Department of Defense

Potential Usage in Military Construction of Cross-Laminated Timber (CLT) A Next Generation Mass Timber Construction System

July 2021

Office of the Assistant Secretary of Defense
for Sustainment

The estimated cost of this report or study for the Department of Defense is approximately $2,540 for the 2021 Fiscal Year. This includes $0 in expenses and $2,540 in DoD labor.

Generated on 2021May25 RefID: A-B85F6D5

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

This report is in response to the request in the Joint Explanatory Statement, page 1764, accompanying the William M. (Mac) Thornberry National Defense Authorization Act for FY 2021 (Public Law 116-283), which directs the Secretary of Defense to provide a report, "at a minimum, a description of potential uses for innovative wood technologies, such as mass timber and cellulose nanomaterials, in new military construction; the sustainment and renovation of existing facilities; and an analysis of any barriers to incorporating these innovative wood product technologies into these areas."

Mass timber is category of structural systems using large panels of solid wood that are six feet or more in width or depth. They are used to form the walls, floors, and roofs of a building, as well as for some non-building uses, such as temporary mud matts for heavy equipment. There are several methods for joining smaller, commodity-sized wood members to form these large panels, such as Cross-Laminated Timber (CLT), Nail Laminated Timber (NLT), Dowel Laminated Timber (DLT), and Glue-Laminated Timber (Glulam). These building systems are not new, but market adoption between them has been varied over time. This report will primarily refer to CLT for simplicity noting that other types are not intended to be excluded from consideration.

For military construction and major renovations, the Department of Defense (DoD) does not mandate the use of specific structural systems. The choice of structural system is determined on a project-by-project basis by each project's team of design professionals in conformance with DoD standard criteria documents and guide specifications. These are produced collectively by the Army, Navy, Air Force, and National Aeronautics and Space Administration (NASA) for DoD. There are no DoD policies or standards that prohibit the use of mass timber. In fact, DoD led the industry by producing guide specifications for CLT, and updating the top-level wood specification to include CLT. Informative webinars and reference documents were also produced to provide the training and instruction to use CLT in practice. DoD also conducted physical testing to ensure that CLT meets the Force Protection / Anti-Terrorism requirements for usage. However, there are factors inherent in military construction that tilt the scales away from CLT being selected as the structural system of choice.

The "sweet spot" economically for CLT is mid to high rise buildings where it competes with heavier steel and concrete. Light-gauge metal stud construction is very economical but is only used as a primary structural system in relatively low-rise construction due to its load capacity limitations. The same is true for unit masonry. Military installations are not typically in urban environments where land area is at a premium so building taller buildings is not commonly justifiable. This makes stud and masonry construction more advantageous than CLT for military construction projects. (This economic comparison was true prior to the current market volatility as well and is not a result of COVID-19 transportation or international policy impacts.)
A lack of domestic availability has been a limitation with CLT, but that changed significantly over recent years. In 2015 when DoD built the first CLT hotel in the United States at Redstone Arsenal, the panels had to be shipped from Canada because there was no domestic CLT production. Now there are more CLT production facilities in the United States than in Canada.

Fire performance is also a consideration. Ironically, when exposed to intense fire, the outer layer of CLT will char, insulating and protecting an inner core of wood such that it will continue to hold after metal has softened and failed. However, CLT is nonetheless considered a "combustible" material in that the charring of that outer layer contributes to the heat and spread of the fire. Metal and masonry are non-combustible so they will not contribute to a fire even if they are more likely to fail due to one. One of the ways DoD protects buildings from structural failure during a fire is by limiting the use of combustible materials in its construction. Where combustible materials are used, such as finishes, there are limits on the maximum Flame Spread and Smoke Development ratings allowed. The combustibility of wood can be off-set by encapsulation in fire-proofing materials, but that brings added cost. Limiting the use of combustible materials in addition to providing fire suppression systems in DoD facilities may be seen by some as a bit of a "belt and suspenders" approach, but the mission of DoD facilities generally necessitates such conservative design.

