JSACE 2/35

Tool Development for Life Cycle Cost (LCC) of Wooden Building Envelope

Received 2024/01/03

Accepted after revision 2014/05/02

Tool Development for Life Cycle Cost (LCC) of Wooden Building Envelope

Roja Modaresi*, Magnus Olai Landaas

Norwegian Institute of Wood Technology (NTI), Børrestuveien 3, 0373 Oslo, Norway

*Corresponding author: **rmo@treteknisk.no**

https://doi.org/10.5755/j01.sace.35.2.35937

Abstract

The main goal of this study is to provide a platform for LCC calculation rules for timber buildings that comply with the Standards EN 16627:2015 and EN 15643-4, by employing a refined technical service life estimation. The database includes economic data for the building envelope and structural elements at the product level. In addition, the use phase of the building is included as maintenance, and the relevant economic data related to design failure, user preferences, and technical defects due to moisture. This model is under development as part of the WoodLCC project, with partners from Germany, Sweden, Norway, Estonia, Slovenia, and Austria, aiming to implement advanced methods to calculate accurate technical service life estimations and give the users the opportunity to evaluate the differences in building and maintenance costs based on different parameters.

In this study, a data structure is created based on the necessary indicators and parameters for LCC calculation. An Excel model is developed, which will be used as a base for a software development in the WoodLCC project. Only wooden material is being considered for building envelope and bearing system. All material price data and installation times for each element is taken from a Norwegian dataset. This data is then modified for the selected European country using country specific labour cost- and material cost-indexes, convertible to the inquired currency. Inflation and escalation rates are considered for calculating the maintenance or repair that will occur in future. Material prices for different species and modification are included.

Improved service life input data will enable more precise LCC for wood-based products, resulting in improved economic impact. LCC finds common acceptance only if reliable input data are available and complemented with knowledge about user expectations. We will evaluate the possibility of future improvements of such models.

Keywords: life-cycle-cost; service life; decay; above the ground; moisture; species; detailing; orientation; UV effect.

Introduction

Under the 2014 EU procurement directive (Medeiros, 2014) a contract must be awarded based on the most economically advantageous tender. The directive further “promote the development and use of European approaches to life cycle costing as a further underpinning for the use of public procurement in support of sustainable growth”. LCC is one of the basic indicators for sustainability assessment and cost effectiveness applicable in construction (Gaus et al., 2022; Rahim et al., 2014). LCC makes it possible to optimize the entire life performance of buildings and other structures. However, it is not yet used to its full potential (Maisham et al., 2019; Manewa et al., 2021), – mainly due to a lack of reliable data that can be used as input instead of guesses and estimates. There has been a need to shift from the era where contractors, clients, and developers were focusing only on the initial capital cost (Sadliwala & Gogate, 2022). In contrary, the relevance of LCC finds increasing acceptance (Alasmari et al., 2023). Increasing interest in the construction industry and the understanding of LCC benefits have led to a growing number of companies adopting the

ktu 1922

Journal of Sustainable Architecture and Civil Engineering
Vol. 2 / No. 35 / 2024
pp. 84-94
DOI 10.5755/j01.sace.35.2.35937

methodology. LCC is also being applied by an increasing number of public authorities across the EU. The 'EU public procurement Directive 2014/24/EU', encourage the use of LCC as a tool to get the 'most economically advantageous tender (MEAT).

Evaluating economic performance within the building sector is standardized across various levels. Fig. 1 provides an overview of European Standards concerning the assessment of building performance. Notably, two key standards focusing on economic performance are highlighted:

1. EN 16627 (2015), which evaluates the economic performance of buildings. This standard draws from ISO 15686-5 and is tailored for sustainability assessment within the European context.
2. EN 15643-4, which addresses economic performance at a framework level. It's important to note that while economic performance is crucial, it's just one facet of a building's sustainability. Other dimensions, such as environmental performance (EN 15643-2) and social performance (EN 15643-3), are integral components assessed within the broader sustainability evaluation framework outlined in EN 15643-1.

