FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Master Thesis

at Carinthia University of Applied Sciences

10.11.2020

KÄRNTEN University of Applied Sciences

ZAG ZAVOD ZA GRADBENIŠTVO SLOVENIJE SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE

SZPV

ZDRUŽENJE ZA BETON SLOVENIJE ZBS

Agenda

- Introduction and overview
- Master Thesis - **Michael Nowak** - Erarbeitung von Bewertungshintergründen zur Einschätzung der Brandwiderstandsdauer genieteter Fachwerkträger aus Stahl (**Elaboration of assessment backgrounds to estimate the fire resistance of riveted steel trusses**)
- Master Thesis - **Johannes Molzbichler** - Umsetzung von Brandschäden in der Brandsimulation zur forensischen Analyse (**Implementation of fire damage in fire simulation for forensic analysis**)
- Master Thesis - **Sebastian Reiter** - Schwelbrandverhalten von Holz / Experimentelle Untersuchung der Abbrandgeschwindigkeit von Fichtenholz bei einem Schwelbrand (**Smoldering fire Behavior of wood / experimental investigation of the burning rate of spruce wood in a smoldering fire**)
- Master Thesis - **Lukas Treffner** - Ermittlung des Bauteilverhaltens und der Sanierbarkeit von Betondecken nach einem Brand (**Determination of the component behavior and the refurbishment of composite concrete slaps after a fire**)

Targets

- The example should show that by using fire simulation programs
  a determination of a realistic temperature determination in the fire room is possible.
- That leads to the more economical evaluation with regard to the profile dimensioning or when verifying during design of fire protection.
- Existing buildings can be retrofitted without any costly upgrades.

Example

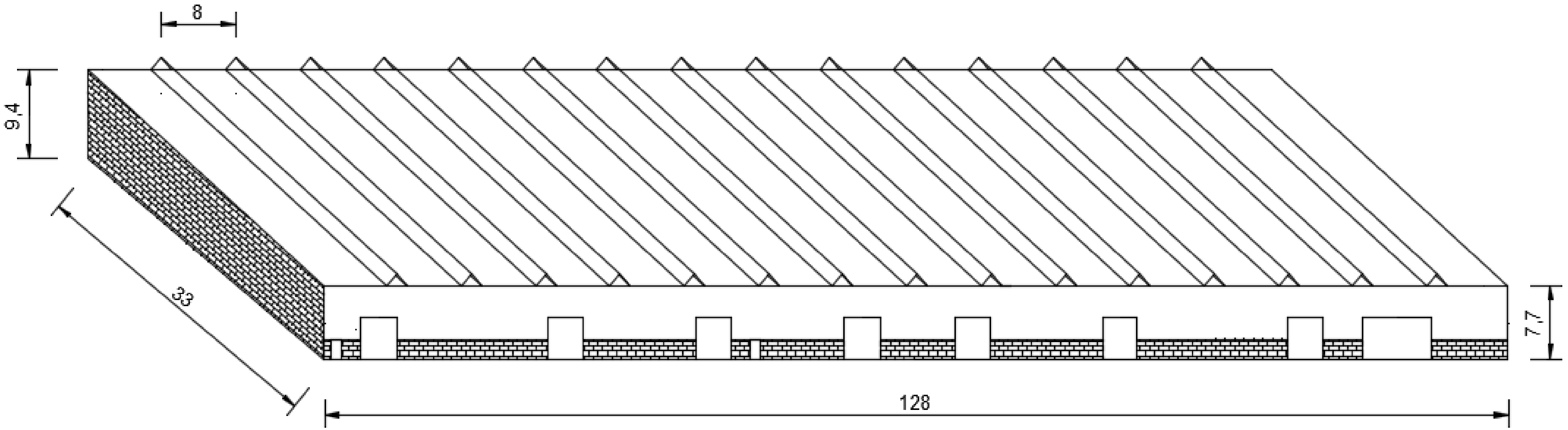
- Technikmuseum Historama – area 2.200 m^2

- Exponates :
  - Antique car
  - Railways and trams
  - Fire engines and utility vehicles
  - Motorbikes
  - Carriages
  - Radio and telecommunication systems

FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

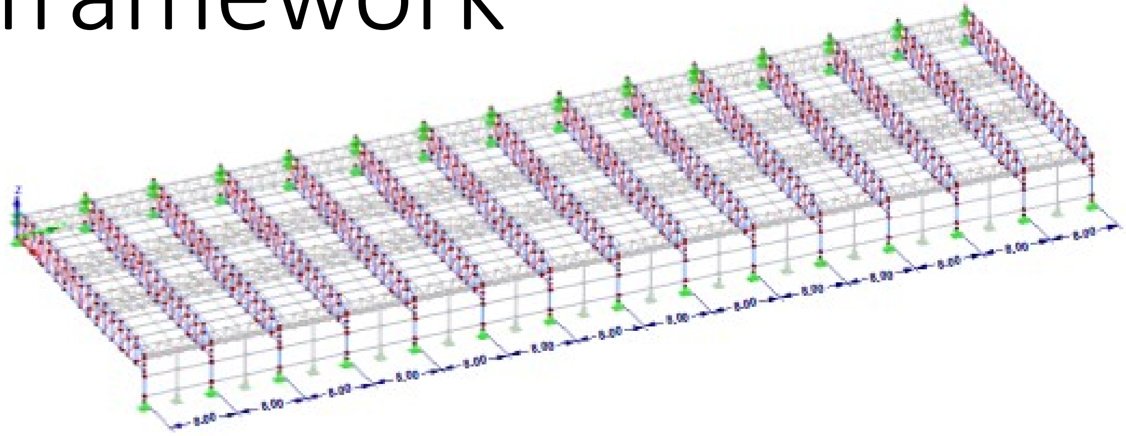
Example - Dimensions



FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – trus binder framework



FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH Evropska unija | Evropski sklad za regionalni razvoj Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – stiffening between the bars

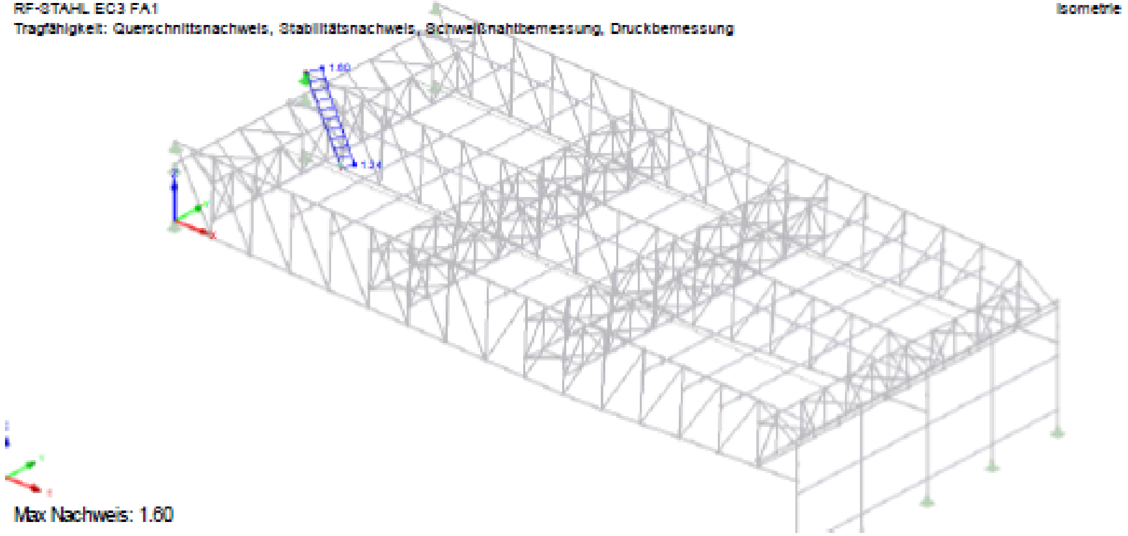
Example – steel bar connected by rivets

Pfette

U 200

-	Stützen	U 200
-	Obergurt:	L 100x150x15
-	Untergurt	L 100x100x13
		L 100x150x15
-	Pfosten	L 100x100x10
		L 90x90x9
		L 70x70x8
		U 160
		U 120
-	Diagonale	L 100x100x10
		L 80x80x12
		L 80x80x10

Example – lead bearing capacity



2.4 Nachweise stabweise

Stab Nr.	A Stelle x [m]	B Belas-tung	C Nachweis Ausnutzung	D	E Nachweis nach Formel
133	Querschnitt Nr. 3 - 2LB L 100x100x10-200.1/8 I EN 10056-1:1998				
	3.96	EK1	1.24	> 1	101) Querschnittsnachweis - Zug nach 6.2.3
	3.96	EK1	0.02	≤ 1	122) Querschnittsnachweis - Querkraft in Achse z nach 6.2.6(4) - Klasse 3 oder 4
	3.96	EK1	1.60	> 1	183) Querschnittsnachweis - Biegung, Quer- und Normalkraft nach 6.2.9.2 - Klasse 3 - Allgemeiner Querschnitt
	3.96	EK1	0.36	≤ 1	332) Stabilitätsnachweis - Biegedrillknicken nach 6.3.2.1 und 6.3.2.2(4) - Allgemeiner Fall

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

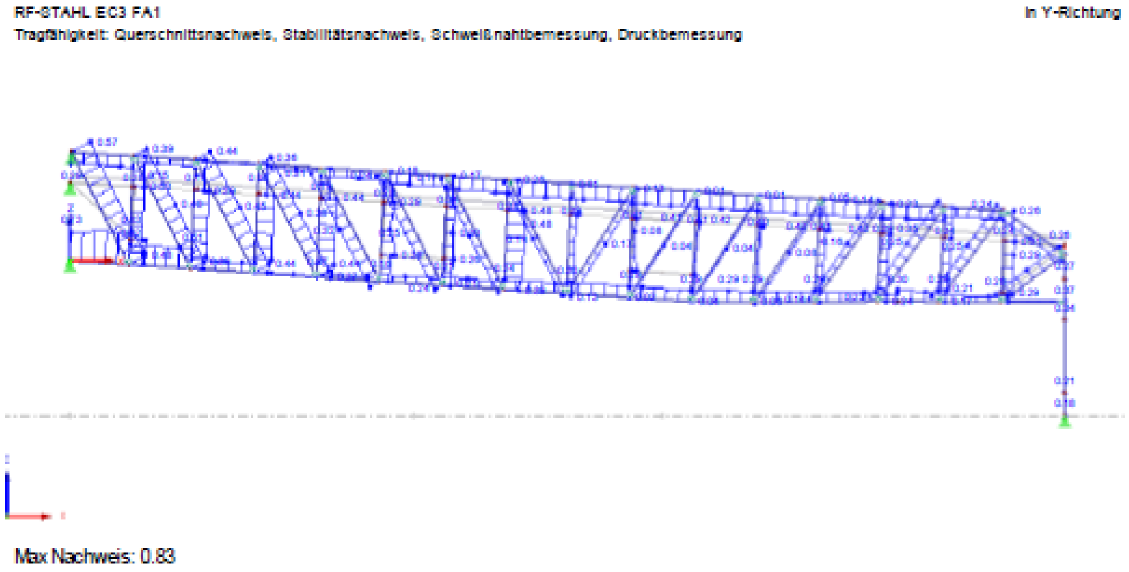
Example – race to the results (load factor)

