CLT Demand Study for the Pacific Northwest

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1 Project Background and Objectives

1.1 CONTEXT
Mass timber, a collective term for several engineered heavy panel wood products, is an emerging building system in North America that offers a variety of benefits including lowering the costs of construction, supporting rural economic development, and—when sustainably sourced—reducing carbon emissions associated with climate change. Of the suite of lam-based, strand-based, and veneer-based mass timber products, cross laminated timber (CLT) and glued laminated timber (GLT) are of particular interest because of 1) the use of sawn lumber, 2) recent codes and standard adoption, 3) maturing technical research, and 4) general awareness by the architecture, engineering, construction, and building operation (AECO) community in North American markets. Because GLT is a mature technology in application and manufacturing, this study has a primary focus on the demand for emerging CLT panels.

CLT is a wood-based alternative to conventional construction materials, with building applications spanning from low- to high-rise construction. It is manufactured by pressing multiple layers of sawn or engineered lamstock and resin with alternating orientation to improve strength, size, and stability. CLT is highly adaptable because it can be made from many different species of wood — including those native to the Pacific Northwest. CLT can utilize small diameter trees, including timber associated with hazardous fuels reduction and other restoration activities. Applications include vertical wall and horizontal floor and roof diaphragms.

Originally developed in Europe in the 1990’s and used increasingly around the world, CLT production and construction as of 2016 is limited in North America. Nonetheless, growing interest in CLT and anticipated, expanded allowances for CLT-based construction in the 2015 International Building Code suggest a market will emerge.
1.2 CLT IN THE UNITED STATES
The first commercial CLT building in the U.S. was Long Hall in Whitefish, MT, completed in 2011. The Sauter Timber Production Facility, in Rockwood, TN was completed in 2014. This industrial production facility covers 9,000 sq. ft., has 23-foot-high walls, and is constructed from CLT roof and wall panels. The first known building in the Pacific Northwest to use CLT is the 45,000 square-foot International Community Health Services Shoreline Clinic, built in Shoreline, WA in the fall of 2014. CLT was utilized for its roof panels, which have large expressed overhangs. Washington State University has two buildings (Brelsford WSU Visitor Center, 2014 and PACCAR Environmental Technology Building, 2016) utilizing CLT floor and roof diaphragms over GLT beams on its main campus in Pullman, WA. Other notable U.S. buildings incorporating CLT, all completed in 2015, include the Cooley Landing Education Center in East Palo Alto, CA; the Chicago Horizon Pavilion in Chicago, IL; and the Redstone Arsenal Hotel in Huntsville, AL. In the latter, over 62,000 sq. ft. of CLT was used for walls, roof panels, and floor panels. Other projects combine use of CLT with other structural systems mostly for roof and floor diaphragms.

In 2015 D.R. Johnson Wood Innovations, located in Riddle, OR, became the first CLT manufacturer in the United States to receive certification from the American Plywood Association (APA) to produce structural CLT panels. In 2016, Smartlam Technologies Group in Columbia Falls, MT became the second U.S. manufacturer to receive certification. Multiple North American manufacturers intend to come online in 2017.

1.3 CLT DEMAND STUDY OBJECTIVES AND PARAMETERS
Projecting demand in the Pacific Northwest is an essential early step for establishing CLT industries in Washington State. To assess potential CLT demand, this study is comprised of three primary elements:

- Construction projection model by building type: How much new construction will occur in the Pacific Northwest?
- CLT utilization model by building type: How much CLT will be used in different types of construction?
- CLT diffusion model: What percentage of anticipated new construction will use CLT over time?

General parameters of the study:

- Geography: Washington, Oregon, Idaho, and Montana
- Relevant construction: Multifamily residential mid- to high-rise (4-17+ stories) and Commercial (4-17+ stories; at least 50,000 sq. ft.)
- Time frame: 20-year projection (2016 - 2035)

1.4 BACKGROUND - PROJECT TEAM
Forterra led the project team for this study. Principal Investigators (PI) Heartland LLC, the Washington State University Institute for Sustainable Design (WSU), and the University of Washington Center for International Trade in Forest Products (UW) conducted its research and analysis.
2 Data Sources

2.1 COSTAR
CoStar is a privately held, subscription-based third party data provider that captures the market fundamentals and development trends of the built environment. Using a combination of technology to access local assessor records, a network of brokers relies on CoStar to inform the market and its primary research team. CoStar touches all of the major metropolitan areas of the U.S. It captures over 4.5 million researched properties spanning all commercial property types, including office, industrial, retail, land, mixed-use, hospitality, and multifamily. This dataset captures the age of construction, building height, and total unit count for multifamily and total rentable square footage for all other commercial buildings.

2.2 NORTHWEST POWER AND CONSERVATION COUNCIL 7TH POWER PLAN
The Pacific Northwest region is unique nationally because of its abundant natural and physical infrastructure including forest resources and potential for hydroelectric and wind power generation. Because of the responsibility to regionally address power generation and ecological conservation, the Northwest Power and Conservation Council (NWPCC) was established to objectively coordinate and plan this balance. NWPCC’s modeling process was progressive early in its history in recognizing energy efficiency as an effective and equal mechanism to meet the region’s power needs. Including energy efficiency requires robust and statistically relevant assessments of existing building stock and details of building types, construction types, and building systems. These models inform ‘Power Plans’ that are updated every five years and project energy and building construction twenty years out. The 7th Power Plan was adopted February 2016. Two of the many assessments that are inputs to the 7th Power Plan are the Commercial Building Stock Assessment (CBSA) and the Residential Building Stock Assessment (RBSA). The CBSA and the RBSA are relevant to this study to establish characteristics and trends in our target office and multifamily building typologies.

2.2.1 NEEA 2014 Commercial Building Stock Assessment (CBSA)
To develop regional policy and planning related to energy generation and conservation in the Pacific Northwest, the Northwest Energy Efficiency Alliance (NEEA) sponsors assessment projects to collect statistically defensible data called the 2014 Commercial Building Stock Assessment (CBSA). This assessment establishes a detailed regional baseline of the existing state of commercial building stock. This data of existing commercial building stock is included in the 7th Power Plan projection models.