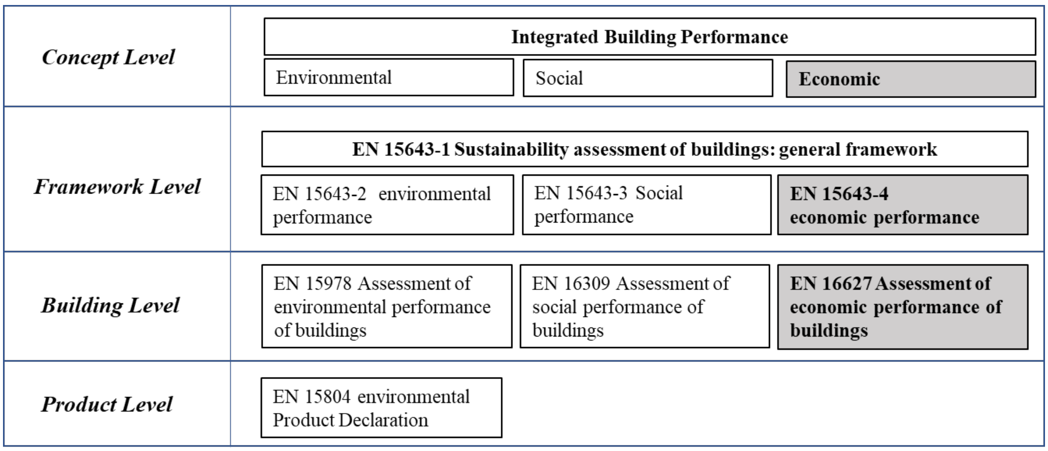

Fig. 1

Overview of European standards to assess building performance in different levels. Economic performance is captured by (EN15643-4, 2021) and (EN16627, 2015)

There has been studies on developing a framework for a construction system based on LCC such as (AbouHamad & Abu-Hamd, 2019), which only considered concrete and steel buildings. Adaption of 'building information modeling' (BIM) on LCC is practiced by some studies including (Alasmari et al., 2023; Potrč Obrecht et al., 2020; Santos et al., 2019). In one article, (Alasmari et al., 2022) systematically reviewed 20 of these studies and elaborated on the model limitations, such as interoperability issues, licence costs, and time consumption based on the previous models from (Alasmari et al., 2023; Liu et al., 2015; Shin & Cho, 2015) studies.

Besides, identifying the type of model users and consequently, decide upon the type of model development is the key to success. A study by (Saridaki & Haugbølle, 2022) identifies the most common persona for the current and potential LCC practitioner; 1) the clip-boarder, 2) the spreadsheet expert, and 3) the programmer. Therefore, in the WoodLCC project, it was decided to develop both an Excel-based model and a Software with similar calculation principles. This development addresses two main personalities of the potential future users of the LCC tool.

In the existing literature and studies, wooden building LCC is compared with alternative material in several studies. LCC assessment by (Arkhangelskaya, 2018) indicated cost-reduction potential for wood building due to its lightweighting, prefabrication and fast installation which leads to cost reduction during the construction phase. Additionally, the aforementioned study reveals that wooden buildings are more cost-efficient over their lifecycle. While stakeholders recognize the cost benefits of wood, some doubts persists due to the dominance of traditional materials in the market and conflicting literature. Another LCC study, (Potkány et al., 2019) showed that investment cost may be slightly higher for wood-based buildings, but there is lower operational costs is involved. LCC study done by (Petrović et al., 2021), claimed that the construction costs (A0-A5) is the main contributor with labour cost taking almost half of it, followed by the maintenance and replacement costs. Another study from the US shows front-end costs for a 12-story building is 26% higher for the mass timber compared to a similar building in concrete. However, the overall LCC is 2.4% less due to the longer service life of the building and higher value of salvaged timber at the end of life(Gu et al., 2020).

As stated earlier, several models and frameworks have already been made. Yet, a major weakness in LCC is the lack of detailed and relevant information on service life estimates, and the expected maintenance, repair, or replacement intervals. LCC requires a detailed and comprehensive knowledge of the service life, the expected maintenance interval, and the costs of the products and labour. Today, LCC user software is employing simplified and conservatively lower value than the technical service life estimates, especially for wood products in exterior applications, which in turn can lead to poor decisions and negative economic and environmental impacts. Besides that, most of the LCC calculations are made for specific case studies and a certain country, with no possibility to see the cost variations in different countries.

This study employs the findings of a model developed by (Niklewski et al., 2023), wherein the service life of outdoor wooden materials depends on: 1) geographical location for assessing weather conditions, including temperature, Relative Humidity (RH), and precipitation, 2) detailing to identify moisture trap in connections 3) shelter or roof overhang, influencing the level of protection. Direct consequence of moisture can be mould, blue stain, decay and deterioration (Norén et al., 2018). In this study, variations among wood species, including their moisture dynamics and inherent resistance to decay, are accounted for using a resistance model developed by(Brischke et al., 2021). It's important to note that this model exclusively addresses decay and does not encompass factors such as mould or blue stain. In addition to that, the study will be able to convert all the cost calculation in the required currency in the chosen six countries around Europe by considering cost differences in material and labour. The study is presenting the Excel model structure which is made for second type of the identified model users mentioned above. The model is going to solve aspects of inaccurate input data in a user-friendly tool.

Methods

The first step in constructing the model is to integrate calculations from a study done by (Niklewski et al., 2023) for determining technical service life of each of the exposed elements.

