WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

QUANTIFICATION OF WOOD MASS IN THE URBAN ENVIRONMENT WOOD STOCK IN SANTIAGO, CHILE

Felipe Victorero[1], Waldo Bustamante[2]

ABSTRACT: The advantages of wood construction from a sustainability and carbon capture perspective are widely recognized. Consequently, multiple countries are promoting wood construction in their cities through various public policies. However, in many countries, questions remain regarding the prevalence and spatial distribution of wooden structures in urban areas, which is crucial for quantifying benefits such as carbon capture and developing circular economy frameworks. This study explores this issue using Santiago of Chile and its 32 municipalities as a case study, considering wood temporal and spatial distribution at city centre, pericentre, and periphery zones. The results show that while wooden structures represent only about 5.4% of the city's total built surface area, this accounts for approximately 459,929 tons of wood, some of which is over 100 years old. Moreover, an analysis of their spatial distribution reveals that older, higher-density municipalities in the pericentre zone have a smaller wooden surface area compared to those with lower density, confirming a trend in which wood appears almost exclusively in low-complexity, small house structures, mostly located in developing peripheral areas of the city. In this context, the prevalence of wooden construction is largely influenced by urban planning policies and the availability of timber construction technologies for developing taller buildings.

KEYWORDS: wood densification, urban wood, wood spatial quantification.

1 – INTRODUCTION

Wood-based products derived from sustainably managed forests have emerged as a renewable alternative to conventional building materials that are heavily reliant on fossil fuels and associated with significant greenhouse gas (GHG) emissions [1–3]. Beyond reducing environmental impacts, the promotion of sustainable wood use can incentivize reforestation and afforestation efforts, driving investment in forest ecosystems and potentially enhancing carbon sequestration through the expansion of forest cover [2].

During tree growth, atmospheric CO_2 is absorbed and stored in the biomass through photosynthesis. When harvested wood is used in durable applications such as building construction, this biogenic carbon remains sequestered for extended periods, ranging from several decades to centuries, depending on the wood building product and the building's lifespan [3]. This storage function transforms timber products into long-term carbon reservoirs, contributing to climate change mitigation strategies. Studies indicate that although a substantial proportion of embodied emissions in timber buildings occurs during the early life cycle stages (i.e., from material production, cradle to gate), a significant share of carbon is offset through storage, particularly when dynamic life cycle assessment methods are employed. This is why keeping track of wood products is of high importance in order to understand what happens to its biogenic stored carbon, especially at the end of its life.

Consequently, in response to international climate goals, several countries have introduced policy frameworks to stimulate the adoption of wood in construction. These policies include regulatory instruments, fiscal incentives, and strategic guidelines aimed at accelerating the uptake of sustainably harvested timber in both residential and commercial buildings. Such measures are increasingly supported by empirical studies highlighting timber's capacity to reduce the whole-life embodied carbon of buildings compared to conventional alternatives.

[1] Felipe Victorero, Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD, ANID BASAL FB210015), School of Architecture, Pontifical Catholic University of Chile, Santiago, Chile, favictor@uc.cl ORCID 0000-0002-3712-7772.

[2] Waldo Bustamante, Centro de Desarrollo Urbano Sustentable (CEDEUS- ANID FONDAP 1523A0004), School of Architecture, Pontifical Catholic University of Chile, Santiago, Chile, wbustamante@uc.cl ORCID 0000-0002-0420-5383.

https://doi.org/10.52202/080513-0072

Additionally, different trends in urban planning and the technological capabilities of a given urban environment play a crucial role in determining the feasibility of wood construction. Traditionally, due to regulatory constraints and limited technical advancements, wood has primarily been used in low-rise buildings, particularly in urban expansion areas. In this context, urban densification processes may pose a challenge to its widespread adoption, leading designers and developers to favour materials such as concrete and steel for larger structures, thus potentially limiting the role of wood in high-density urban settings.

2 – BACKGROUND

Despite the widely recognized environmental and structural advantages of timber in construction, a substantial knowledge gap persists regarding its actual presence, evolution, and spatial distribution within urban environments. Therefore, question such as how many wood-based structures exist in a given city, or how urban timber inventories change over time often remain unanswered. Addressing these types of questions is essential for assessing the carbon storage potential of cities, evaluating the material stocks embedded in the built environment, and integrating timber construction into circular economy strategies. Furthermore, such information is indispensable for formulating effective public policies and designing adequate instruments that could support wood-based construction in different context-specific urban scenarios.