Profil	Ausnutzung nach Einheitstemperaturkurve [%]	Ausnutzung nach Simulationsergebnissen [%]	Ausnutzung bei Kaltbemessung [%]
2LA L 100x100x12-220/6	134	87	51
2LB L 80x80x10-200/8	133	86	45
2LB L 70x70x7-205/8	631	107	48
2 UV U 200-148/10	422	63	34

FIRE EXPERT

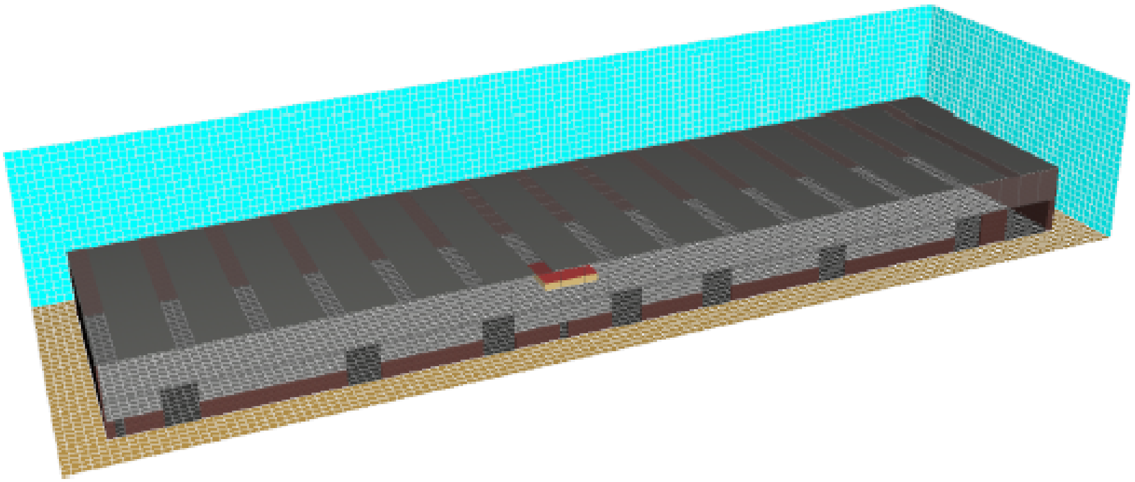
Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – model for hot design



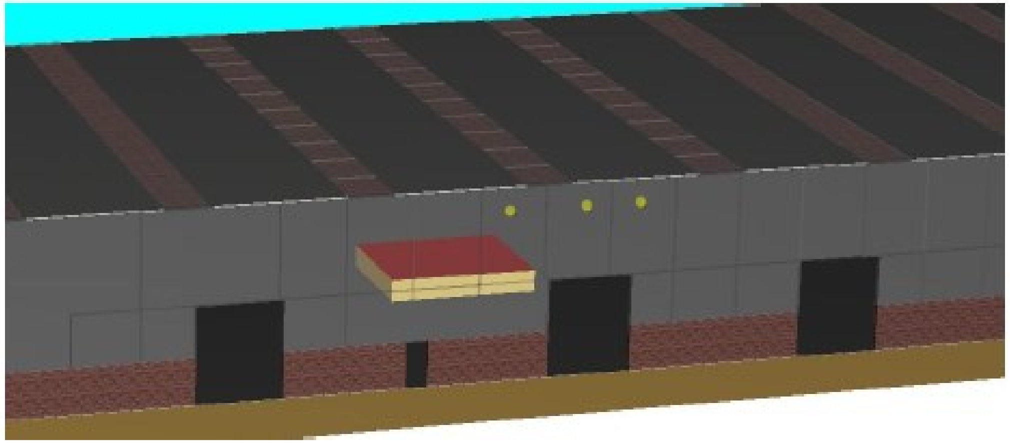
Example – CFD model

- Länge L = 140 m
- Breite B = 40 m
- Höhe H = 20 m.

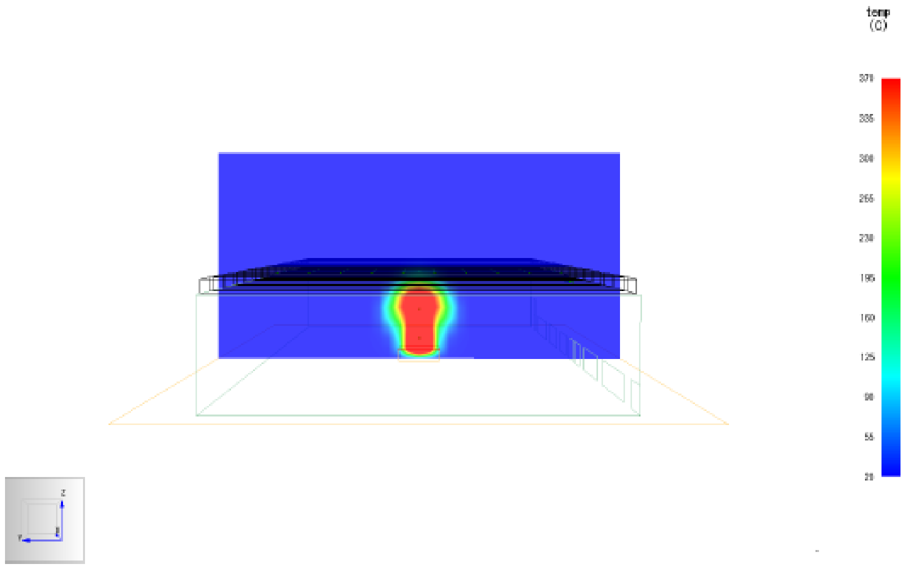


standard – glas in the roof breaks

alternativ – glas in the wall breaks

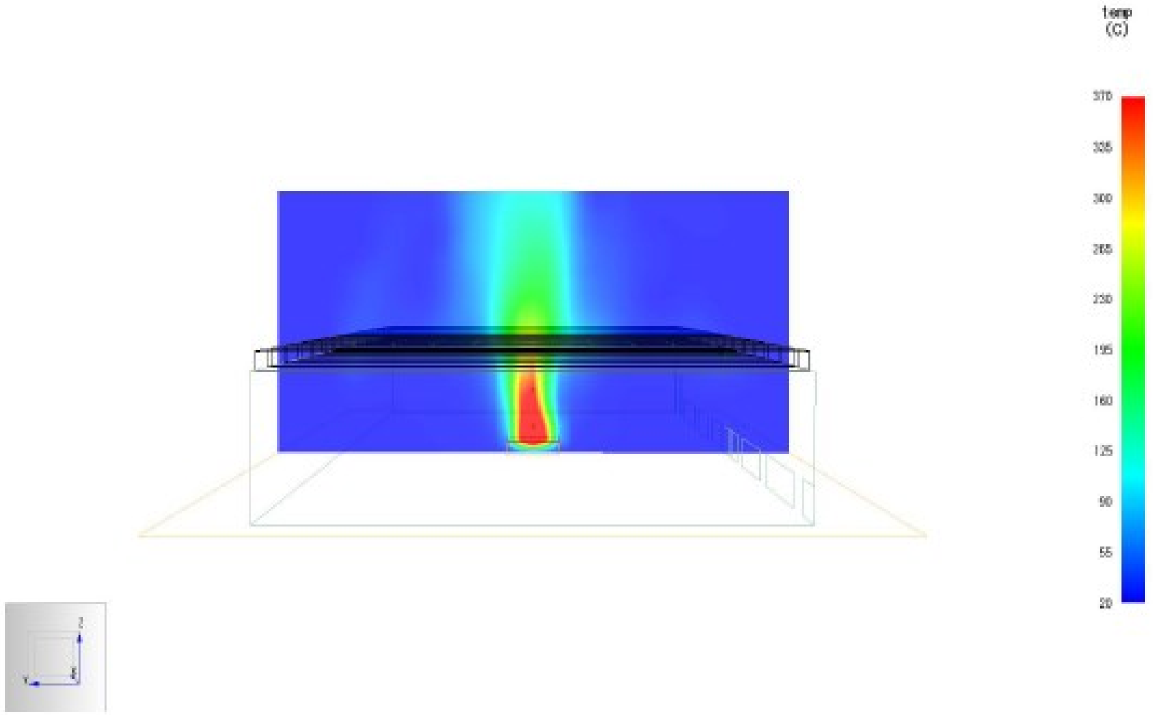


Example – CFD model

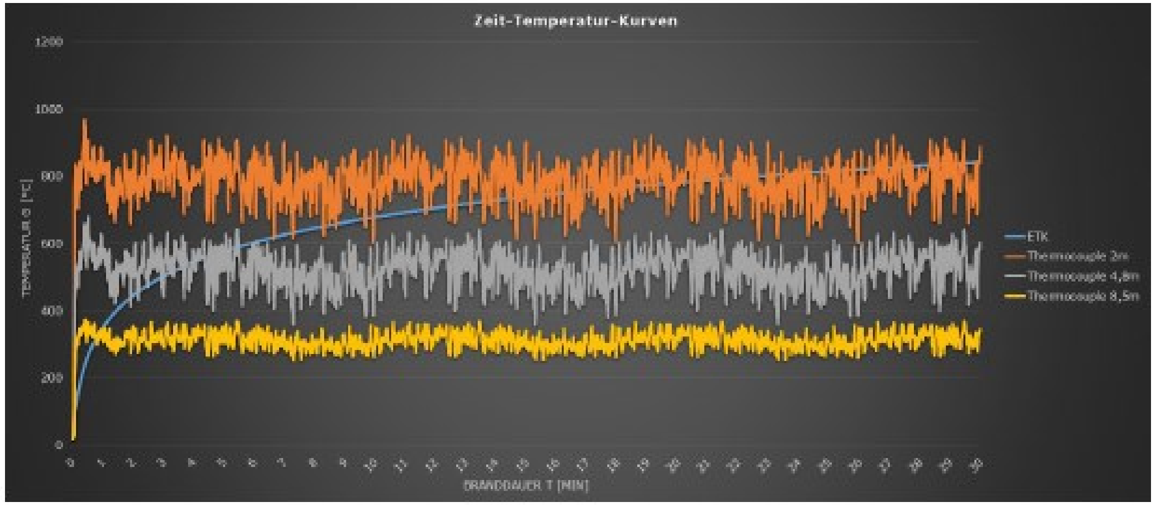


What is the highest temperature at the surface of the bars?