2.2.2 NEEA 2011 Residential Building Stock Assessment (RBSA)
The residential companion to the 2014 CSBA is the 2011 Residential Building Stock Assessment (RSBA). Of note at the time of this study, NEEA is updating the RSBA in late 2016.

Like the CSBA, the RSBA presents data for single family and multifamily buildings collected through statistical analysis, surveys, and site visit verifications. Unlike the CSBA, which presents data in both number of buildings and sq. ft. of floor area, the RSBA only presents data in number of buildings and number of dwelling units. According to the 2011 RSBA, distribution of multifamily units in the Pacific Northwest by building size indicate that, post-2000, approximately 58% are low-rise (1-3) stories, 24% are mid-rise (4-6), and 19% are high-rise (7+) stories. While this distribution implies the focus should be on low-rise typologies, the observed type of structural framing in these three multifamily categories is of importance to this study in defining scope. Wood framing dominates low-rise multifamily structural systems (99%) and mid-rise structural systems (76%). Presumably for low-rise and mid-rise typologies, this wood framing is predominantly light-framed walls and floors with thin wood sheathing. For high-rise multifamily, wood framing is only 13% of the existing stock. Concrete structure (57%) and steel structure (30%) make up the distribution in the high-rise multifamily typologies and are the focus of this study.
3 Building Construction Demand Modeling

3.1 METHODS
To estimate new construction demand for office and multifamily buildings, past delivery trends were observed and used as a baseline to project delivery of new product in the Pacific Northwest. New construction of multifamily product by building height was estimated using CoStar data and historic development cycle trends. This resulted in a baseline growth scenario projecting new construction through 2035. Moderate and aggressive growth scenarios were also estimated using the NWPPCC 7th Power Plan population estimates relative to multifamily development delivery as the modulator.

The baseline growth scenario for office building projections for the Pacific Northwest were based on the 7th Power Plan estimates. For this study the project team focused on “large office” buildings, or office buildings of at least 50,000 sq. ft. The 7th Power Plan estimates provided the baseline growth scenario. Moderate and aggressive growth scenarios through 2035 were estimated using simple accelerated rates of delivery. The following subsections will summarize the delivery trends and projections for multifamily and large office buildings in the Pacific Northwest.

3.2 PACIFIC NORTHWEST MULTIFAMILY BUILDING PROJECTIONS
Over the past 20 years, multifamily development has seen strong growth in the Pacific Northwest. Between 1996 and 2015 a total of 122.8 million sq. ft. of new multifamily product was delivered at a compound annual growth rate (CAGR) of 6.5%. In 1996 approximately 62% of the total multifamily building square footage was in buildings between 4 and 5 stories, 13% were in buildings between 6 and 7 stories, 20% were in buildings between 8 and 16 stories, and 5% were in buildings at least 17 stories. By 2015 this distribution shifted with only 48% of the square footage in buildings between 4 and 5 stories and 26%, 14% and 12% in 6-7, 8-16, and 17+ story buildings, respectively.

Figure 3.1a - Built and forecasted Pacific Northwest commercial floor area by building type (1987-2035, 7th Power Plan)
Based on the growth projections for 20 years between 2016 and 2035, there will be approximately 94.6m sq. ft. (2.1% CAGR) to 277.0m sq. ft. (4.8% CAGR) delivered to the Pacific Northwest under the baseline and aggressive growth scenarios, respectively.

This study also considers CLT adoption by multifamily product type. As the Pacific Northwest continues to attract more households, particularly in the metropolitan areas of Seattle and Portland centers, the modeling reflects a more significant volume of taller buildings housing more people while also maintaining delivery of mid-rise buildings.

**3.3 PACIFIC NORTHWEST OFFICE BUILDING PROJECTIONS**

Office projections were based on the 7th Power Plan estimates for the Pacific Northwest. The focus for these estimates used for the diffusion model are “large” office buildings, or office buildings that are at least 50,000 sq. ft. Figures 3.1a and 31.b show past development in the Pacific Northwest and forecasted growth estimates through 2035. The baseline growth projection is based on 7th Power Plan model with the moderate and aggressive scenarios anticipating more significant growth for this product type in the region.

Between 1996 and 2015 the supply of office buildings over 50,000 sq. ft. in the Pacific Northwest increased by 4.9 million sq. ft., from 2.3 million to 7.2 million sq. ft. This represents a 216% increase at a CAGR of 5.9%. Between 2016 and 2035 the model estimates office growth to increase between 3.4% annually (baseline) and 4.0% annually (aggressive). The rate of growth is slower and is based on a larger office building footprint in 2016. During this period, we estimate there may be 7.2 million sq. ft., 8.2 million sq. ft., or roughly 9.1 million sq. ft. delivered to the Pacific Northwest under the baseline, moderate, and aggressive scenarios, respectively.

![Figure 3.1b](image-url) - Built and forecasted Pacific Northwest commercial floor area by building type (1987-2035, 7th Power Plan)
4 CLT Baseline Building Modeling

4.1 METHODS

To determine projected CLT volumes from projected floor areas, the project established baseline structures for two building types (multifamily and office (4.1.1)), building codes (4.1.2), and zoning (4.1.3) for 6-16 story buildings in the Pacific Northwest. Note, however, the diffusion models (Chapter 5) and overall results consider all low-, mid-, and high-rise buildings (4+ stories) based on logical extension of the baseline CLT building models.

4.1.1 Building Types

The scope of this demand study is constrained by building types (office and multifamily) and building heights 4-17+ stories. Responding to secondary data and expert opinion, this study devoted significant modeling effort to develop CLT baseline building models for 6-16 story building types, as this range was identified as cost competitive for early adoption of CLT. Further, this scope specifically targets demand conditions in Seattle as the dominant metropolitan market in the Pacific Northwest region (refer to Figure 4.1 for historical comparison of high-rise sq. ft. constructed by Pacific Northwest metro area).

