COMSOL CONFERENCE 2020 EUROPE

CULTURAL HERITAGE RESEARCH GROUP

Assessing the risk of cracking for wooden sculptures due to dynamic relative humidity changes

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14-15.10.2020

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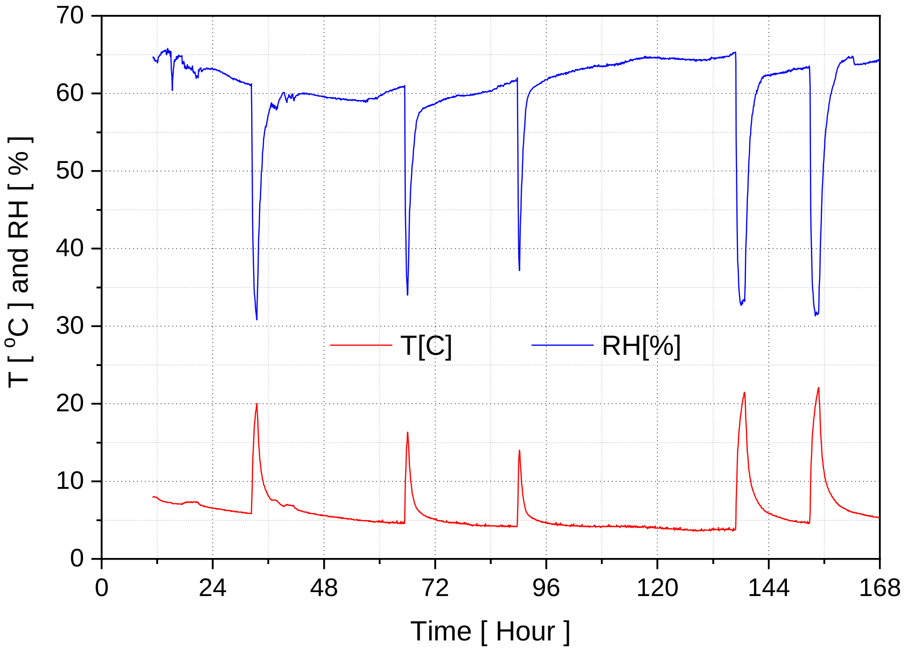
Heating episodes in historic houses and religious buildings



Dynamic, short-term variations of relative humidity (RH) occur in historic interiors due to the intermittent heating. Their impact on wooden objects is the scope of this study.

Importance of the research

Historic interiors are heated for human comfort during commercial or cultural events such as concerts, weddings, conferences and parties.

There is no commonly accepted recommendation what is the optimal strategy of heating historic buildings in terms of the preservation of wooden sculptures.

Presented research aims to address this question by studying damage processes, particularly crack development, in wood using COMSOL Multiphysics®.

Stress development in wood

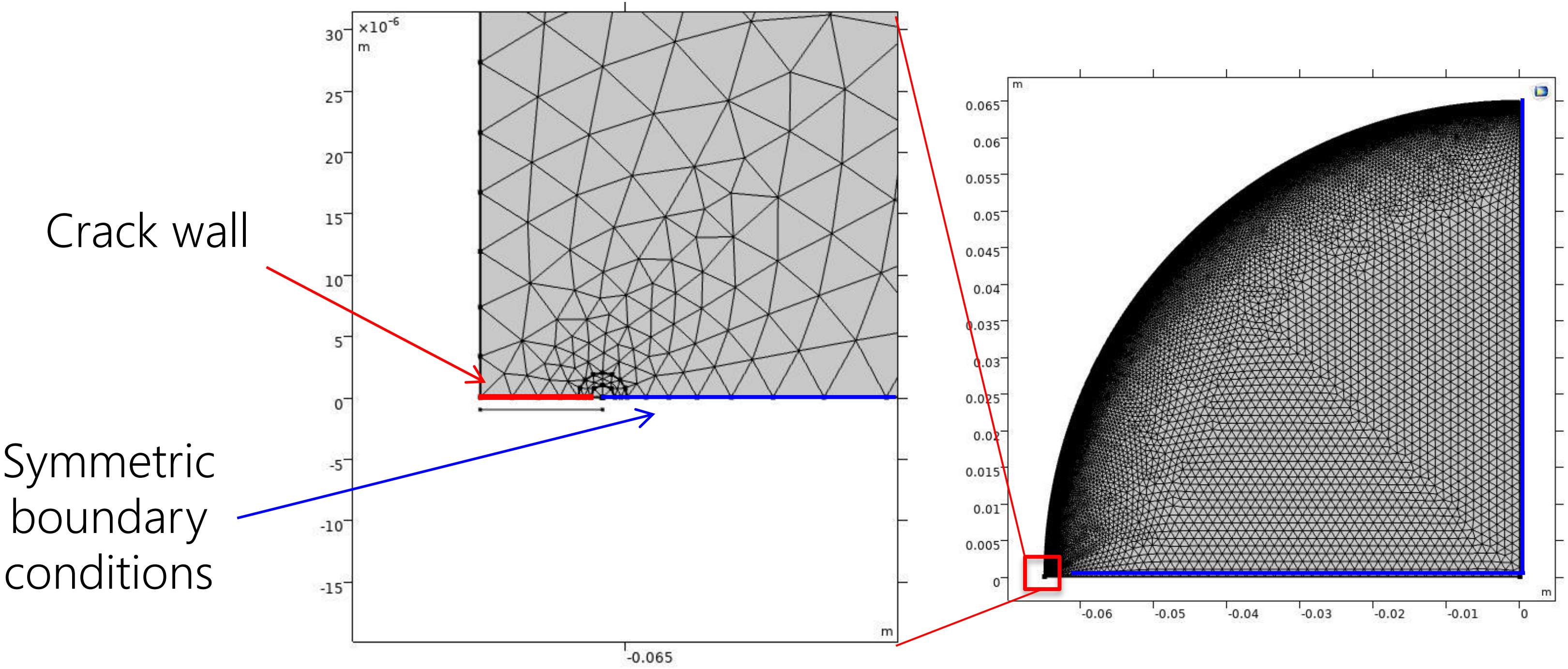
Dynamic changes in RH induce gradients of moisture content in wood.