When does the glas break?



Example – results / discussion



Ermittlung der Stahltemperatur auf Basis der Einheitstemperaturkurve					
Profil- und Materialangaben					
Stabtyp		Untergurt			
Profil	L	100x100x12			
Profilbreite	b	100	[mm]	0,10	[m]
Profilhöhe	h	100	[mm]	0,10	[m]
Profildicke	t	12	[mm]	0,012	[m]
Querschnittsfläche	A	22,70	[cm²]	0,00227	[m²]
Mantelfläche	A_M	0,39	[m²/m]		
Umfang	U	0,39	[m²/m]		
Profilfaktor	A_M/V	166,67	[1/m]		
Profilfaktor	$(A_M/V)_b$	176,21	[1/m]		
Rohdichte Stahl	ρ_a	7850	[kg/m³]		
Beiwerte					
Korrekturfaktor	k_{sh}	1,057			
Emissivität der Bauteiloberfläche	ε_m	0,70			
Emissivität der Flamme	ε_f	1,00			
konvektiver Wärmeübergangs-koeffizient	α_c	25	[W/m²K]		
Konfigurationsfaktor	ϕ	1,00			
Stephan-Boltzmann-Konstante	σ	0,0000000567	[W/m²K]		
Temperaturen nach 30 min auf Basis der Einheitstemperaturkurve					
ETK	$\theta_{ETK,30min}$	842	[°C]		
Stahltemperatur nach ETK	$\theta_{a,ETK,30min}$	824	[°C]		

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

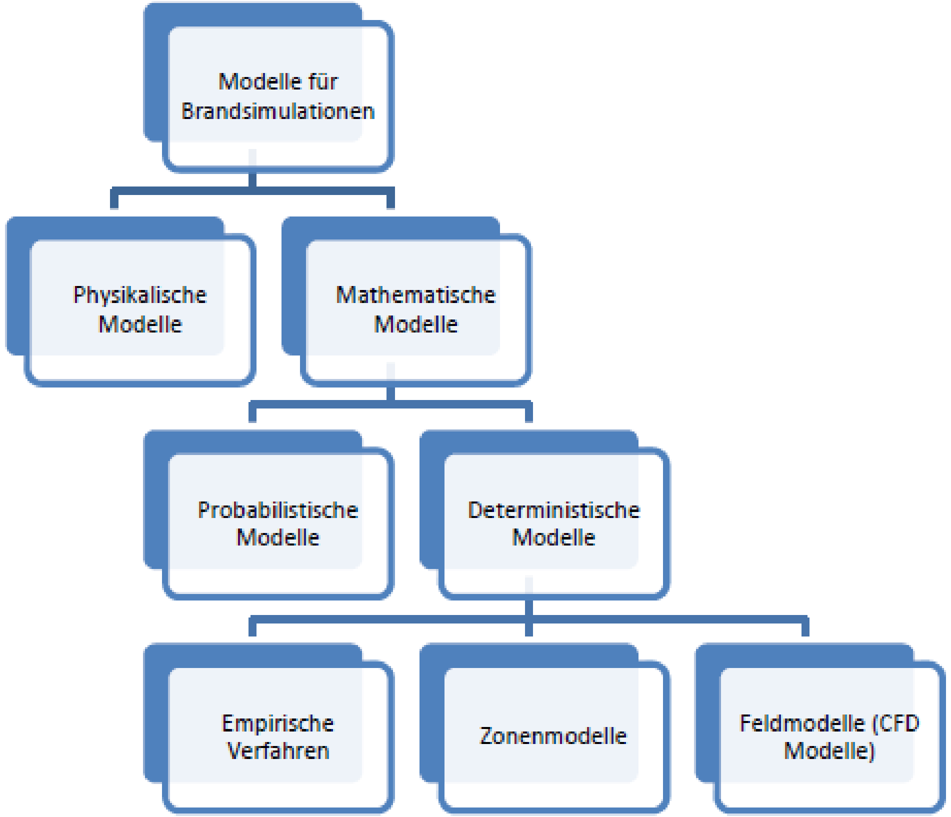
Targets

- The aim of the work is the reconstruction (determination of the cause of the fire) of the church fire.
- The simulation software PyroSim is used for this, which represents a graphical user interface for the Fire Dynamics Simulator (FDS).

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

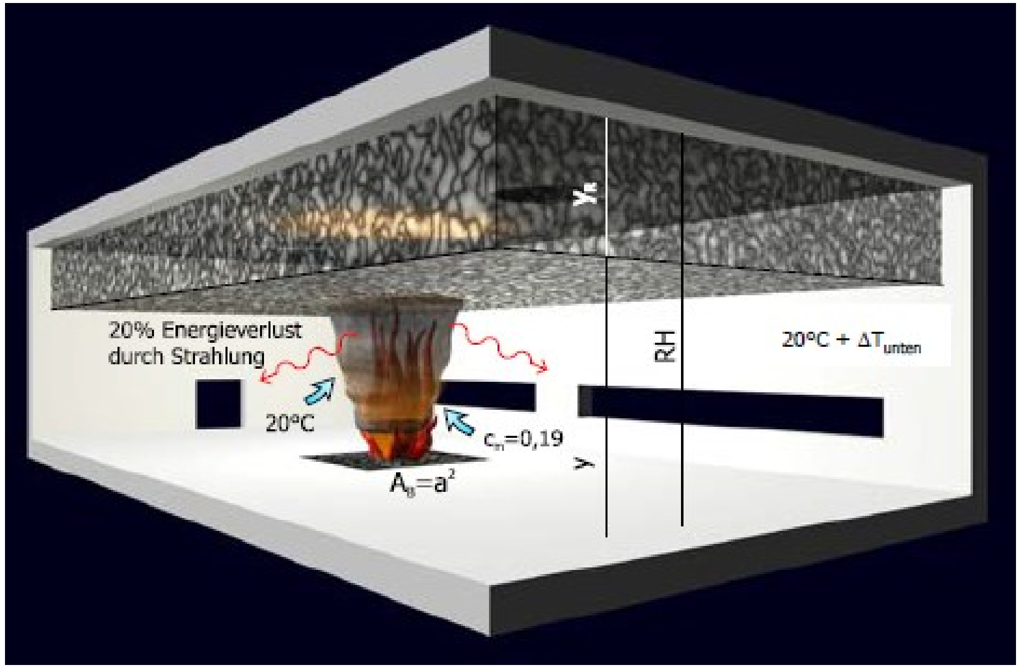
Simulation models

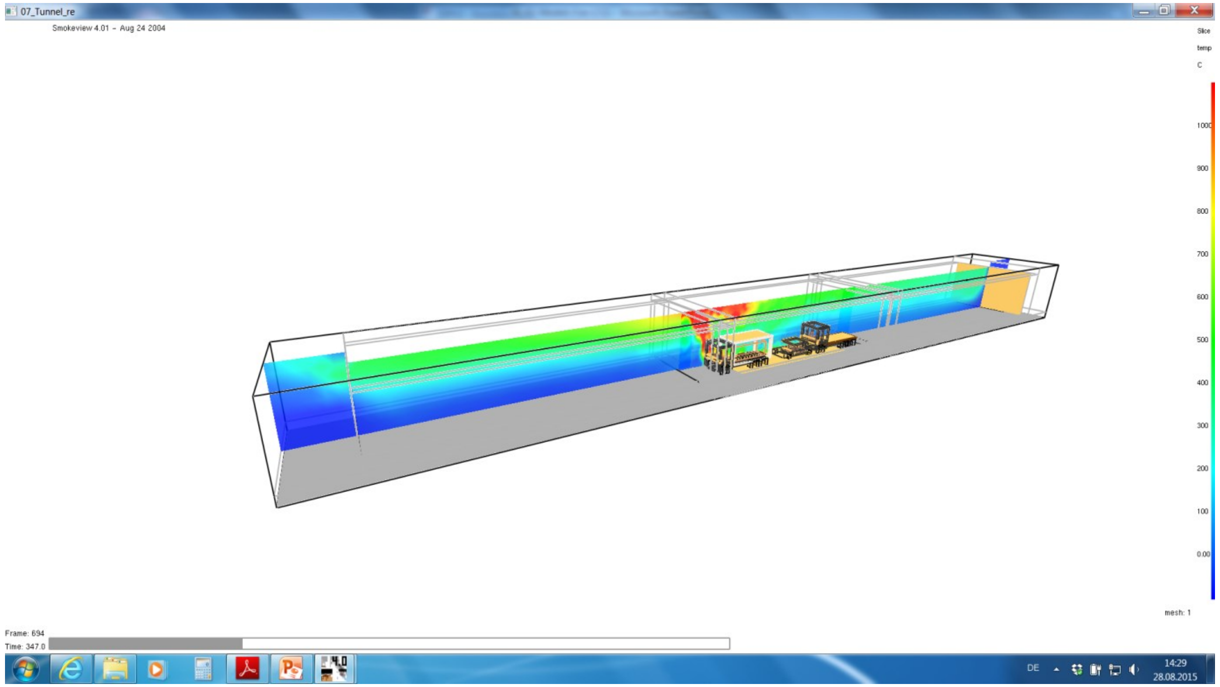


Properties	Analytic methods	Simulation models
temporally development	no	yes
scaling	only for allowed range	yes
plausibility check	easy	easy to complex
error estimation	easy	difficult
complexity	low	middle to complex
information	individual information	system information

Simulation models

MRFC





Simulation models

Properties	Zone model	Field model
geometry	estimated	exact
ventilation	exact	exact
heat source	estimated	estimated
complexity	low	very high
information	global	local
verification	complex	very complex
plausibility check	easy	complex
depends on dimension	not possible	very high
accuracy	estimated	depends on cell size
costs	low	very high

Forensic

- understand the course of the fire (how did the fire develop, what effect do different ventilation conditions have, etc.)
- Analysis of traces of fire (burn-off of fire loads, effect of temperature on surfaces, etc.)
- Visualization of the fire event (three-dimensional visualization of the fire event)
- Checking the timing of a fire event (rate of fire spread, smoke spread, activation and effect of fire protection devices, etc.)
- Checking the survival conditions of people (exposure to heat, flames and smoke gases, visibility, etc.)
- Review of different hypotheses about the course of the fire