Figure 4.1 - Historical comparison of square feet constructed by metropolitan area for 6-16 story high buildings in the Pacific Northwest (1980-2015, CoStar data source)

The methods and models developed are intended to be adapted and applicable for future expansion of scope to other building types and sizes. Considerations leading to selection of office and multifamily building types for this initial study include 1) appropriateness of CLT for structural, acoustic, and fire performance; 2) appropriateness of CLT to affect speed and cost of construction; and 3) appropriateness of CLT to disrupt underserved markets.

1) Appropriateness of CLT for structural, acoustic, and fire performance: As a type of solid construction, early adoption of CLT favors high-performance applications in mid- and high-rise buildings. Low-rise buildings can be cost effectively built with light-framed wood or steel stud construction. As an emerging product, the costs of CLT structure currently exceeds that of light-framed construction (limited to five stories in Seattle and Portland jurisdictions and often four stories in other jurisdictions). Six stories represents the typical transition to higher cost steel and concrete structure due to code and performance limitations. 16 stories represents a typical upper limit due to code and zoning...
limits of approximately 160’-170’. Structurally, CLT construction also has an optimized limit of about 16 stories before high hybridization with steel and concrete construction is necessary. Additionally, there is general consensus in urban sustainability and resiliency discourse of the appropriateness of 6-12 stories for urban density (McLennan, 2009). Future considerations of fire risk (especially during construction), acoustic performance and separation, and prefabrication efficiencies in low-rise construction might increase the viability for CLT use in low-rise construction as commonly observed in Europe.

2) Appropriateness of CLT to affect speed of construction: CLT, as a large-format manufactured building product, inherently favors building typologies with repetitive structures that benefit from mass-produced or mass-customized prefabrication. Because CLT currently has a cost premium in North America over traditional steel and concrete structures, speed of construction will likely be a driving consideration in early adoption. This again favors mid- to high-rise urban buildings that demand fast construction for speed to market or to reduce costly and disruptive construction in urban environments.

3) Appropriateness of CLT to disrupt underserved or challenging markets: In the Pacific Northwest, a gap of buildings between 65’ and 125’ zoning heights exists due to unfavorable economics of steel and concrete construction in low-rise and mid-rise construction. As light-framed wood is limited to 65’ or 85’ heights, CLT has an opportunity to penetrate this underserved range approximately between 6-16 stories. Figures 4.1.2 and 4.1.3 highlight the 6-16 story range in multifamily and office buildings by number of stories and primary structural material.

Figure 4.2 - Built MULTIFAMILY buildings by number of stories and primary structural material type for in Seattle (1980-2015, CoStar data source)
4.1.2 Building Codes
With full International Building Code adoption in 2015 (IBC 2015) and a North American open product standard established in 2012 (APA/ANSI PRG 320-2012), risk for code and standards barriers is low. However, jurisdiction acceptance of wall and floor assembly types ranges from low- to medium-risk as research and built projects emerge. Code-defined construction types establish the types of materials (combustible vs noncombustible) and fire resistance requirements for wall, floor, and roof assemblies. Type I-B construction was determined to be the most representative of likely construction types between 6-16 stories and was set as a baseline for CLT volume calculations in this study.

4.1.3 Zoning
Zoning and land use considerations have a significant market impact in the determination of viable building types and can vary widely by jurisdiction. Building heights and floor areas allowed per construction types in building codes might not align with urban planning and design objectives to define urban form and livable environments. Three representative zoning classifications from the Seattle-Bellevue-Redmond Metropolitan Area are listed in Table 4.1 with typical floor elevation heights to determine number of stories in baseline buildings for the study.
Table 4.1 – Comparison of Seattle-Bellevue-Redmond zones and example floor elevations

<table>
<thead>
<tr>
<th>TYPE I-B (160’- 180’)</th>
<th>R</th>
<th>157.5’ (SM 160)</th>
<th>145.0’</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>132.5’</td>
<td>147.5’</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>120.0’ (SM 125)</td>
<td>132.8’</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>107.5’</td>
<td>118.0’</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>95.0’</td>
<td>95.0’</td>
<td>103.3’</td>
</tr>
<tr>
<td>8</td>
<td>82.5’ (SM 85)</td>
<td>82.5’</td>
<td>88.5’</td>
</tr>
<tr>
<td>6</td>
<td>70.0’</td>
<td>70.0’</td>
<td>73.8’</td>
</tr>
<tr>
<td>TYPE V (65’)</td>
<td>5</td>
<td>57.5’</td>
<td>57.5’</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>45.0’ (podium)</td>
<td>45.0’</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>32.5’</td>
<td>32.5’</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20.0’</td>
<td>20.0’</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.0’</td>
<td>0.0’</td>
</tr>
</tbody>
</table>

4.2 Multifamily Baseline CLT Buildings

Multifamily buildings are dominated by bearing and shear wall typologies and often consist of repeatable dwelling unit layouts. The design of shared walls (party walls) between units are often controlled by fire and acoustic separation concerns and not structural performance. Structural demand for wall or floor assemblies are commonly expressed in demand/capacity (D/C) ratios. A D/C ratio of 1.0 indicates that the structural element (wall, beam, column, etc.) is at its design capacity. For a typical code-limit four or five story (65’ to 85’) light-framed wood multifamily building, the structural walls between units might approach D/C ratios of 1. With higher structural performance characteristics, CLT enables higher building types with proper assembly design and detailing for fire and acoustic performance. Type I-B construction was selected for the baseline multifamily structure.

