Prediction of Raw-Wood Consumption Based on Potential Wood Usage in Public Buildings: A Quantitative Approach Using Building Construction Statistics

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The use of wood in the construction sector to reduce greenhouse gas (GHG) emissions is garnering global interest. In South Korea, the wood usage in public buildings is limited, being influenced by factors such as the high price of wood products and their limited use in large structures. In this work the future wood consumption in South Korea is predicted based on its potential use in current public buildings. The structural wood products required for the buildings were quantified based on the available statistical data. Items investigated were the (1) number of buildings started, (2) ratio of public buildings, (3) ratio of wooden structures, (4) average floor area of wooden buildings, (5) material cost per floor, and (6) wood prices. Assuming that the buildings contain reinforced-concrete and wooden structures, the wood consumption was estimated based on the replacement ratio. The results indicated that the prices of wood products were relatively higher than those of raw timber. The number of buildings is expected to decrease in line with the expected population decline, resulting in the decrease of wood amount required for public buildings. To achieve long-term GHG-reduction goals, it is important to replace the existing public buildings in Korea with wooden structures.

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Keywords: Wood consumption; Construction sector; Statistical data; Greenhouse-gas emissions reduction; Predictive approach; Public buildings; South Korea

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INTRODUCTION

The 2015 Paris Agreement (United Nations 2015) highlighted the need to focus on carbon cycling and greenhouse gas (GHG) reduction. The construction sector, known for its significant energy consumption (European Commission 2014), is showing a growing interest in the use of wood as a material to reduce GHG emissions (Gosselin *et al*. 2017). Owing to its high strength, cyclical use of resources, and low carbon emissions during production, wood presents favorable environment-friendly characteristics compared to modern construction materials (Milaj *et al*. 2017; Pierobon *et al*. 2019; Ruschi Mendes Saade *et al*. 2020). The awareness that it is important for architects to consider not only the requirements of building owners and occupants but also the environmental impact of construction-material selection is increasing (Buchanan and Honey 1994). An increasing number of studies in the literature on the topic suggest that using wood in the construction sector can be an effective way to address the on-going climate crisis, urging decision-makers to prefer wood over modern materials.

Furthermore, the increase in wood usage in the construction sector can be attributed to the environmental and technological improvements in wood products, national initiatives that encourage wood usage, and the fact that wood can complement/be used for diverse architectural structures. In North America, the continuous promotion of wood in the construction sector has been linked to a consistent supply of wood products in the market (Cordier *et al*. 2020). In 2020, South Korea utilized 27,300,000 m^3 of wood and wood products. Among them, raw logs accounted for 6,340,000 m^3 (23.2%), while branches and other raw materials, excluding raw logs, accounted for 543,000 m^3 (2.0%). Notably, imported wood products constitute a significant portion of wood usage, accounting for 20,400,000 m^3 (74.8%) of the total consumption. In terms of raw log sourcing, domestically produced raw logs amount to 3,740,000 m^3, whereas the volume of imported raw logs is 2,600,000 m^3. The data highlight a notable reliance on imported wood over domestically sourced wood, with the utilization rate of domestically sourced wood at 15.7%. In addition, whereas the volumes of sawn timber available for use as construction material produced from imported raw logs and used as sawn timber products are 2,350,000 m^3 and 2,390,000 m^3, respectively, domestically sourced sawn timber amounts to 544,000 m^3, which is comparatively lower. Furthermore, excluding sawn timber (543,000 m^3), fiberboard (1,270,000 m^3), and preservative-treated lumber (10,700 m^3), the majority of domestically produced timber is primarily utilized as fuelwood (Korea Forest Service 2021a).

In 2020, the forest area of the South Korea was 6,290,000 ha, constituting 62.6% of the total land area. The growing stock volume per hectare has exhibited a significant increase from 5.7 m^3/ha in 1953 to 165.2 m^3/ha in 2020. However, despite a steady increase in growing stock volume, there is a notable trend of forest aging, which is particularly evident since 2009, with a sharp rise in the volume of IV–V age classes growing stock, alongside a gradual decline in II–III age classes growing stock (Han and Lee 2021). Consequently, there are concerns over the downward trends in the greenhouse gas absorption rate of the forested areas in South Korea, which declined from 12.4% in 2000 to 8.9% in 2010, and further to 6.4% in 2017. Considering the carbon storage and substitution effects of wood and wood products, utilizing domestically produced wood and wood products for buildings that are expected to have longer lifespans (such as public buildings) can have long-term benefits (Amiri *et al*. 2020). In South Korea, policies are being developed to encourage the use of domestic wood and wood products in public buildings, while recognizing the potential market changes and product management system transformations initiated by the government.

This study predicts the volume of future domestic sawn timber usage in South Korea based on the potential wood usage in public buildings. To predict the volume of domestic sawn timber usage, a model based on Cordier *et al*. (2020) was employed to quantify the consumption of wood products based on the building permits in the country; the model was adjusted to fit the available statistical data for South Korea. There was a collation of data on the (1) total number of buildings started, (2) ratio of public buildings in total buildings, (3) ratio of wooden structures in public buildings, (4) average floor area of wooden buildings, (5) material costs per floor area, and (6) wood price. In addition, assuming the replacement of steel-concrete structures in public buildings with wooden structures, the volume of sawn timber usage was predicted based on the replacement ratio.