Resulting compressive and tensile stresses along with the stresses developed due to the difference in dimensional response of wood in its various anatomical directions can cause **cracking.**

Massive objects are the most vulnerable.

Modelling in COMSOL: geometry

Massive wooden sculpture is approximated by a disc with plane strain condition and radial crack of length CL.



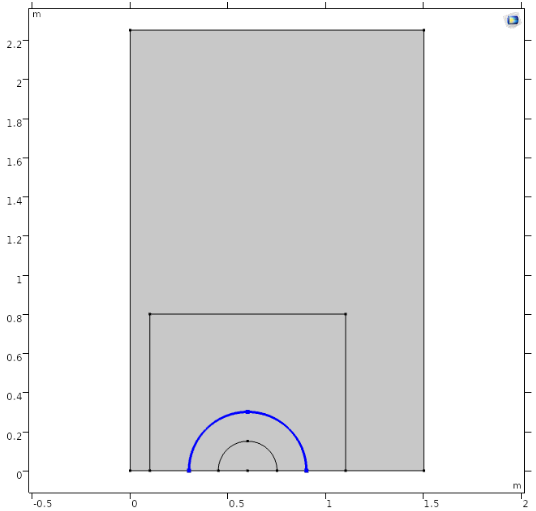
Modelling in COMSOL: model settings

- Thermal stress multiphysics – due to the same mathematical laws describing heat and moisture diffusion

heat flux represents **moisture flux**, generating moisture gradient

- Time-dependent study – simulating an arbitrary change in RH conditions
- Parametric sweep – over various lengths of a crack CL

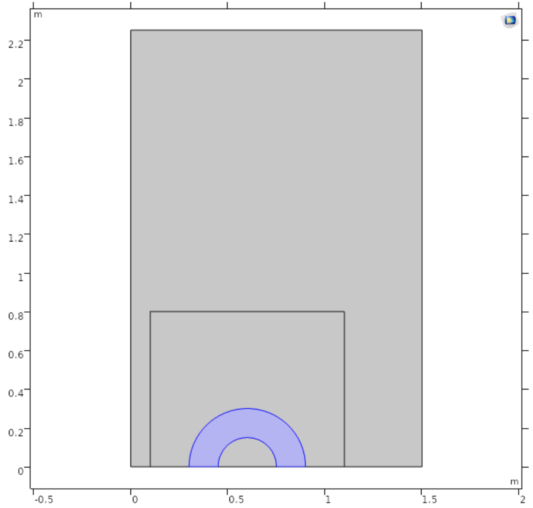
Method: *J*-integral reformulated for orthotropic material and moisture gradients