Multifamily - 85’ (Construction Types: V-A*, V-B*, IV)
Multifamily - 125’ (Construction Types: IV*, I-A, I-B)
Multifamily - 160’ (Construction Types: I-A, I-B)

4.3 OFFICE BASELINE CLT BUILDINGS

Office buildings in the 6-16 story range are market driven by large (20,000 to 24,000 gross sq. ft.) wide open floor plates with centralized elevator, stair, bathroom, and mechanical cores. This formula defines a radically different structural strategy than common in multifamily construction. This is especially relevant in seismic regions like the Pacific Northwest that demand strength and ductility to resist and absorb energy from earthquakes. Type I-B construction was selected for the baseline office structure.

Office - 85’ (Construction Types: III-A, III-B, IV, V-A, V-B)
Office - 125’ (Construction Types: IV*, I-A, I-B)
Office - 160’ (Construction Types: I-A, I-B)
5 CLT Diffusion Model

5.1 MODELING BACKGROUND
Despite the size and the importance of the building construction sector within the U.S. economy, relatively few studies have looked at the process of innovation or the adoption and diffusion—referring to product market penetration—of new construction materials in this industry (Blackley and Shepard 1996; Taylor and Levitt 2004). One of the first known published works dealing with innovation adoption and diffusion in the residential construction industry was by Beal (1960), who examined the diffusion of information regarding the construction of farm houses. Since 1960 only a few efforts have been made to empirically assess innovation adoption and diffusion within the residential construction industry.

Innovation adoption in any industry is a function of the characteristics of the industry, the interrelationship between the companies in the industry (intensity of rivalry), the characteristics of firms within the industry and, above all, the characteristics of the innovation. Ignoring any of these factors leads to a partial understanding of the market characteristics and results in contradictory or non-generalizable research results. Further, the conclusions in most of these studies are based on anecdotal evidence and are not substantiated by empirical evidence.

The limited availability of CLT in the national market has been an important barrier to the successful adoption and diffusion of the material in the U.S. There is limited commercial production of CLT in the U.S. for structural purposes, making it difficult to specify CLT over more readily commodity materials. Opting for a CLT solution implies increased risk due to limited regional sourcing, limited competition of manufacturers, and proprietary performance and material differences.

5.2 METHODS
One of the very important features of the housing materials market is the repeat purchase by the builders. The repeat purchase probability at any point in time can be defined as the revised utility estimate of the product conditional on the first time usage of the product. The following box identified the parameters in the model.

The parameters used in the CLT diffusion model

- Purchase probability is a function of the difference in the perceived utility obtained from the new generation product (CLT) from that of the previous generation product.
  - Utility Markup of CLT - \( \phi \)
- Purchase probability of CLT at any point is also a function of information dissemination defined by parameters
  - ‘a’ (how informed the market is) and
  - ‘b’ (rate of information dissemination)
- Finally, prior beliefs about the characteristics of the product (resulting in perceived utility) gets revised after firms’ initial usage of the product denoted by the coefficient.
  - Confidence Factor - \( \alpha \)

Box 2.1: CLT diffusion model parameters. Source: Adapted from Ganguly repeat purchase diffusion model (Ganguly 2008)

In this model for diffusion of CLT the utility function, including the base utility of the product \( \phi \) and the additional confidence factor \( \alpha \) gained from first time usage of the product, can be written as

\[
(1 - \frac{1}{2} e^{-\phi + \alpha})
\]

may be termed the probability of repeat purchase. Hence, the density function of overall purchase at any point of time should include first time purchase and repeat purchase.
\[ f(t) = f_f(t) + (1 - \frac{1}{2} e^{-\phi+\alpha}) F_f(t) \]  

Where, 

\( f(t) \) is the probability density function of purchase of the new generation product with repeat purchase, 

\( (1 - \frac{1}{2} e^{-\phi+\alpha}) \) is the probability of repeat purchase. Here, the initial utility markup perception of the product \( \phi \) gets adjusted by a ‘confidence factor’ \( \alpha \). The value of \( \alpha \) can be positive or negative depending on whether the market perception of the utility of the product has gone up or down.

Equation 1 can be written in the following form:

\[ f(t) = \left[ \frac{(1+e^{-(a+b)t}) \left( \frac{p}{b} \right) \left( 1 - \frac{1}{2} e^{-\phi} \right) (e^{-a}) \left( \frac{p}{b} \right)}{1+e^{-(a+b)t}) \left( \frac{e^{-a}}{b} \right) \left( \frac{p}{b} \right) \left( e^{-a} \right) \left( \frac{p}{b} \right) \left( 1+e^{-(a+b)t}) \left( \frac{p}{b} \right) \left( e^{-a} \right) \left( \frac{p}{b} \right) \left( e^{-a} \right) \left( \frac{p}{b} \right) \right]} + \left(1+e^{-(a+b)t}) \left( \frac{p}{b} \right) \left( e^{-a} \right) \left( \frac{p}{b} \right) \left( e^{-a} \right) \left( \frac{p}{b} \right) \right] \]  

Where, 

\( (1 - \frac{1}{2} e^{-\phi}) = p \) and \( (1 - \frac{1}{2} e^{-\phi+\alpha}) = q \)

Here it may be noted that the resultant product usage density function is a degenerate density function as it doesn’t integrate to 1. The degeneracy of the density function is by choice as it reflects the actual market situation where the sales of the product which has appealing features and some competitive advantage over its competitor(s) does not die down automatically.

**5.3 PARAMETERIZING THE DIFFUSION MODEL FOR THE NORTH AMERICAN CONSTRUCTION MARKET**

To be able to parameterize the model, various innovative engineered wood products production data are used. In the following section, the North American production data for innovative wood products with varied degrees of similarity to CLT are presented. Production data through 2006 is considered, as the following economic downturn was caused by factors beyond the scope of any market diffusion model. However, the forecasted downturn is introduced in the models economic and market saturation analytic section. Hence, it will be reflected in the overall projected market demand model.
From the above Figure 5.1 it can be observed that it took more than 20 years for plywood to enter the growth phase, whereas I-joists took almost 12 years to enter the growth phase. I-joists can be considered an architectural or generational innovation, whereas, structural panels can be considered a combination of architectural, generational, and radical innovation, given their various construction applications. In terms of the level of innovativeness, CLT has similar innovative characteristics in 2016 as structural plywood had in the 1920s. Laminated veneer lumber (LVL), which can be considered more of an incremental innovation had a smoother growth rate relative to the other engineered wood products presented.
Accordingly, the diffusion model is parameterized for the Pacific Northwest construction market using the structural panel data. The parameters are presented in Table 5.1. The primary purpose of using the previous innovations in engineered wood products in the U.S. is to get a fair estimate of the innovation adoption characteristics of the U.S. construction industry. These parameters are taken as starting points and are modified in the later subsections in order to get CLT and end-use specific diffusion curves.