European exposure table: The exposure table contains the coordinates for European cities along with the efficacy of detailing and sheltering on construction elements within those cities. This data has been used to determine the difference in service life depending on location and building envelope (Niklewski et al., 2023).

Resistance threshold: The resistance threshold dataset is the sum of two parts and the outcome of ClickDesign project. The first dataset contains the 22 most common tree species combined with types of modification and their above ground resistance to decay given in days (Brischke et al., 2021). Above ground resistance to decays is defined as the number of days under ideal fungal conditions before the first signs of decay start appearing. This dataset is then combined with the European exposure table discussed previously. The result of this combination gives us a rough estimate to the technical service life of each element depending on location and the species of wood chosen.

A data structure is created based on the necessary indicators and parameters for LCC calculation. In this project, wooden material used for the bearing system in addition to building envelope is considered. The following elements are defined in the model; bearing system, outer walls and façade, doors and windows, outer roof (flat or angled) both for bearing system and roof terrace or thatching, and balcony.

All material price data and installation time: Material price is taken from a Norwegian dataset (*Norsk prisbok* 2023). This dataset is used in tandem with the price level data to estimate local prices, for other selected European countries.

These prices are adapted for the selected European country using country specific labour cost-(Eurostat, 2021a) and material cost-indexes from (Eurostat, 2021b). Material price index for different species and modification are included (Brischke et al., 2021).

Currency data: Currency exchange rates is used to compare costs across three currencies (NOK, SEK, EUR) and comes as a built-in Excel functionality which refreshes the exchange rates each time the worksheet is opened or refreshed.

Price level index: The differences in price levels between countries is based on the 2021 Eurostat price level index for furniture using data.(Eurostat, 2021b)

Labor Factor: Eurostat average hourly labor cost is being used for 2021.(McEvoy, 2022)

Gpt Price factor: There is a price variation factor dependent on the species and treatment of an element. This factor was found using chatgpt. Note: While GPT isn't highly reliable, it was the only option available for accessing generic factors. These factors are presented in table 1 to ensure the reproducibility of the model by other researchers.

Inflation and escalation rates: can be chosen by the user for calculating the maintenance or repair that will occur in future.

LCC – Calculations

The total construction cost is calculated once for the selected country and materials. Maintenance costs including major replacement will be calculated by having replacement intervals and considering the price elevation in future. The user will have the ability to choose any interest or escalation rate.

Construction cost: The initial building costs of the building is the sum of the total cost of each element. The total cost of an element i can be expressed as θ_i. The total cost can be expressed as a function of the price of the material, $P_{ISY,i}$, the material price factor γ_i , relative price level δ_C, currency factor τ_i and the local labor cost L_C. This is elaborated in (Eq. 1).

$$\theta_i = p_{ISY,i} * \delta_{C,i} * \tau_i * \gamma_i + L_C \quad (1)$$

Where: $P_{ISY,i}$– ISY Material price; and the other factors are $\delta_{C,i}$, τ_i , γ_i which presented in (Eq. 3, 4, and 5); L_C is presented in (Eq. 6)

Thus, the initial building cost can simply be expressed as the sum of the costs of all elements i, which is shown in (Eq. 2).

$$IBC = \sum \theta_i \quad (2)$$

θ_i – Total cost of element i; IBC – Initial building cost

The price factors can be expressed in the following equations:

$$\delta_{C,i} = \frac{Count_i}{Count_{NORWAY}} \quad (3)$$

$$\tau_i = \frac{curr_{NOK}}{curr_i} \quad (4)$$

$$\gamma_i = \frac{p_i}{p_{NSpruce}} \quad (5)$$

List of variables are: δ_C – *Relative price level*; $Count_i$ – *Country i price level*; τ_i – *Currency factor*; $curr_i$ – *Currency i*; γ_i – *Material price factor (ChatGPT)*

And Labor cost can be calculated with the use of (Eq. 6).

$$L_C = u_{ISY,i} * Q_i * \mu_C * \tau_i \quad (6)$$

L_C – *Labor cost* C_i; $u_{ISY,i}$ – *ISY Installation Unit time*; Q_i – *Material quantity*; μ_C – *Relative Labor pricelevel (*From EuroStat dataset*)*

Maintenance cost

For calculating the costs incurred throughout the building's service life, the model from Niklewski (2023) is being used to estimate the service life of each element. We assume that structural components and elements within the building envelope will have the same expected service life as the building. According to Niklewski the service life can be estimated by the exposure dosage of the elements divided by the species resistance to decay, expressed as:

$$SL = RD/D_E \quad (7)$$

SL – *Service Life*; RD – *Resistance Dose (Brischke et al., 2021)*; D_E – *Exposure dosage (Niklewski et al., 2023)*

