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Construction Productivity Comparison Between Cast-in-Place Concrete and Mass-Timber Framing: A Case Study of the Nation's Largest Mass-Timber Building

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One main barrier to the proliferation of sustainable mass-timber structures across the United States, is construction and development teams' unfamiliarity with scheduling and efficiently managing the construction of mass-timber structural system. A comprehensive understanding of the schedule associated with the construction of mass-timber versus typical concrete structures provides important data metrics for teams deciding on utilizing this material and method. This study compares simulated manpower loaded schedules of traditional concrete construction applications with that of a real-time, mass-timber construction project. The study produces practical outputs that highlight schedule efficiencies in mass-timber applications, when compared to cast-in-place concrete method. The study found that the mass-timber crew erected 2,323 square feet of structure per day, while a concrete crew would erect 1,825 square feet per day. Additionally, the study found that the concrete crew had more than twice as many workers as the mass timber crew with less production.

Key Words: Mass Timber, Productivity, Manpower, Concrete, Cross-Laminated Timber, Glue-Laminated Timber.

Introduction

In 1960, urban populations accounted for 34% of the global population. By 2014, urban populations had surpassed rural populations and accounted for 54% of the total global population (WHO, 2014). As of 2018, there were around 4.2 billion people (55.3%) in urban areas and 3.4 billion (44.7%) in rural areas (Ritchie & Roser, 2019). The number of people in urban areas continues to grow and is projected to increase by an average of 1.64% per year until 2030 (WHO, 2014). It is projected that the number of people living in urban areas will have increased to over 6 billion by the year 2050: up from 3.6 billion in 2011 (Macomber, 2013; Ritchie & Roser, 2019). The current and projected population increases have raised the demand for new urban buildings. To meet the demand for more built spaces, governments and developers must rely on construction alternatives that are fast, economical, and environmentally friendly.

The steady rise in the global population demands a proportional increase in production of goods and services to meet the increased need. Most of our production practices are harmful to the ecosystem and the world climate. A present argument is that human activity is very likely the cause of global warming evidenced since the mid-20th century. Some of the human activities including deforestation, burning of fossil fuels, and increased land use produce greenhouse gases such as carbon dioxide, methane, and nitrous oxide, which have caused much of the observed increase in Earth's temperature over the years (NASA, 2021). Faced with shortages of natural resources and the concern for protecting the environment, there is a shift to more renewable resources that are sustainable. The debate has largely shifted onto ways to reduce further human impact on the environment and to find ways to adapt to the change that has already occurred over the past several decades (UNFCCC, 2021). A huge part of this movement includes the sustainable use of renewable resources such as timber.

Over the past few years, tall wood buildings have been successfully constructed around the world. Proponents of mass timber construction have argued that building taller with wood is not only good for the environment because it reduces carbon emissions, but it is also a viable building method because it is cost effective, contributes to well-being with good thermal and sound insulation, and performs well under fire (FPInnovations and Binational Softwood Lumber Council, 2013). A major argument fronted by mass timber advocates is that the time-to-delivery of a mass timber building can be significantly shorter than that of the conventional methods. The manpower requirement for this construction method is also comparatively lower than that of steel and concrete (WoodWorks, 2021). A shorter schedule coupled with lower manpower requirement, can translate to cost savings and lower carbon footprint during the construction phase of the facility's life cycle. This paper analyzes the manpower requirement and production rates observed during the framing of the nation's largest mass timber building and compares it to the manpower and production requirements of a concrete framed structure. The building, located in Cleveland, Ohio, is a $145 million-dollar mixed use, multi-family, high rise building consisting of two hundred and eighty-eight (288) apartments, ten luxurious penthouses, and a multitude of retail spaces, including an event space.

Reinforced Concrete Structures

The first concrete-like structures began to emerge in southern Syria and northern Jordan around 6500 BC (Gromicko & Shepard, 2020). Overtime, technological advances have driven both quality and breadth of application. Currently, concrete is the most widely used material in the world (Chilton, 2016) and plays a significant role in nearly all commercial construction projects. The high strength of concrete (exceeding 10,000 psi in some applications), its ability to withstand harsh climates, its wider availability, and our knowledge of its applications continue to drive consumption even higher. The Fortune Business Forecast Market Research Report (2021) projects an 8.7% annual growth in the concrete market, as rapid urbanization bolsters demand.