EXPERIMENTAL

Methods

The literature on quantifying the consumption of materials used in the construction sector is limited to residential buildings because of the scarcity of available data for public and commercial buildings (Augiseau and Barles 2017; Cordier *et al*. 2020). To quantify the wood consumption in commercial buildings, while using limited data, Geskin Conseil (2008) considered the price of wood and the permit ratio for wooden structures. This methodology was used to quantify the structural wood products required for newly constructed commercial buildings (Cordier *et al*. 2020). In the present study, the volume of wood to construct public buildings in South Korea was estimated by employing four variables, namely, BP [building permits of new (NR) buildings], SCs (structural cost share), WBs (wood building share), and WSp (wood structure price), as shown in Eq. 1,

$$\text{Estimated volume of structural wood} = \frac{\text{BP} \times \text{SCs} \times \text{WBs}}{\text{WSp}} \tag{1}$$

where BP is construction cost for newly permitted building (USD), and WSp is unit cost of structural wood per volume (USD/m^3). The method for quantifying the wood-product usage in commercial buildings presented in Eq. 1 was modified to estimate the volume of wood used in public buildings in educational and social sectors, as shown in Eq. 2,

$$R = {(a \cdot b \cdot c) \times (d \cdot e)} / {f} \tag{2}$$

where *a* is the total number of building starts, *b* is the share of public buildings in the education and society sector in total buildings (%), *c* is the share of wood structures in public buildings (%), *d* is the average floor area of the wooden buildings (m^2), *e* is the material cost per floor-area [South Korean Won (KRW)/m^2], *f* is the unit cost of wood materials per volume (KRW/m^3), and *R* is the raw-wood consumption (m^3).

Assuming that the steel-concrete structures in public buildings would be replaced by wooden structures, the volume of sawn timber usage was predicted based on the replacement ratio (*x*), as shown in Eq. 3.

$$R = \{a \cdot b \cdot (1-c) \cdot x\} \times (d \cdot e) / f \tag{3}$$

where *x* is the replacement ratio of wooden structures in public buildings of education and society sector (%).

Statistics of Building Start

The Statistical Yearbook of the Ministry of Land, Infrastructure and Transport (MOLIT 2022), provided by the South Korean Ministry of Land, Infrastructure, and Transport, presents the building start status in South Korea for 2010–2021 (see Table 1). Since 2010, the number of buildings under construction in South Korea has been increasing steadily, peaking at 255,941 units in 2015 before declining gradually. Similarly, the number of wooden buildings exhibits a trend comparable to the overall building count, peaking at 14,945 units in 2016 and decreasing subsequently to 10,897 units, as of 2021. However, the proportion of wooden buildings out of the total buildings has remained relatively stable, ranging from a minimum of 5.05% to a maximum of 6.67%. The annual average proportion stands at 5.66%.

Table 1. Status of Building Start and the Proportion of Wooden Structures by Year (for 2010–2021)

Year	2010	2011	2012	2013	2014	2015
Total number of building starts	188,470	198,863	190,589	187,545	199,390	255,941
Number of wooden-building starts	9,585	10,037	10,369	10,339	11,493	13,595
Proportion of wooden buildings (%)	5.09	5.05	5.44	5.51	5.76	6.02
Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Total number of building starts	231,972	208,935	216,102	194,947	185,640	185,841
Number of wooden-building starts	14,945	13,938	11,828	10,011	10,102	10,897
Proportion of wooden structures (%)	6.44	6.67	5.47	5.14	5.44	5.84

Table 2 presents the start status of buildings in the education and social sectors (classified as public buildings) for 2010–2020. The buildings in the education and social sectors in South Korea include school dormitories and cultural, assembly, religious, medical, educational, research, infant and toddler, training, sports, broadcasting and communication, and power facilities. The number of buildings in the education and social sectors has been decreasing steadily since 2010, with a decrease of 33.4% in 2020, compared with the number of buildings in 2010. The average floor area of the buildings in the education and social sectors was 1,095 m^2, whereas that of wooden buildings was 66.6 m^2. The annual average number of building-starts in the education and social sectors was 6836, with wooden buildings accounting for a relatively small proportion of 6.84%.

Table 2. Building Start Status and the Proportion of Wooden Structure in the Education and Social Sectors by Year

Year	2010	2011	2012	2013	2014	2015
Total number of building starts in the education and social sectors	8,853	7,455	7,938	7,268	6,551	7,223
Total number of wooden-building starts in the education and social sectors	760	419	576	468	350	431
Proportion of wooden buildings (%)	8.58	5.62	7.26	6.44	5.34	5.97
Year	**2016**	**2017**	**2018**	**2019**	**2020**	
Total number of building starts in the education and social sectors	6,489	5,554	6,085	5,885	5,892	
Total number of wooden-building starts in the education and social sectors	421	348	550	339	204	
Proportion of wooden structures (%)	6.49	6.27	9.04	5.76	3.46	

Predicting the Number of Building Starts Based on the Population Model

To predict the building-start status in South Korea up to 2050, a correlation analysis was carried out between the population and the number of buildings whose construction began in 2001–2020. Figure 1 illustrates the linear regression model used in the present study, expressing the correlation between population (x) and number of building starts (y). The linear regression model can be expressed as follows:

$$y = 0.0198x - 807,844 \quad (3)$$

where x is the population of South Korea, and y is the number of building starts.