Path-independent line integral

Single Edge Crack
COMSOL tutorial

Equivalent Domain Integral conversion



Domain-independent **area** integrals

Hein J., Kuna M.,
THEOR APPL FRACT MEC, 2017

Model optimization: mesh element size, time step

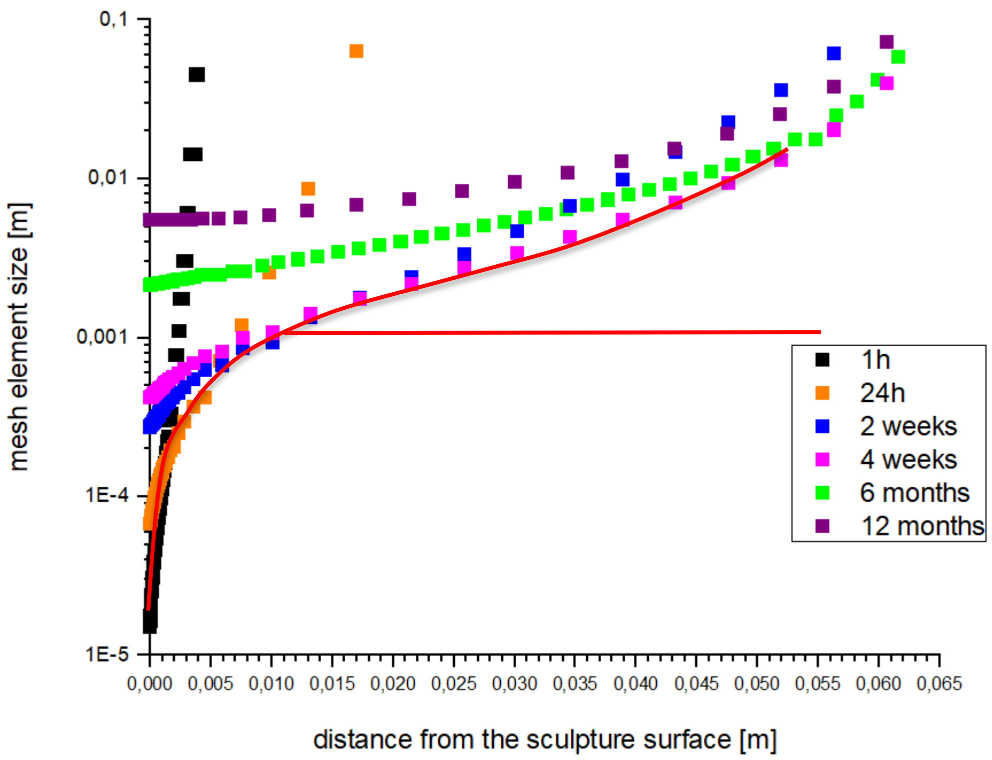
Criteria: change of RH inside every mesh element of size l should not exceed 1%:

$$\Delta l = \left(\frac{dRH}{dl}\right)^{-1} \cdot \Delta RH$$

Analogous condition was adopted for determination of the time step.

Mesh element size changes according to the lowest values, but is no larger than 1 mm.

External conditions: step RH from **50** to **20%**



Wood properties and parameters necessary for modelling

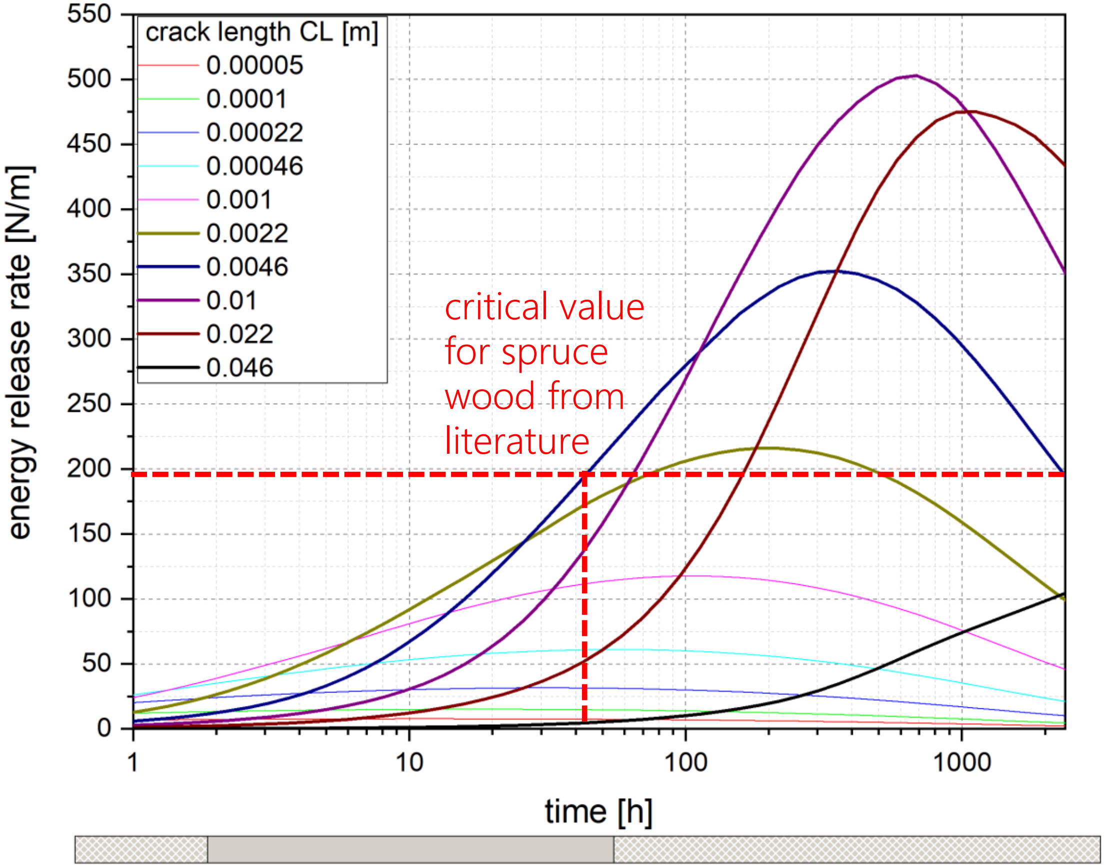
Material properties		
Young's moduli in radial (R) and tangential (T) direction	$E_R(RH), E_T(RH)$	$[MPa]$
Poisson's ratio in R direction caused by stress in T direction	ν_{TR}	$[-]$
Shear modulus in RT plane	$G_{RT}(RH)$	$[MPa]$
Moisture diffusion coefficient	$D(RH,T)$	$[\frac{kg}{m \cdot s \cdot Pa}]$
Density	ρ	$[\frac{kg}{m^3}]$
Environmental parameters		
External mass transfer coefficient	SEC	$[\frac{kg}{m^2 \cdot s \cdot Pa}]$