Productivity on Concrete-Framed Structures

A main benefit of concrete's long history in commercial applications is the availability of data relative to production. Publications exist in both the purely academic and professional publications that offer robust results. Our study focused on the inclusion of publications that offer real-world case studies as their main data source. The literature points to the standard "pour-and-set" cycle that projects generally follow, dependent on site-specific factors. It is traditionally accepted that the standard production rate for concrete in multi-story applications is five to six working days (Kolchedantsev et al., 2019). The industry status quo is pegged at six working days per floor, depending on size and design (Pietz, 2017). Past projects like "Sixty 11th", a 28,000 square ft mixed use apartment building, based their plan on six working day pour schedules (Sibley, 2016). The cycles are clear due to the repetitive process and curing required for typical flooring applications.

Faster floor completion cycles are possible in certain applications. Grossman (1986) outlines a 2 day per floor, formwork and reshoring cycle. Specialty provisions and precise execution is required to achieve floor production rates in this range. Interestingly, existing studies discuss production in terms of floors in relation to working days. Presenting on speed of formwork placement, pouring, shoring makeup and repeat (Daniel, 2012). The lack of manpower loading, crew makeup, and universal production rates that provide more detail than "floor" cycle rates is important to note.

Mass Timber Construction

Massive or "mass" timber is a category of engineered wood products typically characterized using large solid 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. 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. The continual development and availability of mass timber products is increasingly providing opportunities for the use of lumber instead of steel or concrete in building large commercial and multifamily residential buildings (Anderson, Dawson, & Muszynski, 2021). Wood, unlike concrete and steel, is a renewable material when harvested sustainably. Sustainable forestry guarantees that trees are planted and harvested in a way that ensures the long-term health of our forests, while meeting our need for forest resources like wood. Sustainable forestry coupled with the practice of planting trees as a crop to be harvested for commercial use can massively contribute to the construction of more sustainable built environments (Onsarigo & Mirando, 2021).

Over the past few decades, mass timber has evolved from being a technologically feasible option to a viable alternative to reinforced concrete and steel construction (Evison, Kremer, & Guiver, 2018). In the United States, Mass timber is emerging as a viable option for developers. As of June 2021, there were five-hundred and forty-five (545) mass timber projects either under construction or completed, and an additional six-hundred and twenty-four (624) projects in the design phase (WoodWorks, 2021). The mass timber family of products includes cross-laminated timber (CLT), nail-laminated timber (NLT), glued-laminated timber (GLT), dowel-laminated timber (DLT) and structural composite lumber SCL). The project under study utilized CLT and glulam which are briefly discussed here.

Cross-Laminated Timber (CLT)

CLT consists of three, five, seven, or nine layers of dimension lumber oriented perpendicular to each other and glued together to form panels with superior strength (Figure 1). In certain cases, the layers can be nailed (nail-bonded solid wood wall, also called Massiv-Holz-Mauer or MHM) or dowelled (dowel-bonded CLT) together using hardwood dowels (Anderson, Dawson, & Muszynski, 2021). Because of the cross-laminations, CLT offers two-way span capabilities and is especially suitable for floors, walls, and roofs (reThink Wood, 2016).

Glued-Laminated Timber (glulam).

Glulam consists of dimension lumber that is placed and bonded together using durable, moisture-resistant adhesives (Figure 2). This engineered wood is usually used for beams and columns and can be used for other elements such as floor beams and roof trusses.

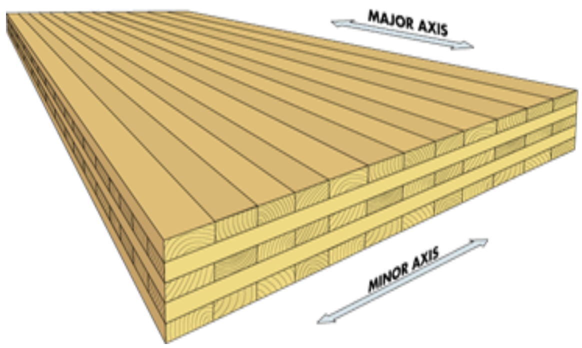

Figure 1. Cross-Laminated Timber (CLT) Panel (Breneman, 2016).

Figure 2. Glulam (Pehlivan, 2019)

Productivity on Mass Timber Construction Projects

Being a relatively new technology in the United States, research on mass timber productivity is limited. However, there is research on this topic relative to other global geographical locations that may not be directly replicated in the US industry. Forsythe and Fard Fini (2019) measured the productivity of CLT site installation in a multi-story building project in Australia. Their study found that the crew of twelve installed an average of 130m^2 (1,400SF) of mass timber per day. They used time-lapse photography to gather site assembly information and statistically analyzed the data to derive productivity rates in meters squared per hour. A significant difference between the Forsythe and Fard Fini (2019) study and the current study is that while Forsythe and Fard Fini (2019) analyzed both load-bearing and non-load bearing elements (mass timber wall and floor panels), the current study examined the load bearing elements of the structure (the current project does not include any mass timber wall panels, but included glulam beams and columns, and CLT floor panels.