Wood is a renewable resource, and CLT sequesters more carbon than released during its life cycle if disposed of properly. It is widely considered a much more sustainable material than steel and concrete. However, sustainability certification programs, such as U.S. Green Building Council's (USGBC) LEED program, look for wood products to be certified and stamped as from source using sustainable forestry practices. CLT manufactures are an intermediary between forest and project, and there is no provenance system in place to maintain certification. Also, a significant benefit of CLT manufacturing is that it can make use of waste wood that would otherwise be unsuitable for timber construction, such as forest stands killed by beetle infestations, construction clearing, or possibly uprooted by a natural disaster. Allowing stands of killed trees to simply rot contributes to Greenhouse Gas (GHG) emissions by the biogenic off-gassing of decay. Some rigid sustainable labeling requirements inadvertently limit the ability to use other, more preferable sustainable sources and practices. The entire roof structure of an arena for the 2010 Winter Olympics in Canada was built very sustainably from "beetle kill" wood CLT after a major Mountain Pine Beetle blight decimated millions of acres of forest, but that wood ironically could not be Forest Stewardship Council (FSC) certified as sustainable. None of the Environmental Product Declaration labels (EPDs) for North American CLT available on the market include traditionally sustainable cradle-to-grave criteria or FSC certifications. This is by no means an indication that CLT is not sustainable, especially compared to concrete and steel alternatives.

A policy that prioritizes sustainability attributes over metal and masonry could tip the scales toward the use of CLT for military construction but going against life-cycle cost effectiveness may still need to be enabled legislatively. Other life-safety liabilities inherent in prioritizing combustible materials over non-combustible materials would also have to be addressed at the higher levels before DoD would be able to broadly implement CLT as a structural material. Until then, DoD's use of CLT will likely remain anecdotal and where non-routine influences promote it. Once these hurdles are overcome, the military construction program would need an increase in Planning and Design funding. Currently, savings are being realized through standardized facility designs and details that would require re-design to accommodate CLT construction. DoD facilities built to date using CLT were built through external partners who provided the design documents for those projects.

II. REVIEW OF THE IMPLEMENTATION OF CLT IN DoD TO DATE

The Department of Defense has actively pursued innovative wood technologies, especially regarding CLT, in two ways. First, DoD, working in concert with private industry has been an early adopter of this technology, with 5 buildings of 389,376 total square footage built or under construction to date. Second, as part of this process the Department has conducted a series of key product tests, validating the ability of this technology to meet DoD's blast, fire, and construction standards and shared this knowledge with industry and building code authorities to advance market acceptance.

In the course of its work with CLT the Department has collected and analyzed key data regarding the technology's costs, labor requirements, sustainability features, and construction times. In general, CLT building construction increases skilled manufacturing jobs, while reducing unskilled labor on site, primarily due to reduced construction times. Prefabricated and modular construction systems such as these provide a safer and cleaner work site. The Department is also able to affirm the significant sustainability features of CLT constructed buildings. These features do raise initial construction costs significantly, although early indications are that this will be offset by much lower life-cycle costs, especially if consideration is also given to sequestered carbon and end-of-life material reuse.

As a result of these efforts, the Department can affirm the potential for CLT technologies to meet several military construction requirements, primarily for mid-rise buildings with common features such as barracks and administrative activities. Early research into the ballistic resistance characteristics of CLT indicate the potential for in-theatre use as Forward Operating Base/Contingency operating base facilities. The Department has very few buildings above 85 feet in height and those that do exist normally have a unique, special use. Given this the Department is not a good market for structures higher than 85 feet and cannot comment on CLT's applicability for such use cases.

The development of mass timber composites using nano-materials, graphene, fiberglass, metals, etc. may provide additional uses in the DoD environment.

DoD is still pursuing CLT as a potential building material because the current cost premium for initial construction costs for low-rise facilities is expected to decrease over time as the industry matures, or if financial incentives or other consideration is given to the positive sustainability attributes inherent in CLT construction such as lower GHG emissions, life-cycle energy savings, and the value of derived from end-of-life reuses.

III. INCREASING MARKET AVAILABILITY

A cross-laminated "composite lumber" product was first patented in 1923 in Tacoma, Washington. The product wasn't well adopted by the market at that time and the patent fell into the public domain. Much later, CLT was independently developed and fabricated in Austria and Germany in the 1990s, but this time became a versatile and robust engineered wood product on the market which is experiencing the early stages of adoption back in the United States.