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example

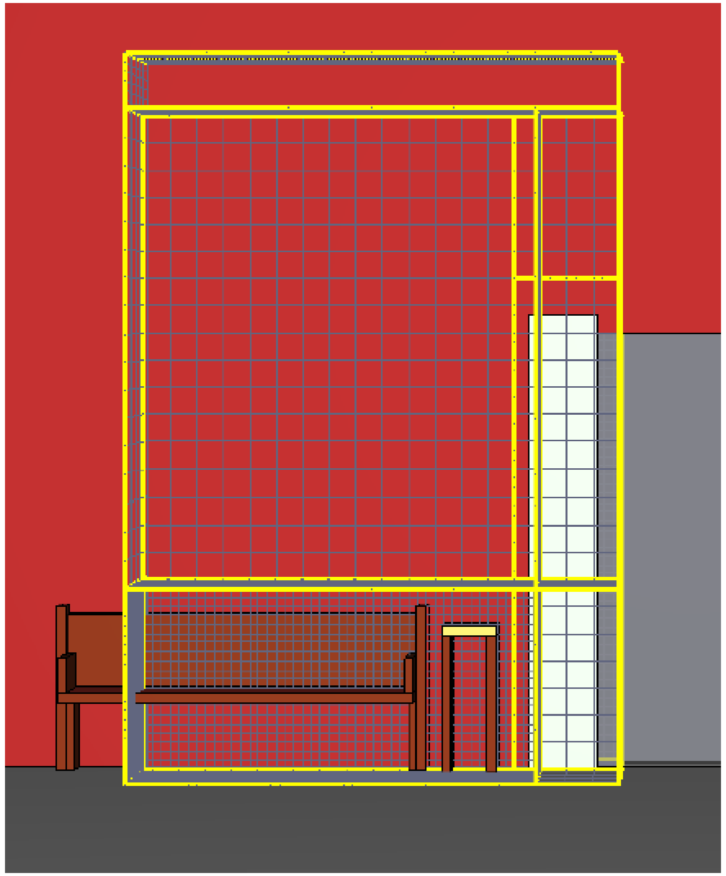
FIRE EXPERT

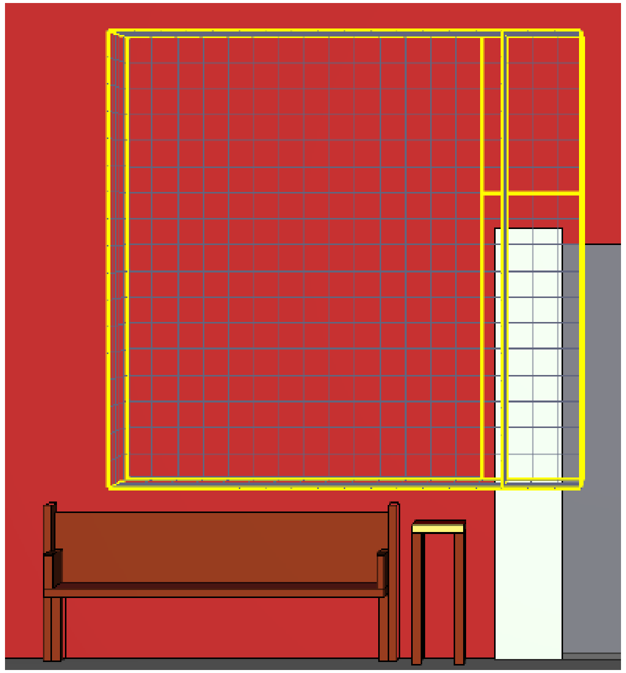
Example

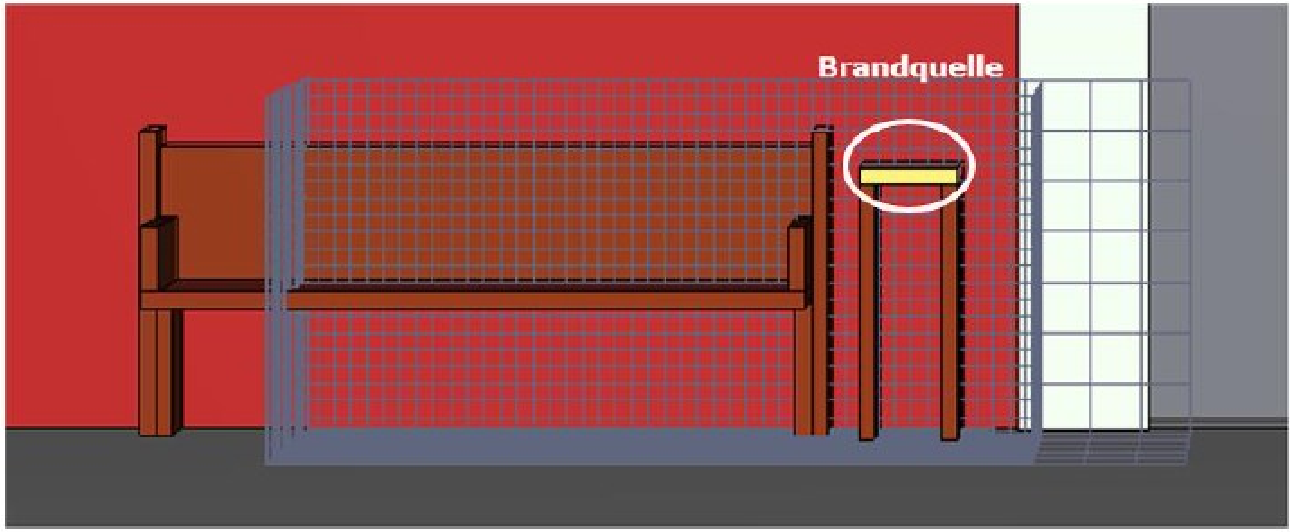
FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example - Simulation





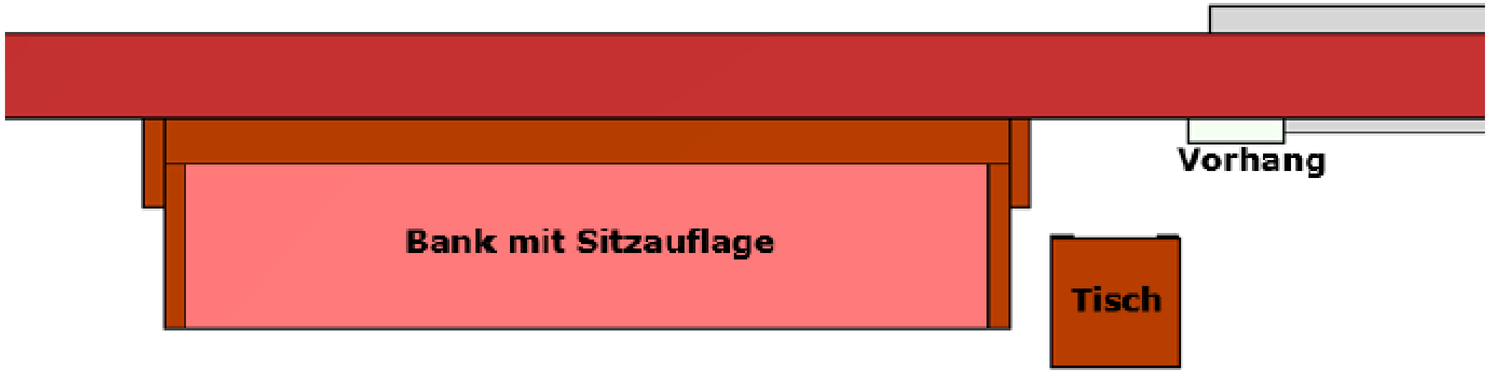


Example – Simulation (fire load)

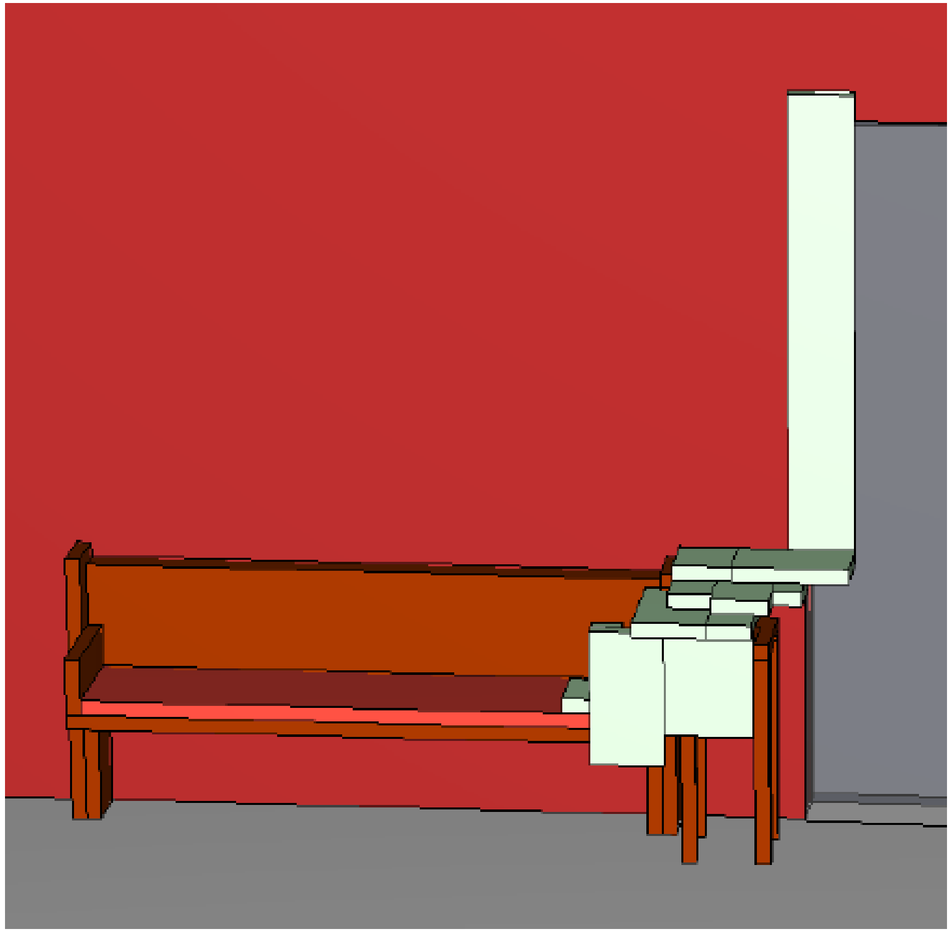
Brandlast	Thermophysikalische Eigenschaften	Farbe im Modell **(siehe Abbildung 49)**
Bank	Eichenholz*	braun
Orgelstuhl	Eichenholz*	braun
Sitzauflage Bank	Polsterstoff*	hellrot
Vorhang	Vorhangstoff*	hellgrün

