Fringe Timber: Informing Regional Mass Timber Urban Environments with Biodiverse Forests

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Abstract. Trees present a vast array of performance in density, growth speed, height, fibre strength, and rates of carbon absorption. This paper explores how biodiverse mass timber is a way to support forest health and improve the health conditions of the most vulnerable—those who have experienced the pollution of mineral-based materials for generations. This symbiotic relationship between forests and urban environments incentivizes better care for both spaces, the transfer of materials should be reciprocal. Fringe Timber looks at the forest surrounding a city to inform its scale of growth and reduce its carbon footprint. Using three case studies in New York City, Denver, and Tulsa, this paper posits city-specific, species-driven supply chains beyond softwoods for mass timber, including hardwoods and hybrids, to support the appropriate scale and speed for urban development.

Keywords: Mass timber, biodiversity, resource management, case studies, renewable materials

1. Introduction
Biodiverse mass timber has the potential to connect the forest and the city like never before. For current forest biodiversity to last, species data must be made relevant and accessible to designers and support mass timber construction and other forms of urban growth. They also celebrate existing understandings of the forest through mixed species relationships and ecological communication. This relationship has the potential to transform the city and forest into dependable carbon sinks. In regards to what constitutes a healthy forest, the IPCC notes that “In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre, or energy from the forest, will generate the largest sustained mitigation benefit.”[1] Biodiverse forests for mass timber increase the value of existing forests and prevent deforestation by way of agricultural and urban sprawl. [2] But, are there enough trees to support an increase of mass timber construction?

1.1. Background
The U.N. predicts that over the next 40 years, 2.4 trillion square feet of space will be added to the planet. Constructing all this new space with mass timber would require 1-2 billion acres of forest, depending on building utilisation and a host of other factors. The planet currently hosts 9.8 billion total acres of forest, 30% of which are actively managed, putting this future well within our planet’s capacity.[3] Under this scenario, approximately 25.8 billion tons of carbon could be temporarily stored in the buildings and 10 billion tons of carbon emissions would be averted from using less concrete. [4]
Today, the capital expense of plant-based urban construction can be higher than that of mineral-based construction because it is less established, and the operational costs can be higher with increased maintenance. However, the costs of climate change-induced health disparities are rarely included in this evaluation. Mineral-based materials increase air pollution, and the violent effects are not equally distributed, disproportionately harming Black, Indigenous, and People of Colour.[5] In a warming world, lower embodied carbon can be synonymous with improved local and nonlocal health conditions and should be taken into consideration when choosing a structural material.

Mass timber, specifically Cross Laminated Timber, is made from primarily spruce, pine, and fir, and sometimes incorporates larch, oak, and beech. There are studies exploring the use of hemlock and white pine as well.[6] However, there are thousands of other tree species that risk being disincentivized in a future of mass timber. This wide array of species exhibits differences in growth density, speed, height, fibre strength, rates of carbon absorption, and networks of relationships with fungi, animals, and other plants. Incorporating many species into mass timber will continue to incentivize biodiversity and prevent the replacement of ‘low-value’ species for ‘high-value’ species, a common forestry strategy of the past.

This study includes three sections. As an extension of the introduction, Section 1 includes an outline of known baseline measurements for mass timber’s performance as an urban structural material mandated by international building code. Section 2 describes the species growth patterns, embodied carbon, and carbon storage of nine tree species. Section 3 uses these metrics to imagine a future of locally sourced biodiverse mass timber in three American cities: New York, Tulsa, and Denver. The case studies demonstrate that biodiverse forests and mass timber cities have the capacity to support each other, reduce pollution, and improve public health.

1.2. Baseline Assumptions
Mass timber buildings perform differently from concrete, but can be a competitive option in buildings from 1-18 stories. The lifespan of both concrete and mass timber is around 50-100 years, depending on maintenance and quality of construction. Mass timber buildings can be designed to achieve the requirements outlined by the International Building Code in the IBC2021 for Type IV-A, Type IV-B, and Type IV-C construction.[7] The operational energy of mass timber buildings is potentially lower as mass timber elements may have improved air tightness and therefore better retention of conditioned air. The indoor air quality of mass timber environments vary by their wood species, adhesive type, finishes, and maintenance routines. High Volatile Organic Compounds (VOCs) can be avoided by specifying low VOC adhesives and designing appropriate ventilation. The speed of mass timber construction is generally 25% faster than that of concrete construction because the elements are prefabricated and light weight, with significant savings in construction costs.[8]

At the site of extraction, direct access to the forest can improve health, something that other landscapes of extraction cannot boast. Continuous stress contributes to many health problems, such as high blood pressure, heart disease, obesity and diabetes.[9] In Japan, Shinrin-yoku, or “forest bathing” is viewed as a medical remedy for stress. In one study, being in the forest for only 15 minutes significantly lowered participants’ average cortisol levels, heart rate, systolic blood pressure; and diastolic blood pressure.[10] Forests in immediate proximity to the city would be productive places for improving the public’s health.

