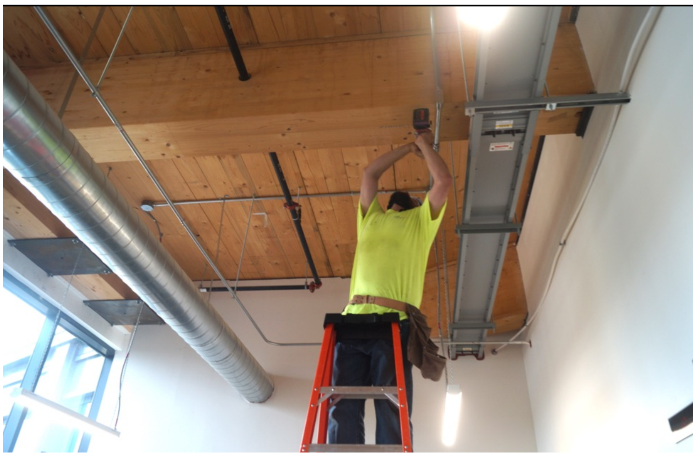
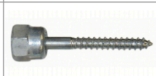


**Figure 4:** Foreman installing ⅜” fasteners into the bottom on the mass-timber beam.

#### *4.2.2 Fastener Types*

The fastener types used in this study deserve detailed breakdown of the exact specification, size, and imagery to show the vertical hanger system used. There are several products available on the market, and distinguishing the fasteners used in this study is important, as differing types/brands may elicit different results. Input from the union foreman was integral in understanding the different fastener types and in selecting the correct and comparable types to use in this study. The contractor recommended the “Sammy” system because of its simplicity, reliability and widespread use. While the researchers acknowledge that here are many other fastener types that could be used for these installations, experimenting with a variety of fastener brands to determine what effect (if any) they might have on the results was deemed beyond the scope of this study. See Appendix A for complete detail on the selected fasteners.

| Fastener Name/Model | Size | Material | Light/Heavy | Image |
|---|---|---|---|---|
| Fastener A – No. 8059957 | 5/16” D X 1 ¾” L | Concrete | Heavy |  |
| Fastener A – No. 8008957 | ¼” D X 2” L | Mass-Timber | Heavy |  |
| Fastener B – No. 51542 | ¼” D X 1 ¼” L | Concrete | Light |  |
| Fastener B – No. 31078 | #8-15 X 1 ½” L | Mass-Timber | Light |  |

### 4.1 Data Analysis

The collected data was analyzed using SPSS 29 (Statistical Package for the Social Sciences) software program. Descriptive statistics, which encapsulate the measures of central tendency, variability, and frequency distribution, enable us to understand the primary characteristics of the dataset. As mentioned above, a two-sample (independent) t test was also used to determine whether there is a significant difference in productivity when installing fasteners in concrete versus mass timber (CLT). This inferential statistical test determines whether there is a statistically significant difference between the means in two unrelated groups (Laerd, 2023). For the two-sample t test, it was predicted that mass-timber fastener installation would take less time than post-tension concrete installation process.

This study also used prevailing wage rates to estimate the cost savings resultant of the efficiency improvements. Since the test project was constructed with union plumbers, sheet metal workers, boilermakers, electricians, etcetera, averaging approximately $71.34 per hour (ACT Ohio, 2023), this estimated labor rate was used in the cost analysis.

### 4.4 Simulated Cost Saving

The total cost savings on fastener installation in a commercial mass timber project were estimated. The following assumptions were made:

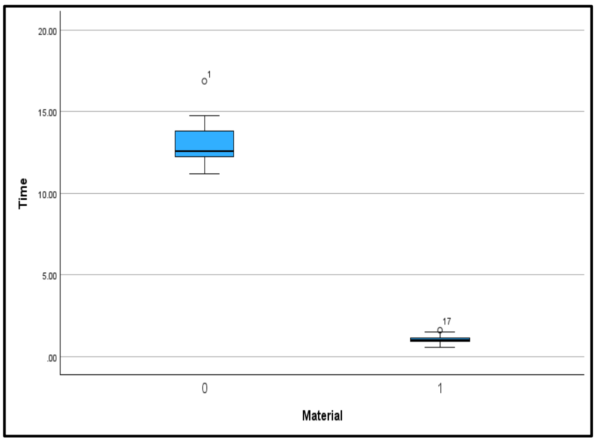
- Building size is 512,000 square feet. This is the actual size of the mass timber building selected for the study. The building is 9 stories, over 180 rooms, and is in Cuyahoga County, Ohio
- 0.4 fasteners per square foot for commercial buildings: both light- and heavy-duty. The number of overhead fastener installations in a project is dependent on numerous factors including size and weight of overhead systems, scope, end use, existing conditions, design, and owner need. However, the estimate used in this study was provided by the selected project's development team who determined the numbers from the BIM model showing overhead fastener counts and location.
- Average prevailing wage rates for two MEPFP trades in Cuyahoga County, Ohio were used: Plumber ($70.99 per hour) and Sheet Metal Worker ($71.68 per hour) (ACT Ohio, 2023).