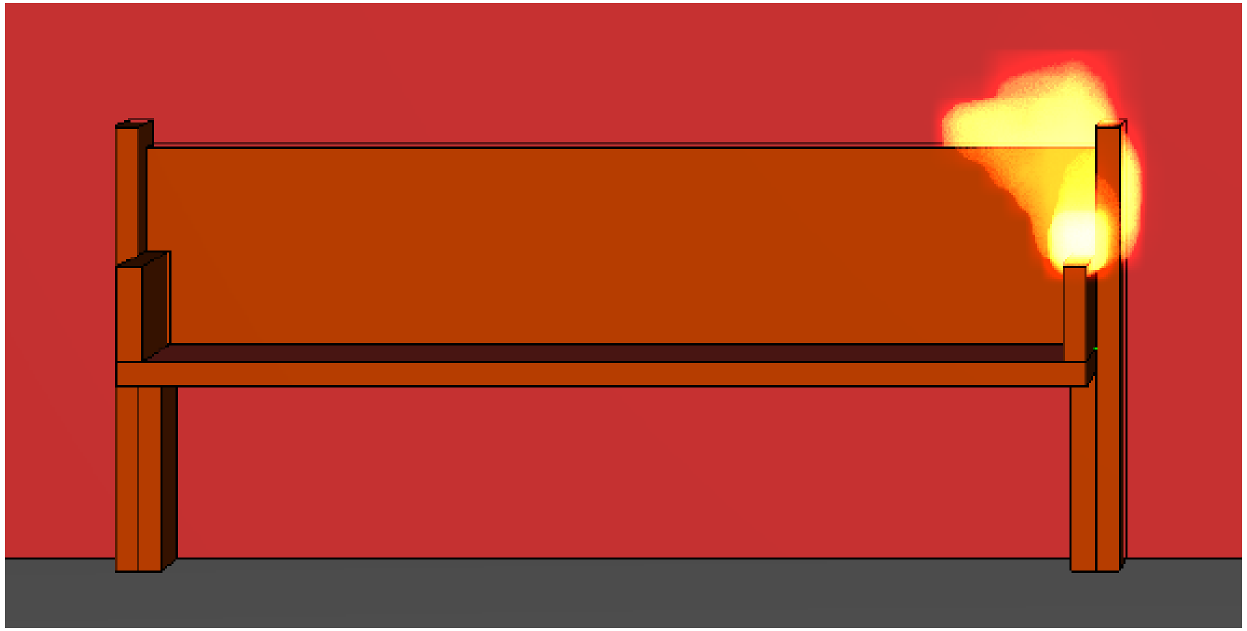
Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – Simulation set

