Modelling of service life and durability of wooden structures

Hannu Viitanen¹, Tomi Toratti¹, Lasse Makkonen¹, Sven Thelandersson², Tord, Isaksson², Eva Früwald², Jöran Jermer³, Fin Englund³, Ed Suttie⁴

¹) Technical Research Centre of Finland VTT, Finland
²) Lund University, Div. of Structural Engineering, Sweden
³) SP Technical Research Institute of Sweden, Wood Technology
⁴) BRE, Building Research Establishment, United Kingdom
The present paper presents

- In this paper, attempts to model the service life of wood structures is developed by utilising earlier durability experiments and relating the decay models to a hygrothermal analysis of building physics.
- The model is also used in connection with the ERA-40 weather observations in Europe to assess the geographical dependence on service life related to durability.
- These studies provide new tools to evaluate the durability and service life of wooden commodities and a preliminary European wood decay map, is presented in this paper.
- A further enhancement of the model, which is currently under development, is the assessment of the effects of the various structural choices (e.g. protection to driving rain, coatings, etc.) and other parameters (e.g. geographical location and orientation) on the durability of wooden structure.
A building is subjected to different water sources, ageing processes and damages during the life time. Exposure conditions -> durability, service life.

- **Facades**
  - Cladding
  - Use class 3.1 (EN 335-1)

- **Balconies**
- **Terraces**
- **Fences**
  - Use class 3.2 (EN 335-1)
Critical parts of the building for exposure modelling

- **Indoor surfaces**
  - Wet rooms, attic, indoor rooms
- **Structural parts / envelopes**
- **Outdoor structures**
  - facades, windows, fences, balconies, terraces
- **Intended use conditions**
- **Critical details**
- **Mould / decay / other organisms**

Use of model organisms to simulate and modelling the critical conditions for decay development under controlled conditions

RH, moisture temperature, exposure time materials
Activation process:

- **α parameter**, which is initially 0 and gradually grows depending on the air conditions to a limit value of 1. This process is able to recover (**α can get lower values**) in favourable conditions for wood (dry air) at a given rate (no experimental evidence of recovery is available).

- In this model, these processes only occur when the temperature is 0..30 °C and the relative humidity is 95% or above (other temperatures were not tested).

\[
\alpha(t) = \int_0^t d\alpha = \sum_0^t (\Delta\alpha) , \text{ where} \\
\Delta\alpha = \frac{\Delta t}{t_{crit}(RH,T)} \quad \text{or (in favorable conditions of decay)} \\
\Delta\alpha = -\frac{\Delta t}{17520} \quad \text{(in unfavorable conditions of decay)} \\
\]

\[
t_{crit}(RH,T) = \left[ \frac{2.3T + 0.035 RH - 0.024 T \times RH}{-42.0 + 0.14T + 0.45 RH} \right] \times 30 \times 24 \quad \text{[hours]} 
\]
MODELLING THE DECAY DEVELOPMENT IN WOOD

Mass loss process:
- This occurs when the activation process has fully developed ($\alpha=1$) otherwise it does not occur. This process is naturally irrecoverable.

Mass loss process when $\alpha \geq 1$

$$ML(t') = \int_{t \text{ at } \alpha = 1}^{t'} \frac{ML(RH,T)}{dt} dt = \sum_{t \text{ at } \alpha = 1}^{t'} \left( \frac{ML(RH,T)}{dt} \times \Delta t \right)$$

$$\frac{ML(RH,T)}{dt} = -5.96 \times 10^{-2} + 1.96 \times 10^{-4} T + 6.25 \times 10^{-4} RH \ [\% / \text{hour}]$$
Measured climate data (Helsinki) used in the decay activity model for one year (Viitanen et al 2010).

No activation of growth or decay development during the first and second years, an activation of decay process after 4 years exposure may be expected.

Decay model presented by Viitanen et al 2010.
Outdoor exposure conditions in different part of Europe based on the decay activity model (uncovered situation)

Modelled mass loss (in %) of small pieces of pine wood that are exposed to rain in 10 years in Europe (from [Viitanen et al. 2010]).

Solar radiation in Europe.

For sheltered structure, the exposure to water and solar radiation is lower.
Relative decay potential for Europe (Brischke et al 2011)

Dose response model 1  Dose response model 2
An example on a calculation method to evaluate the service life of wooden cladding and decking -> www.kstr.lth.se

Design Guidelines for wood in outdoors above ground applications

Design condition $I_{sd} = I_{skgd} \leq I_{Rd}$

### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{s1}$</td>
<td>1.2</td>
</tr>
<tr>
<td>$k_{s2}$</td>
<td>0.85</td>
</tr>
<tr>
<td>$k_{s3}$</td>
<td>1.5</td>
</tr>
<tr>
<td>$k_{s4}$</td>
<td>0.6</td>
</tr>
<tr>
<td>$I_{so}$</td>
<td>1</td>
</tr>
<tr>
<td>$c_s$</td>
<td>1</td>
</tr>
<tr>
<td>$I_{sk}$</td>
<td>0.92</td>
</tr>
<tr>
<td>$\gamma_d$</td>
<td>0.8</td>
</tr>
<tr>
<td>$I_{sd}$</td>
<td>0.73</td>
</tr>
<tr>
<td>$I_{Rd}$</td>
<td>1</td>
</tr>
</tbody>
</table>

### Consequence class, $\gamma_d$

- 1 Moderate
- 2 Medium
- 3 High

### Local conditions, $k_{s1}$

- Light
- Medium
- Heavy
- Severe

### Basic exposure index, $I_{so}$

- Continental Europe
  - Own value: 1.5

### Sheltering, $k_{s2}$

- $e > 0.5d$
- $0.15d - 0.5d$
- $< 0.15d$

### Distance from ground, $k_{s3}$

- $> 300$ mm
- $300 - 100$ mm
- $< 100$ mm

### Resistance class, $I_{Rd}$

- 1
- 2
- 3
- 4
- 5

### Rating of details, $k_{s4}$

- Decking
  - Excellent
  - Good
  - Medium
  - Fair
  - Poor

- Cladding
  - Uncoated
  - Coated
An example 2 on a calculation method to evaluate the exposure conditions and service life of wooden cladding and decking.