Proximity to wood surfaces has similar benefits to forest bathing. Being in a room with exposed wood increases productivity and well-being, minimises stress, promotes focus, and reduces physical recovery time. While forest bathing reduces cortisol levels by 12.4% and blood pressure by 1.4%, a wooded indoor environment reduces cortisol levels by 7.5% and blood pressure by 0.4%.[11]

In terms of sustainable forestry, there is currently a lack of biodiversity and supportive infrastructure for the urgent research, development and adoption of biodiverse products. The American National Standards Institute (ANSI) and The Engineered Wood Association (APA) requires Cross Laminated Timber be made with “softwood lumber species or species combinations with a minimum published specific gravity of 0.35” which has governed the species included in this study.[12] Another shortcoming of forestry, and by association locally-sourced mass timber in the United States is unequally distributed
land ownership and economic opportunity. Most forests in the U.S. are privately owned. Of the 4 million family-owned forests with more than 10 acres in the United States, only 6.6% are owned by racial and ethnic minorities, who make decisions for only 5% of the total 265 million acres. It has been found that minority landowners steward their land differently. They are more likely to be co-located with their forests, with less aggressive management techniques.[13] For example, the Tapash Sustainable Forest Collective, operating on indigenously owned land and publicly owned land, is gradually restoring the forest where a history of checkerboarding prevented the movement of wildlife and plants.[14] Other studies have found that local mass timber production creates greater regional benefit than traditional concrete frame construction.[15] Local forests that provide mass timber to support urban growth would enable forests to be more inclusive and accessible to those who do not currently have access.

2. Methodology & Metrics

Our sources for this paper include studies of human and forest impact across scales and across the lifespan of mass timber. To imagine how a diversity of species in the forests might contribute to a vibrant built environment, three sets of metrics are correlated to explore the larger impact of mass timber buildings including avoided carbon, species carbon storage, and species growth patterns.

2.1. Species Growth Patterns

Rates of tree growth, average stand density, age of maturity, carbon storage, and carbon sequestration all vary among species, and specimens. Some species grow slower and farther apart, which reduces the potential construction or increases the area of cultivation required. One parameter that can range widely and is the time for harvest. Trees reach an age of maturity where their growth slows, a range of which is shown in figure 1. Harvesting trees at this moment of maturity increases both the forest’s ability to sequester carbon and the amount of mass timber that can be manufactured. However, species characteristics vary by climate, soil conditions, surrounding habitat, and so on. The role of old age in a forest is also a rich field of research today.[16] For these reasons, the growth patterns in table 1 represent averages based on close reading of the USDA Silvics Manuals.

| Tree species | New York | Colorado | Oklahoma |
|--------------|----------|----------|----------|
| Mature height (ft) | 75 | 84 | 84 |
| Mature DBH (ft) | 2 | 1.15 | 1.31 |
| Mature age (yrs) | 75 | 100 | 200 |
| Canopy Diameter (ft) | 40 | 30 | 40 |
| Stand density (trees/acre) | 27 | 48 | 27 |
| Tree type | H | C | H |
| Wood density (lbs/ft³) | 38 | 28 | 45 | 31 | 26 | 28 | 35 | 35 |

*a* Data derived from USDA Silvics Manuals [17]

*b* 1 acre ÷ Canopy Diameter²

*c* H = Hardwood, C = Conifer

*d* Data derived from The Wood Database

*e* Mixed Conifer includes douglas fir, white fir, and rocky mountain juniper
2.2. **Embodied Carbon**
Cradle-to-gate embodied carbon refers to the carbon emissions that arise from the manufacturing, transportation, and installation of building materials. In one case study, mass timber buildings were shown to have an embodied carbon ranging from 21.75 - 35.21 lbs CO\(_2\)e/ft\(^2\) (an average of 31 lbs CO\(_2\)e/ft\(^2\)) while concrete buildings have a higher embodied carbon range of 41.53 - 57.63 lbs CO\(_2\)e/ft\(^2\) (an average of 49 lbs CO\(_2\)e/ft\(^2\)).[18] Therefore, on average, 1ft\(^2\) of mass timber avoids 18 lbs CO\(_2\)e of embodied carbon compared to concrete. The study also finds that the embodied carbon benefits of mass timber are greatest when locally sourced. Longer transport distances, whether over land or sea, start to diminish the advantages of mass timber’s lower embodied carbon.