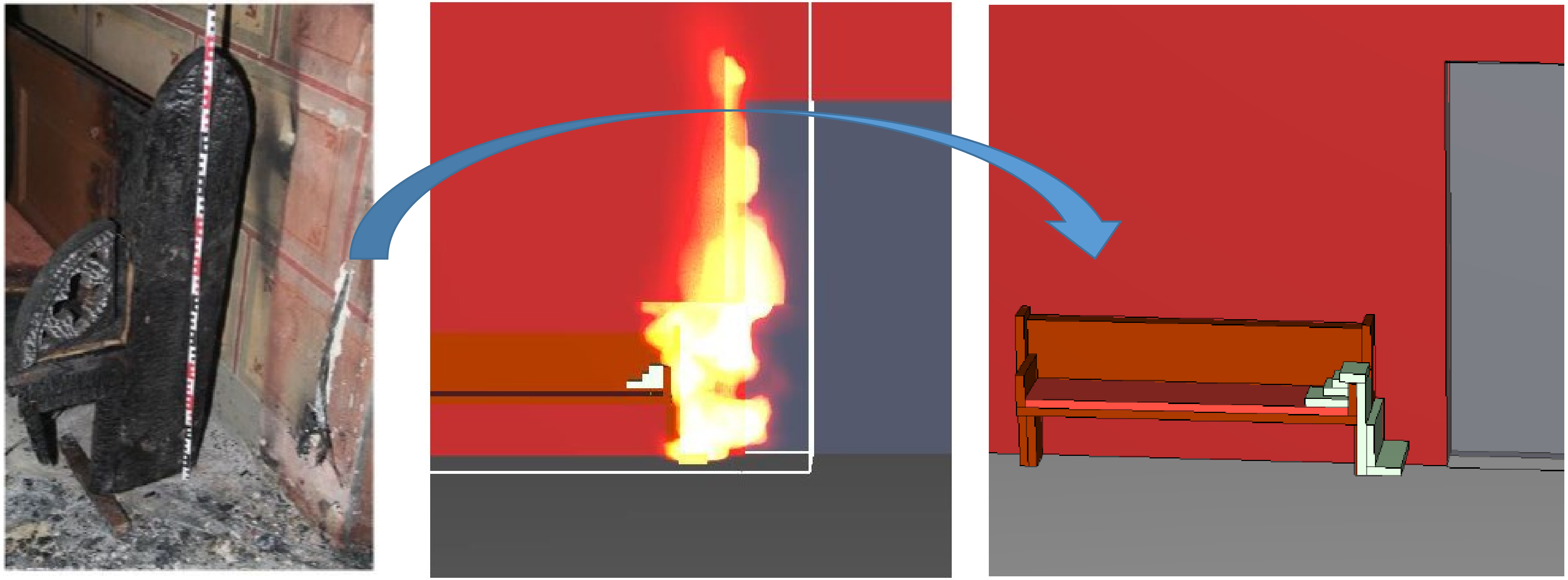


Example – Simulation set





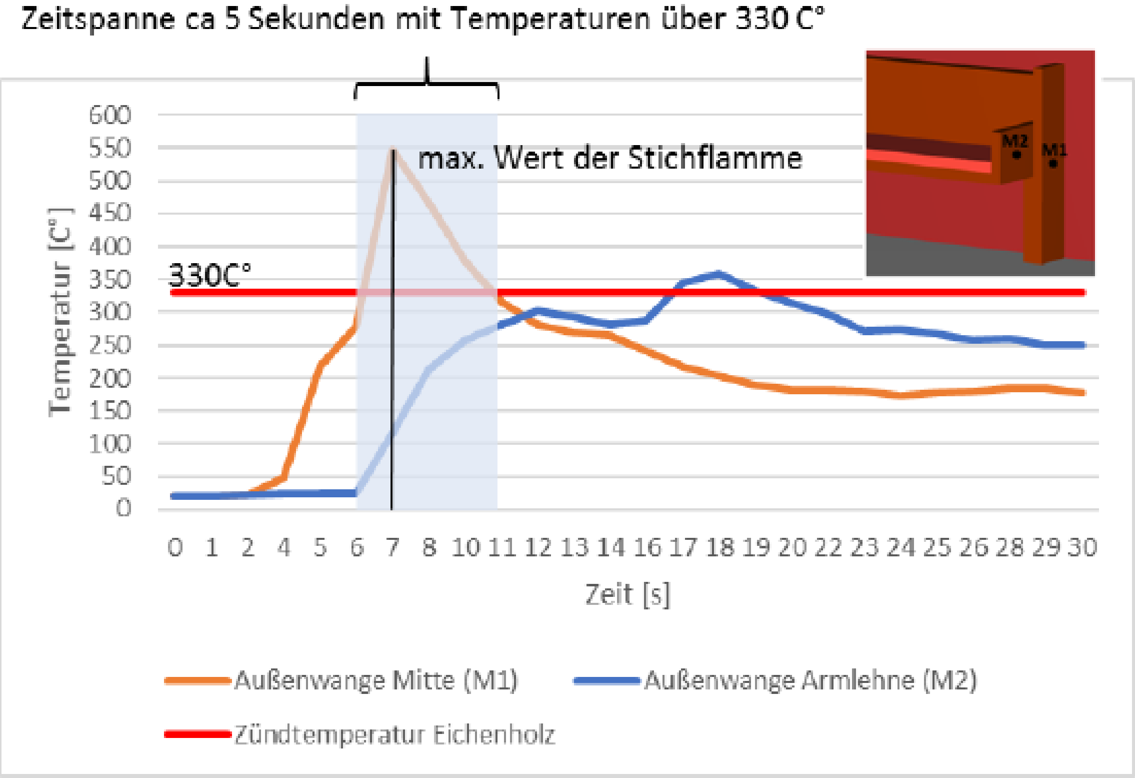
Example – Simulation set

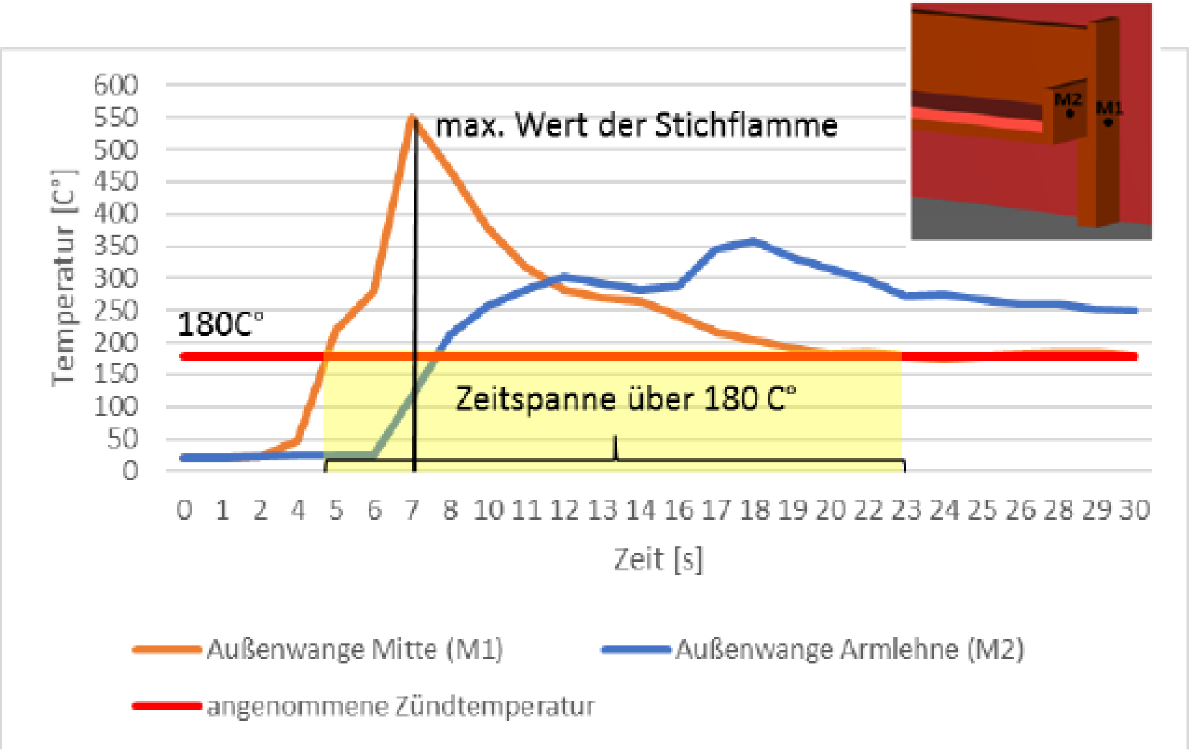


FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – Simulation results



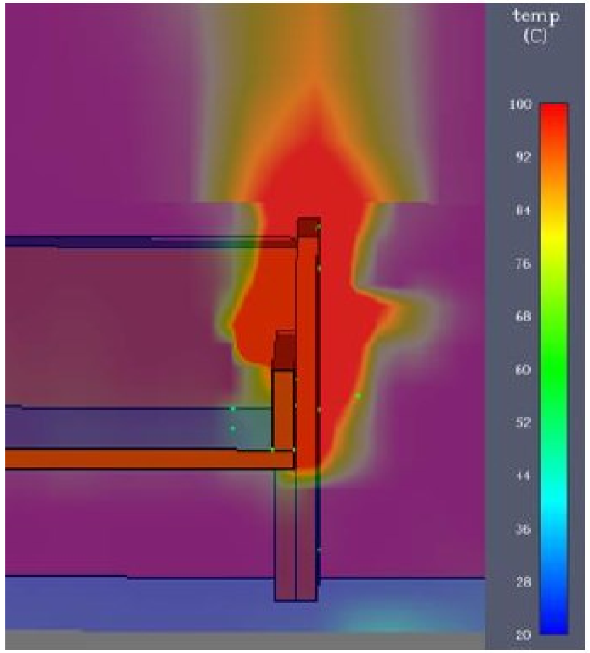


FIRE EXPERT

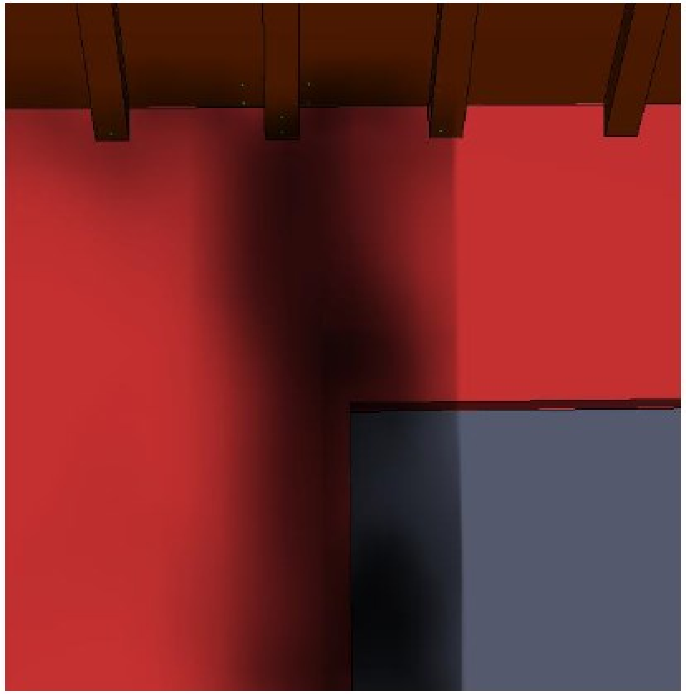
Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Example – Simulation results

Example – Simulation results



Example – Simulation results



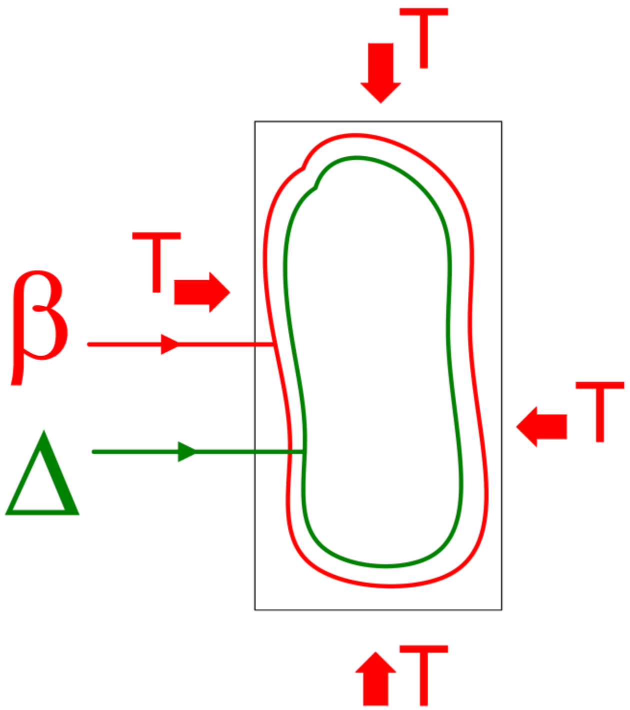
Targets

- The development of a corresponding test facility to carry out smoldering fire tests.
- The test results should be used to determine whether and to what extent the rate of combustion of spruce wood in a smoldering fire changes compared to the rate of combustion related to the standard fire, and whether this confirms the influence of the temperature and the combustion air supply on the rate of combustion.

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH

Background



- continuous, slow fire
- combustion rate ca. 0,7 mm/min
- no droping, no melting
- small heat conductivity
- insulation of wood charcoal layer
- load bearing capacity is given for a long time
- no collaps
- Good estimation of end of the load bearing capacity

Eq. combistion layer:

$$d_{char} = \beta \cdot t$$

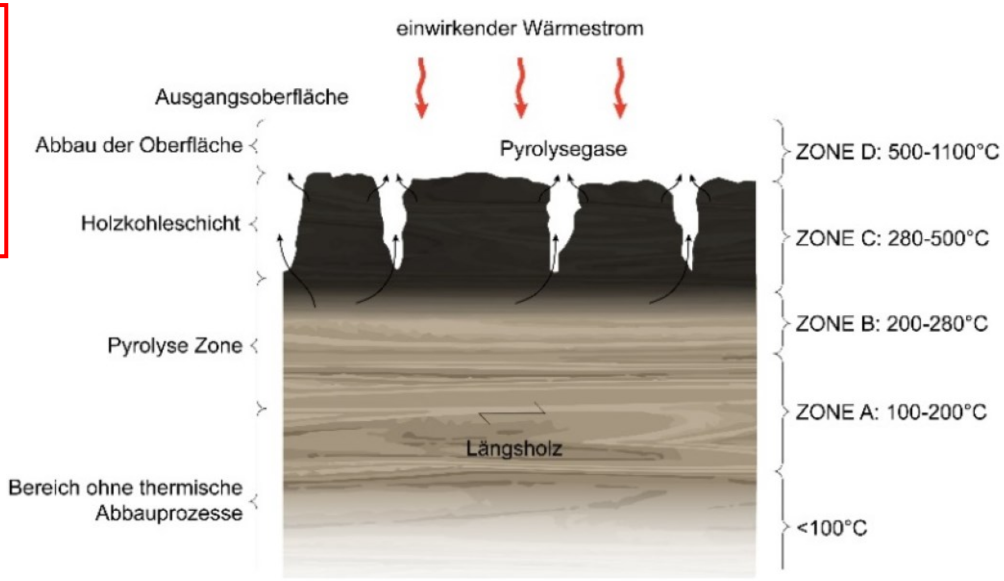
FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