In another research, Brisland, Forsythe, and Fard Fini (2019) studied three mass-timber multi-story buildings located in New South Wales (NSW), Australia. Their study found daily productivity of 111.15 m^2 (1196.4SF), 91.95 m^2 (989.7SF), and 66.75 m^2 (718.5SF) for towers A, B, and C respectively. While their study focused on the crane cycles productivity of the installation of mass timber, the current study focused on the entire crew installing the mass timber.

Methodology

When properly monitored and documented, construction projects can offer a plethora of valuable data including project performance, payroll, productivity, and material data. Traditional evaluation methods exist for examining these types of datasets to provide guidance for improved productivity, processes, materials, and systems. This section will outline the data collection process and techniques used to compare the productivity of mass timber and concrete framing.

In order to accurately compare the schedule of mass timber with concrete structures, a baseline production rate for concrete high-rise construction will be established. Since concrete structures have dominated the commercial construction market for so long, data relative to efficiency and schedule is widely available. Professional literature has identified the 6-day floor cycle as status quo, for typical high-rise construction applications (Kolchedantsev et al., 2019; Leung, 2003; Pietz, 2017; Sibley, 2016; Smisek, 2019). In addition to substantive literature review, a local, third-party concrete contractor was solicited to manpower load a schedule for the same zone erected with mass timber.

Data Collection and Analysis

The mass timber was erected in two distinct phases: zones A and B first, followed by zone C (See Appendix A). This was a new technology for the construction crew and consequently, there was an expected learning curve during construction of zones A and B. By the time they were constructing zone C, the crew had gained tremendous experience working with each other and were familiar with the mass-timber installation process, particularly the handling of CLT and glulam, and the different jointing methods. We therefore elected to use the zone C production rates in our comparison study.

Observation and recording of data for zone C was conducted from May 26, 2021, to July 1, 2021. Real-time data was collected through daily reports generated by the onsite foreman, digital photographs taken by two time-lapse cameras placed on the jobsite, and OpenSpace's 360-degrees construction photo documentation system. Daily reports capture the daily building conditions, weather conditions, manpower expenditures, production levels, and any other significant occurrence impacting construction on the respective day. Too often daily reports are prepared with minimal detail and are never reviewed by onsite management (Pogorilich, 1992). However, the research team in this project pre-planned the data collection process for the carpentry crew installing the mass-timber superstructure to ensure that the critical data was collected and recorded by the site foreman. This ensured detailed daily reporting of the mass timber installation process.

Schedule estimates using concrete were obtained through a number of sources. First, the concrete contractor who performed all concrete specifications on the project, produced a complete schedule, by zone of the whole structure of the project. The schedule simulation was produced as if the contractor would continue the structural work of the entire project. Crews, shoring, equipment, and management would continue from the foundational work that was contracted, and subsequently work floor by floor. The schedule simulation was conducted by one of the biggest concrete contractors in the region and is based on a multitude of past project experience.

Secondly, an extensive literature review was conducted to obtain professional and academic insights relative to floor sequencing and scheduling. The exhaustive literature review encompassed both academic and professional publications. Strength in professional publications relative to real world project data is paramount to consider and include in the data. The review focused on publications that utilized real-world case study projects that were of similar type to our case study.

A simple square-foot comparison of average mass timber installed by a carpenter in one day and concrete installed by a concrete worker was conducted. Evaluating production and efficiency at the square-foot or cubic-foot level is a common practice amongst contractors, architects, and engineers. For instance, unit cost method of estimating construction projects is an industry-wide accepted method of preparing approximate estimates (Peurifoy & Oberlander, 2014).

Findings

The broadness of floor cycle production rates was identified as a weakness of the existing literature. Our study closes the gap by providing extrapolatable, square foot production data. Overall, the mass-timber erection crew completed approximately 2,323 square feet of structural floor, columns, and beams per working day. The contractor simulated concrete structure, pegs overall production at 1,825 square feet, per working day. This represents a 24% production rate difference in favor of mass-timber. Additionally, the mass-timber structure was actually erected in 33 working days; significantly less than the concrete contractor plan of 42 working days.