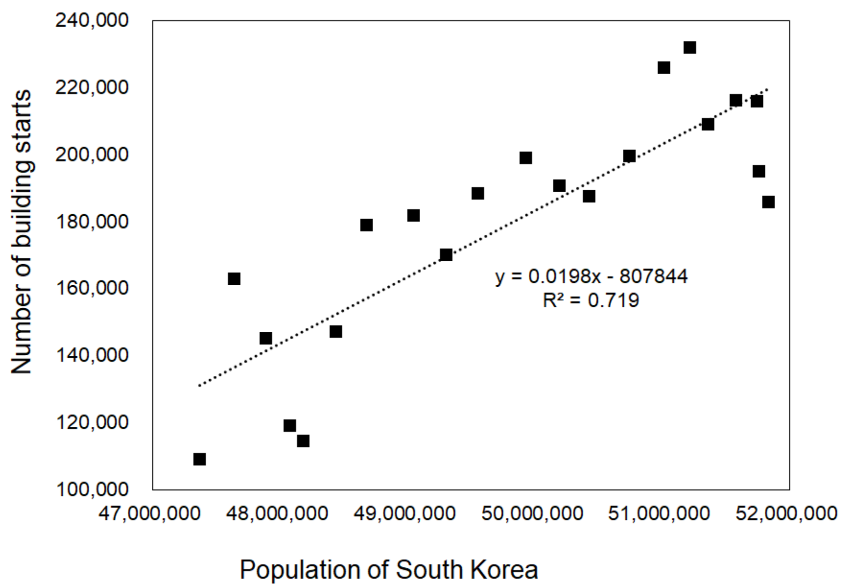

Fig. 1. Graph portraying the correlation between number of building starts in South Korea and population of the country; coefficient of determination (R^2)

Table 3. Population Estimates for 2021–2050 According to the Three Groups (Middle, High, and Low), based on the Population Projection Model

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Average (in thousand)	51,745	51,628	51,558	51,500	51,448	51,397	51,348	51,300	51,251	51,199
Maximum (in thousand)	51,746	51,681	51,724	51,805	51,908	52,012	52,119	52,226	52,332	52,436
Minimum (in thousand)	51,743	51,582	51,421	51,268	51,102	50,921	50,735	50,545	50,349	50,147
Year	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Average (in thousand)	51,143	51,083	51,019	50,948	50,869	50,775	50,660	50,525	50,369	50,193
Maximum (in thousand)	52,535	52,629	52,716	52,794	52,864	52,920	52,954	52,967	52,958	52,928
Minimal (in thousand)	49,937	49,720	49,496	49,267	49,027	48,772	48,495	48,198	47,884	47,553
Year	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Average (in thousand)	49,998	49,784	49,551	49,300	49,030	48,739	48,427	48,093	47,737	47,359
Maximal (in thousand)	52,880	52,812	52,723	52,614	52,485	52,334	52,160	51,963	51,742	51,497
Minimal (in thousand)	47,204	46,839	46,457	46,062	45,650	45,221	44,774	44,310	43,831	43,333

To predict the building-start status until 2050 based on future population projections, the population estimates were placed into three groups: average (middle), maximum (high), and minimum (low) population, as shown in Table 3 (Statistics Korea 2022). The population projection model considers factors such as the birth rate and life expectancy in South Korea and the rate of international migration outside the country.

The linear regression models described in Eq. 3 were employed to predict the changes in the number of buildings based on the future population estimates until 2050 (Fig. 2). The estimations for the middle and low ranges, based on the population prediction model, portrayed a decreasing trend in the number of buildings starting in 2021, as the population is declining. By contrast, the high range estimated from the population prediction model indicated that the number of buildings would begin reaching its peak in 2039, with a gradual increase in population; this would be followed by a decreasing trend.

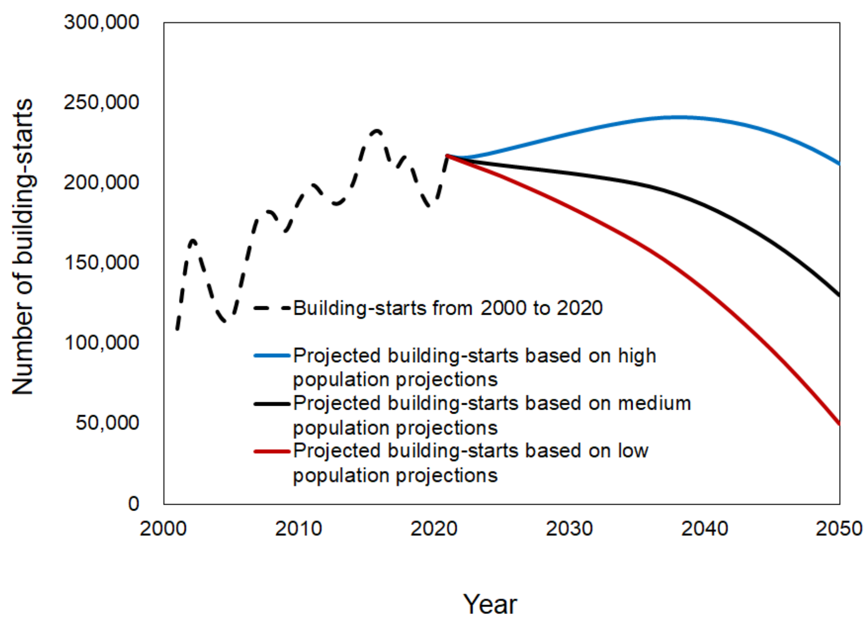

Fig. 2. Prediction of total building-starts based on the future population projections for South Korea

Estimating the Amount of Wood Products and Cost of Material Required for Building Wooden Structures