On the other hand, timber construction development can vary considerably across neighbourhoods or municipalities within the same metropolitan area. This heterogeneity often reflects discrepancies in urban planning regulations, policy support, and technical capacity. However, these trends can be altered through strategic planning reforms, the implementation of adaptive regulatory frameworks, and the adoption of instruments that explicitly prioritize wood as a primary construction material.

In this context, significant advances in tall timber building technologies have been achieved over the past decade in high-income countries—particularly in Europe, North America, and Oceania. However, this progress has not been mirrored in other regions such as Latin America, Asia, or Africa. The disparity is largely attributable to differences in regulatory frameworks and the prioritization of sustainability in construction agendas. Thus, in many developing regions, the absence of institutional support and the lack of technical expertise continue to constrain the widespread adoption of timber in mainstream construction practices, and affects biogenic carbon stored in urban structures as well as its future growth.

3 – PROJECT DESCRIPTION

This paper aims to present the case study of Santiago, Chile, to examine how wooden structures are spatially and temporally distributed within the urban environment of a capital city in a developing country with a high demand for infrastructure. This analysis considers the city's urban structure in relation to the development of its various municipalities and the evolution of wood as a primary building material in the city different zones – centre (downtown), pericentre, and periphery, thus allowing for a better understanding of the expansion or contraction of the use of wooden structures in the built environment and the associated biogenic carbon stored in them.

Consequently, the case of Santiago, Chile, is analysed in detail to understand how wood structure inventories are spatially and temporally affected by urban densification patterns, considering the geographic distribution of the 32 municipalities that make up the province of Santiago (or "Santiago city" for the purpose of this work). This analysis provides valuable insights into the current state of wood usage in the city and how various factors have influenced wood inventories and the types of timber building typologies being employed today.

Furthermore, many countries are increasingly interested in quantifying and understanding the availability of wood construction materials within the urban environment, each facing distinct challenges. A common obstacle is the lack of comprehensive data on wooden structures and their temporal evolution, which limits the ability to conduct thorough analyses. In this context, this study aims to contribute valuable insights that may support researchers seeking to examine the development of wooden structures in diverse urban settings

4 – DESIGN PROCESS

This study examines the extent of timber construction and its associated biogenic carbon storage in Santiago, Chile, by integrating two publicly available national databases. The combined use of these databases also enables comparisons across municipalities, taking into account variations in urban conditions and local planning regulations. The first database is sourced from Chile's Internal Revenue Service (SII) and covers the period from 2018 to 2024 (previous years are not publicly available through its platforms). It offers comprehensive city-wide information on individual buildings, including their geographic location, year of construction (based on final municipal approval), primary construction materials (particularly those used in load-bearing walls), total built surface area, functional classification, and construction quality, categorized into five standardized levels [4]. Although the database contains additional auxiliary variables, these were excluded from the analysis due to their limited relevance to the study's objectives. Nevertheless, it is important to notice that this database lacks buildings' height or number of floors information regarding any of the recorded projects.

The second database, provided by the Chilean National Institute of Statistics (INE), consists of records on approved building permits issued since 2002, instance in which the record started [5]. Unlike the SII database, this source captures design and construction intentions rather than verified built structures. It contains relevant data on building typologies such as structural height, location, surface area, use, and main construction materials associated with load-bearing systems. Despite its broader temporal range and inclusion of height information, the INE database has critical limitations such as not having record of buildings erected prior to 2002 and does not verify whether authorized permits resulted in completed structures or underwent modifications during construction that lead for example to change in their structural materials.

To ensure comparability across a similar time range, this study analyses records from 2018 to 2024 from the SII database and from 2017 to 2023 in the INE database. This allows for a six-year overlap in data while also accounting for the temporal lag that often exists between the issuance of building permits and the actual completion of construction. The analysis focuses primarily on timber structures, which represent the majority of urban biogenic carbon storage. Also, although other buildings may contain wooden elements, such as roofing systems or internal partitions, these components could not be individually identified or quantified within the scope of this study.

Moreover, to estimate the total wood mass present in the urban built environment, a wood material intensity coefficient of 33.8 kg/m² was applied to the timber surface areas identified in the databases [6]. The analysis was disaggregated by building function and by municipality within the metropolitan region.

5 – RESULTS

The results are first presented through the analysis of the historical database of the Internal Revenue Service (SII), followed by trend analysis using data from the National Institute of Statistics (INE), and finally, the quantification of wood mass based on built surface area, along with projections based on the authorized wooden structure surface area.