DE can be expressed in (Eq. 8):

$$D_E = D_s + e(L, v, r) * D_r \quad (8)$$

While Dr can be calculated in (Eq. 9)

$$D_r = D_{ref} - D_s \quad (9)$$

Where: D_s – *Shelter dose*; D_r – *Rain dose*; $e\ (L,v,r)$ – *Exposure, given location, vertical and roof overhang*; D_{ref}– *Reference dose*;

Exposure value is dependent on 3 conditions: location, direction of installation and roof overhang. Each of the explained conditions is getting a factor. For example, a vertical element with a roof overhang is getting a relatively low factor since it is getting low exposure to the elements. On the other extreme, a horizontally mounted element with no roof overhang will be completely exposed and is therefore described by a factor of 1. The maintenance costs are calculated using the technical service life of each individual element. 6 maintenance intervals of 10-year periods are defined for 60 years of building service life. 0 =<Maintenance Year (MY)< 10, 10 =<MY< 20, ...50 =<MY< 60.

To calculate the maintenance calculations, cost factors (SCA, SPV^*) is used to account for the increased prices in the future in addition to the interest rate.

Single Compound Amount (SCA) is the estimated price factor given expected escalation can be found by using (Eq. 10):

$$SCA = (1 + \lambda)^n \quad (10)$$

The SCA factor is used to determine the price of an element in period n given an escalation rate λ. To determine the present value equivalent of the SCA in current prices, the rate to the SCA resulting in the modified Single Present Value (SPV^*):

$$SPV^* = \left(\frac{1+\lambda}{1+i}\right)^n \quad (11)$$

Where: i – *interest rate*; λ – *escalation rate*; n – *years in the future*

In practice, this process is executed for every item within the [User Input] worksheet. It involves utilizing the Service Life calculation to determine the service life of each individual element. Subsequently, these elements are categorized into six distinct 10-year service periods, as mentioned above. The data in this table is then fed to the Maintenance calc worksheet which calculates the SCA and SPV for each element in each maintenance period.

Results and Discussion

The model is a user-friendly Excel tool for LCC calculation based on accurate technical service life. It will provide insight for a demo software development which is planned at the end of WoodLCC project.

Table 1 shows the chosen species and type of modification based on the mentioned study and discussions with experts.

Table 1

The most common species and treatment use in the European market

Common Name	Scientific name	Type of modification	Material Price factor (γ_i)
Norway spruce	Picea abies	none	1.00
		Thermal modification OHT (Oil, Heat treatment), UC 3	2.00
		Thermal modification, UC 3	1.71
Silver birch (Downy birch)	Betula pendula / pubescens	none	1.29
Sweet chestnut	Castanea sativa	none	1.71
Common beech	Fagus sylvatica	none	1.57
		Thermal modification, UC 3	2.29
English oak	Quercus robur	none	3.00
Black locust	Robinia pseudoacacia	none	2.57
Teak	Tectona grandis	none	5.14
European larch	Larix decidua	none	1.71
Siberian larch	Larix sibirica	none	2.14
Scots pine	Pinus sylvestris	none	1.29
		Thermal modification, UC 3	2.00
		Thermal modification OHT, UC 3	2.71
		Furfurylation, UC 4	3.71
Scots pine sapwood	Pinus sylvestris	Copper organic, UC 3	2.29
		Metal free, organic, UC 3	2.00
Douglas fir	Pseudotsuga menziesii	None	1.57
Ash	Fraxinus excelsior	Thermal modification OHT, UC 3	2.86
Southern yellow pine	Pinus spp.	Acetylation, UC 4	2.29
		Furfurylation, UC 4	2.57

Here is a brief explanation for the chosen types of modification mentioned in Table 1. (Militz & Altgen, 2014; Zelinka et al., 2022):

Thermal modification, UC 3: This treatment involves heating the wood to high temperatures (180-220°C) in a controlled environment with limited oxygen supply, which changes the wood's cellular structure and reduces its ability to absorb moisture. This makes the wood more dimensionally stable, less prone to warping, and more resistant to decay and insects. UC 3 treated wood is suitable for outdoor use above ground.

Thermal modification (Oil-Heat Treatment, OHT), UC 3: This treatment is like thermal modification but also involves the use of vegetable oils to enhance the wood's color and durability. OHT treatment can also improve the wood's fire resistance and acoustic properties.

Furfurylation, UC 4: This treatment involves impregnating the wood with furfuryl alcohol, a natural substance derived from agricultural waste, and then curing it under high heat and pressure. Furfurylation changes the wood's cell structure and chemistry, making it highly resistant to decay, insects, and moisture. It also improves the wood's stability, strength, and durability. UC 4 means the treated wood is suitable for outdoor use in contact with soil or freshwater, such as landscaping, bridges, or piers.