## 5 Findings

Inspection of the Q-Q Plots showed normal distribution for both groups and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (see Figures 5 and 6). The independent t-tests were run on the data with a 95% confidence interval (CI) for the mean difference. Box plots for both samples identified outliers that were analyzed and removed. For instance, Fastener A exhibited a couple of outliers (Figure 5) consequently, installation 1 and 17 were removed from each material installation type. These outliers are a result of either human error and/or mechanical failure. In one case a tap-con sheared from over tension while in the other the installer fumbled the fastener.

### 5.1 t-tests

Two independent-samples t-tests were conducted to compare differing fastener installation speeds, in both concrete and mass-timber material applications. The first independent-samples t-test (Fastener A) was conducted to compare installation time for fasteners in concrete and mass-timber conditions. Test A produced a significant difference in the results for heavy-duty fasteners in concrete ($M$=12.82, $SD$=1.11) and mass-timber ($M$=1.01, $SD$=.23) conditions; $t(26)$=38.72, $p$=<.001, Cohen's $d$ (.80643). These results suggest that mass-timber fastener installation in the heavy-duty category is significantly quicker than concrete, by a mean difference of 11.08 seconds.



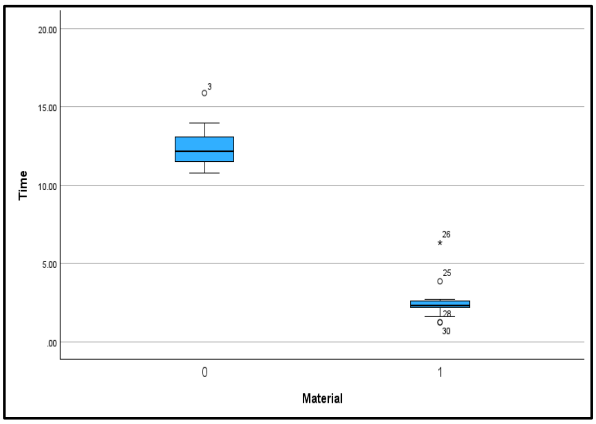




**Figure 5.** Fastener A Heavy-Duty Boxplot Comparison (Note: 0=Concrete and 1=Mass Timber) Figure 6. Fastener B Light-Duty Boxplot Comparison (Note: 0=Concrete and 1=Mass Timber)

The second test was conducted to compare installation time for fasteners in concrete and mass-timber conditions when light-duty fasteners (Fastener B) are used. This fastener size is used for hanging smaller items, and lighter items than those for Fastener A. Test B produced significant differences in the results for light-duty fasteners in concrete ($M$=12.18, $SD$=.93) and mass-timber ($M$=2.32, $SD$=.30) conditions; $t(23)$=33.56, $p$=<.001. (Figure 7) These results suggest that mass-timber installation in the smaller size, for lighter applications, is also significantly quicker than concrete, by a mean difference of 9.85 seconds.

### 5.2 Cost Saving

Using the quantities provided by the BIM model and development team, it was determined the commercial mass timber project had approximately 0.4 fasteners per square foot. This translated to 204,800 overhead fasteners for our selected building (512,000 square feet). Some of those fasteners were