2.3. **Species Carbon Storage**
At the age of maturity, the tree’s rate of carbon sequestration can slow in relation to its growth pattern. Table 2 below represents the carbon storage potential of nine forests, according to their average age of maturity.

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**Figure 1.** A selection of tree species and their age at maturity
Table 2. Average carbon storage of tree species.

| Tree species | New York | Colorado | Oklahoma |
|--------------|----------|----------|----------|
|              | Red Maple | Eastern Hemlock | American Beech | Mixed Conifer | Quaking Aspen | Ponderosa Pine | Oak | Hickory | Cottonwood | Shortleaf |
| Tree volume (ft³/tree) | 59 | 22 | 28 | 72 | 9 | 262 | 68 | 111 | 42 |
| Tree volume (BF/tree) | 707 | 262 | 339 | 861 | 109 | 3,140 | 816 | 1,332 | 509 |
| Tree mass (lbs/tree) | 2,237 | 610 | 1,270 | 2,085 | 237 | 7,237 | 3,206 | 4,014 | 1,486 |
| Carbon storage (lbs/tree) | 3,202 | 874 | 1,817 | 2,984 | 339 | 10,487 | 4,588 | 5,746 | 2,126 |
| Carbon storage rate (lbs/ft³) | 54 | 64 | 45 | 37 | 40 | 71 | 50 | 50 |

- a $\pi \left(\frac{DBH}{2}\right)^2 \times \text{Tree height} / 4$
- b Since 1 cubic foot equals 12 board feet, this row is the above row multiplied by 12
- c $\text{Tree volume} \times \text{Wood density}$ Table 1 provides Wood density for each species
- d $\text{Tree mass} \times 65\% \times 50\% \times 120\% \times 3.67$ (some generalisations: 35% of the green mass of a tree is water so 65% is dry mass; 50% of the dry mass of a tree is carbon; 20% of the tree biomass is below ground level in roots; a factor of 3.67 determines the equivalent amount of carbon dioxide) [19]
- e Carbon storage per tree ÷ Average tree volume

3. Case studies

Mass timber cities and cultivated forests change and grow over time, which is why the growth rates of both city and species are studied for their potential impact on each other. We selected three cities in the US, New York City (NY), Denver (CO), and Tulsa (OK), because of their differences in base population, growth rate, and forest composition. Using the tables from Section 2, the case studies explore two scenarios. In the first scenario, urban growth that is entirely mass timber dictates the shape of the forest environment. In the second scenario, forest growth dictates the planning of an entirely mass timber urban environment. The case studies rely on many often invisible partnerships that are required to support the forest and the city. For example, the studies assume that all harvested trees are replanted, which would require the funding of land trusts, forest management plans, planters, and more. Another key assumption is that each occupiable square foot requires 5.8 board feet (BF) of mass timber. This was derived from an extensive study on Brock Commons, a 18-story mass timber residential building.[20]

3.1. Impact of the Urban on the Forest

3.1.1. New York City, NY. In 2019, over 57 million square feet of new floor space was added.[21] If construction growth remains at this pace, adding 57 million square feet annually, the city will have accumulated close to 4 trillion square feet in 75 years and almost 114 trillion in 200 years. New York state has 18.6 million total acres of forested land, in which three of the most common species are Red Maple, Eastern Hemlock, and American Beech. Table 3 explores the extent to which each of these species could individually support NYC’s growth if all new construction were mass timber.
Table 3. Forest capacity for 57 million annual sf of mass timber construction in New York City.