<table>
<thead>
<tr>
<th>Coeff</th>
<th>Definition</th>
<th>Estimated Parameters</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>coeff. of base info. level</td>
<td>4.399</td>
</tr>
<tr>
<td>B</td>
<td>coeff. of info. dissemination rate</td>
<td>0.1305</td>
</tr>
<tr>
<td>P</td>
<td>probability of trial purchase</td>
<td>0.0295</td>
</tr>
<tr>
<td>Q</td>
<td>probability of repeat purchase</td>
<td>0.9211</td>
</tr>
</tbody>
</table>

Table 5.1: Estimated parameter for the diffusion model

The following graph in Figure 5.2 shows that the Ganguly repeat purchase model fits the panel data quite well for all the phases of the innovation diffusion process. In the following section these parameters are modified to make the model applicable to the various end use applications of CLT.

![Figure 5.2: Fit of the Ganguly repeat purchase model with the structural panel data](image-url)
5.4 END USE SPECIFIC ADOPTION METRIC

As discussed in the previous section, the CLT applications for this study were divided into two major applications, diaphragms (horizontal floor and roof applications) and walls (vertical applications). Within the diaphragm and wall applications, CLT use was further divided into bare sections (3, 5, 7, and 9-ply), composite concrete section (5-ply), and wood composite section (6, 8 and 10-ply). Among the wall applications, CLT use was divided into bare sections (3, 5, 7 and 9-ply), and wood composite section (6 and 10-ply). It may be noted that the 6-ply refers to two 3-ply composite, 8-ply refers to one 3-ply and one 5-ply composite, and the 10-ply refers to two 5-ply composite. The various CLT applications were then modeled for multifamily and commercial office buildings, ranging in height from 4 stories to 17+ stories (to place the target 6-16 stories in context).

In order to conduct the diffusion modeling, each of the end use applications was classified into six different categories, based on existing risk associated with (1) building codes and standards adoption and jurisdiction acceptance, (2) technical design and engineering, and the (3) manufacturing and construction cost of adoption.

1. Within the building Codes and Standards category, the aspects of code acceptance and jurisdiction acceptance for the specific end use applications are considered.

2. Within the Design and Engineering category, material adoption risk and uncertainty associated with architectural design, seismic engineering, fire engineering, acoustic engineering, and vibration engineering are considered.

3. Within the Cost of Adoption category, only the opportunity cost of using CLT over the traditional building material is considered. However, it may be noted that with the increased availability of CLT, the cost may go down and this modeling exercise does not include the dynamics associated with long term cost reductions for CLT production.

At this point in time, challenges exist in terms of building code acceptance, especially for the seismic design and fire protection design requirements. Currently building codes are being adapted to facilitate the adoption of CLT. With the inception of the 2015 International Building Code, commercial structures built of wood frames have increased to larger building sizes (allowed by the upper limits of each of the legacy building codes). In January 2015, the State of Oregon Building Codes Division approved a statewide alternate method (N. 15-01) that allows the use of CLT for Type VI, Heavy Timber buildings. The Pacific Northwest states’ (WA, OR, ID, MT) local authorities having jurisdiction are currently at various stages of code development and acceptance.

Based on the expert opinions of the authors and Pacific Northwest architects and engineers familiar with the use of CLT as a building material, the risks and uncertainties associated with building codes and standards and the design and engineering of specifying CLT for various end use applications are divided in 3 different groups (low, medium and high risks), summarized in the risk assessment matrix in Figure 5.3 on the following page.
The adoption potential for each of the end use applications of CLT is categorized by the risk/challenges associated with these two summary metrics. For example, an end use application will be labeled ‘Low-High’ when the building codes and standards risk associated with adoption of CLT is low, but the design and engineering risk/challenges associated with specifying CLT for the end use application are high.

If any particular application is cost competitive with the traditional material it is assumed to reach the full potential. However, if any of the applications entail a higher cost of usage, it will only appeal to a niche market and will not reach its full market potential, as modeled by the unrestricted diffusion curves. In the ‘market potential’ column of Table 5.2, the value ‘1’ indicates that the application is price competitive to the traditional material and will be able to reach 100% of the market potential. Any number less than 1 will not be able to reach its full market potential. Based on expert opinion we assumed that the bare-section (3 & 5 ply) floor diaphragm application will likely be price competitive and will be able to reach its full market potential. Wood composite section (6, 8 and 10 ply) for wall application will be least price competitive to traditional material and will reach only 58% market potential, with all other factors remaining constant.
Finally, the parameters for a Best Case Scenario (low-low) are presented in Table 5.2, where it is assumed that none of the code/standards barriers exist for use of CLT in tall buildings, resulting in a low risk. In this scenario it is also assumed that the design and engineering risks are absent for usage of CLT in tall building constructions. Within the best case scenario, it is also assumed that CLT has 100% price parity with the traditional building materials it is likely to replace, resulting in 100% market penetration potential. This best case scenario is hypothetical and does not reflect the market/technical realities.

In the curves presented in Figures 5.4-5.6, a baseline adoption curve for ‘U.S. wood panel industry’ is used as a reference for all of the end use specific CLT adoption diffusion curves. The ‘baseline U.S. wood panel industry’ adoption diffusion curve represents a generic wood panel adoption curve based on past adoption behavior of the U.S. wood-based industry and is primarily used as a reference line in these figures. The baseline curve indicates that on average the innovative wood panels market share is projected to grow by up to 35% for the specific end uses modeled in this report within 20 years. Note this is the baseline for the model and is not the application-weighted adoption curve for CLT and is a generic U.S. wood panel adoption curve. A more nuanced CLT version of this curve is presented in the following sections.