To estimate the material costs of wood products used in the construction of wooden structures, two public buildings were considered (National Institute of Forest Science 2019, 2020). Both the buildings were designed using hybrid wood and reinforced-concrete structures. The first building considered in this work was a public building in Suwon, a four-story building, with the construction and total areas being 1,395.55 and 4,552.55 m^2, respectively; the building structure consisted of engineered wood products. In total, 498.86 m^3 of wood products (including interior and exterior materials) were used in the building. Based on the completion statement, the material costs of wood products for carpentry, wood-structure construction, and interior work were 148,300,000 KRW, 811,900,000 KRW, and 60,500,000 KRW, respectively, accounting for 14.8% of the total construction cost. The material cost of wood products was 224,000 KRW/m^2, and the cost of wood products per cubic meter was 2,046,000 KRW/m^3. The second was a public building in Yeongju, with a construction area of 425.00 m^2 and a total floor area of 1,233 m^2. The building was a five-story building constructed using cross-laminated timber (CLT). A total of 190.96 m^3 of wood products (including interior and exterior materials) were used in the building. The material cost of wood products for carpentry and wood-structure construction was 239,100,000 KRW, accounting for 8.9% of the total construction cost. The material cost of wood products per square meter of floor area was 193,900 KRW/m^2, and the cost per cubic meter was 1,252,000 KRW/m^3. Table 4 presents the quantities of wood products used in the two public buildings. The building in Suwon had a higher usage of wood for interior work, whereas the building in Yeongju utilized CLT extensively and did not require separate interior work; thus, there were differences in the material costs per square meter of floor area for both the buildings.

Table 4. Amount of Wood Products used in the Public Buildings in Suwon (General Research Building of Forest Bioresources Department) and Yeongju (HAN-Green wooden building)

Suwon (General Research Building of Forest Bioresources Department)			**Yeongju (HAN-Green wooden building)**		
Country of origin	Purpose of use	Usage (m^3)	Country of origin	Purpose of use	Usage (m^3)
Domestically grown wood	Structural member	210.35	Domestically grown wood	Structural member	109.30
	Interior material	36.33		Interior material	-
	Exterior building material	-		Exterior building material	-
Imported wood	Structural member	105.55	Imported wood	Structural member	73.43
	Interior material	127.76		Interior material	5.30
	Exterior building material	18.87		Exterior building material	2.93
Total		498.86	Total		190.96

Market Price Trends and Predictions for Domestic Solid Wood

Table 5 presents the annual trends in the market prices for the major domestic wood species grown in South Korea, while focusing on the fourth quarter of 2021 (Korea Forestry Promotion Institute 2022). In South Korea, wood is categorized into grades, *e.g.*, 1st, 2nd, and 3rd grades. Table 5 presents the annual average prices of 1st-grade wood. Generally, structural lumber is produced from wood of grade higher than 1st grade. The wood market prices in South Korea have increased since 2020; this could be attributed to global logistics issues arising from the COVID-19 pandemic. The annual price change rates for the different wood species, as shown in Table 5, were –6.21% for Korean red pine, 0.94% for Japanese larch, and 0.33% for Korean pine. Notably, the exchange rate considered for our study was 1 USD = 1331 KRW, even though the exchange rate varied every year.

Table 6 illustrates the import-price trends for coniferous and deciduous timber (Korea Environmental Corporation, 2022). The price trends for imported timber in South Korea portrayed a similar pattern to that of the domestic timber prices presented in Table 5, indicating a significant increase from 2020 to 2021. The import prices of coniferous and broadleaf tree wood in South Korea increased by 4.15 and 3.19%, respectively, portraying a cumulative average increase of 3.67% between 2002 and 2021. As shown in Table 5, the market prices for coniferous timber are presented as price per cubic meter (m^3), whereas for oak timber, the prices are presented as price per ton. However, in Table 6, the market prices for both coniferous and broadleaf timber are shown in terms of price per ton, resulting in differences in the measurement units between the two tables.

Table 5. Solid-Wood Market Price Trends for the Major Tree Species in South Korea

Year	2014	2015	2016	2017	2018	2019	2020	2021
Korean red pine wood (KRW/m^3; USD/m^3)	260,000; 195	236,600; 178	229,200; 172	229,100; 172	229,100; 172	224,300; 169	201,400; 151	214,700; 161
Japanese larch wood (KRW/m^3; USD/m^3)	150,600; 113	145,600; 109	144,800; 109	148,000; 111	151,900; 114	152,200; 114	149,900; 113	164,100; 123
Korean pine wood (KRW/m^3; USD/m^3)	145,400; 109	141,400; 106	139,400; 105	141,200; 106	144,600; 109	144,600; 109	143,400; 108	147,400; 111
Oak wood (KRW/ton; USD/ton)	145,900; 110	132,000; 99	125,100; 94	124,700; 94	124,700; 94	124,700; 94	125,000; 94	125,000; 94

Table 6. Import Prices of Raw-Wood Material for Coniferous and Broadleaf Tree Wood

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Coniferous tree wood (USD/ton)	445	482.9	578.3	540.8	627.6	764.8	769.8	519.2	788.8	853.3
Broadleaf tree wood (USD/ton)	435	462.5	490.8	539.2	583.3	649.6	743.3	534.2	742	675.3
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Coniferous tree wood (USD/ton)	710.7	716.6	753.2	788.4	612.5	642.8	842.8	695.3	590.3	800.6
Broadleaf tree wood (USD/ton)	593.6	622.1	585.4	613.5	517.7	589.7	767.6	615.8	458.8	617.8

The annual growth rates of market prices for domestically sourced major timber species were calculated by considering the market prices of domestic timber and the trends in raw-material imports. A growth rate of 0.94% was noted for Japanese larch, the most commonly used species for structural purposes in South Korea; this rate was used as the average. The growth rate of 3.67% (for raw-material import) was considered the maximum, and the growth rate of Korean pine (0.33%) was considered the minimum. By applying the average, greatest, and least increase rates, we predicted the market price changes for Korean red pine, Japanese larch, and Korean pine by 2050 (Fig. 3).