5.1 SII DATABASE – HISTORICAL WOODEN STRUCTURES

Analysis of historical building data from the national tax revenue office reveals a notably lower proportion of timber construction in Santiago compared to the national average. While wood structures account for over 20% of the built surface area at the national level, in Santiago they represent only 5.4% Figure 1. The registry shows a modest annual growth rate of about 0.21% in timber-built surface area, which amounts to nearly 200,000 square meters of additional wooden structures over the seven-year study period.

Figure 2 further highlights the temporal distribution of timber buildings across the city at city centre, pericentre and periphery. While some wooden structures, particularly in the historic centre of Santiago, are over a century old, the majority of timber surface area is concentrated in peripheral municipalities. Thus, the graph shows how outer municipalities experienced a rapid urban expansion over the last decades of the 20st century, often characterized by low-rise, two-story dwellings and lower construction standards. Moreover, although all municipalities show some increase in timber-built area over time, this growth has noticeably slowed over the last years, coinciding with Santiago's broader transition toward a denser urban form.

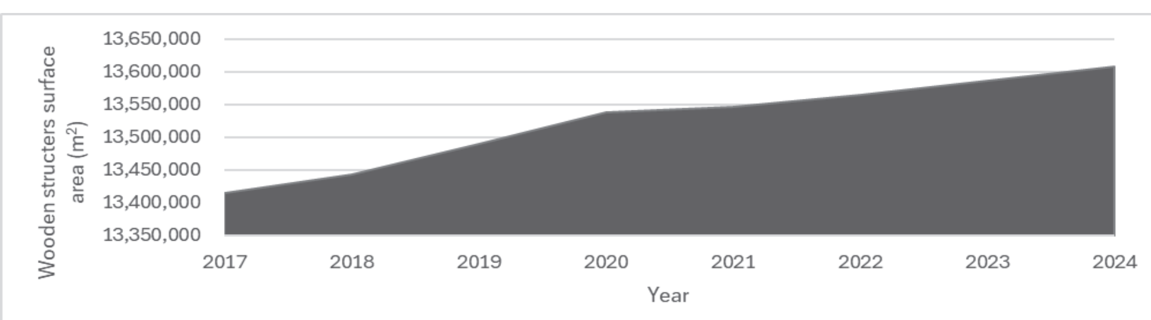


Figure 1. Annual total wooden structure surface area in Santiago.

https://doi.org/10.52202/080513-0072

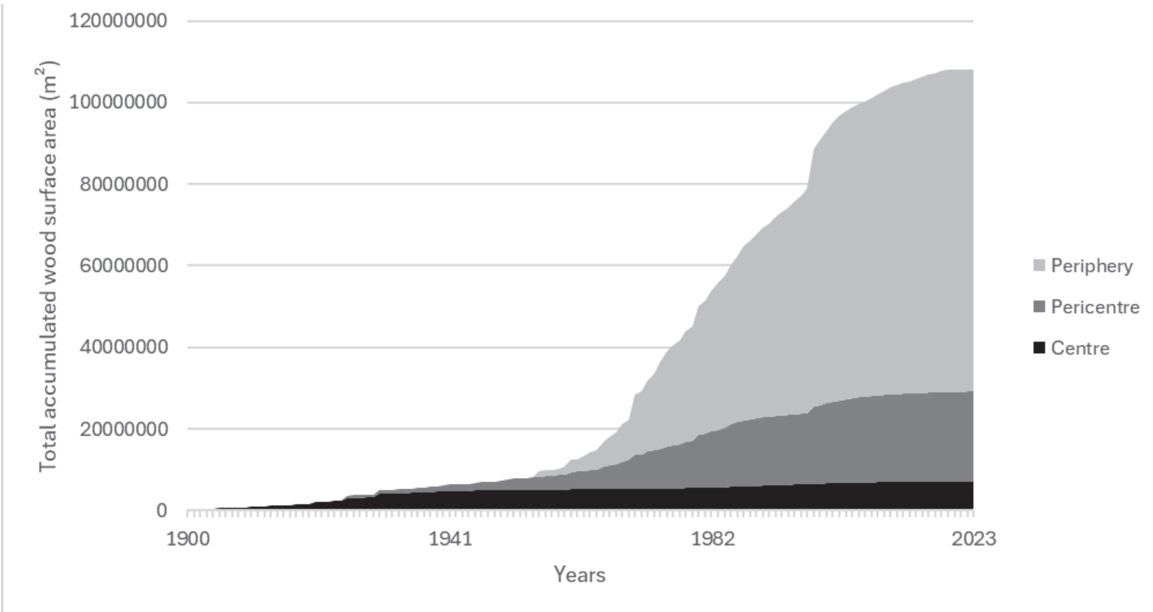


Figure 2. Age of wooden structures and surface area (m²) by zone (Centre, Pericentre and Periphery).