Table 2

Mass timber v concrete production rates

	Mass timber	**Concrete**
Total zone floor area (square feet)	76,644	76,644
Floor levels	6	6
Square feet per level	12,774	12,774
Total working days	33	42
Total man-days	218	756
Total man-hours	1,744	6,048
Manpower average	6.6	18.0
Square feet per day	2,322.5	1,824.9
Square feet per man-day	351.6	101.4

On an individual tradesman production basis, the mass-timber crew member contributed 352 square foot per day of structural member installation. Conversely, the average concrete tradesman production is roughly a third, or 102 square foot of concrete structure installation per workday (figure 7).

A major finding includes the identification of the massive manpower discrepancy between the construction methodologies. The mass-timber erection crew averaged 7 carpentry tradesmen per working day. The simulated workforce more than doubled that of the actual and would average 18 varying tradesmen per workday.

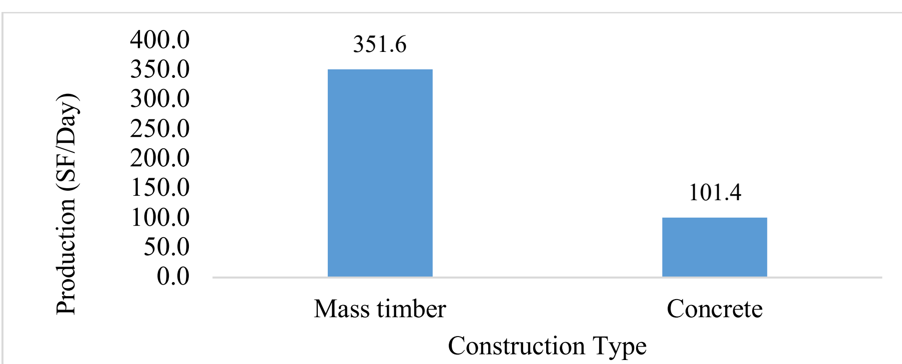

Figure 7. Daily worker production rates

Discussion, Limitations, and Conclusion

The study provides practical and verifiable evidence of increased schedule production rates in mass-timber structural applications versus traditional concrete structures. An overall 24% higher square feet production per day was identified on the real time mass-timber structure. The production difference equates to 9 working days, over 6 stories. The impact in terms of schedule is clear and quantifiable, allowing for broader discussion of the effect on subsequent trades and unforeseen schedule disruption. A major difference between the two construction methodologies is the presence of supporting framework in the concrete application. Cycle rates in the literature and subcontractor simulation represent the relationship between pouring the concrete and next level formwork installation. In concrete applications, each floor leaves behind a pre-engineering shoring system that restricts loading, subsequent subcontractor production, and lowers efficiency due to the repetitive handling of formwork. The mass-timber application requires no need for substantial, 28-day long engineered shoring systems on poured floors. Our project utilized non-structural 2” topping slabs on each CLT deck for sound and fire protection, prior to metal framing. In some applications, framing and MEP layout can begin immediately after setting the mass-timber CLT flooring structure. The lack of long-term shoring systems opens opportunities for trades to safely begin work with reduced lag. Combined with square foot efficiencies identified within this study, the schedule benefit extends past the mass-timber structural system to include faster floor availability for critical trades.

Just as important, this study identified a major manpower difference between the differing methodologies. Mass-timber required an average of 6.6 carpentry tradesmen per working day to erect the structure. The same concrete structure requires approximately 18 varying tradesmen per day, to install less square footage. Trade makeup and type is important to discuss as concrete construction processes require carpenters, laborers, pump operators, finishers, and testing agencies to complete floor cycles. Varying trades, processes, product sensitivity provide barriers to efficiency in concrete construction. These hurdles are less frequent in the consistent, smaller, more efficient carpentry crews.

The variability of site factors including crew makeup, shop drawing availability, delivery methods, location, weather, and managerial approaches can affect realized productivity across applications. It should be noted that construction projects offer unique variables that are difficult to completely quantify. Concrete structures have a broad range of floor, column and beam designs and layouts; as does mass-timber. A degree of variability should be considered when applying the results found here. Additionally, this study utilized data from a single project and a simulation of the same project. The results can be verified with comparison of multiple projects completed using both methods under study once these projects are available. This study does, however, create a baseline for such comparisons and can serve as a basis for more robust investigations.

References

Anderson, R., Dawson, E., & Muszynski, L. (2021). *2021 International Mass Timber Report.* Self-Publishing Services LLC.

Breneman, S. (2016). "Cross-Laminated Timber Structural Floor and Roof Design." Structural Design Jun 2016. Online. <https://www.structuremag.org/?p=10054>.

Brisland, R. E., Forsythe, P., & Fard Fini , A. A. (2019). Mass timber productivity-the significance of reduction in non-value add activities during on-site installation sequence. *Modular and Offsite Construction Summit.* Modular and Offsite Construction Summit.