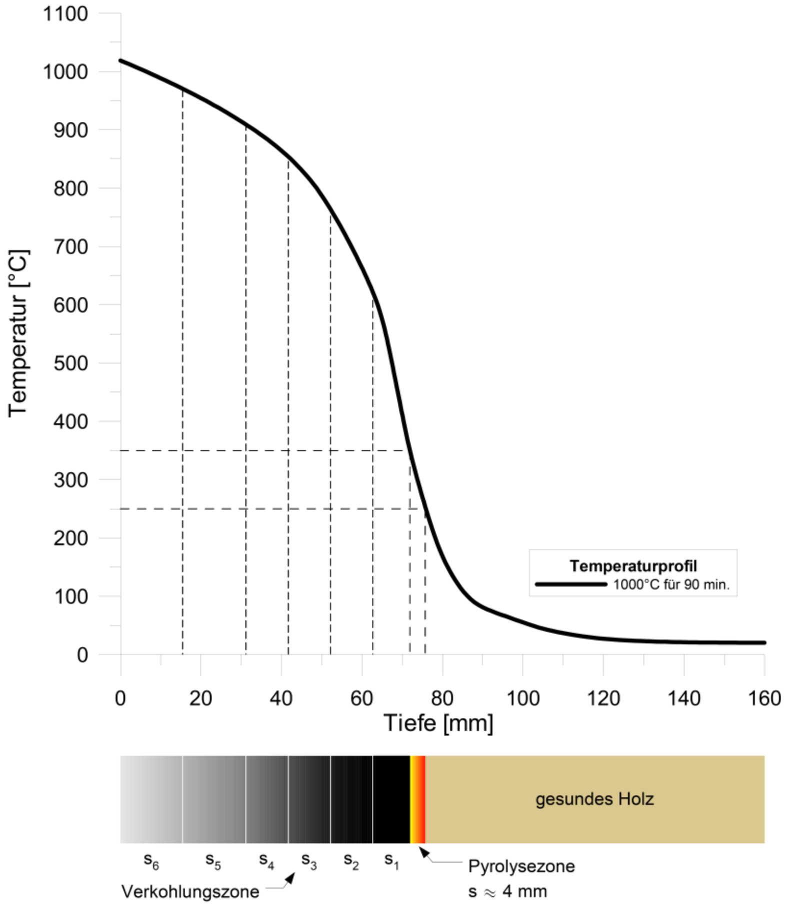
Background – Smoldering fire

Smoldering fire

Drying
↓
Pyrolysis
↓
Combustion of fire gases
↓
Combustion of the wood charcoal



Zones of wood fire

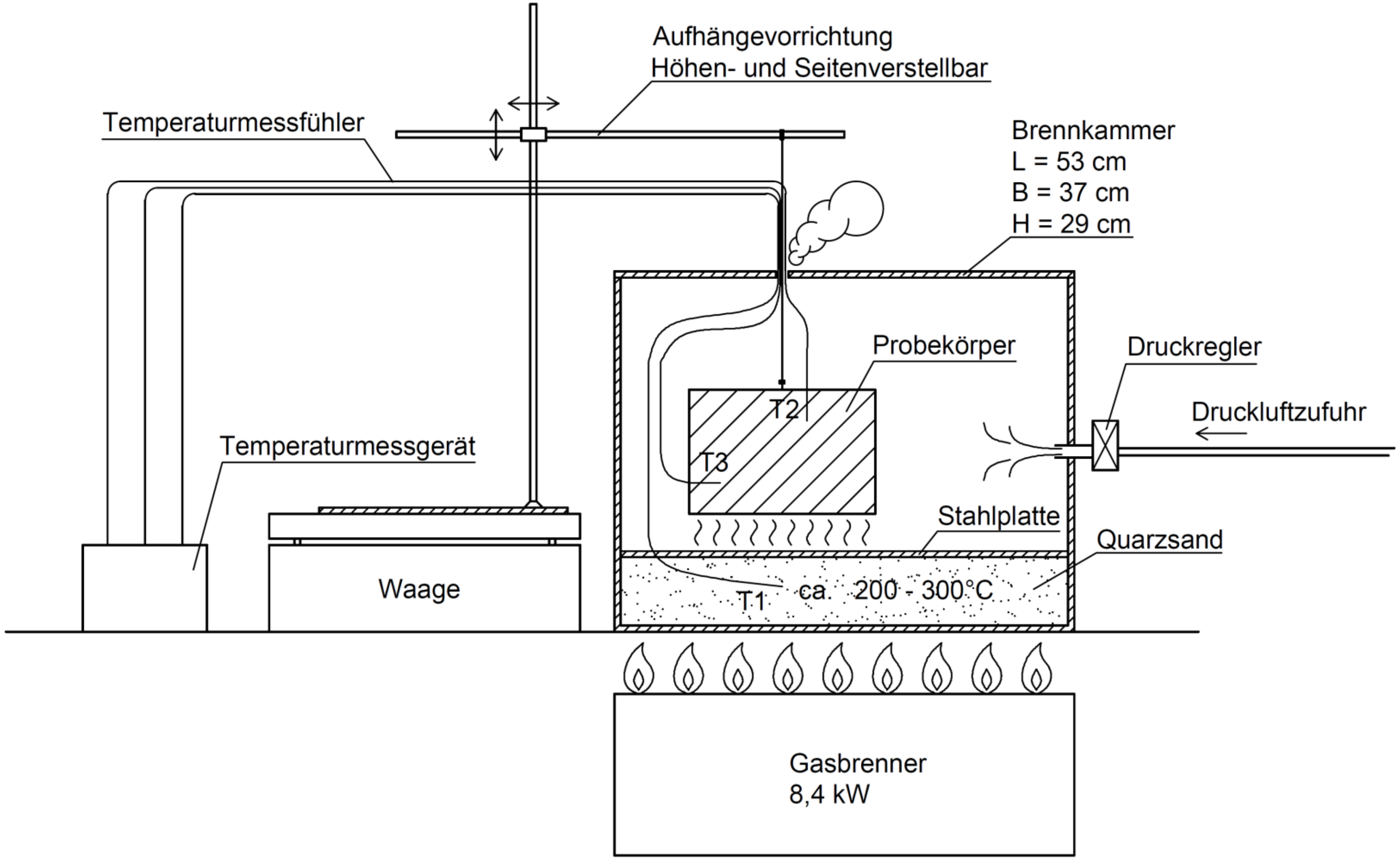


Temperature distribution in the wood cross section

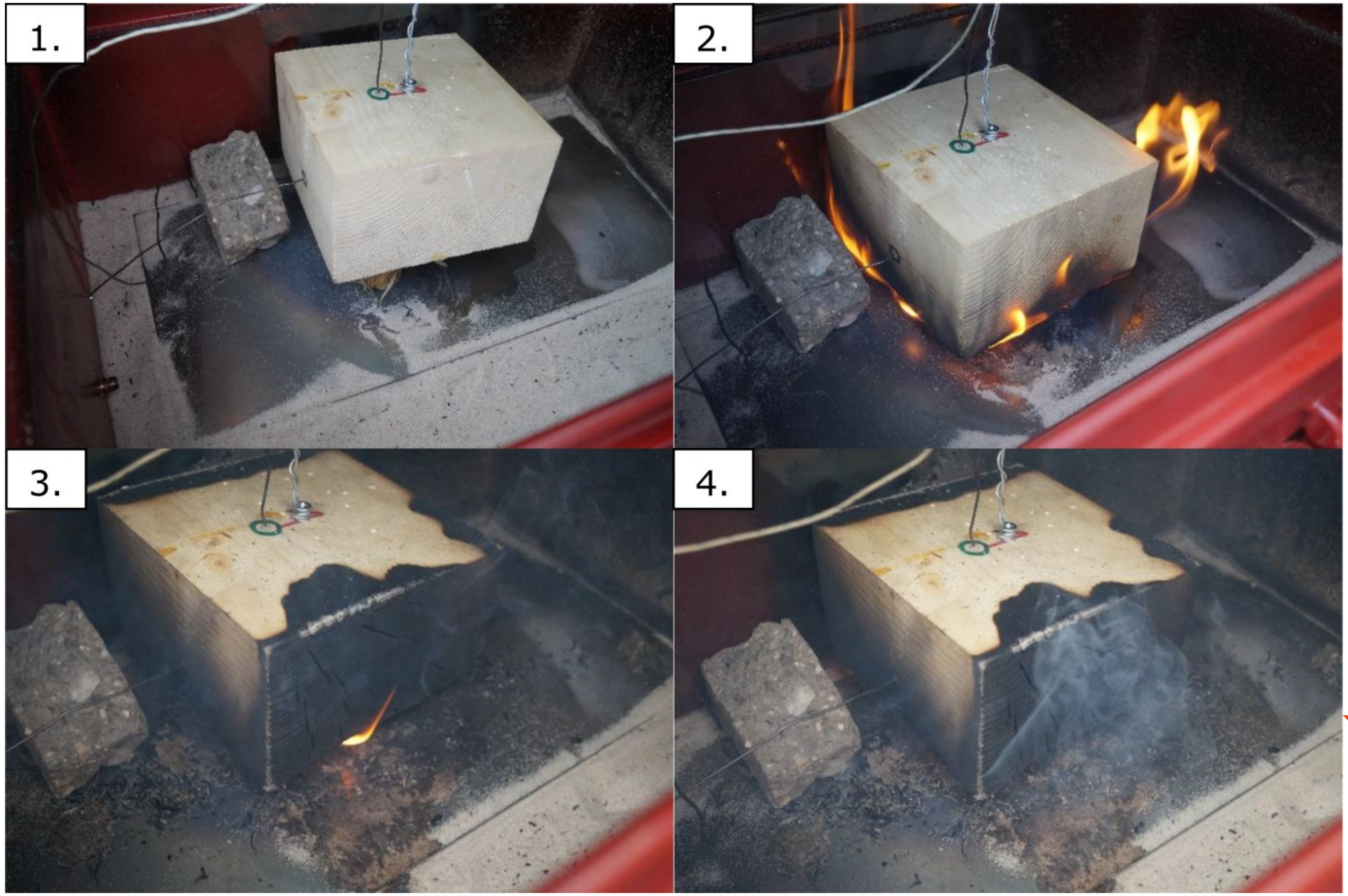
FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

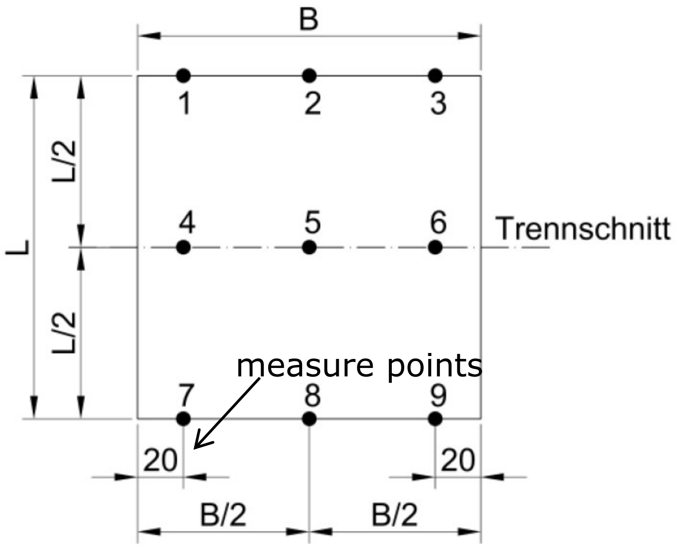
Test setup

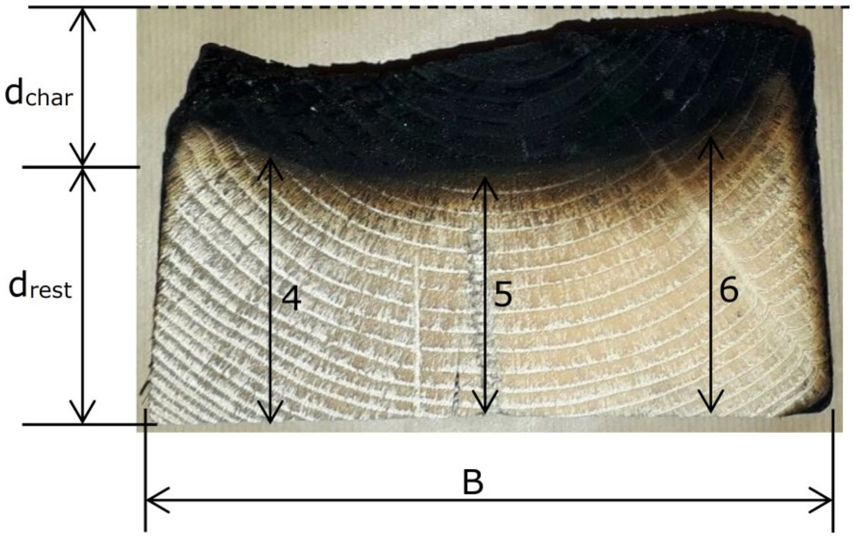


FIRE EXPERT



1. Specimen in the combustion chamber
2. Start of combustion
3. Subside of flame
4. Start of smoldering fire





$$d_{char} = d_0 - d_{rest}$$

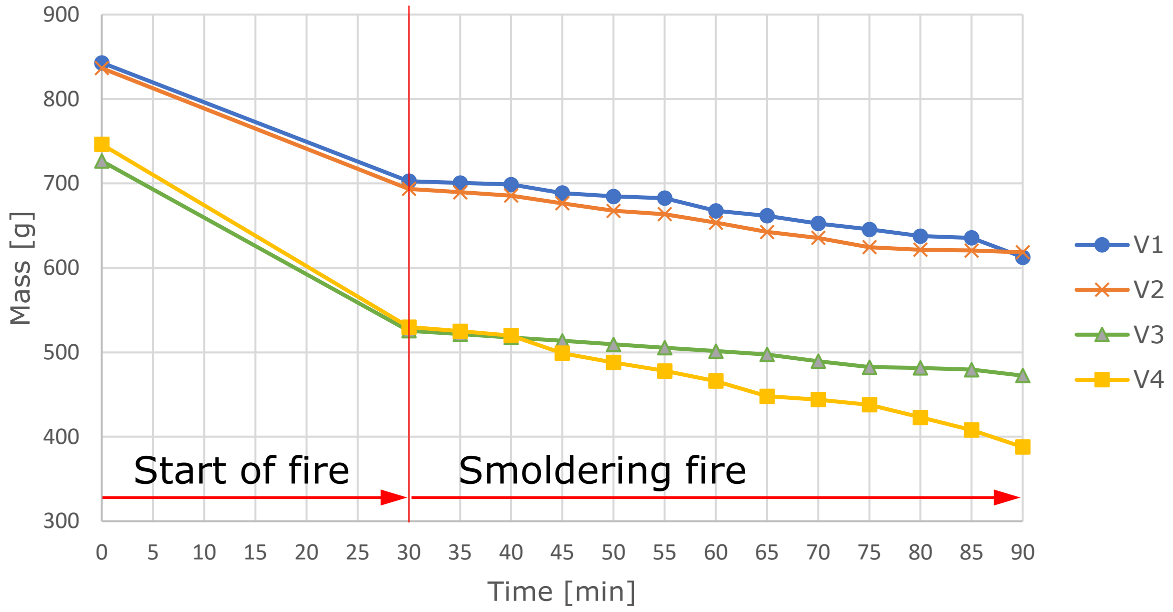
d_0 origin high

d_{rest} residual high

d_{char} combustion rate

$$\beta = \frac{d_{char}}{\Delta t}$$

1. Quenching of specimen
2. Cut the specimen for measuring
3. Clean the surface
4. Check the residual high
5. Calculate of ▯