Simulation results: critical time of change

Step RH from **50** to **20%**

The highest values of the energy release rate G are reached for cracks longer than ca. 2mm, between 100 – 1000h.

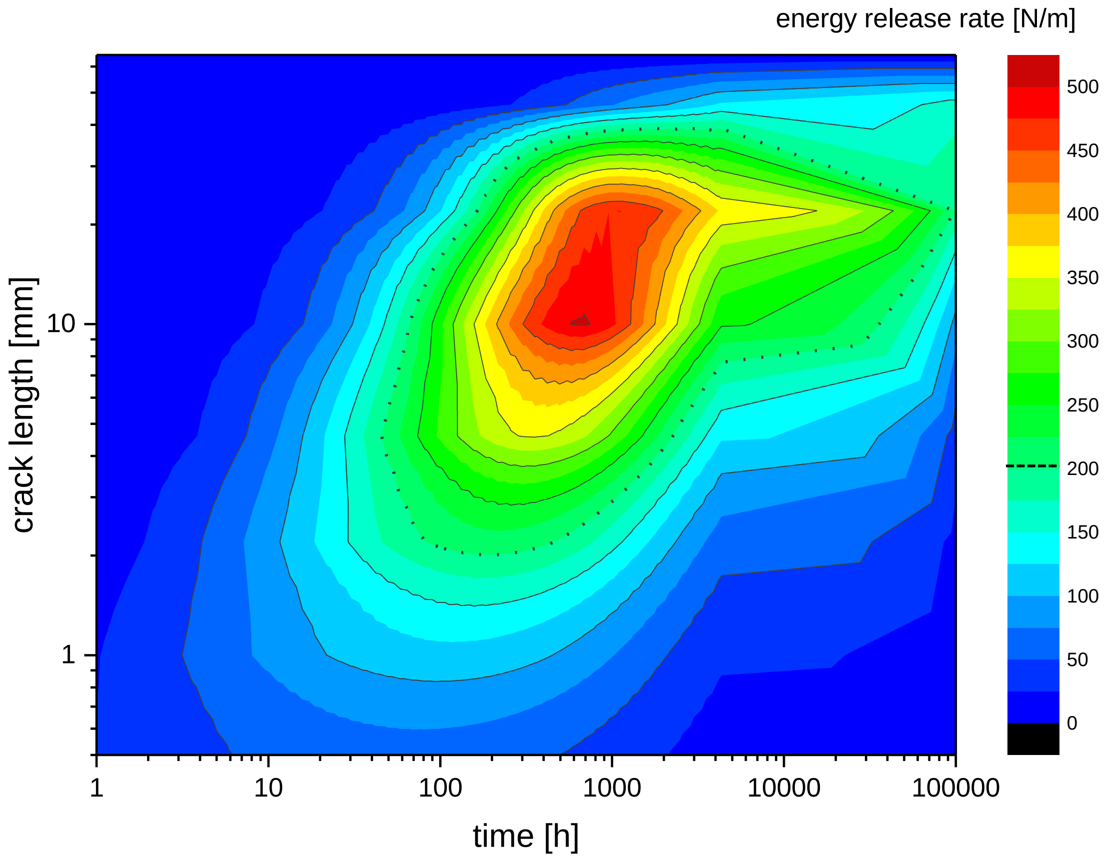
The shortest time to reach the critical level is 48 hours.