Although CLT offers the construction industry a suitable, sustainable, and efficient alternative to traditional building materials, initial higher material costs remain a barrier to widespread acceptance as were most green-building initiatives of the past. Construction utilizing CLT requires long-distance and costly shipment from manufacturing facilities in Canada or use of the limited product currently manufactured in the United States. The type of fast growth timber used in the manufacture of CLT is widely and readily available in the U.S., and the material can be manufactured sustainably, unlike traditional mineral and ore-based alternatives. Support for manufacture of a regional or local CLT product would bring construction costs down, promote the adoption of an otherwise interesting and competitive material, and create efficiencies in local economies.

CLT is an engineered wood panel product consisting of multiple layers (i.e., plies) of dimension lumber or structural composite lumber aligned edge-to-edge, stacked orthogonally, and bonded on their wide faces with structural adhesives. CLT is often used as framing, and as walls, floors, ceilings, stairs, and roofs. CLT is now a well-established building material in Europe and Canada and has been gaining worldwide popularity as CLT manufacturing facilities spread in the 2010s. The use of CLT as a building material in the United States has been growing since the opening of the first North American manufacturing facilities starting in 2012.

Global and North American predicted CLT market value growth is projected to keep pace with the 2018 prediction of 13 percent to 16 percent year-on-year growth through 2024. The manufacture of CLT requires skilled workers, which creates well-paying jobs that strengthen regional and rural economies. CLT panels are fabricated offsite and are modular in construction assembly.

Prior to the construction of the hotel at Redstone Arsenal, there were no CLT manufacturers in the United States. CLT was sourced from Canada or Europe. Six years later, U.S. manufacturing facilities exceed the number of those in Canada. These are the current manufacturers of CLT in the United States:

- SmartLam North America, Columbia Falls, Montana and Dothan, Alabama
  www.Smartlam.com
- Katerra, Spokane, Washington
  www.katerra.com
- Vaagen Timbers, LLC, Colville, Washintgon
  www.vaagentimbers.com
- DRJ Wood Innovations, Riddle, Oregon
  www.drjwoodinnovations.com
- Kaliesnikoff Mass Timber, Inc., Castlegar, British Columbia – planning a U.S. facility
  www.kalesnikoff.com
- Freres Lumber Co., Inc. (manufacturers “Mass Plywood Panels”), Lyons, Oregon
  www.frereslumber.com
- Sterling, Phoenix, Illinois and Lufkin, Texas
  www.sterlingsolutions.com

- Structurlam Mass Timber Corporation, Penticton, British Columbia – a Canadian manufacturer with new plant in Conway, Arkansas, and sales and engineering offices in Portland, Oregon, Granite Bay, California, and Austin, Texas www.structurlam.com
- Binderholz GmbH, Fugen, Austria, developing a plant in Enfield, North Carolina, business locations in Live Oak, Florida, and a sales and engineering office in Atlanta, Georgia [binderholz | nature in architecture]

IV. DoD's PRIVATIZED ARMY LODGING EXPERIENCE

The Department of Defense has directly facilitated the construction of five medium size CLT buildings totaling over 350,000 square feet. To date there are the four Army hotels constructed by Lendlease, the Army's Privatized Army Lodging (PAL) program partner and construction firm. These four CLT structures include the Candlewood Suites® hotels at Redstone Arsenal, Alabama (92 rooms); Fort Drum, New York (99 rooms); Joint-Base Lewis-McChord (JBLM), Washington, (127 rooms) and Ft. Jackson, South Carolina (West Building 171 rooms).