Service life estimator for claddings and deckings

1. Is this a decking (horizontal structure)? Tick here if yes
   Otherwise this is a cladding (vertical structure)

   CC 1 = cladding
   CC 2 = decking close to ground
   CC 3 = decking and balcony

   Is the solution acceptable

   Acceptable

   Service life factor [OK if > 1]
   Consequence class factor
   Wood material
   Surface coating
   Design /structural details
   Construction works
   Climate conditions
   Repair and service procedures

   Service life factor = Consequence class factor x A1 x A2 x B x C x D x F

Hannu Viitanen, Lasse Makkonen, Ruut Peuhkuri, Tomi Toratti

VTT
Factors for service life of wooden facades (modified based on Vesikari et al 2001).

<table>
<thead>
<tr>
<th>Code</th>
<th>Factor</th>
<th>Parameters / factors for estimated service life</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>Wood material</td>
<td>Wood species, decay and weather resistance, water permeability, board quality, dimension, wood modification, preservation</td>
</tr>
<tr>
<td>A₂</td>
<td>Coating</td>
<td>Coating type and properties (thickness, opacity, color), needs for repainting (maintenance)</td>
</tr>
<tr>
<td>B₁</td>
<td>Structure, design,</td>
<td>Structure of the houses: eaves, height of the wall and foundations (B₁). Structure of the façade; board type, bonds and joints, ventilation, protection of joints and end grains, fixing (B₂)</td>
</tr>
<tr>
<td>B₂</td>
<td>especially details</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Work execution</td>
<td>Achievements and treatments details, fixing, wood moisture content, storage condition</td>
</tr>
<tr>
<td>D</td>
<td>Indoor environment</td>
<td>Temperature, RH, condensation (not so important for exterior structure)</td>
</tr>
<tr>
<td>E₁</td>
<td>Exposure conditions</td>
<td>Point of compass, type of environment (protective – exposed) macroclimate (E₁) and local conditions, exposure to driving rains (E₂) ➔ microclimate conditions</td>
</tr>
<tr>
<td>E₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Use conditions</td>
<td>Indoor environment, moisture stress, mechanical injuries</td>
</tr>
<tr>
<td>G</td>
<td>Maintenance</td>
<td>Care of accidental damage, serviceable, repainting (opaque – stains) time of repaint</td>
</tr>
</tbody>
</table>
### Definition of local conditions (Factor E2, see the table 2)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Local conditions have little impact on performance as the three features all offer sheltering (i) land topography (ii) local buildings (iii) &gt;5km from the sea (so no maritime effect).*</td>
</tr>
<tr>
<td>Medium</td>
<td>Local conditions have some impact on performance as one of the three features does not offer sheltering (i) land topography (ii) local buildings (iii) &gt;5km from the sea (so no maritime effect).</td>
</tr>
<tr>
<td>Heavy</td>
<td>Local conditions have an impact on performance as two of the three features do not offer sheltering (i) land topography (ii) local buildings (iii) &gt;5km from the sea (so no maritime effect).</td>
</tr>
<tr>
<td>Severe</td>
<td>Local conditions have a significant impact on performance as the three features do not offer sheltering (i) land topography (ii) local buildings (iii) &gt;5km from the sea (so no maritime effect).**</td>
</tr>
</tbody>
</table>

* e.g. Building is sheltered by hills and neighbouring buildings and is inland.
** e.g. Building is on a flat plain, with no nearby buildings and is 1km from the sea.
## Rating of design details (Factor B2)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Excellent</td>
<td>Excellent design with features to maximize water shedding and ability to dry when wet. The end grains are well protected.</td>
</tr>
<tr>
<td>2. Good</td>
<td>Good design with features to provide water shedding and ability to dry when wet (corresponds to the reference of a horizontal board without possibility of moisture trapping)</td>
</tr>
<tr>
<td>3. Medium</td>
<td>Design with a limited probability of water trapping, and with some ability to dry when wet</td>
</tr>
<tr>
<td>4. Fair</td>
<td>Design with medium probability of water trapping and limited ability to dry when wet</td>
</tr>
<tr>
<td>5. Poor</td>
<td>Design with high risk of water trapping and very limited ability to dry when wet. The end grains are not protected.</td>
</tr>
</tbody>
</table>

(1) The index is for well coated cladding
Conclusions

- The presented numerical decay development model is based on experimental results from laboratory studies under controlled conditions using model organisms, e.g. *Coniophora puteana*.
- New attempts have been made to develop calculation methods for service life estimations for different exposure conditions.
- It still remains to be verified with field experience.
- So far the comparison of the method result to practice has been encouraging.
- The variation of the material sensitivities is high, estimation of a product sensitivity class is difficult without testing under controlled conditions.
- The evaluation of the actual conditions in the critical material layers may include uncertainties.
ACKNOWLEDGMENTS

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