Copper organic, UC 3: This treatment involves impregnating the wood with copper-based preservatives and organic co-biocides that protect the wood from decay and insects. Copper organic treatment is an option for outdoor wood products that are not in contact with soil or freshwater.

Metal free, organic, UC 3: This treatment is similar to copper organic but uses only organic co-biocides that are free of heavy metals such as chromium or arsenic. Metal-free, organic treatment is an option for wood products that may encounter food or sensitive environments, such as playgrounds or gardens.

The Excel file is provided as supplementary material and briefly presented here in Fig. 2, 3 and 4. Users can change values according to their specific building. We have not yet come up with a real case study that gives us the possibility to use the real input data. This will be done in the next steps of the project. Here is an illustration of the 'LCC Calculator- User Input' with some arbitrary inputs.

In the initial stage, users can select one of six countries, each offering few city options. The currency will then automatically appear. Users have the option to select one preferred currency in addition to the currency of their chosen country. (See Fig. 2).

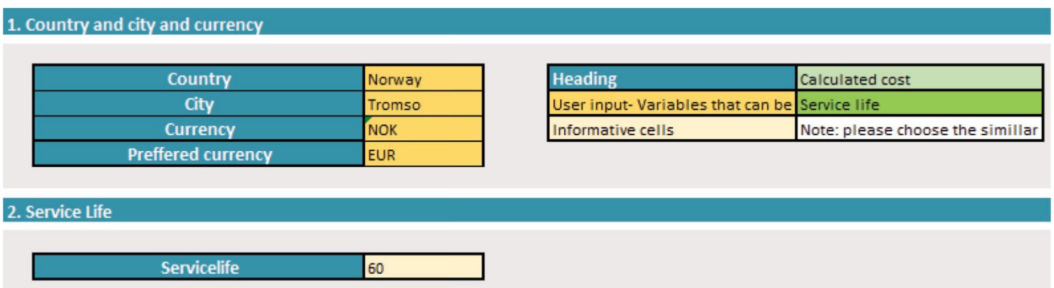

Fig. 2
User interface illustration, where the user can choose country and city and the preferred currency. Service life of a building is given as information

Further, users have the possibility to choose construction elements, as shown in Fig. 3. Users can choose from various elements via a drop-down list under 'description'. The same selection process applies to species, detailing, and, if applicable, roof overhang. Based on the chosen combination of variables, the service life is displayed in the last column. If the service life exceeds 60 years, it indicates that the element remains in place without requiring replacement throughout the building's service life.

The last part of the interface is the LCC calculation results (Fig. 4). Users are giving the discount rate and Escalation rate as input to the model and as a result, future building cost will be presented based on discount rate and escalation rate, while maintenance cost will be calculated based on escalation rate. A brief reminder is that discount rate is the general inflation rate and escalation rate is the increase in the specific product category, for example building wood material. The escalation rate can be higher or lower than the general inflation rate depending on several factors.