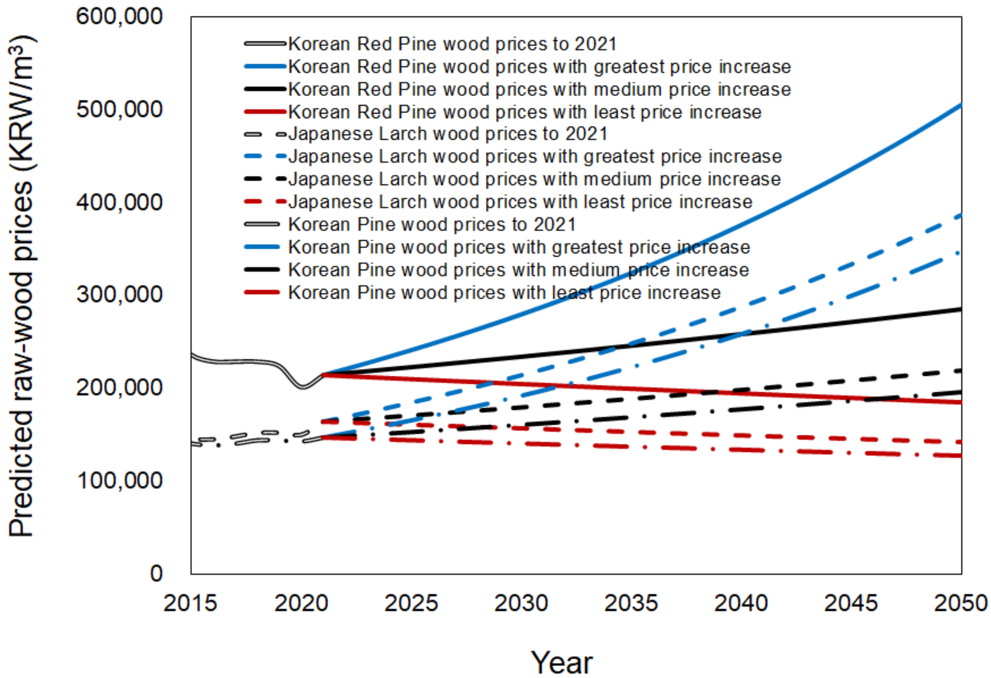

Fig. 3. Prediction of future raw-wood prices for Korean red pine, Japanese larch, and Korean pine, based on the annual increase in the prices during the previous years

RESULTS AND DISCUSSION

Estimation of Raw-Wood Consumption Based on Methodology Using Building Starts

To calculate the raw-wood consumption for public buildings in the education and social sectors in 2020, the following values were substituted into Eq. (2): a = 185,640, b = 5,892/185,640 (= 0.032), c = 204/5,892 (= 0.035), d = 74 m^2, e = 209,050 KRW/m^2, f_1 = 214,175 KRW/m^3 (Korean red pine), f_2 = 164,100 KRW/m^3 (Japanese larch), and f_3 = 147,355 KRW/m^3 (Korean pine). Applying these prices to Korean red pine, Japanese larch, and Korean pine, the estimated wood consumption (R) was 14,707, 19,195, and 21,373 m^3, respectively.

Applying the methodology to the public building in Suwon [a = 1, b = 1, c = 1, d = 4,553 m^2, e = 224,224 KRW/m^2, f_1 = 214,175 KRW/m^3 (Korean red pine), f_2 = 164,100 KRW/m^3 (Japanese larch), f_3 = 147,355 KRW/m^3 (Korean pine)], the wood consumption was calculated to be 4,766, 6,221, and 6,926 m^3 for Korean red pine, Japanese larch, and Korean pine, respectively. The estimation for the processing yield from round wood to lumber products was 48.7% and that from lumber to CLT was 26.7% (Han *et al*. 2016). Based on these findings, it was assumed that the processing yield of the final wood products used in the construction was 20%. Assuming this value, the required amounts were estimated to be 953, 1,244, and 1,385 m^3 for Korean red pine, Japanese larch, and Korean pine, respectively. These values were significantly higher than the actual amount of wood products used in the public building in Suwon (499 m^3). This discrepancy may be attributed to the hybrid structure of the building (with wooden and reinforced-concrete elements), resulting in a relatively low material cost per floor area (e).

Applying the same method to the public building in Yeongju [a = 1, b = 1, c = 1, d = 1,233 m^2, e = 193,876 KRW/m^2, f_1 = 214,175 KRW/m^3 (Korean red pine), f_2 = 164,100 KRW/m^3 (Japanese larch), f_3 = 147,355 KRW/m^3 (Korean pine)], the wood consumption was calculated to be 1,116, 1,457, and 1,622 m^3 for Korean red pine, Japanese larch, and Korean pine, respectively. Applying a processing yield of 20%, the final wood product consumptions were estimated to be 223, 291, and 324 m^3 for Korean red pine, Japanese larch, and Korean pine, respectively. When the price of Korean red pine wood was applied, the calculated final wood product requirement of 223 m^3 was compared with the actual application of wood products in the public building, which was 191 m^3. The margin of error was approximately 16.8%. Even though the public building in Yeongju (similar to that in Suwon) consisted of a hybrid structure (with wood and reinforced concrete), excluding the elevator section, it was mostly constructed with a CLT structure. This led to more accurate estimations in the material cost per floor area (National Institute of Forest Science 2019), compared to the estimations conducted for the building in Suwon. Furthermore, the public building in Yeongju utilized CLT (instead of engineered wood products) as the structural material, resulting in a reduced margin of error, compared to the building in Suwon.

Through the analysis of the two cases, it was concluded that in South Korea, the prices of wood products produced through processing are relatively higher than those of raw timber. Additionally, because there are few instances of wood application in large public buildings in the country, further studies are required to evaluate the applicability of the proposed methodology.