|                                | Red Maple | Eastern Hemlock | American Beech |
|--------------------------------|-----------|-----------------|----------------|
| Yield per acre (ft²/acre)      | 1,603     | 1,055           | 768            |
| Construction potential (ft²/acre) | 801       | 528             | 384            |
| Carbon storage (lbs/ft²)       | 27        | 20              | 32             |
| Existing forest (acres)        | 3,952,500 | 1,739,100       | 1,785,600      |
| Construction supported by existing forest each year (ft²) | 42,235,674 | 9,175,390 | 3,429,398 |
| Forest area to meet annual demand for mass timber (acres) | 5,334,078 | 10,795,454 | 29,687,500 |
| Percentage of existing forest  | 135.03%   | 620.75%         | 1,662.60%      |

*a Stand Density (trees per acre) × Volume per tree (ft³)

*b Yield per acre (ft²) ÷ 2 (At Brock Commons, a student residential building widely cited in mass timber literature, 162,700 ft² of gross area required 78,858 ft³ of timber; we deduced for the purpose of this calculation that 1 ft² of gross area requires roughly 1 ft³ of timber)

c Carbon storage rate of each species is listed in Table 2; this calculation assumes that 1 ft² of gross area requires roughly 1 ft³ of timber

d Modelled distributions of 12 tree species in New York [22]

e Mature Age × Yield per acre

For each species:

- Red Maple: 57,000,000 sf / 384 ft² = 149,102 acres
- Eastern Hemlock: 57,000,000 sf / 800 ft² = 71,250 acres
- American Beech: 57,000,000 sf / 530 ft² = 107,886 acres

Figure 2. Environmental and built area impacts of 1 acre of Red Maple, Eastern Hemlock, American Beech forests in New York.

None of the three species can alone support NYC’s annual construction; NYC needs a mixed species harvesting strategy or a reduction in construction. In this scenario, it is helpful to examine the construction supported by each forest annually. At a growing cycle of 75 years, 42 million square feet of red maple mass timber could be supplied every year without ever being exhausted. Similarly, 9 million square feet of eastern hemlock mass timber and 3 million square feet of American Beech mass timber could be built every year without ever being exhausted.
3.1.2. Denver, CO. In 2022, $14B is projected to be added to Denver’s residential, commercial, and institutional sectors at an average cost of $600/ft², which roughly translates to 24 million square feet (SF) per year.[23,24] Across the state, there are 24.5 million total acres of forests. Table 4 lists construction-oriented specifics of the area’s most prolific forest types, Mixed Conifer (Douglas Fir, White Fir, Rocky Mountain Juniper), Quaking Aspen, and Ponderosa Pine.[25]

|                  | Mixed Conifer | Quaking Aspen | Ponderosa Pine |
|------------------|---------------|---------------|----------------|
| Yield per acre (ft³/acre) | 10,903        | 634           | 15,635         |
| Construction potential (ft²/acre) | 5,451        | 317           | 7,818          |
| Carbon storage (lbs/ft²) | 22            | 19            | 20             |
| Existing forest (acres) | 1,800,000     | 5,000,000     | 2,000,000      |
| Construction supported by existing forest each year (ft²) | 213,300,000 | 79,250,000 | 195,450,000 |
| Forest area to meet annual demand for mass timber (acres) | 202,531      | 1,514,195     | 245,587        |
| Percentage of existing forest | 11.25%      | 30.28%        | 12.27%         |

See calculations in Table 3 for a,b,c,e,g. Forest Types Colorado State Forest Service.

![Figure 3. Environmental and built area impacts of 1 acre of Mixed Conifer, Quaking Aspen, Ponderosa Pine forests in Denver, CO.](image)

In Colorado state, the construction potential of all three forests are relatively similar. While Ponderosa Pine is more efficient because it is a large tree that grows fast, the smaller existing population makes its utilisation as a primary source of mass timber risky. Ideally, it would be combined with more species to reduce the percentage of existing forest that is required. The Mixed Conifer forest grows...
densely and sequesters the most carbon per acre; its efficiency makes up for its lower existing forest area. While Quaking Aspen has a larger existing area, it produces less volume per acre, which requires a larger percentage of its existing area than that of the Mixed Conifer forest.