In relation to the spatial distribution at municipality level (Figure 3), it is possible to identify particular patterns in the distribution and temporal evolution of wood-based construction within the urban fabric. The results indicate that the central municipality of Santiago retains the highest concentration of historical timber structures, reflecting the city's wooden architectural heritage. In contrast, the adjacent pericentral municipalities display a notably lower presence of timber buildings in the current built environment. This decline is primarily attributed to a cultural association of sawn wood with smaller, low-cost structures and the gradual replacement of older timber buildings with higher structures made from more contemporary materials such as reinforced concrete. Meanwhile, the expanding peripheral municipalities exhibit a greater extent of timber-built surface area, largely resulting from recent urban development characterized by low-rise, wood-framed dwellings.

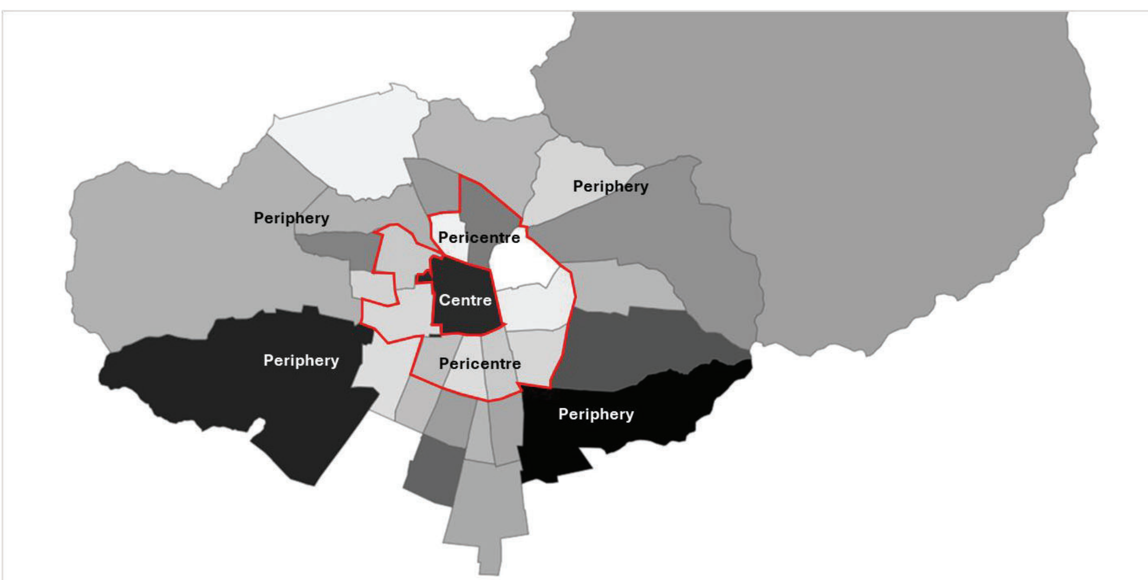


Figure 3. Distribution of wooden structure surface area by municipality (darker more wood and lighter less wood).

5.2 INE DATABE - TRENTS FOR FUTURE WOODEN STRUCTURES

As illustrated in Figure 4, data from 2023 shows that timber-based constructions account for only approximately 0.7% of the total surface area approved through building permits in Santiago, significantly lower than the national average of 14% according to the same database. This disparity can be largely attributed to Santiago's high population and urban density, which favour the use of concrete and steel in high-rise, large-scale developments. Nevertheless, while the share of timber construction had been steadily declining since previous 2017, recent years have shown a modest rebound, with timber regaining a portion of the newly permitted building surface area. This trend may be explained by the typical use of materials in Chile, where concrete is primarily applied to technically complex, high-density projects, while sawn timber is more often used in small-scale, low-cost residential buildings. In this context, timber construction may have emerged as a more accessible and adaptable solution for addressing housing needs under economic constraints. Economic constrains that are explained by the effects of the COVID-19 pandemic of 2020 and the subsequent economic downturn that the country has experience since then.