Fig. 3

User interface for material input and defining other variables

3. Construction

Bearing system								
Columns	Description	Amount	Unit	Species	Detailing	Orientation	Roof Overh	Service Life
a Column (select desired width and lenght)	Column (Vertical), Width 140mm, B x D = 140 x 133 mm,impregnated	30	m	Norway spruce	End-grain contact	Vertical		Longer than 60 years
Fasteners for columns	DELIVERY OF MECHANICAL FASTENERS - QUANTITY Fastener: Other fa:	1	item					0.00
Beams	Description	Amount	Unit	Species	Detailing	Orientation	Roof Overh	Service Life
a Beams (select desired width and lenght)	Beam (Horisontal), width 115 mm, b x h = 115 x 360 mm	10	m	Norway spruce	End-grain contact	Horizontal		Longer than 60 years
supplementary steel components for beams	SUPPLEMENTARY STEEL COMPONENTS MOUNTED IN PLACE - QUANTITY	5	item					0.00
Outer walls, façade, Heavy								
Description		Amount	Unit	Species	Detailing	Orientation	Roof Overh	Service Life
a Outer walls, façade, Heavy	SOLID WOOD WALL ELEMENT t = 240 mm, Joining method: Optional	100	m^2	Norway spruce, Therma	End-grain ventilated	Vertical	Yes	Longer than 60 years
b Outer walls, façade, Heavy	SOLID WOOD WALL ELEMENT t = 160 mm, Joining method: Optional	0	m^2	Scots pine, Thermal mc	End-grain ventilated	Vertical	Yes	Longer than 60 years
c Outer walls, façade, Heavy	Additional cost: visible surface solid wood element inside outer w	1	m^2			Vertical	Yes	17.73
Outer walls, façade, Light								
Description		Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Outer walls, façade, Light	Board cladding, composite board with visible, natural veneer	50	m^2	Norway spruce, Therma	End-grain contact	Vertical	Yes	Longer than 60 years
b Outer walls, façade, Light	Lacquered steel cassettes against climate wall	50	m^2		None	Vertical	Yes	17.73
c Outer walls, façade, Light	Board cladding, fiber cement, against climate wall, surface treated with imp		m^2	Norway spruce, Thermal modification, OHT, I		Vertical	Yes	Longer than 60 years
Doors								
Doors	Description	Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Doors	Wooden exterior door 10 x 21 M outward-striking	1	item		End-grain contact	Vertical	Yes	9.54
b Doors	Wooden window door 24 x 21 M sliding door u-value < 08	1	item			Vertical	Yes	17.73
Garage Doors								
Doors	Description	Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Garage Doors	Articulated garage in wood W x H = 2400 x 2100 mm for residential g	1	item		None	Vertical	Yes	17.73
Windows								
Windows	Description	Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Windows	Windows aluminum-sheathed openable U-value < 12	25	item	Scots pine, No treatme	None	Vertical	Yes	Longer than 60 years
b Windows	Wooden Windows fixed u-value = 07	5	item	Scots pine, No treatme	None	Vertical	Yes	Longer than 60 years
Outer roof- Flat roof- Bearing element								
Bearing Element	Description	Amount		Species	Detailing			Service Life
a Outer roof- Flat roof- Bearing element		0			End-grain contact			0.00
Outer roof- Flat roof- Roof Terrace								
Terrace	Description	Amount		Species	Detailing			Service Life
a Outer roof- Flat roof- Roof Terrace		0			End-grain contact			0.00
Outer roof- angled roof - bearing system								
Bearing system	Description	Amount		Species	Detailing			Service Life
a Outer roof- angled roof - bearing system		0			End-grain contact			0.00
Outer roof- angled roof - Thatching								
Bearing system	Description	Amount		Species	Detailing			Service Life
a Outer roof- angled roof - Thatching	Thatching pitched roof - roof board, impregnated	155	m^2	Norway spruce, Therma	End-grain contact	Horizontal	No	Longer than 60 years
Steps / Stairs								
Steps / Stairs	Description	Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Steps / Stairs	Staircase in solid wood inside one straight barrel finished surface	1	item	Norway spruce, Therma	End-grain contact	Horizontal	Yes	Longer than 60 years
Balcony, with different treatents								
Balcony element (foundation)	Description	Amount		Species	Detailing	Orientation	Roof Overh	Service Life
a Balcony, with different treatents	Terrace floor on balcony 28 x 120 mm royal impregnated brown	20	m^2	Norway spruce, Therma	End-grain contact	Horizontal	No	Longer than 60 years
Surface treatments								
Treatment	Description	Amount						Service Life
a Type of treatment	Single coat of paint	150	m^2					14.91

Fig. 4

LCC calculation including the building cost in current and future value, and maintenance cost in future value

4. Cost calculations

Servicelife (yrs)	60
Discount rate	3%
Escalation rate	4%

Building costs	NOK
Initial building costs	NOK 1,123,597.13
uture Value of Building (year=60) (Discout ra	NOK 6,619,788.34
Future building cost (year=60) (Escalation)	NOK 11,819,823.17

	Maintainance costs
Maintainance year (MY)	Future value (Escalated LCC)
0 =<MY< 10	NOK 17,684.32
10 =<MY< 20	NOK 209,023.16
20 =<MY< 30	NOK 115,303.25
30 =<MY< 40	NOK 344,675.78
40 =<MY< 50	NOK 252,643.61
50 =<MY< 60	NOK 755,227.09
Sum	NOK 1,694,557.21

Results in preffered currency	
Building costs	EUR
Initial building costs	€ 95,056.32
uture Value of Building (year=60) (Discout ra	€ 560,034.09
Future building cost (year=60) (Escalation)	€ 999,957.04

	Maintainance costs
Maintainance year	Future value (Escalated LCC)
0 =<MY< 10	€ 1,496.09
10 =<MY< 20	€ 17,683.36
20 =<MY< 30	€ 9,754.65
30 =<MY< 40	€ 29,159.57
40 =<MY< 50	€ 21,373.65
50 =<MY< 60	€ 63,892.21
Sum	€ 143,359.54

Conclusions

In this study, the data structure and the necessary indicators and parameters were identified for LCC calculation for a timber building. The improved service life input dataset enables more precise LCC estimation for wood-based products. The model serves as a flexible tool, enabling users to examine the impact of material choices on the cost of both the load-bearing elements and the building envelope, as well as on the maintenance expenses throughout the building's service life. We identified some strength and limitations which can help us to improve the modelling for a LCC calculation.