Prediction of Future Raw-Wood Consumption for Replacing Modern Construction Materials in Public Buildings with Wood

With respect to the public buildings in the education and social sectors from 2010 to 2020, the average floor area for wooden buildings (66.6 m^2) was significantly lower than the overall average (1,095 m^2). This indicated a lower utilization of wooden structures in large buildings. By applying the substitution ratio (x) to Eq. 3, it was possible to estimate the amount of wood required to replace the modern materials in public buildings with wooden structures.

The following values were substituted into Eq. 3: a = 185,640, b = 5,892/185,841 (= 0.032), c = 1 – 204/5,892 (= 0.965), d = 1,222 m^2, e = 209,050 KRW/m^2, f_1 = 214,175 KRW/m^3 (Korean red pine); the wood consumptions for various substitution ratios (x) of 0.01, 0.05, and 0.10 were calculated as 67,800, 338,800, and 677,600 m^3, respectively.

Prediction of Future Raw-Wood Consumption for Public Buildings Using the Current Wooden Building Ratio

Using the building statistics data for 2010–2020, the annual averages were calculated to predict the changes in the raw-wood consumption for public buildings for 2021–2050. By using the variables in Eq. (2), values were estimated for a (building starts; based on the middle range population model), b (annual ratio of public buildings in the education and social sectors; 3.35%), c (annual ratio of wooden structure; 6.38%), d (average floor area; 66.6 m^2), e (material cost per floor area; based on the medium price increase of 0.94%), and f (wood price; based on the medium price increase of 0.94%).

Table 7. Estimation of Future Raw-Wood Consumption for Public Buildings using Current Wooden Building Ratio

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Wood Consumption (m^3)	31,457	31,121	30,920	30,753	30,602	30,458	30,317	30,178	30,037	29,888
Year	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Wood Consumption (m^3)	29,726	29,554	29,369	29,166	28,938	28,668	28,339	27,950	27,501	26,997
Year	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Wood Consumption (m^3)	26,437	25,821	25,152	24,430	23,653	22,817	21,920	20,961	19,938	18,850

As shown in Table 7, from 2021 (31,457 m^3) to 2050 (18,850 m^3), the wood consumption is predicted to decrease by 40.0% due to the continuous decline in the building numbers (corresponding to the expected decrease in population). This trend was even more evident when a lower-population model was used to predict the start of a building. Figure 4 depicts the changes in future raw-wood consumption for public buildings based on the variations in the building starts.

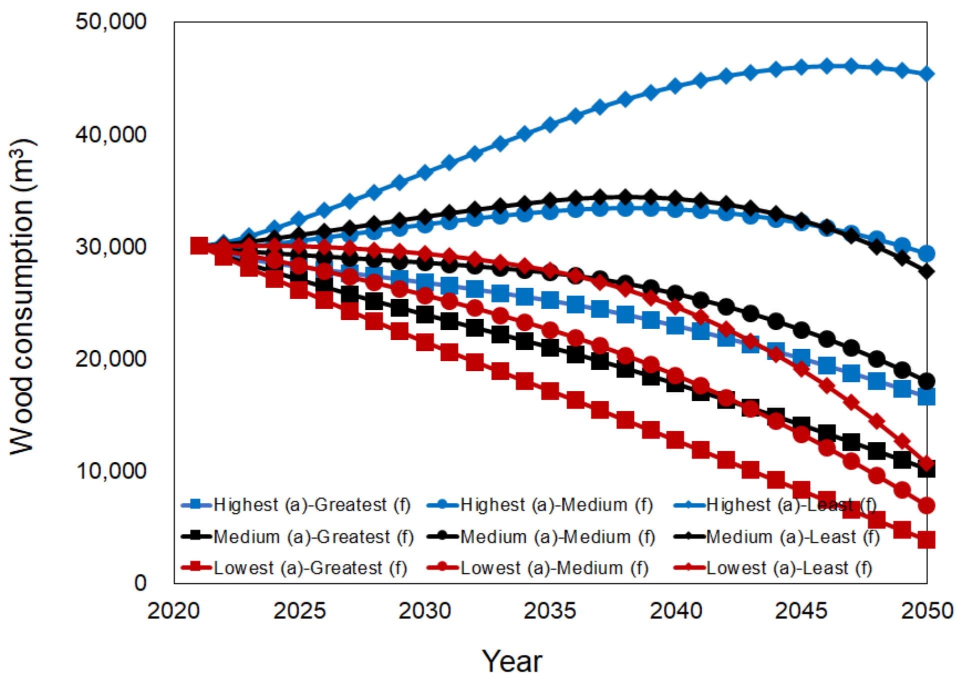

Fig. 4. Changes in the future raw-wood consumption for public buildings based on the changes in building starts and lumber prices, while applying the (a) high, middle, and low population models and considering the changes in Korean red pine wood prices and (f) greatest, medium, and least price-escalation rates

Prediction of Future Raw-Wood Consumption for Replacing Materials in Public Buildings with Wood

From 2010 to 2020, the average floor area of public buildings in the education and social sectors was 1,095 m^2, whereas that of wooden structures was only 66.6 m^2. Based on the statistics for the two large public buildings in Suwon and Yeongju, an estimate was made of the future wood consumption for replacing a building with an area of 1,095 m^2. The variables in Eq. (3) were calculated using the average values from the statistical data of 2010–2020; the results were consistent with the future wood consumption estimated using the current proportion of wooden structures (shown in Table 7): a = middle population model, b = 0.0335, c = 0.0638, d = 1,095 m^2, e = applying the medium price escalation rate based on 209,050 KRW/m^2, f = applying the medium price escalation rate based on 214,175 KRW/m^3 (Korean red pine). Assuming that 1% of the public buildings in the education and social sectors, with a floor area of 1,095 m^2, are to be replaced with wooden structures, the substitution ratio (x) was set as 0.01. Table 8 presents the future wood consumption estimated using Eq. (3).