<table>
<thead>
<tr>
<th>Diffusion Parameters</th>
<th>coeff. of base info. level</th>
<th>coeff. of info. dissemination rate</th>
<th>probability of trial purchase</th>
<th>probability of repeat purchase</th>
<th>market potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor CLT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare section (3 &amp; 5 ply)</td>
<td>low</td>
<td>high</td>
<td>0.8798</td>
<td>0.261</td>
<td>0.01475</td>
</tr>
<tr>
<td>Bare section (7 &amp; 9 ply)</td>
<td>low</td>
<td>medium</td>
<td>0.8798</td>
<td>0.261</td>
<td>0.04425</td>
</tr>
<tr>
<td>Composite concrete section (5 ply)</td>
<td>medium</td>
<td>medium</td>
<td>4.399</td>
<td>0.261</td>
<td>0.04425</td>
</tr>
<tr>
<td>Wood composite section (6, 8 and 10 ply)</td>
<td>medium</td>
<td>high</td>
<td>4.399</td>
<td>0.261</td>
<td>0.02065</td>
</tr>
<tr>
<td>Wall CLT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare section (3, 5, 7 &amp; 9 ply)</td>
<td>high</td>
<td>low</td>
<td>4.399</td>
<td>0.1305</td>
<td>0.0885</td>
</tr>
<tr>
<td>Wood composite section (6 &amp; 10 ply)</td>
<td>high</td>
<td>medium</td>
<td>4.399</td>
<td>0.19575</td>
<td>0.04425</td>
</tr>
</tbody>
</table>

Table 5.2: Estimated end-use specific parameters for CLT diffusion trajectory
5.4.1 Floor/Roof Diaphragm CLT Applications

There are currently no significant hurdles on building code acceptance for floor/roof diaphragm CLT applications (see Figure 5.3). However, there are some issues associated with the jurisdiction acceptance of the building code and standards, as is presented in section 5.4 of this report. There are some design and engineering specification challenges associated with using CLT for floor/roof diaphragm applications. The primary challenges are associated with fire and vibration engineering. It was also determined that all of the 3 and 5 ply CLT applications will have a similar material cost compared to the traditional materials and its adoption will not be impacted by higher cost. In contrast, the adoption of CLT in bare section 7, 8, 9 and 10 ply applications are more likely to be negatively impacted by higher material cost as compared to concrete.

Based on all these criteria, the floor/roof diaphragm applications are modeled to follow four distinctive diffusion trajectories, based on the diffusion parameters presented in Table 5.2. However, within the existing architectural scenarios developed only two of the end-use scenarios have been modeled. The CLT in wall construction application are assumed to follow two distinctly different diffusion categories.

a. The floor/roof diaphragm bare section 3 and 5 ply CLT specifications are considered low code/jurisdictional acceptance risk. Though there is no risk associated with the building code acceptance for these end use applications, some uncertainty is still present on the jurisdiction acceptance aspect. On the Design and Engineering aspects, the bare section 3 and 5 ply options are considered to have higher adopted risk due to difficulty in achieving the necessary vibration performance. As a result, the floor/roof diaphragm CLT applications, bare section 3 and 5 ply end-use applications are considered to have a low building code/jurisdiction acceptance risk but a high design and engineering challenge/risk, and this application is assigned an overall ‘Low-High’ risk adoption diffusion profile.

b. In the bare section adoption-diffusion curves presented in Figure 5.4 we observe an initial boost (early adoption), given the low adoption risk associated with the code acceptance for the floor/roof bare section CLT panel applications. However, significant engineering and design challenges may slow down the adoption of CLT panels in this particular category, leading to a slow growth rate. However, given the low cost of using CLT for these applications, its market share in the long run is projected to grow to 60% of the potential market share in the medium to high-rise category in 40 years.

c. The floor/roof diaphragm CLT applications, composite concrete section (5-ply) is considered to have a medium building code and jurisdiction acceptance risk. Though there is no risk associated with the code acceptance for these end use material specifications, there is some

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Figure 5.4: CLT floor assemblies’ diffusion curves
uncertainty associated with the jurisdiction acceptance for these specifications. On the Design and Engineering aspects, composite concrete section (5-ply) applications are considered to be medium adoption and specification risk, due to engineering challenges associated with achieving the required seismic engineering attributes. As a result, the floor/roof diaphragm CLT applications, composite concrete section (5-ply) end-use applications are considered to have a medium building code/jurisdiction acceptance risk and a medium design and engineering challenge/risk, and this application is assigned a ‘Medium-Medium’ risk adoption diffusion profile.

d. In the composite concrete adoption-diffusion curve presented in figure 5.4 we observe that there is initial slower growth of 5 ply CLT panels for composite concrete floor applications, due to marginally higher jurisdictional acceptance uncertainties associated with this specific end-use application. However, the lack of significant engineering and design specification challenges associated with this end use suggests that the floor diaphragm application of composite concrete section 5 ply CLT will enjoy healthy growth. Given that the cost of using CLT for this application is not significantly higher, the market share of CLT for this application in the long run is likely to reach exceed the 60% mark. This particular application of CLT is modeled only for IB and IIIB construction scenarios.