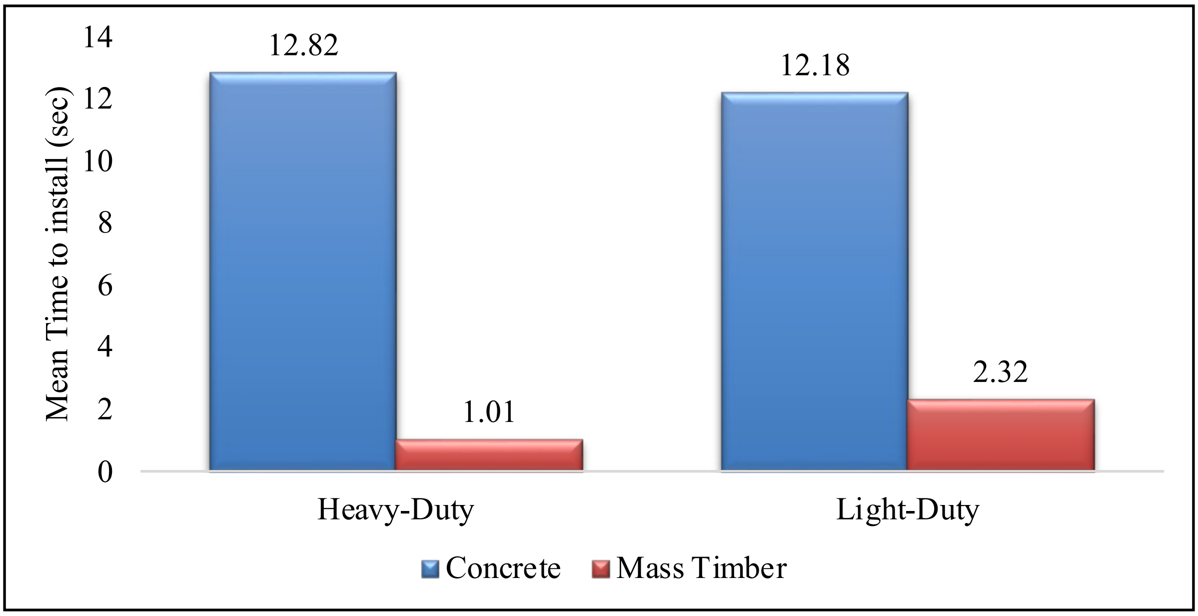



**Figure 7.** Mean Installation Time for Fasteners in Concrete and Mass Timber

heavy-duty and some were light-duty (See figure 7) presenting an average time savings of 10.5 seconds. The average cost of two different MEPFP trades (plumbers at $70.99 per hour and sheet metal workers at $71.68 per hour) was used in the estimate. The total direct time savings were calculated to be 595.34-man hours, which translates to $42,468.74 direct cost savings.

Peripheral cost savings should also be considered when estimating installation time for mass timber projects. For example, installers will not require costly silica mitigating hammer drills that cost $750 each, plus costly diamond tipped drill bits. Using a conservative estimate of ten hammer drills, across the MEPFP trades, equates to $7,500, plus $3,500 in drill bits for the entire project, totaling $11,000.00. Combined with direct labor savings, the total direct costs can be calculated as approximately $53,468.74.

## 6 Discussion, Example, Recommendations, and Conclusion

### 6.1 Discussion

The aim of this study was to quantify time and cost savings for MEPFP fastener installation in CLT versus reinforced concrete substrates. The following outcomes relative to this study will be outlined and discussed here. First, material type has a substantial impact on fastener efficiency. Secondly, fastener size and type can have an impact on productivity. Thirdly, mass timber is a better material to work with from an ergonomic perspective, translating to better health and longevity for the construction workers. Fourthly, installations in concrete generate considerably more noise, dust and debris which have associated environmental, health, and cleaning costs. The fifth point is that there are risks involved with drilling in reinforced concrete as opposed to installing fasteners in mass timber. Finally, there are cost savings that can be realized when installing fasteners in mass timber as opposed to concrete.

#### *6.1.1 Material type*

Material type has a significant impact on fastener installation efficiency. While this is not groundbreaking, the differences in installation time is incredibly large. For the heavy-duty fasteners, installation in mass timber was over 12 times faster than installation in concrete which included pre-drilling and insertion of a tapcon. For the light-duty fasteners), installation in mass timber was over five times faster than installation in reinforced concrete. While a difference in efficiency certainly was hypothesized, the time disparity was much greater than anticipated. One of the reasons for the significant difference in time is the fact that mass timber installations did not require pre-drilling while concrete installation did. This two-step process, coupled with the fact that the installer used two separate tools (a drilling tool and a driving tool) and had to switch between the two with each installation, are the primary reasons why the installation in reinforced concrete took much longer than in mass timber.

#### *6.1.2 Fastener type and size*

The type and size of fastener used can have an impact on the level of productivity in mass timber projects. In this study, there was a determined speed difference when installing smaller fasteners in the wood versus installing thicker screws. The difference is not as substantial as the one between mass timber and concrete, but still represents a 56% decrease in production when installing the light-duty fasteners as opposed to the heavy-duty fasteners. This slower productivity is attributed to the installer often fumbling with smaller screw sizes and having to slow pre-drill to get the fastener started. The larger screw afforded better grip and was consequently installed without as many slips or miscues. Evaluating the fastener type during the pre-construction phase of the project is critical to ensuring efficiency in installation.