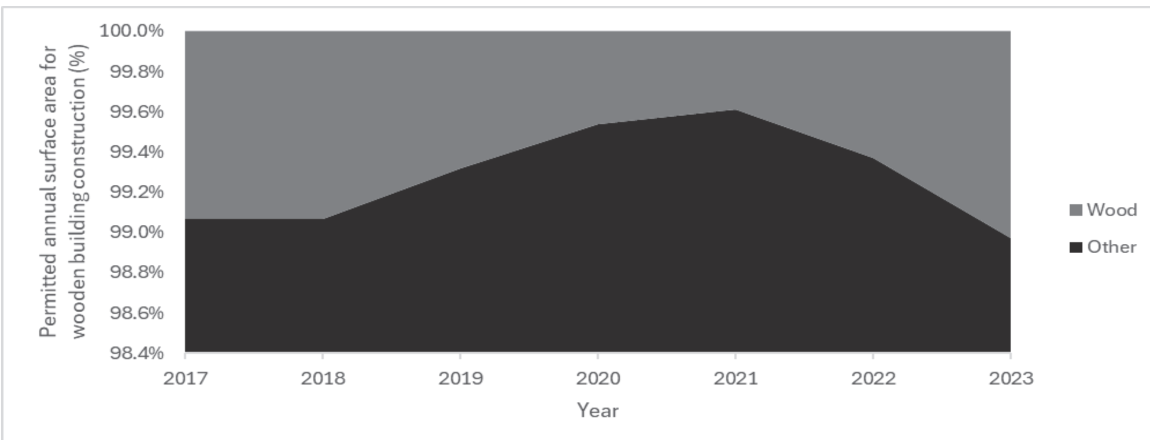


Figure 4. Wood Building Permits surface area versus other materials in Santiago.

As shown in Figure 5, the average height of approved building permits in Santiago showed a steady upward trajectory prior to the COVID-19 pandemic, peaking in 2020 and maintaining in 2021 during the initial post-pandemic economic recovery. Also, when weighted by surface area of each project heights, the average number of floors for permitted buildings across the study period exceeds six stories, with 2021 reaching a notable peak of 12 floors. In contrast, timber-based projects consistently show an average of less than two stories, underscoring the material's limited application in multi-story construction in the Chilean context.

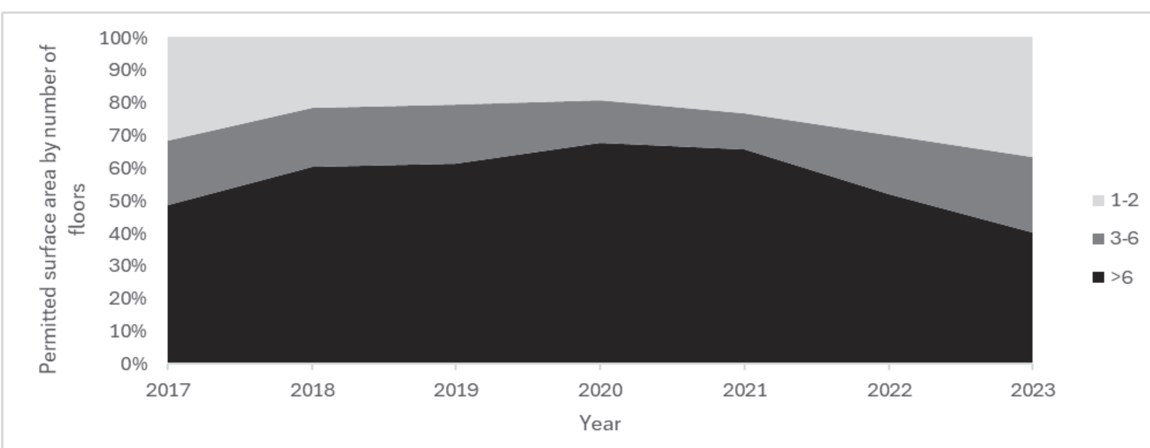


Figure 5. Annual permitted surface area percentage, grouped by number of floors.