Model Strength are:

- The model gives a first picture on the overall LCC of a wooden building and how maintenance intervals may affect the cost.
- Input data are clearly documented. The model includes all the essential elements for calculation, complying with the LCC standards.
- It can be applied in many European countries. The results can be given in a chosen currency.
- It is in Excel and easy to use for many users.
- It can be utilized and further refined as a foundational template model for more advanced software development, a plan that is part of the WoodLCC project. The model has the potential for integration with Building Information Modelling (BIM).

Model limitations:

- The current dataset is limited to only one price dataset from one country.
- The list of material is also derived from the same dataset, which limits the number of products. In addition, some of the product names can be very confusing for users. The input data for material quantity is a critical data input for a typical user, but the contractor have good estimation.
- Not all the species and type of treatments can be applied in all materials. This makes the model complicated to choose from the drop-down list of species. In this model, the user should have enough knowledge and experience not to use strange combinations, such as Southern yellow pine, Furfurylation, UC 4 for bearing system.
- Ultimately, a notable constraint lies in the substantial uncertainty stemming from multiple factors, which could potentially lead to error propagation and biased outcomes. This uncertainty is present in nearly all input data, and it's important to note that user behaviour is finally the one significant factor in cost calculations.

Suggestions for Further Development:

- Improvement is needed in finding more tuned input data and assumption, specifically price databases with more detailed while comprehensible product names. It will be ideal if the choices can be visualised with product pictures.
- For future enhancements, the model could incorporate aesthetic service life to provide users with insights into how their choices may impact the LCC of a building.
- Moreover, the model could potentially incorporate an assessment of how construction practices impact costs, comparing the expense of having a shelter during construction to not having one, thereby potentially increasing the likelihood of damaging the elements.

Tool Availability: The Excel file is included as supplementary material in this article. For updates on the latest versions of the Excel model and the software, please visit the official LinkedIn page of the WoodLCC project.

Acknowledgements

Project WoodLCC is supported under the umbrella of ERA-NET Cofund ForestValue by funding agencies from Slovenia, Finland, Norway, Sweden, Estonia, and Germany. ForestValue has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773324.

References

AbouHamad, M., & Abu-Hamd, M. (2019). Framework for construction system selection based on life cycle cost and sustainability assessment. Journal of cleaner production, 241, 118397. https://doi.org/10.1016/j.jclepro.2019.118397

Alasmari, E., Martinez-Vazquez, P., & Baniotopoulos, C. (2022). A Systematic Literature Review of the Adoption of Building Information Modelling (BIM) on Life Cycle Cost (LCC). Buildings, 12(11), 1829. https://doi.org/10.3390/buildings12111829

Alasmari, E., Martinez-Vazquez, P., & Baniotopoulos, C. (2023). An Analysis of the Qualitative Impacts of Building Information Modelling (BIM) on Life Cycle Cost (LCC): A Qualitative Case Study of the KSA. Buildings, 13(8), 2071. https://doi.org/10.3390/buildings13082071

Arkhangelskaya, Y. (2018). Economic assessment of a wood building: Life cycle cost and key stakeholders' decision-making.

Brischke, C., Alfredsen, G., Humar, M., Conti, E., Cookson, L., Emmerich, L., Flæte, P. O., Fortino, S., Francis, L., & Hundhausen, U. (2021). Modelling the material resistance of wood-Part 2: Validation and Optimization of the Meyer-Veltrup Model. Forests, 12(5), 576. https://doi.org/10.3390/f12050576

EN15643-4. (2021). Sustainability of construction works. Assessment of buildings - Framework for the assessment of economic performance. In.

EN16627. (2015). 16627; Sustainability of Construction Works-Assessment of Economic Performance of Buildings-Calculation Methods. In.

Eurostat. (2021a). Labour cost index (lci).

Eurostat. (2021b). Price level index for energy, furniture, household appliances and consumer electronics.

Gaus, J., Wehking, S., Glas, A. H., & Eßig, M. (2022). Economic Sustainability by Using Life Cycle Cost Information in the Buying Center: Insights from the Public Sector. Sustainability, 14(3), 1871. https://doi.org/10.3390/su14031871

Gu, H., Liang, S., & Bergman, R. (2020). Comparison of building construction and life-cycle cost for a high-rise mass timber building with its concrete alternative. Forest Products Journal, 70(4), 482-492. https://doi.org/10.13073/FPJ-D-20-00052

Hosseini, S. H., Niklewski, J., & van Niekerk, P. B. (2023). Moisture prediction of timber for durability applications using data-driven modelling. World Conference on Timber Engineering (WCTE 2023), https://doi.org/10.52202/069179-0495