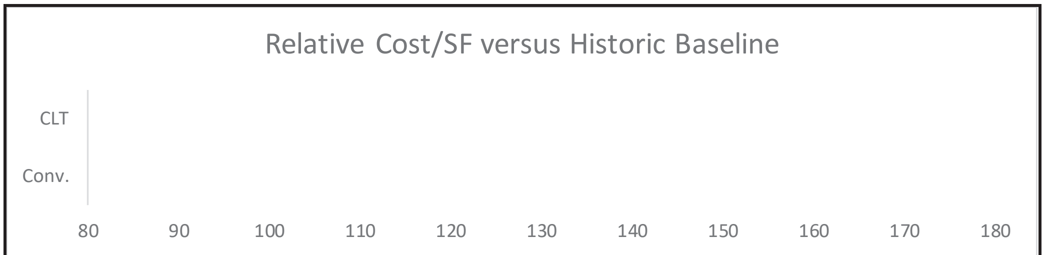
One additional CLT hotel is currently under construction at Fort Jackson, South Carolina, (East Building, 146 rooms) will be completed in July 2021. Pictured below is the handsome CLT-constructed Candlewood Suites hotel at JBLM, which was delivered in November 2019.

When the Army reviewed the construction data from the first CLT hotel – completed at Redstone Arsenal, it found not only that the project was completed 20 percent faster overall but also that the structure was built with 44 percent fewer personnel hours than similar hotels. The construction crew utilized just 11 people to assemble the prefabricated panels. The crew of three experienced carpenters and eight laborers (local combat veterans), and just one crane built the four-story, 56,415-square-foot hotel structure in just 45 days, 37 percent faster than traditional construction. Completed in December 2015, the project exemplified two of the biggest benefits of CLT: construction efficiency and speed of execution. The chart below summarizes the actual efficiencies captured in the CLT project versus the historical PAL hotel construction baseline.

PAL Portfolio	Typical New PAL Hotel (Actual*)	Redstone Arsenal (Actual)	Difference
Gross square feet (sf)	**54,891**	**62,688**	**14%**
Average # of employees	**18 (peak 26)**	**10 (peak 11)**	**-43%**
Structural duration (days)	**123**	**78**	**-37%**
Structural person hours	**14,735**	**8,203**	**-44%**
Structural production rate/day	**460 sf**	**803 sf**	**75%**
Overall schedule	**15 months**	**12 months**	**-20%**

*** PAL New Build Hotel Historical Average Source: Lendlease**

While use of cross-laminated timber resulted in significant construction process efficiencies, there were inherent financial costs that were higher. Various trade costs were reduced no doubt due to the prefabricated nature of the CLT projects. However, extensive testing of panels due to insufficient code coverage, logistics planning, and long hauls from manufacturing sites in Canada to Alabama added costs to this pioneering project. While the exact cost breakdown is proprietary information, it appears the initial construction costs for CLT PAL hotels was significantly more expensive on average than for a similar conventional hotel project on a per square foot basis, although their cost ranges overlap indicating that may not always be the case. Below is a comparison between similarly sized CLT and Conventional projects by year showing their relative vertical construction costs. It is very important to caution that there were many other variables at play unrelated to the choice in structural system, and this is too small of a sample to form a quantitative conclusion. Specifically, even though the average CLT project cost almost 23 percent more, some were less than their conventional counterparts. An external study comparing structural systems alone estimated CLT to cost only 2-6 percent more for low-rise construction.



Installation	Calendar Year Completed	Keys	Construction Type	Relative $/SF to Baseline
Redstone Arsenal	2016	92	CLT	111%
Fort Belvoir	2016	141	Conventional	128%
Fort Drum	2018	99	CLT	149%
Fort Bliss	2018	123	Conventional	95%
JB Lewis-McChord	2019	127	CLT	159%
Fort Carson	2019	128	Conventional	128%
Average CLT		106		139.7%
Average Conventional		131		117.0%
			Difference between Averages:	22.7%

CLT as a structural material becomes increasingly economically competitive as the height of the building increases. Both light wood framing and CLT are relatively stable as building height grows, in terms of cost/square foot, unlike non-wood building materials. While light wood framing is generally the least expensive option, it is not feasible for buildings built beyond a certain height. Traditional building materials such as reinforced concrete, concrete masonry units, or steel rise in cost as the structural height increases. With light wood framing not allowed by code above 85' or five stories, and non-wood materials price rising beyond the more stable CLT, CLT is left as the most economically attractive material at a building height of 8 to 18 stories (U.S. Army Corps of Engineers 2016, adjusted for 2020 Woodworks study).