https://doi.org/10.52202/080513-0072

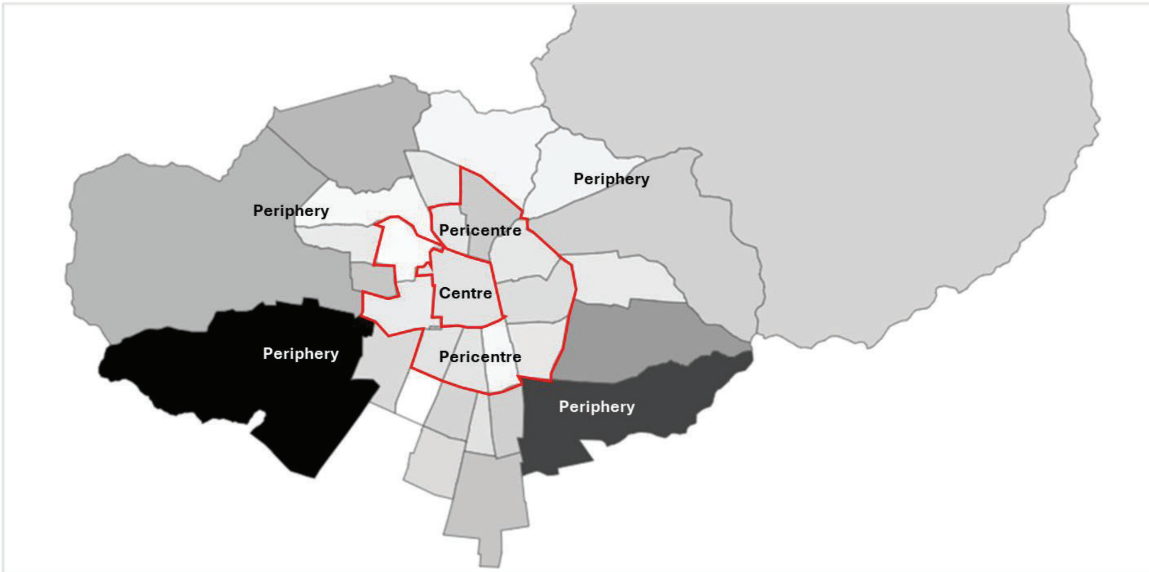
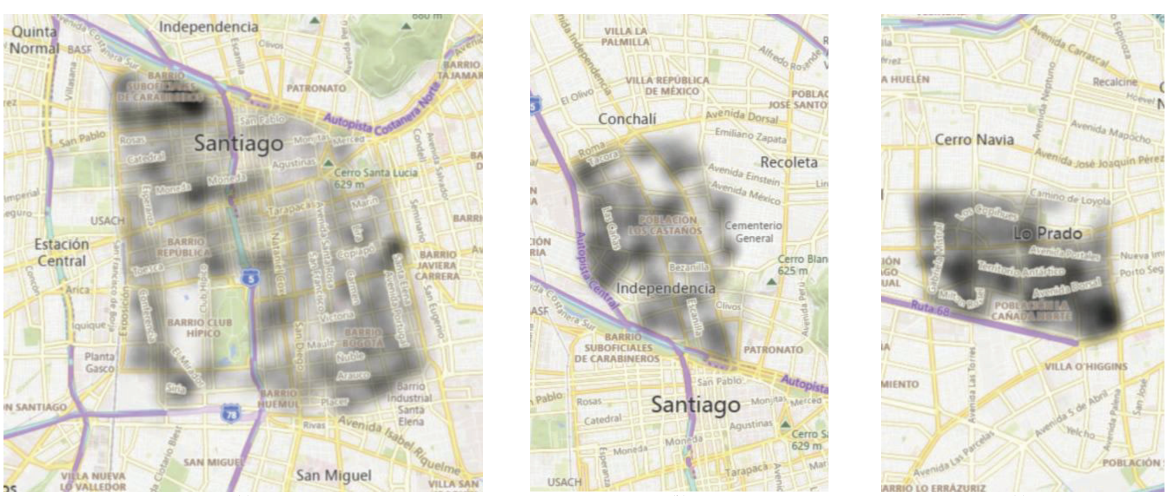


Figure 6. Distribution of wooden structure surface area from building permits by municipality (darker more wood and lighter less wood).

Regarding spatial distribution of wooden structures building permits, these findings are consistent with historical patterns derived from the national tax revenue office database, which indicate that new timber construction is primarily concentrated in the city's peripherical municipalities, where urban expansion remains active (Figure 6). Conversely, central and pericentral zones demonstrate limited interest in approving new wood-based projects.

5.3 WOOD MASS ESTIMATION AND PROYECTION BY MUNICIPALITY

Using the built area of wooden structures obtained from the SII database and an average Wood Material Intensity for Chilean building structures of 33.8 kg/m², as explained in the design process section, it is possible to estimate that Santiago and all its municipalities contain approximately 459,929 tons of wood. At the municipal level, La Florida (periphery) has the highest total wood mass; however, when considering wood mass per square kilometre, San Ramón (pericentre) stands out as the municipality with the highest density. On the opposite end, as expected, Providencia (pericentre) has the lowest total wood mass, both in absolute terms and relative to its municipal surface area. Additionally, municipalities such as Maipú (periphery) show a significant reduction in total wood mass, as their larger territories contrast with central municipalities, and they have undergone their own densification processes in recent years.



(a) (b) (c)

Figure 7. Wood mass in: (a) Centre municipality Santiago;(b) Pericentre representative municipality Independencia; (c) Periphery representative municipality Lo Prado.

Table 1: Santiago city's wooden structure mass.