Liu, S., Meng, X., & Tam, C. (2015). Building information modeling based building design optimization for sustainability. Energy and Buildings, 105, 139-153. https://doi.org/10.1016/j.enbuild.2015.06.037

Maisham, M., Adnan, H., Ismail, N. A. A., & Mahat, N. A. A. (2019). Developing a research methodology for life cycle costing framework for application in green projects. IOP Conference Series: Earth and Environmental Science, https://doi.org/10.1088/1755-1315/385/1/012066

Manewa, A., Siriwardena, M., & Wijekoon, C. (2021). Life cycle costing in construction: Current trends and emerging directions. https://doi.org/10.31705/WCS.2021.35

McEvoy, O. (2022). Average hourly labor cost in the European Union, by country (in Euros).

Medeiros, R. (2014). The new Directive 2014/24/EU on public procurement: a first overview. 2nd European Conference on e-Public Procurement, Portugal.

Militz, H., & Altgen, M. (2014). Processes and properties of thermally modified wood manufactured in Europe. In Deterioration and protection of sustainable biomaterials (pp. 269-285). ACS Publications. https://doi.org/10.1021/bk-2014-1158.ch016

Niklewski, J., Sandak, J., Bester Van Niekerk, P., Brischke, C., Acquah, R., & Sandak, A. (2023). Simplified environmental analysis of the long-term performance of wood cladding and decking. Proceedings of the World Conference on Timber Engineering (WCTE 2023), Oslo, Norway, https://doi.org/10.52202/069179-0075

Norén, J., Pousette, A., & Sandberg, K. (2018). Moisture Safety of Tall Timber Facades-LCA and LCC Calculations of Damage Scenarios. Cold Climate HVAC Conference, https://doi.org/10.1007/978-3-030-00662-4_79

Norsk prisbok (2023).

Petrović, B., Zhang, X., Eriksson, O., & Wallhagen, M. (2021). Life cycle cost analysis of a single-family house in Sweden. Buildings, 11(5), 215. https://doi.org/10.3390/buildings11050215

Potkány, M., Debnár, M., & Škultétyová, M. (2019). Life cycle cost analysis for reference prototype building in alternatives of silicate and wood-based structure. Acta Facultatis Xylologiae Zvolen res Publica Slovaca, 61(2), 137-152.

Potrč Obrecht, T., Röck, M., Hoxha, E., & Passer, A. (2020). BIM and LCA integration: A systematic literature review. Sustainability, 12(14), 5534. https://doi.org/10.3390/su12145534

Rahim, F., Muzaffar, S., Yusoff, N. M., Zainon, N., & Wang, C. (2014). Sustainable construction through life cycle costing. Journal of building performance, 5(1).

Sadliwala, M. S., & Gogate, N. G. (2022). Life Cycle Costing Methodology for Sustainable Construction. IOP Conference Series: Earth and Environmental Science, https://doi.org/10.1088/1755-1315/1084/1/012023

Santos, R., Costa, A. A., Silvestre, J. D., & Pyl, L. (2019). Integration of LCA and LCC analysis within a BIM-based environment. Automation in Construction, 103, 127-149. https://doi.org/10.1016/j.autcon.2019.02.011

Saridaki, M., & Haugbølle, K. (2022). Recognising diversity of data management approaches towards lifecycle costing through personas. Journal of Information Technology in Construction, 27, 1042-1059. https://doi.org/10.36680/j.itcon.2022.051

Shin, Y.-s., & Cho, K. (2015). BIM application to select appropriate design alternative with consideration of LCA and LCCA. Mathematical Problems in Engineering, 2015. https://doi.org/10.1155/2015/281640

Zelinka, S. L., Altgen, M., Emmerich, L., Guigo, N., Keplinger, T., Kymäläinen, M., Thybring, E. E., & Thygesen, L. G. (2022). Review of wood modification and wood functionalization technologies. Forests, 13(7), 1004. https://doi.org/10.3390/f13071004

About the Authors

ROJA MODARESI

Senior Researcher

Norwegian Institute of Wood Technology (NTI)

Main research area

Environmental System Analysis, Circular Economy, Industrial Ecology (LCA, MFA, EPD, LCC, etc.), Environmental Standards

Address

Børrestuveien 3, 0373 Oslo, Norway

Tel. (+47) 402 95 791

E-mail: rmo@treteknisk.no

MAGNUS OLAI LANDAAS

Consultant

Norwegian Institute of Wood Technology (NTI)

Main research area

Modelling, Data Science, Economics, Sustainability reporting, MFA, LCC, EPD

Address

Børrestuveien 3, 0373 Oslo, Norway

Tel. (+47) 474 65 051

E-mail: mla@treteknisk.no