3.1.3. **Tulsa, OK.** A construction investment of $571M estimated for multi-family, commercial, and institutional sectors in 2021 at an estimated rate of $600/ft² accounts for around 1 million square feet of construction each year.[26,27] Oklahoma state has a total of 12.3 million acres of forests that include many species, including the mixed forests of Oak Hickory, Elm Ash Cottonwood, and Loblolly Shortleaf Pine, the construction-oriented characteristics of which are listed in table 5.[28]

![Figure 4](image)

**Figure 4.** Environmental and built area impacts of 1 acre of Oak Hickory, Elm Ash Cottonwood, Loblolly Shortleaf forests near Tulsa, OK.

|                     | Oak Hickory | Elm Ash Cottonwood | Loblolly Shortleaf Pine |
|---------------------|-------------|--------------------|-------------------------|
| Yield per acre (ft³/acre) | 3,251       | 2,303              | 4,243                   |
| Construction potential (ft³/acre) | 1,626       | 1,152              | 2,121                   |
| Carbon storage (lbs/ft²) | 35          | 25                 | 25                      |
| Existing forest (acres) | 6,700,000   | 1,400,000          | 1,200,000               |
| Construction supported by existing forest each year (ft²) | 765,668,148 | 165,094,222 | 147,720,672 |
| Forest area to meet annual demand for mass timber (acres) | 30,142 | 19,683 | 14,141 |
| Percentage of existing forest | 0.45% | 1.41% | 1.18% |

*a,b,c,e,g* See calculations in Table 2

* Mature age × \( \frac{1,000,000 \text{ sf}}{\text{Construction potential}} \)

In Oklahoma state, the construction potential of an acre of a Loblolly Shortleaf Pine forest is much higher than that of its counterparts, as it grows denser, faster, and taller. Oak-Hickory and Elm-Ash-Cottonwood forests produce a similar amount of mass timber per acre. Although there is a far greater area of Oak-Hickory trees available, the percentage required from each forest is very similar, tracking
with their growing efficiency. Any of these species could easily support the relatively low amount of growth happening in Tulsa.

3.2. Impact of the Forest on the Urban
Forest utilisation is not only a tool to design the size and style of forest management areas, it can also be a tool to determine urban growth. Species-driven metrics are correlated to housing potential in table 6, and then used as a design tool to determine urban growth patterns.

| Forest dominant species       | Construction potential (ft²/acre) | Housing potential (people housed/acre) |
|------------------------------|-----------------------------------|---------------------------------------|
| Red Maple                    | 801                               | 2                                     |
| Eastern Hemlock              | 528                               | 1                                     |
| American Beech               | 384                               | 1                                     |
| Mixed Conifer                | 5,451                             | 14                                    |
| Quaking Aspen                | 317                               | 1                                     |
| Ponderosa Pine               | 7,818                             | 20                                    |
| Oak Hickory                  | 1,626                             | 4                                     |
| Elm Ash Cottonwood           | 1,152                             | 3                                     |
| Loblolly Shortleaf Pine      | 2,121                             | 5                                     |

a See Tables 3, 4, 5
b Assumes 400ft² per person

Referencing the above data, table 7 enumerates the number of housing units that can be built in NYC with each species with multiple areas of forest available for harvest in a given year.

| Forest dominant species       | Forest available for harvest (acres) | Mass timber construction (ft²) | Housing (number of people) |
|------------------------------|--------------------------------------|-------------------------------|----------------------------|
| Red Maple                    | 8,000                                | 6,411,488                     | 16,029                     |
| Eastern Hemlock              | 2,000                                | 1,055,188                     | 2,638                      |
| American Beech               | 4,000                                | 1,536,468                     | 3,841                      |
| Total                        | 14,000                               | 9,003,144                     | 22,508                     |

a Hypothetical values
b Forest available for harvest × Construction potential (Table 6)
c Forest available for harvest × Housing potential (Table 6)

4. Conclusion
Through an analysis of state-based species and urban data, this paper finds that local forests can meet the expected needs of housing construction with mass timber, but should be carefully studied and planned with local land trusts and foresters. This focus on biodiversity would result in multiple benefits, including increased carbon storage, better construction environments, lower transportation costs and lower amount of energy loss in the built environment, as well as economic benefits for those in the industry. In addition, more city dwellers may benefit from the stress reduction of exposed mass timber, potentially extending lifespans by 2.5 years.[29]

The potential of biodiverse mass timber is a reason to manage local forests and the built environment together towards a common goal, rather than continue to source mineral-based materials from elsewhere and convert local forests into agriculture or urban sprawl. As a modern material, mass timber is quite young, however research is emerging about its impact on public health, environmental health, manufacturing and harvesting innovations, and construction techniques. Interdisciplinary planning
between the forest and the urban realm would welcome a more pluralistic relationship with nature and eventually grow into a foundational framework for the future of cities.

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