5.4.2 Wall CLT Applications

Significant uncertainties and hurdles exist both on the building code acceptance and jurisdiction acceptance aspects of CLT use for wall applications (see Figure 5.3). However, there are a number of factors within the design and engineering aspects which are perceived to be architecturally less challenging relative to the floor applications. The primary challenges for CLT wall applications are the fire engineering aspect of wood composite (6/10 ply CLT) sections and the acoustic engineering associated with single CLT panel (3/5/7/9 ply) applications. It was also determined that all of the 3 and 5 ply CLT applications will have a similar cost compared to the traditional material; its adoption will not be impacted by higher cost. In contrast, the adoption of the bare sections with 7 and 9 ply and wood composite sections with 6 and 10 ply applications are more likely to be negatively impacted by higher material costs as compared to traditional counterparts. Based on these criteria, the CLT adoption for wall applications were modeled to follow two distinctive diffusion trajectories.

a. The wall bare section 3/5/7/9 ply CLT specifications are considered to be high building code/jurisdictional acceptance risk. It is perceived that there is a moderate level of uncertainty associated with the building code acceptance for these end use material specifications, and a high level of uncertainty is still present on the jurisdiction acceptance aspect. On the Design and Engineering aspects, the bare section 3/5/7/9 ply CLT options were determined to have no architectural design challenges and a low level of seismic engineering challenges. Some engineering challenges may also be associated with the acoustic engineering. However, in general the bare wall section 3/5/7/9 ply CLT applications is considered to be relatively less risky and can be associated with greater engineering and design certainty. As a result, bare wall section 3/5/7/9 ply CLT end-uses applications are considered to have a high building code/jurisdiction acceptance risk but a low design and engineering challenge/risk, and this application is assigned a ‘High-Low’ risk adoption diffusion profile. In the adoption-diffusion curve presented in Figure 5.5 we can observe that initially there is a slower adoption of 3/5/7/9 ply CLT panels for wall bare section applications due to the high building code and jurisdictional acceptance uncertainties associated with this end-use application. However, the relatively positive

![Figure 5.5: CLT wall assemblies' diffusion curves](image-url)
engineering and design specification profile associated with this end use for the wall application of 3/5/7/9 ply CLT panels for bare sections is expected to experience rapid growth. This end-use application will follow a typical product diffusion curve associated with initial end-user resistance, with a very slow start followed by a high growth leading to a very prominent S-shaped curve. Given that the cost of using CLT for this end-use application is not significantly higher than competing materials (except for the 7 and 9 ply), the market share of CLT for this application in the long run is expected to exceed 70% by the 30th year after which it is expected to flatten out. This particular application of CLT panels has only been modeled for commercial office buildings in our adoption-diffusion scenarios.

b. In the wall adoption-diffusion curve presented in Figure 5.5 CLT panels, there is an initial slow rate of adoption of 6/10 ply CLT panels for wall wood composite section applications due to high building code and jurisdictional acceptance uncertainties associated with this end-use application. Moreover, there are significant engineering and design specification challenges associated with this specific end use with respect to both seismic and fire engineering issues. This end-use application is expected to follow a typical product diffusion curve associated with initial resistance, with a slower start followed by rapid growth which results in a very prominent S-shaped curve. Given that the cost of using CLT panels for this end-use application is not significantly higher than for competing materials (except for the 7 and 9 ply CLT panels), the market share of CLT for this end-use application in the long run is likely to exceed 70% by the 30th year before leveling off. This particular end-use application for CLT panels was modeled only for commercial office buildings in our construction scenarios.

c. The best case adoption-diffusion curve presented in Figure 5.6 represents no initial code/standards restrictions and no significant engineering and design challenges, resulting in a high initial rate of adoption. As compared to more realistic scenarios, the best case scenario reaches a high market share (almost 90%) within the first 20 years of introduction and levels out at 90% of the potential market share, within the constraints of the proposed applications. The cost of using CLT panels for this end-use application is also assumed to be at par with or cheaper than the traditional materials resulting in no economic barriers to adoption.

5.5 CLT ADOPTION TIMELINE

In any innovation diffusion model the year of introduction of the product to the market, generally termed as the ‘year 0’, is of critical importance. Though CLT was first introduced in the early 1990s in Austria and Germany, its introduction in the U.S. is fairly recent. Though the first CLT construction in the U.S. can be dated back to 2011, the first known CLT use in a major metropolitan jurisdiction in the Pacific Northwest was 2014. Hence, we set 2014 as the starting point of the CLT diffusion model. In this report we present a 20-year timeline, ranging from 2016 to 2035, with the hypothetical beginning of the diffusion timeline at 2014.

5.5.1 Diffusion Modeling Results
This section provides end-use specific and construction type specific diffusion of CLT in the Pacific Northwest. Here, we combine the results obtained in chapters 3 and 4 of this report and apply the diffusion trajectories presented earlier in this chapter (Chapter 5). In the following subsection we present the diffusion forecast of CLT specific end uses (i.e., wall vs floor) in different building types (i.e., multifamily vs office buildings).

In analyzing the results of the adoption-diffusion models, specifically for multifamily construction, most of the future demand for CLT is expected to be in mid-rise construction (Figure 5.8), i.e., 4-6 story buildings. However, in the short term (4 to 6 years) most of the demand for CLT panels for multifamily construction is expected to be in in higher-
storied buildings (7+) to compete with steel and concrete construction until CLT reaches cost parity at mid-rise heights. Moreover, the results from our analysis clearly suggest that all the different multifamily building categories will combine to play a sizeable role in the overall CLT demand.

a. In terms of end use applications, Figure 5.7 suggests that the floor/roof concrete composite section (5-ply) will play the most significant role in the overall demand for CLT panels in both multifamily and office building construction. In the medium to long run the market for wall wood composite section is likely to increase. However, given the limited volume demand for this application and the potential higher cost markup of using this option, the overall market share for this end use application is expected to play a more moderate role. The modeling also reveals that it is unlikely that bare section floor/roof 3/5 ply CLT panels will play a dominant role in the overall demand for CLT panels in multifamily building construction.

b. The results of our modeling also suggest that 4-5 story office buildings will dominate the overall demand for CLT (Figure 5.8, bottom panel). In the medium to long term, the market share of CLT in the 6-7 story building category will begin to take off as well. Based on the modeling results, 4-7 story office buildings are predicted to represent over 90% of the overall CLT demand in this sector. In addition, the bare floor/roof applications are expected to play an important role in the overall demand for CLT panels in office buildings in the short run, although the demand for this specific end-use application is expected to remain relatively constant over the years. The floor/roof concrete composite application will have a lower overall demand in the initial years, given the building code/jurisdictional acceptance uncertainties. However, in the medium to long term this particular end-use application will begin to dominate the overall demand for CLT panels based on its ease of use and competitive cost relative to steel and concrete. CLT use in wall applications will likely play a minor role in the overall demand of CLT for office constructions.