Santiago			SII - Data on Historically Wooden Built Structures (2024)			INE - Data on Building Permits for Wooden Structures (2016–2023)				Projected Average Growth (2025-2030)		
Municipality (Zone)		Surface area (km2)	Built area (m2)	Built mass (t)	Built mass (t/km2)	Permitted area (m^2)	Avg. annual permitted area (m^2)	Avg. annual permitted mass (t)	Avg. annual permitted mass (t/km2)	Potentially built annually (t)*	Added mass (t)	Growth (%)
Centre	Santiago	22	860,530	29,085.9	1,322	6015	752	25.4	1.2	20.33	101.65	0.35%
Pericentre	Estacion Central	14	254,612	8,605.9	615	4816	602	20.3	1.5	16.28	81.39	0.95%
	Independencia	7	168,046	5,680.0	811	5337	667	22.5	3.2	18.04	90.20	1.59%
	Macul	13	261,443	8,836.8	680	5159	645	21.8	1.7	17.44	87.19	0.99%
	Nunoa	17	184,881	6,249.0	368	6811	851	28.8	1.7	23.02	115.11	1.84%
	Pedro Aguirre Cerda	10	343,146	11,598.3	1,160	5988	749	25.3	2.5	20.24	101.20	0.87%
	Providencia	14	111,125	3,756.0	268	5224	653	22.1	1.6	17.66	88.29	2.35%
	Quinta Normal	12	303,202	10,248.2	854	2132	267	9.0	0.8	7.21	36.03	0.35%
	Recoleta	16	585,845	19,801.6	1,238	9580	1,198	40.5	2.5	32.38	161.90	0.82%
	San Joaquin	10	304,814	10,302.7	1,030	2583	323	10.9	1.1	8.73	43.65	0.42%
	San Miguel	10	238,366	8,056.8	806	5729	716	24.2	2.4	19.36	96.82	1.20%
Periphery	Cerrillos	21	238,089	8,047.4	383	7451	931	31.5	1.5	25.18	125.92	1.56%
	Cerro Navia	11	570,009	19,266.3	1,751	5025	628	21.2	1.9	16.98	84.92	0.44%
	Conchali	11	482,980	16,324.7	1,484	5223	653	22.1	2.0	17.65	88.27	0.54%
	El Bosque	14	682,888	23,081.6	1,649	7211	901	30.5	2.2	24.37	121.87	0.53%
	Huechuraba	45	371,124	12,544.0	279	3018	377	12.8	0.3	10.20	51.00	0.41%
	La Cisterna	10	463,992	15,682.9	1,568	8332	1,042	35.2	3.5	28.16	140.81	0.90%
	La Florida	71	1,042,791	35,246.3	496	32345	4,043	136.7	1.9	109.33	546.63	1.55%
	La Granja	10	438,082	14,807.2	1,481	9146	1,143	38.6	3.9	30.91	154.57	1.04%
	La Pintana	31	437,456	14,786.0	477	10690	1,336	45.2	1.5	36.13	180.66	1.22%
	La Reina	23	377,564	12,761.7	555	4932	617	20.8	0.9	16.67	83.35	0.65%
	Las Condes	99	513,107	17,343.0	175	8798	1,100	37.2	0.4	29.74	148.69	0.86%
	Lo Barnechea	1,024	465,870	15,746.4	15	8321	1,040	35.2	0.0	28.12	140.62	0.89%
	Lo Espejo	7	349,202	11,803.0	1,686	1117	140	4.7	0.7	3.78	18.88	0.16%
	Lo Prado	7	274,927	9,292.5	1,328	10483	1,310	44.3	6.3	35.43	177.16	1.91%
	Maipu	133	918,202	31,035.2	233	43605	5,451	184.2	1.4	147.38	736.92	2.37%
	Penalolen	54	744,954	25,179.4	466	17791	2,224	75.2	1.4	60.13	300.67	1.19%
	Pudahuel	197	408,797	13,817.3	70	13115	1,639	55.4	0.3	44.33	221.64	1.60%
	Quilicura	58	173,177	5,853.4	101	12803	1,600	54.1	0.9	43.27	216.37	3.70%
	Renca	24	399,103	13,489.7	562	2547	318	10.8	0.4	8.61	43.04	0.32%
	San Ramon	7	382,142	12,916.4	1,845	6140	768	25.9	3.7	20.75	103.77	0.80%
	Vitacura	28	256,900	8,683.2	310	3441	430	14.5	0.5	11.63	58.15	0.67%
TOTAL		**2,030**	**13,607,366**	**459,929.0**	**227**	**280,908**	**35,114**	**1,186.8**	**0.6**	**949.47**	**4,747.35**	**1.03%**