Simulation results – map

Step RH: **50-20%**

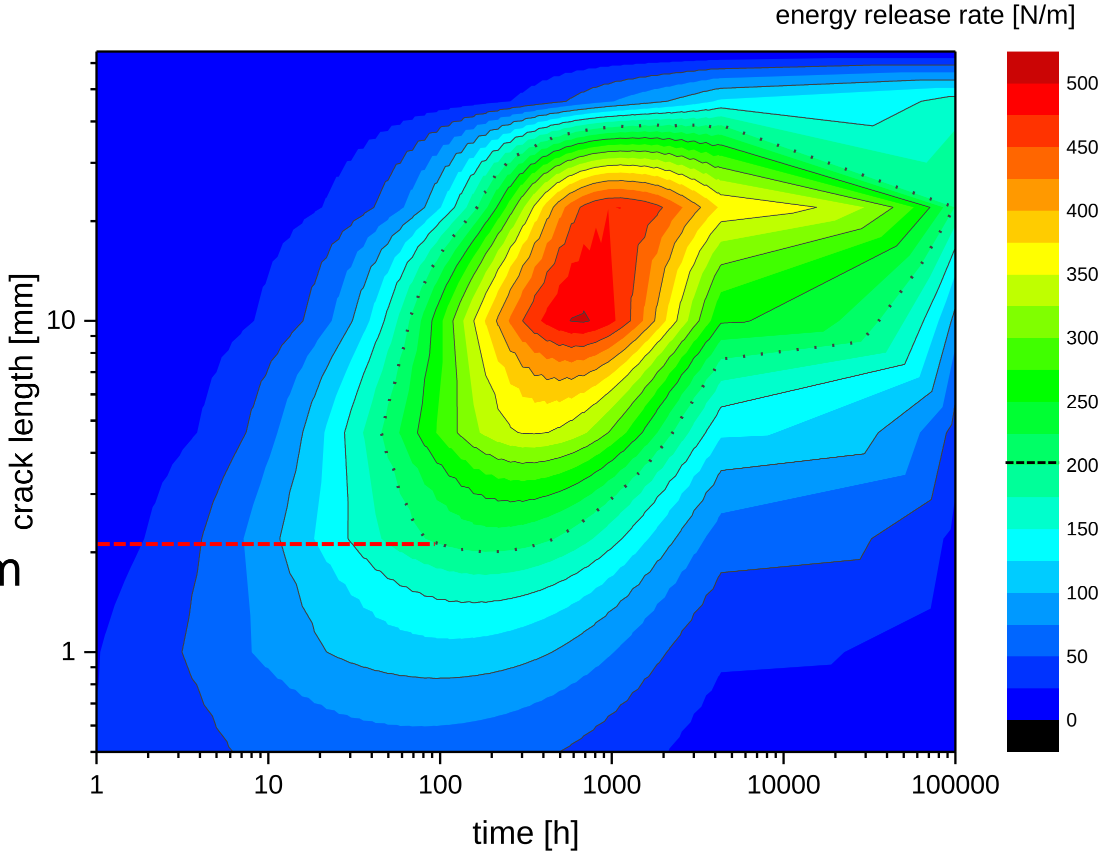
The dotted line marks the critical level of the energy release rate G, which is the threshold for the process of the crack growth.