Table 8. Changes in Future Raw-Wood Consumption for Replacing Non-Wooden Buildings with Wooden Buildings

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
x = 0.01 (m^3)	75,893	75,083	74,597	74,195	73,831	73,483	73,143	72,809	72,467	72,108
Year	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
x = 0.01 (m^3)	71,718	71,303	70,857	70,366	69,817	69,166	68,371	67,432	66,350	65,134
Year	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
x = 0.01 (m^3)	63,783	62,297	60,682	58,941	57,067	55,049	52,885	50,571	48,103	45,477

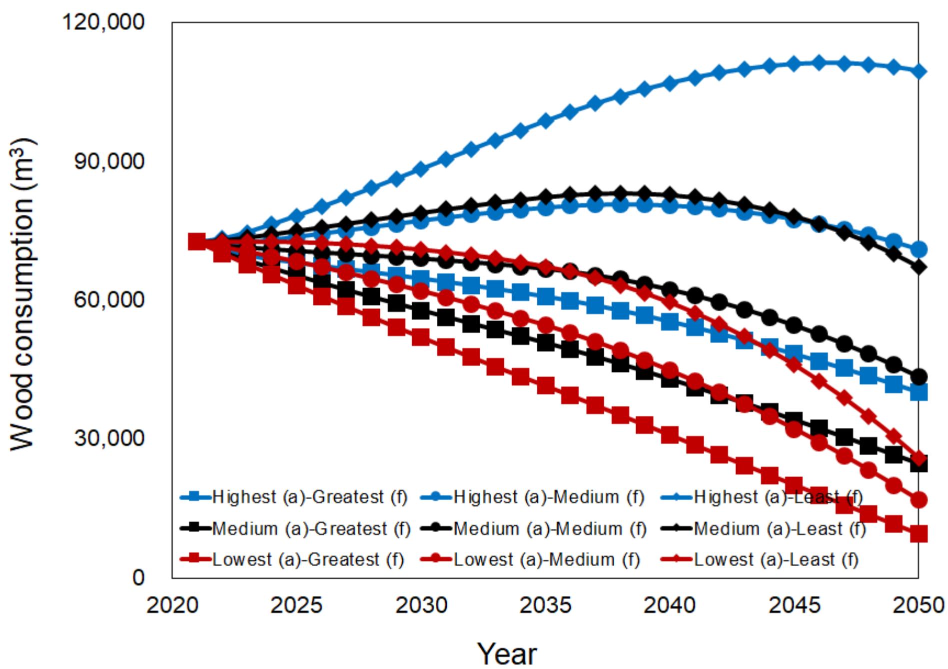

Fig. 5. Changes in the future raw-wood consumption for replacing non-wooden building materials with wooden building products, based on the changes in the building starts and lumber prices, while (a) applying high, middle, and low population models and considering the changes in Korean red pine wood prices and (f) applying greatest, medium, and least price-escalation rates

The wood-consumption estimation for 2050, resulting from 1-% substitution with wooden structures (Table 8), indicated a 40-% decrease compared with the wood consumption in 2021. This outcome aligns with the results shown in Table 7, highlighting the continuous decline in the population of South Korea, leading to an overall decrease in construction initiatives for all buildings. Figure 5 illustrates the estimated changes in the future wood consumption resulting from a 1-% substitution of modern building materials with wooden structures, while considering the variations in the building starts.

Analyzing the Contribution of Harvested Wood Products (HWPs) to the Net Uptake of Carbon Dioxide in South Korea's Nationally Determined Contributions (NDCs) through Wood-Substitution in Public Buildings

South Korea's Nationally Determined Contributions (NDCs) have set targets for the net carbon uptake by harvested wood products (HWPs) by 2030 and 2050 (150,000 and 220,000 tCO_2-eq, respectively) (Korea Forest Service, 2021b). Various suggestions have been proposed for achieving this goal. Based on the 2021 HWP carbon uptake of 669,115 tCO_2-eq, meeting the targets requires an annual increase of 250,000 m^3 in the raw-wood production from 2021 to 2030 and a subsequent annual increase of 150,000 m^3 from 2031 to 2050, resulting in a total wood production of approximately 9,000,000 m^3. Additionally, to maintain a 30-% input ratio of lumber into construction structural components that have a relatively long half-life, it is important to achieve a lumber production and carbon uptake of 1,818,300 m^3 and 2,039,144 tCO_2-eq by 2030 and 2,718,300 m^3 and 2,164,842 tCO_2 eq. by 2050, respectively (National Institute of Forest Science, 2024).

Assuming a processing yield of 48.7% from log to lumber (Han *et al*. 2016), the calculated raw wood production for 2030 and 2050 was estimated to be 3,733,676 and 5,581,725 m^3, respectively. As shown in Table 7, by maintaining the current ratio of wooden structures in the public buildings of the educational and social sectors, the minimal contribution to the HWP carbon-uptake target for 2030 and 2050 would be 0.80% and 0.34%, respectively; however, if 10% of large public buildings (by floor area) are replaced by wooden structures, the contribution will increase significantly to 19.3% and 8.15%, respectively. The current situation calls for novel strategies that can promote larger-scale wooden public buildings and replace the existing reinforced-concrete structures with wooden alternatives.

Sensitivity Analysis

To predict the wood usage in public buildings, a sensitivity analysis was conducted to compensate for the lack of important data (*e.g.*, the material cost per floor area). In scenarios where actual averages are used, the results can be underestimated or overestimated, depending on the ranges covered by the factors (Cordier 2020). A sensitivity analysis was performed for predicting the wood-consumption in the future, based on the wood ratio of the two public buildings in 2020, as presented in Eq. (2). The predictions of wood consumption for the public buildings based on the future changes in building starts, wood prices, and substitution ratios are outlined in Eq. 3.