Daniel, J. S. (2021). High-Rise Building Construction Cycles. Slideshare. Retrieved November 1, 2021, from https://www.slideshare.net/JihadDaniel/jihad-daniel-paper-for-high-rise-building-construction-cycle#:~:text=In%20cast-in-place%20multi-storey%20concrete%20buildings%20a%20%E2%80%9Ctypical%20floor%E2%80%9D,performance%2Fproductivity%20%26%20learning%20curve%20and%20advanced%20planning%20techniques.

Evison, D. C., Kremer, P. D., & Guiver, J. (2018). Mass timber construction in Australia and New Zealand—Status, and economic and environmental influences on adoption. *Wood and Fiber Science*, 50 (Special), 128-138.

Forsythe, P., & Fard Fini, A. A. (2019). *Productivity in Multi-storey Mass Timber Construction.* Sydney: Forest and Wood Product Australia.

Fortune Business Insights. (2021). Ready-Mix Concrete Market Size, Share & Industry Analysis, By Application (Residential, Commercial, Infrastructure, and Others), and Regional Forecast, 2020-2028. Mumbai: Fortune Business Insights.

FPInnovations and Binational Softwood Lumber Council. (2013). *CLT Handbook: cross-laminated timber.* (E. Karacabeyli, & B. Douglas , Eds.) U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, BSLC.

Gromicko, N., & Shepard, K. (2020). "The History of Concrete." *International Association of Certified Home Inspectors*. 15 November 2021. <https://www.nachi.org/history-of-concrete.htm>.

Grossman, J. S. (1986). Two-day construction cycle for high-rise structures based on use of preshores. Building Structural Design Handbook, 1–5. Retrieved November 15, 2021, from https://structurepoint.org/publication/pdf/CI-Two-Day-Cycle-Floor-Construction.pdf.

Kolchedantsev, L., Adamtsevich, A., Stupakova, O., & Drozdov, A. (2018). Measures to reduce construction time of high-rise buildings. E3S Web of Conferences, 33, 03062. https://doi.org/10.1051/e3sconf/20183303062

Leung, A.W. (2003). scheduling for high-rise building construction using simulation techniques.

Macomber, J. D. (2013, July-August). Building Sustainable Cities. *Havard Business Review*(91), pp. 40-50.

NASA. (2021, October 12). The Causes of Climate Change. Retrieved from NASA Global Climate Change: Vital Signs of the Planet: https://climate.nasa.gov/causes/

Onsarigo, L., & Mirando, A. (2021) Construction Productivity on Mass-Timber Framing: A Case Study of the Nation's Largest Mass-Timber Building. *Associated Schools of Construction Region 3 Conference.* ASC

Pehlivan, R. (2019, August 7). *Glued Laminated Timber (Glulam) and Its Advantages*. Retrieved from Aida Swings: https://www.aida-swings.com/glued-laminated-timber-glulam-and-its-advantages

Peurifoy, R. L., & Oberlander, G. D. (2014). *Estimating Construction Costs.* New York: McGraw-Hill.

Pietz, J. (2019, December 5). Five is the new six: Concrete pour cycle GLY Construction. GLY Construction. Retrieved November 14, 2021, from https://www.gly.com/blog/five-is-the-new-six-concrete-pours

Pogorilich, D. A. (1992). The daily report as a job management tool. *Cost Engineering, 34*(2), 23.

reThink Wood. (2016, August). *Mass Timber in North America: Expanding the possibilities of wood building design.* Retrieved from Think Wood: https://www.thinkwood.com/education/mass-timber-north-america

Ritchie, H., & Roser, M. (2019, November). Urbanization. Retrieved from Our World in Data: https://ourworldindata.org/urbanization

Sibley, T. R. (Ed.). (2016, August 23). Brasfield & Gorrie completes sixty 11th Apartments. Brasfield & Gorrie. Retrieved November 14, 2021, from https://www.brasfieldgorrie.com/news/brasfield-gorrie-completes-sixty-11th-apartments/.

UNFCCC. (2021, October 13). Race To Zero Newsletter. Retrieved from United Nations Framework Convention on Climate Change: https://unfccc.int/climate-action/race-to-zero/race-to-zero-newsletter

WHO. (2014). *Global Health Observatory (GHO) data: Urban Population Growth*. Retrieved from World Health Organization: https://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

WoodWorks. (2021). U.S. Mass Timber Construction Manual. In WoodWorks, *U.S. Mass Timber Construction Manual* (pp. 21-28). Washingron, DC: Wood Products Council.

Appendix A: Zone Depiction