In combining both building types, commercial office and multifamily, our results suggest that the 4-5 and 6-7 story building categories will represent the largest markets for the use of CLT panels (Figure 5.8). Our modeling results indicate that by 2020, the overall demand for CLT panels is expected reach 1.2 million cubic feet. Given these modeling results, it is also likely that from 2020 onwards the demand for CLT panels will double every 5 years within the building construction market. Based on the previous diffusion trends observed for in plywood and OSB panels, this scenario may be considered conservative, given that the building code/jurisdiction approvals do not impose any significant setbacks.

Figure 5.7: CLT adoption diffusion forecast by end use in the Pacific Northwest

Figure 5.8: CLT adoption diffusion forecast by building type
c. Finally, in Figure 5.9, we present a realistic demand estimate for CLT demand (green section), based on end use specific demand estimates, and the additional demand associated with the best case scenario projection (green + yellow). In the best case scenario projections, all the building types and material end uses follow a low-low diffusion curve trajectory. Given the best case scenario assumes no initial risks associated with either the building codes or the engineering and the design aspects, the difference between the realistic projection and the best case scenario is the largest in the earlier phases. For example, the 2016 best case scenario is 10 times that of the realistic scenario. However, this difference narrows down towards the end of the forecast period, with the 2035 CLT demand for the best case scenario is less than double than that of the realistic scenario.

Figure 5.9: CLT adoption diffusion forecast vs best case scenario for all building construction in the Pacific Northwest
6 Conclusions

This study developed methodologies to predict volume of finished CLT product in tall wood buildings based on projected construction within the four-state Pacific Northwest (Washington, Oregon, Idaho, and Montana) between 2016-2035. It developed baseline building models for tall wood building types between 6-16 stories, which are prominent in current mass timber discourse and policy proposals. However, overall results consider all low-, mid-, and high-rise buildings (4+ stories) through modeling and analysis using real estate and power planning datasets.

The predicted results indicate that by 2035 overall demand for CLT panels in the Pacific Northwest could range from 6 – 12 million cubic feet annually for 4+ story construction types, with a best estimate at 6.6 million cubic feet annually. Over the 20-year prediction period (2016 to 2035), the cumulative demand for CLT panels in the Pacific Northwest is estimated to be approximately 56 million cubic feet. It is important to note the results reflect market diffusion that grows over time based on predicted trial and adoption of CLT assembly systems. A typical characteristic of ‘new product diffusion models’ is slow initial adoption (trial phase) followed by a faster rate of adoption (growth phase) leading to market saturation (maturity phase). To highlight this phenomenon, consider that, while 2035 annual demand is estimated at 6.6 million cubic feet, CLT panel demand in 2020—much earlier in the adoption cycle—is estimated at 1.3 million cubic feet. While this study provides a more nuanced and definitive assessment of potential CLT demand within specific end use applications, assembly systems, and building types, its estimates are within the potential demand range provided by FPinnovations’ 2013 study in terms of the overall demand for CLT panels in the U.S. market.

To provide a lumber demand framework for these numbers, the total harvest of industrial roundwood in the Pacific Northwest, just for lumber production, is over 1,000 million cubic feet. Hence, the predicted demand for softwood lumber to manufacture CLT panels represents less than 1% in the annual Pacific Northwest timber harvest. Approaching results through a different lens: In 2015 the total volume of logs and lumber exported from the western U.S. is estimated to be approximately 160 million cubic feet. Hence, this study’s predicted annual volume demand for CLT in 2035—6.6 million cubic feet—represents less than 5% of the annual wood volume currently exported to China, Japan, and Canada from the western states of the U.S. So while CLT can expect significant diffusion into 4+ story construction types by 2035, based on the assumptions and parameters of this study it is likely to serve a complementary, value-added role rather than supplant existing lumber production industries.

As noted, a common focus within discourse and policy proposals concerning CLT construction is the development and application of high-performance CLT floor and wall assembly systems for high-rise building types. Amongst other arguments, it is a compelling focus given the financial infeasibility in some markets for 6-16 story construction built from conventional materials. Low- and mid-rise construction with CLT is often dismissed due to cost considerations relative to light-framed construction. That said, within the considered building types, this study predicts most of the demand for CLT panels will come from low- to mid-rise multifamily/office buildings (4-7 stories). This is logical considering the preponderance of these building heights across markets, but it nonetheless is a germane finding for planning discourse regarding mass timber construction.

The results suggest that, under a demand estimate of 6.6 million cubic feet (or 187,000 cubic meters) annually, by 2035 the Pacific Northwest 4+ story construction market could support at least four small- to mid-sized CLT plants producing 20,000-50,000 cubic meters per year each. That number grows when considering an expanded suite of potential construction types (e.g. warehouses, schools, etc.) not included in this analysis or product exports outside of the Pacific Northwest region.

Finally, it should be noted that, despite the limited wood fiber demand for CLT from regional forests, the demand estimated by this study is sufficient to support localized economic and ecological policy objectives. A CLT-based industry in the Pacific Northwest would support timber harvesting, sawmilling, and value-added wood industry jobs in resource-dependent communities. It likewise would create downstream opportunities, notably across advanced manufacturing, engineering, architecture, and construction sectors. Given the wide mix of wood species and lumber grades that can be used in CLT production, it ideally would create a market for less desired/valued types and species,
such as small-diameter timber harvested for fuels reduction or other ecological restoration objectives—encouraging responsible management of previously harvested forests.