V. DoD TESTING AND DATA SHARING: BLAST AND FIRE TESTS

In cooperation with industry (U.S. Department of Agriculture Forest Service's Forest Products Laboratory, Softwood Lumber Board, Woodworks, Lendlease and CLT manufacturers Smartlam, Nordic, and D.R. Johnson) the Department, through the U.S. Army Corps of Engineers and the Air Force Civil Engineering Center at Tyndall AFB, subjected CLT to a range of tests, which collectively demonstrate the product's ability to meet stringent DoD fire, anti-terrorism, and building durability requirements.

Terrorism is a growing threat for civilian and military buildings (e.g., iconic structures, corporate headquarters, military installation facilities and barracks), which is necessitating building designers to incorporate blast resistance into their designs. Protective Design Center Technical Report (PDC-TR) 18-02 Analysis Guidance for Cross-Laminated Timber Construction Exposed to Airblast Loading was publicly released to enable engineers trained in structural dynamics to analyze and design CLT structures for blast loads.

The orientation of the outermost panel plies is termed the “major strength direction” and that of the crosswise panel plies is termed the “minor strength direction”. Two grade classifications exist for CLT panels certified in accordance with ANSI/APA PRG 320-2018: Standard for Performance-Rated Cross-Laminated Timber – (1) “E” or engineered, which utilizes machine stress-rated (MSR) lumber in the major strength direction, and (2) “V” or visually-graded, which utilizes visually-graded lumber in the major strength direction. The specific combination of ply number, ply thickness(es), lumber species, and lumber grade is referred to as the panel’s “layup.”

As CLT panels are routinely used as load-bearing walls, it is important that the strength directions and phases of blast-load be considered when analyzing these panels for structural soundness. CLT panels comply with the Unified Facilities Criteria (UFC), which incorporates the requirements of the International Building Code (IBC) plus DoD-specific and anti-terrorism provisions. UFC 4-010-01 requires that inhabited DoD buildings constructed of mass timber structural systems be analyzed for air blast loads. CLT blast demonstration testing has been performed at Tyndall Air Force Base in Panama City, Florida. For CLT systems, the presence of multiple plies allows for measurable residual strength. The two-way action inherent in CLT provides a means for load distribution across the panel, thus limiting the damage at the location of peak applied load during a blast or similarly in the dynamic forces experienced in a seismic event.

When Lendlease and the Army were considering CLT for on-post hotel construction, the parties had to consider these UFC Anti-Terrorism and Force Protection (ATFP) standards. CLT was not listed as a conventional building type for meeting ATFP standoff, blast resistance and progressive collapse, so the design team gained approval from the U.S. Army Corps of Engineers Protective Design Center (USACE PDC). Lendlease, their design consultants, and the CLT manufacturer supplied extensive engineering analyses to prove compliance with the structure needed to meet the requisite ATFP standards. These analyses were subsequently validated by the in-situ testing at Tyndall AFB.

CLT provides excellent fire protection performance as well, generally quite similar to heavy timber. Further, due to the solidity of partition walls and floors when compared to traditional internal framing, CLT assemblies have few concealed internal cavities. This reduces the possibility of undetected spread of fire. Although the fire performance characteristics of CLT are generally suitable for Type IV construction, both the type of adhesive used and the thickness of each component layer affect the vulnerability to fire. CLT manufactured to ANSI/APA standards will have adequate fire safety performance in regard to the adhesive.

Full compartment fire tests with a two story CLT structure, performed at the ATFE test facilities in Maryland proved the resistance and resilience of CLT to a real-world fire event. The test structure was designed as a two-story apartment building and was fully furnished for the testing. The tests used exposed CLT and CLT encapsulated with gypsum wallboard in several configurations. The testing showed fire resistance of up to 3.5 hours for some configurations and a minimum of 1.5 hours overall.

The testing results were provided to the ICC ad hoc Committee on Tall Timber Buildings and used in their development of the mass timber provisions that have been included in the 2021 IBC, as well as the National Design Specification (NDS) and ASCE 7 design guides. Currently, DoD still uses the 2018 version of the IBC pending completion of a tri-service review and analysis of the impact of all the other changes between the two versions.