*The "Potentially built annually" column is estimated based on the relationship between the average annual wood construction recorded in the SII database, which consists of 28 thousand sqm, and the average INE authorized building permits of 35 thousand sqm. This indicates that approximately 20% of the authorized wooden structures are either not being built or are being converted to other materials.

https://doi.org/10.52202/080513-0072

6 – CONCLUSION

First, it is crucial to acknowledge the importance of buildings information databases that enable this type of study, particularly those that identify building areas and materials, allowing for future life cycle assessments and circularity analyses of the built environment. Additionally, having separate data for built structures and building permits, which reflect the intention of developing new construction, helps to understand building trends and the evolution of material use in a given city. Similar research in Europe and Australia has faced challenges in accessing such data, highlighting the need for developing countries, such as those in Latin America, to work on this matter. This is especially critical for public policies that promote the retention of wood construction products within the built environment or facilitate the inclusion of taller timber buildings as alternatives to concrete structures.

Although the Chilean database presents interesting research opportunities, it is important to acknowledge that it is not without challenges. In this regard, while the databases are updated every six months in the case of the tax revenue office and annually for building permits, some records may not be fully updated, leading to discrepancies that, although not significant at the citywide level, might be relevant for specific municipalities or neighbourhood analyses. Additionally, while it would have been ideal for the tax revenue office to incorporate project height, this is not considered, as the database records individual units within a building rather than the structure as a whole. Similarly, the building permit database does not distinguish between approved projects and those that are actually built. Furthermore, particularly for circularity analyses, it is crucial to include more detailed information on the materials used in structures, reducing reliance on material intensity data, which can vary significantly between projects and across different decades or centuries.

Regarding the results of this study, the case of Santiago demonstrates how the presence of wooden structures can vary significantly within a metropolitan area, depending on the densification processes and urban planning approaches of each municipality. In this context, historically central municipalities tend to preserve their heritage wooden structures, while peripheral municipalities such as La Florida tend to increase their total wooden surface area through urban expansion. In contrast, pericentral municipalities like Providencia have lost most of their wooden structures due to densification process.

Finally, although peripheral municipalities are increasing their wood mass annually, they could eventually follow the path of pericentric municipalities, losing their wooden structures in favour of taller concrete buildings. Therefore, finding alternatives to incorporate wood into high-rise buildings will be crucial to preventing significant wood mass losses from Santiago's built environment in the future. In this regard, Chile's newly developed capacity to produce mass timber—particularly cross-laminated timber (CLT) and industrialized timber frame panels—could shift some of the trends observed in this study. An example of this is the recent announcement of a 10-story wooden building in downtown Santiago, which could mark the beginning of a new phase of wood-based urban densification in the city centre and pericentre zones.

7 – REFERENCES

[1] Hildebrandt, J.; Hagemann, N.; Thrän, D. The Contribution of Wood-Based Construction Materials for Leveraging a Low Carbon Building Sector in Europe. *Sustain Cities Soc* **2017**, *34*, 405–418, doi:10.1016/j.scs.2017.06.013.

[2] Churkina, G.; Organschi, A.; Reyer, C.P.O.; Ruff, A.; Vinke, K.; Liu, Z.; Reck, B.K.; Graedel, T.E.; Schellnhuber, H.J. Buildings as a Global Carbon Sink. *Nat Sustain* 2020, *3*, 269–276.

[3] Ramage, M.H.; Burridge, H.; Busse-Wicher, M.; Fereday, G.; Reynolds, T.; Shah, D.U.; Wu, G.; Yu, L.; Fleming, P.; Densley-Tingley, D.; et al. The Wood from the Trees: The Use of Timber in Construction. *Renewable and Sustainable Energy Reviews* 2017, *68*, 333–359.

[4] Servicio de Impuestos Internos Detalle Catastral y Rol de Cobro Available online: https://zeusr.sii.cl/AUT2000/InicioAutenticacion/IngresoRutClave.html?https://www4.sii.cl/sismunInternet6/?caller=DETALLE_CAT_Y_ROL_COBRO (accessed on 21 October 2024).

[5] Instituto Nacional de Estadísticas Permisos de edificación Available online: https://www.ine.gob.cl/estadisticas/economia/edificacion-y-construccion/permisos-de-edificacion (accessed on 23 October 2024).

[6] Victorero, F.; Bustamante, W. Timber Biogenic Carbon Stock in the Urban Environment: Santiago City as a Second Forest. *Sustainability (Switzerland)* **2025**, *17*, doi:10.3390/su17020529.