In Eq. 2, if any numerator value changes by ±x%, the result changes by ±x%. In contrast, if the denominator value changes by ±x%, the result changes according to the respective percentages of change. The impacts of these factors on the predicted results are depicted in Table 9, calculated using the methodology proposed by Cordier (2020).

Table 9. Effects of Changes in Parameters on the Results (Cordier 2020)

If	one numerator	is changed by	+ x%	then, the result changes by	+ x%
			– x%		– x%
	one denominator		+ x%		– y% (|y|<|x|)
			– x%		+ z% (|x|<|z|)

The results of the sensitivity analysis for wood consumption, predicted by applying the wood structural ratio of public buildings (as of 2020) shown in Eq. (2), are listed in Table 10. As only the wood price factor (*f*) is present in the denominator (and assuming that all factors are independent of each other), *f* can be considered the most influential factor for the increase and decrease in the results. In Table 10, the cases that yield the maximum and minimum predicted values are highlighted in blue and red, respectively. Except for the predicted *a* values, calculated using the unique population model, the same factors were used for the numerator. The sensitivity-analysis results for *a* and *f* are presented in Fig. 6.

Table 10. Results of Sensitivity Analysis of Raw-Wood Consumption Calculated by Applying the Wood Structural Ratios of the two Public Buildings as of 2020

Numerator	*a*, *b*, *c*, *d*, *e*	is changed by	–4.84~–0.07%** ± 0% ± 0.94%	then, the result changes by	–4.84~–0.07% ± 0% ± 0.94%
Denominator	*f**		+ 0.33%		–0.33%
			+ 0.94%		–0.60%
			+ 3.67		–2.63%

* Wood-price reduction model and species-specific price differences were not applied
** Annual average of statistics of building start

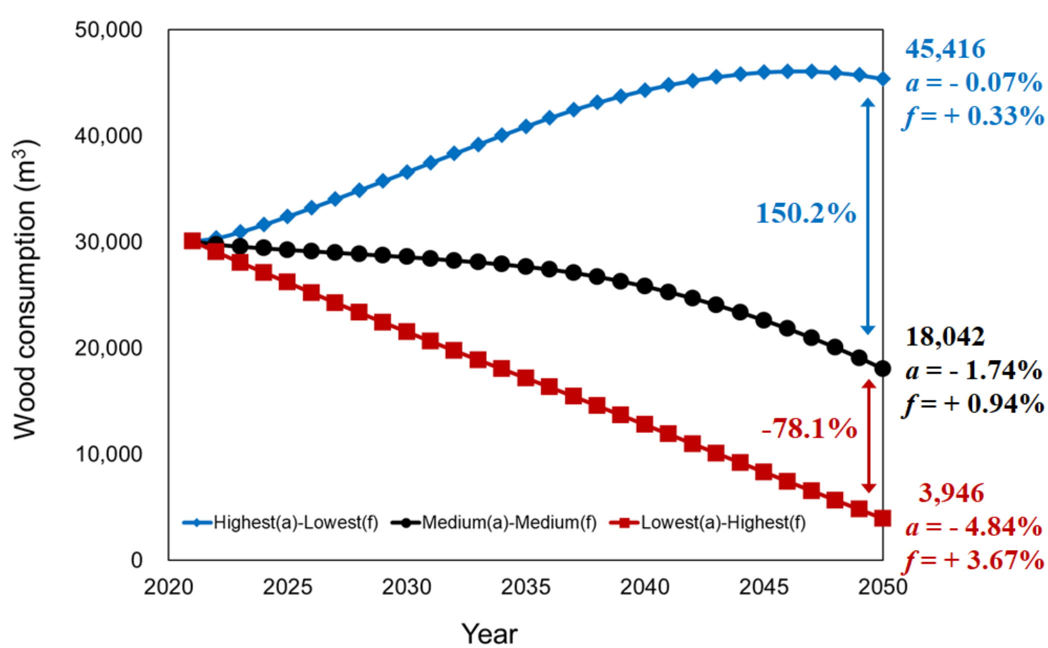

Fig. 6. Maximum and minimum predicted values of raw-wood consumption for the public buildings in 2050, using the current wooden building ratio

The results obtained by applying Eq. 2, to predict the maximum and minimum wood consumption of public buildings by 2050, are presented in Fig. 6. In the predictions, the middle-range model (a = –1.74%, f = +0.94%) portrayed an increase of 150.2%, compared to the result of 18,042 m^3. The high-range model (a = –0.07%, f = +0.33%) portrayed an increase of 78.1%, while the low-range model (a = –4.84%, f = +3.67%) portrayed a decrease of 78.1%.

CONCLUSIONS

1. Estimation and Application of Wood Consumption for Public Buildings: A methodology was proposed to calculate the raw-wood consumption for public buildings in the education and social sectors in 2020. When applied to two public buildings in South Korea (one each in Suwon and Yeongju), the estimated wood consumption was higher than the actual usage, emphasizing the need to consider wood structure ratios and pricing for estimations.
2. Predicting Future Wood Consumption: The future wood consumption in South Korea in the construction sector was predicted by altering the ratio of wooden structures. For the current ratio, the analysis indicated a 40% decrease in the wood consumption by 2050; however, increasing the wooden structure ratio in large buildings increased the wood consumption.
3. Nationally Determined Contribution (NDC) Goals and Wood Carbon Sequestration: An increase in wood production is necessary to achieve the NDC goals. Maintaining the current wooden structure ratio contributes a small percentage; thus, it is important to increase the wooden structure ratio in large buildings.

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