*6.1.3 Ergonomics on the jobsite*

Construction has consistently been ranked as one of the most dangerous industries, not just because of the comparatively higher death rates, but also because of the number of injuries involved (National Safety Council, 2023). A substantial number of these are ergonomic injuries including back, hand, neck, and shoulder injuries. Employers have an obligation to protect their employees by providing a safe and healthy workplace. One of the suggested ways employers can do this is by applying ergonomic principles (OSHA, 2023) which may include methods and materials that promote these practices. This study shows that fastener installation in MT is ergonomically superior to concrete for several reasons. First, the installer only needs one tool for MT applications. Typically, this is in the form of an impact driver, with a hex head. Compared to concrete applications which require a much heavier, rotary hammer drill that can weigh in excess of 15 pounds, in addition to the impact driver. So not only does the installer benefit from less overhead motion in that no pre-drill is required, it is less demanding to penetrate as represented by the time difference outlined in the study. Certainly, the wear and tear on a worker's body is more difficult to quantify, however, it cannot be argued that less overhead repetitions, less demanding penetration requirements, and the use of lighter equipment have a positive impact on efficiency and health of the construction worker.

*6.1.4 Other health and environmental considerations*

Concrete penetrations create more noise, dust, and debris than wood surfaces. Pre-drilling into post-tension concrete often creates plumes of dangerous silica debris that can cause respiratory illnesses (Dement, et al., 2003). Modern tools with dust collectors, and respiratory protection can help mitigate inhalation risk at the cost of added weight and added annoyance. And even with the use of vacuum dust control measures, construction workers are still exposed to respirable silica (Cooper, Susi, & Rempel, 2012). The use of hammer drills for pre-drilling penetrations in concrete has also been known to radiate noise of 85 decibels or higher to the adjacent room, enough to cause hearing impairment (Carty, et al., 2017). These health and environmental issues simply do not exist when working with mass timber surfaces.

*6.1.5 Other associated risks*

There is significantly more risk in penetrating reinforced concrete overhead slabs and beams. Firstly, both post-tensioned cables and rebar reinforcement are at risk of being touched by drill bits and fasteners. The fasteners in this study penetrated up to 2", which was right around where the lower reinforcement steel bars would be placed. In order to mitigate the risk of hitting a cable, we ran our test on the bottom of a rebar reinforced beam. However, one fastener hit a piece of rebar and sheared off the tapcon head from the force. Not only are cables and rebar at risk for being interfered with, conduit, in-slab heating systems and other hidden components, if not coordinated, could cause major issues. Those risks are not present in a mass timber setting as these components are not compiled within the flooring or beam systems.

*6.1.6 Cost Saving*

Based on this study, there is evidence of direct cost savings when installing MEPFP services in mass timber. Determination of the number of fasteners needed in a project can help estimate the direct cost savings, however these direct savings are only a proportion of the overall benefits to the project cost and schedule. There are potential resultant savings to subsequent activities and trades. It is also important to note that there are aspects of the job that are more difficult to quantify including the abandonment of respiratory protection and expensive silica mitigating techniques/tools in mass-timber applications. Similarly, reduced ergonomic impact should translate to less injuries.

**6.2 Conclusion**

Seconds add up, especially on the scale of commercial, high-rise construction. This study identified several important findings relative to mass-timber's efficiency in the critical MEPFP trades. The study determined that mass-timber surfaces provide a faster installation process in both fastener sizes, when compared to post-tension concrete. Furthermore, risk of damaging bits, fasteners, or hitting post-tension cables is mitigated in mass-timber applications. Readers can use the findings presented here for planning, cost, and scheduling purposes. Importantly, manpower efficiency rates can be added to historical cost databases. Project teams who invest pre-construction resources in evaluating fastener details and locations in mass-timber structures can benefit from the statistically significant data presented here.

**6.3 Recommendations**

*6.3.1 Industry Recommendations*

Project teams should pay attention to all aspects of the building process including the small details, especially in the case of processes that are on the critical path. This study provides data showing increased overhead fastener installation rates on mass-timber structures. Teams can use this information in several ways. This section outlines recommendations from the findings sections that could benefit the reader.

Teams should dedicate pre-construction resources to evaluating MEPFP fastener type and quantity to discuss time savings, potential monetary concessions from installation subcontractors, and to determine the impact fastener efficiency will have on the schedule. Fastener submittal data should not be rubber stamped from the construction manager as it often is, as this little detail could have cost and schedule ramifications, previously overlooked. Furthermore, integration of this data into a BIM model (where applicable) may help coordination and the estimator's ability to provide more accurate cost estimates.

*6.3.2 Future Research Recommendations*

Further research is required to understand the efficiencies (and potential inefficiencies) on mass-timber protects. Benefits of manpower efficiency exist beyond the reaches of MEPFP fasteners. A multitude of other aspects that are similar and/or related to this study can be examined. Another area that needs extensive research is health, safety, and ergonomic studies relative to overhead installation of these systems. Mass-timber structures immediately remove 50% of overhead penetrations, in friendlier material, with less payload on installers, and with less silica debris. Outside of the direct quantifiable costs, hidden costs like accidents and injuries should be examined and quantified.

*Conflict of Interest Statement:*

The authors whose names are listed above certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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