Simulation results – map

Step RH: **50-20%**

initial crack length: **2mm**

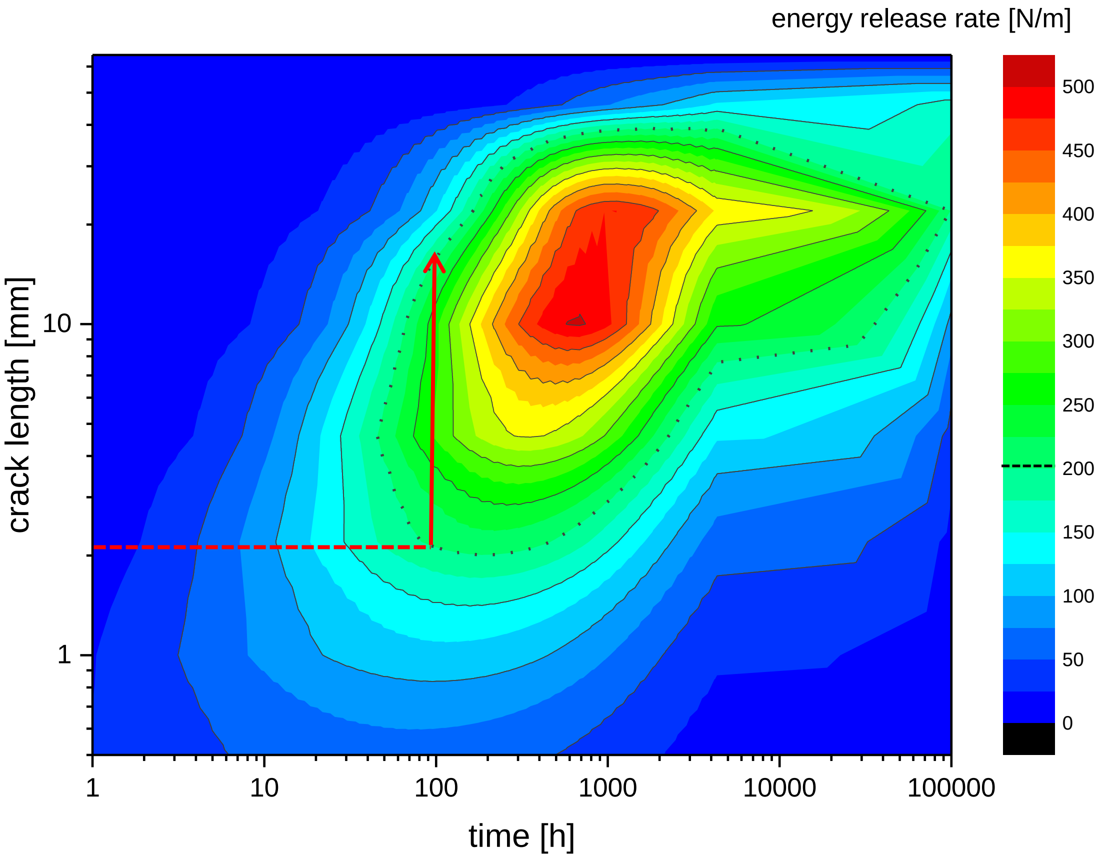


Simulation results – map

Step RH: **50-20%**

Catastrophic crack growth

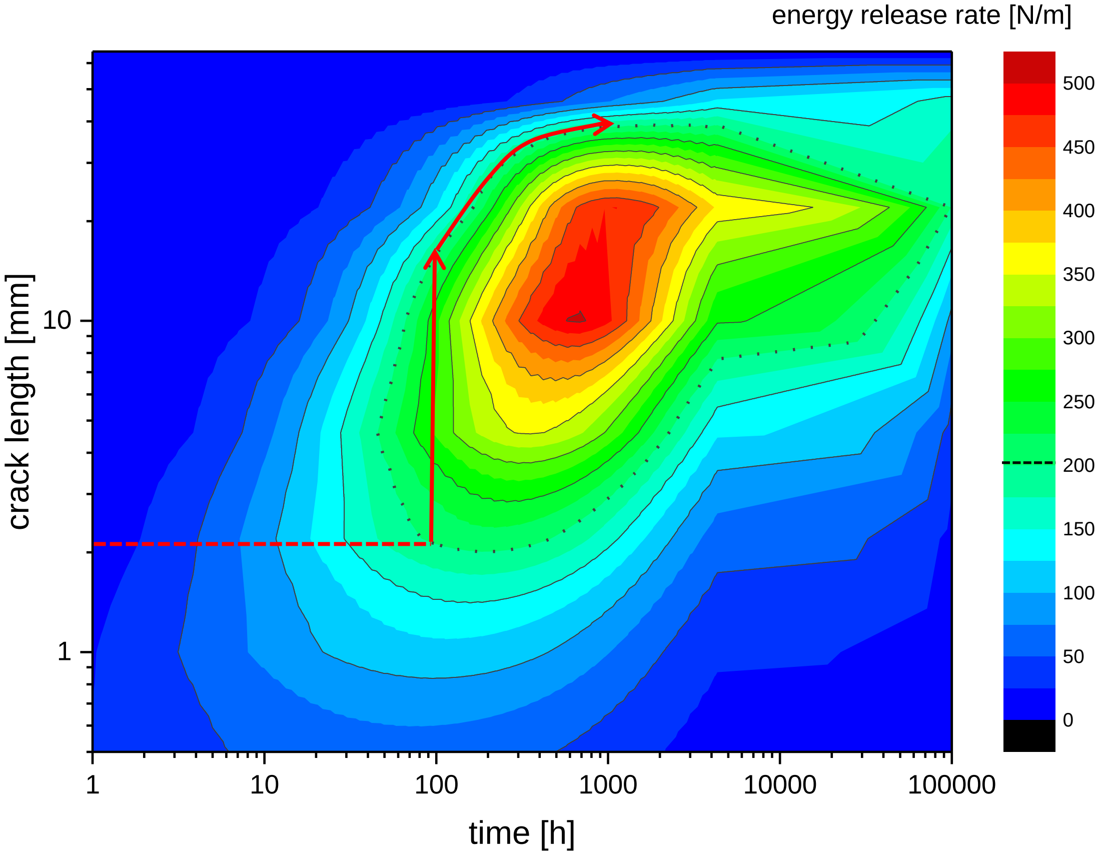
after **100h** crack immediately grows to almost **20mm**