VI. CODE ADOPTION

In the performance-based (engineered) path, the design team provides specific calculations showing that the structural design meets code, including additional seismic considerations. A design must meet the requirements of ASCE/SEI 7 and NDS for Wood Construction in addition to the International Building Code. ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures (ASCE 7) contains code-required loading and analysis methods for buildings. The NDS for Wood Construction contains code-referenced standards for the design of structural wood materials and connections.

In 2016, the interdisciplinary committee International Code Council (ICC) Tall Wood Building Ad Hoc Committee began formulating building code recommendations for tall wood buildings. In 2018, the committee's proposals were approved for inclusion in the 2021 International Building Code. In 2018, Oregon officials issued the Statewide Alternate Method (SAM) No. 18-01, providing a prescriptive path for utilization in Oregon of the code requirements developed by the International Code Council (ICC) Tall Wood Building Ad Hoc Committee, before these code sections become part of the 2021 IBC. SAM allows for early technical consideration and approval on a statewide basis. Through a similar process, other states could adopt the recommendations prior to the 2021 IBC. The key recommendations of the committee establish four sub-types for type IV construction that allow for taller mass timber buildings up to 14-stories. Additionally, they require that mass timber CLT elements shall be tested and labeled for heat-performing adhesives in accordance with ANSI/APA PRG-320 standards.

The use of CLT as the gravity-resisting structure is well-established and allowed in IBC 2015. However, CLT's usage for lateral and seismic resistance currently requires an extensive performance-based code approval. Current research is defining a basis for lateral and seismic resistance for future building codes. The 2015 International Building Code allows for the use of CLT under prescriptive or performance-based approval paths. The 2021 International Building Code contains expanded code approved CLT options.

The 2015 IBC incorporated requirements for CLT as type IV construction (heavy timber) under the prescriptive path for approval. Heavy timber (type IV) construction is "construction in which the exterior walls are of noncombustible materials and the interior building elements are of solid or laminated wood without concealed spaces." CLT can also be used in type III (combustible) construction or type V (wood frame) construction. Usage beyond the defined allowances requires approval via a performance-based path for code compliance. However, the

2021 International Building Code will have expanded allowances and new building types for mass timber structures.

In the prescriptive design path, a building is designed to meet the building code's span table and specific detailing requirements to create a code compliant design. For instance, building type IV specifies required sizes and thickness of timber elements that will be fire resistive. Getting approval through the prescriptive path is relatively fast and requires fewer additional calculations than the performance-based path. The American Wood Council conducted a fire-resistance test on a load bearing CLT wall in 2012, the positive results of which contributed to the inclusion of CLT in the 2015 IBC. DoD adopted the 2015 IBC, and then the subsequent 2018 version. The new 2021 version will be adopted after the completion of a standard tri-service review and impact analysis.

VII. CONCLUSION

The Department of Defense recognized the potential for CLT to offer a more sustainable building material where steel and concrete have traditionally been used, and validated its ability to mitigate hazards associated with blast loads, and analyzed reported time-to-delivery, and life cycle cost benefits. CLT systems add further value due to their sustainability and light carbon footprint, ability to be accurately shop-fabricated, and speed of installation. By leveraging the Forest Service-funded testing and analysis guidance prescribed in PDC-TR 18-02, an engineer can collaborate with architects to facilitate the use of CLT by ensuring that specified panels can resist seismic loads and meet the requisite code and other DoD standards. There is a still current cost premium to the use CLT as a structural system in the military construction context and some projected long-term benefits have yet to be validated in the field. Nonetheless, as performance requirements requiring additional custom engineering and testing continue to be replaced by standardized code language and validated assumptions and the market matures, the use of CLT is expected to become more and more attractive. Currently, there is a spike in the market pricing for wood products with respect to other materials, but this appears to be an anomaly which will likely recede. DoD is continuing to monitor the market and provide guidance to our engineers and architects in the field. The economic forces tipping the scales away from CLT currently are external to DoD. DoD is prepared to implement CLT once these forces shift to the point where CLT becomes indicated as the most appropriate structural design solution for a project, all requirements considered.