Simulation results – map

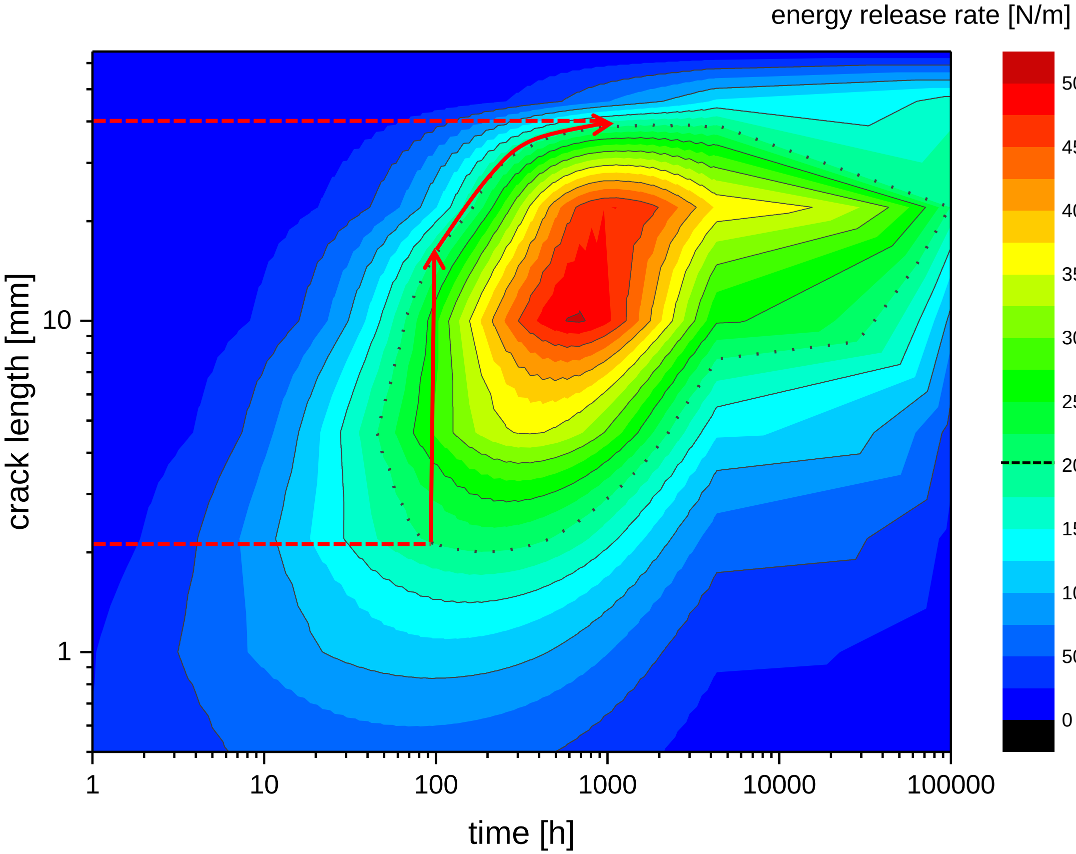
Step RH: **50-20%**

with time the crack continues to grow



Simulation results – map

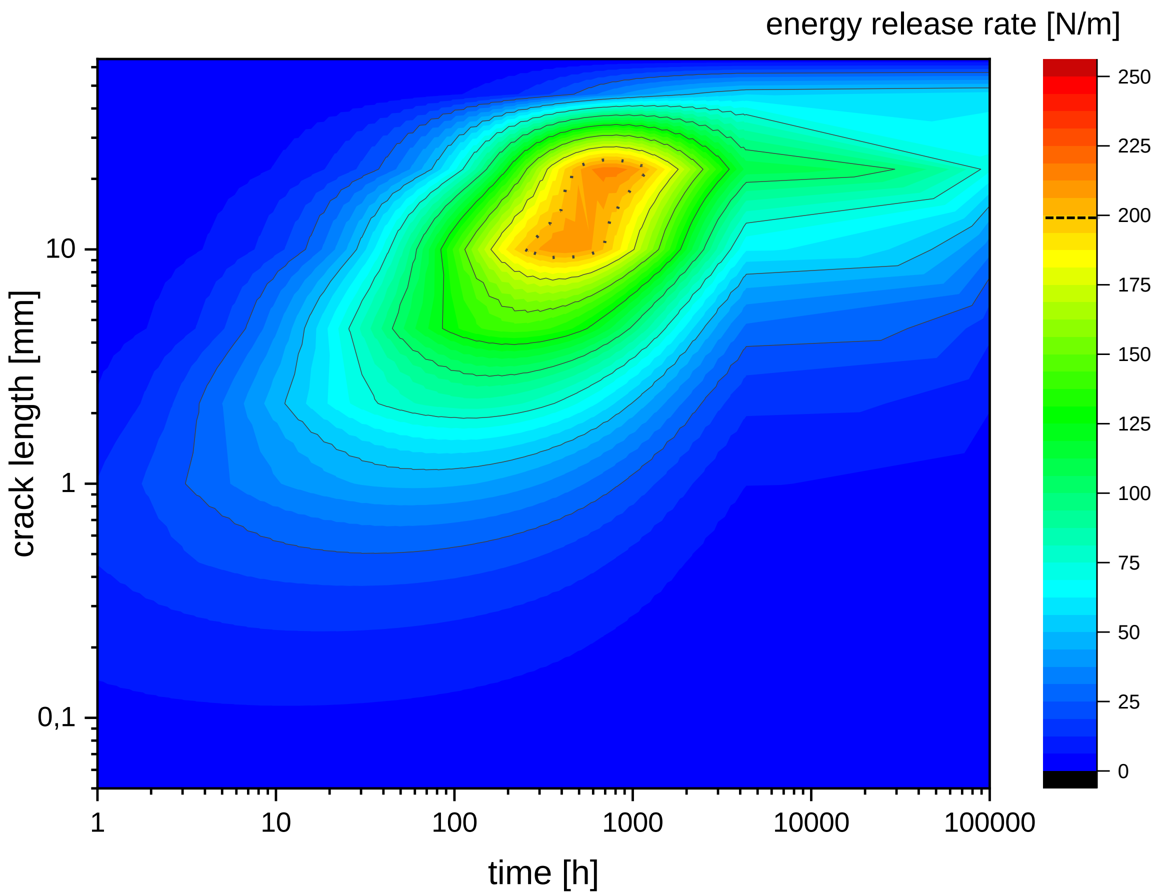
Step RH: **50-20%**



with time the crack continues to grow until reaching a maximum length of 40mm after 1000h

Simulation results – different RH amplitude

Step RH: **50-30%**



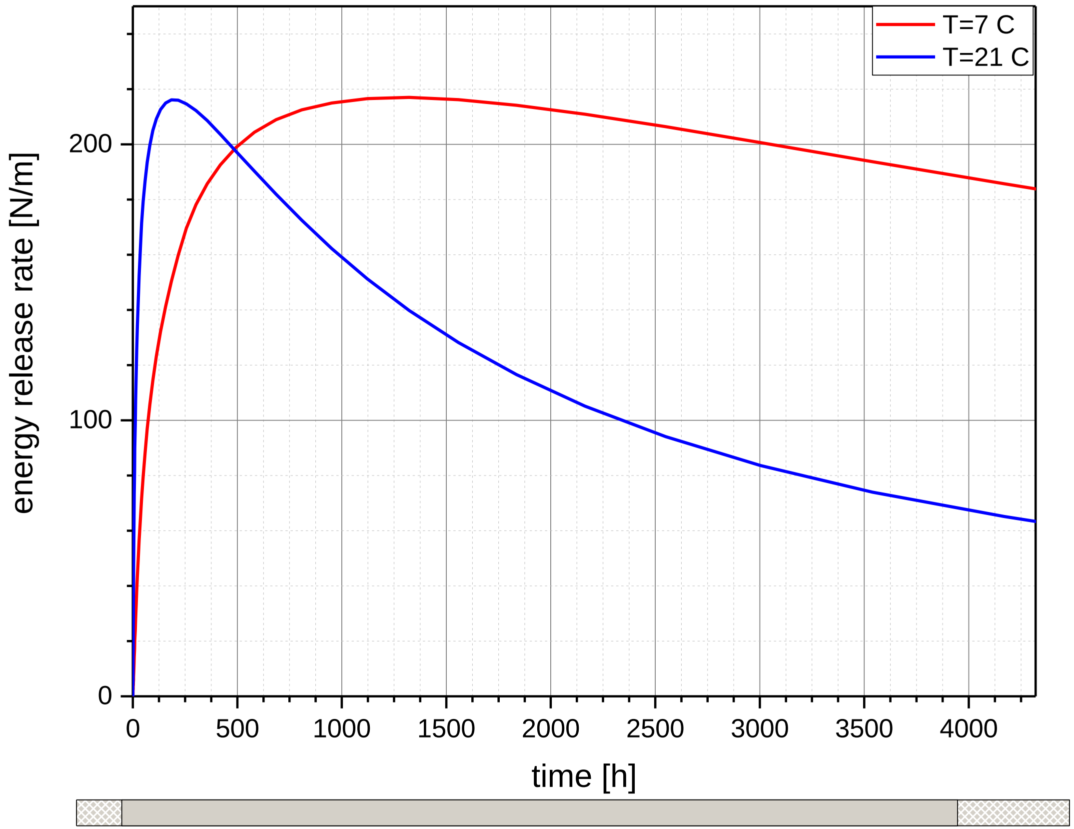
Any step change with an amplitude **less than 20%** from **an initial RH level of 50%** can be considered as **safe**.

Simulation results – various T

Step RH: **50-20%**

Crack length:
2,2 mm

In lower temperatures energy is released slower.



Conclusions and future work

The model allow determining **maximal amplitude of RH variation (~20%)** and **duration of heating episode/event (48 hours)** that are safe for wooden sculptures independently on the crack size.

This research will support development of environmental guidelines, standards and policies for museum and historic buildings.

This results needs to be experimentaly validated both in laboratory and in situ, most probably using acoustic emission.

Acknowledgements

SyMBoL
Sustainable Management of heritage Buildings in a Long-term perspective

Project number 274749