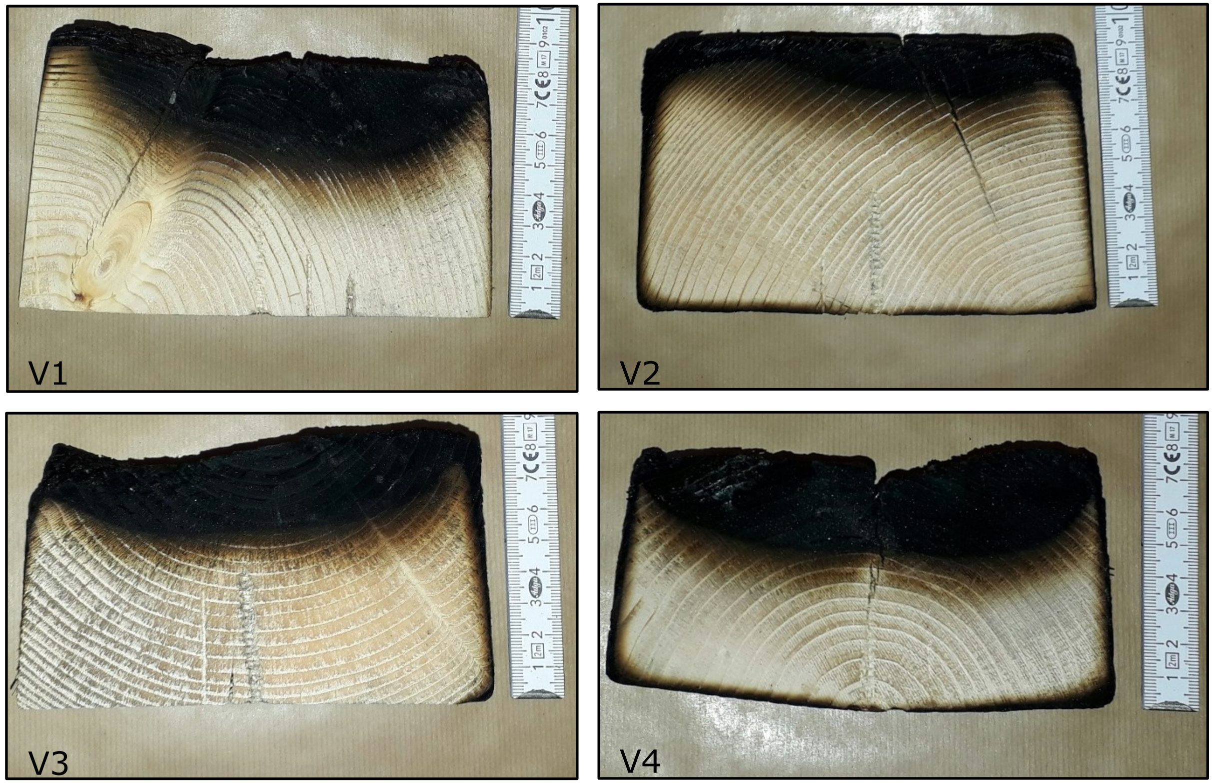
Exper.	m_1 [g]	m_2 [g]	Δm [g]	Δt [min]	$\dot{m}$ [g/min]
V1	842,8	612,6	230,2	90	2,6
V2	836,6	618,5	218,1	90	2,4
V3	726,5	472,5	254,0	90	2,8
V4	746,2	387,9	358,3	90	4,0

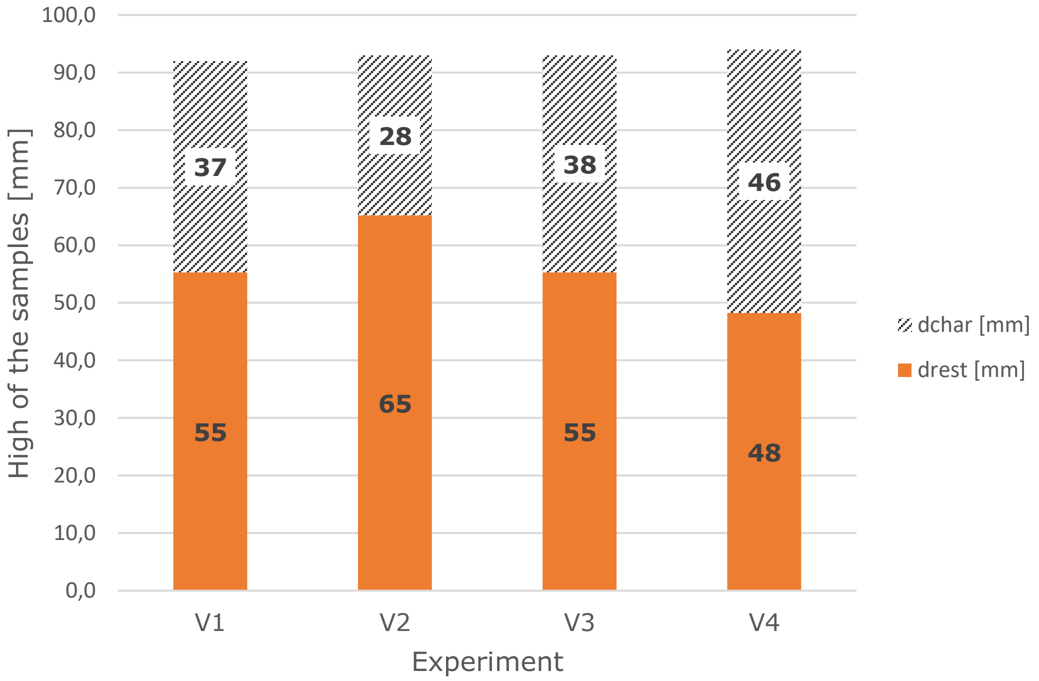
loss of mass

$$\dot{m} = \frac{(m_1 - m_2)}{\Delta t} \approx 3\ g/min$$

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung





Reiter – Wood fire

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Comparison

Exp.	Δt [min]	d_0 [mm]	d_{rest} [mm]	d_{char} [mm]	β [mm/min]
V1	90	92,0	55,3	36,7	0,41
V2	90	93,0	65,2	27,8	0,31
V3	90	93,0	55,3	37,7	0,42
V4	90	94,0	48,2	45,8	0,51
Average				37,0	0,41

$$\beta = \frac{d_{char}}{\Delta t}$$

→ average combustion rate β = 0,41 mm/min

Experiment	max. Temp.	Duration	Comb. Layer	Comb. Rate
Werther [6]	ca. 600 °C	60 [min]	27 [mm]	0,44 [mm/min]
Fornather [37]	ca. 700 °C	90 [min]	38 [mm]	0,42 [mm/min]
Reiter	ca. 400 °C	90 [min]	37 [mm]	0,41 [mm/min]

fully dev. fire
β = 0,65 mm/min

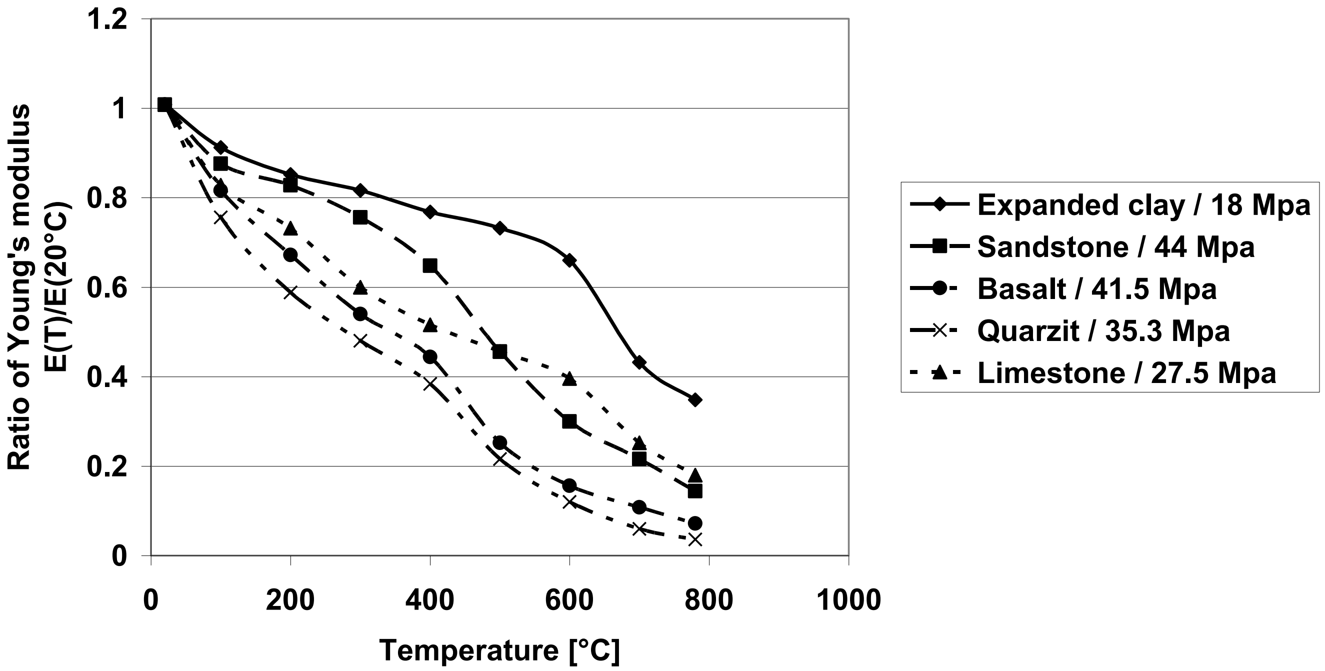
Smoldering fire
β = 0,4 mm/min

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

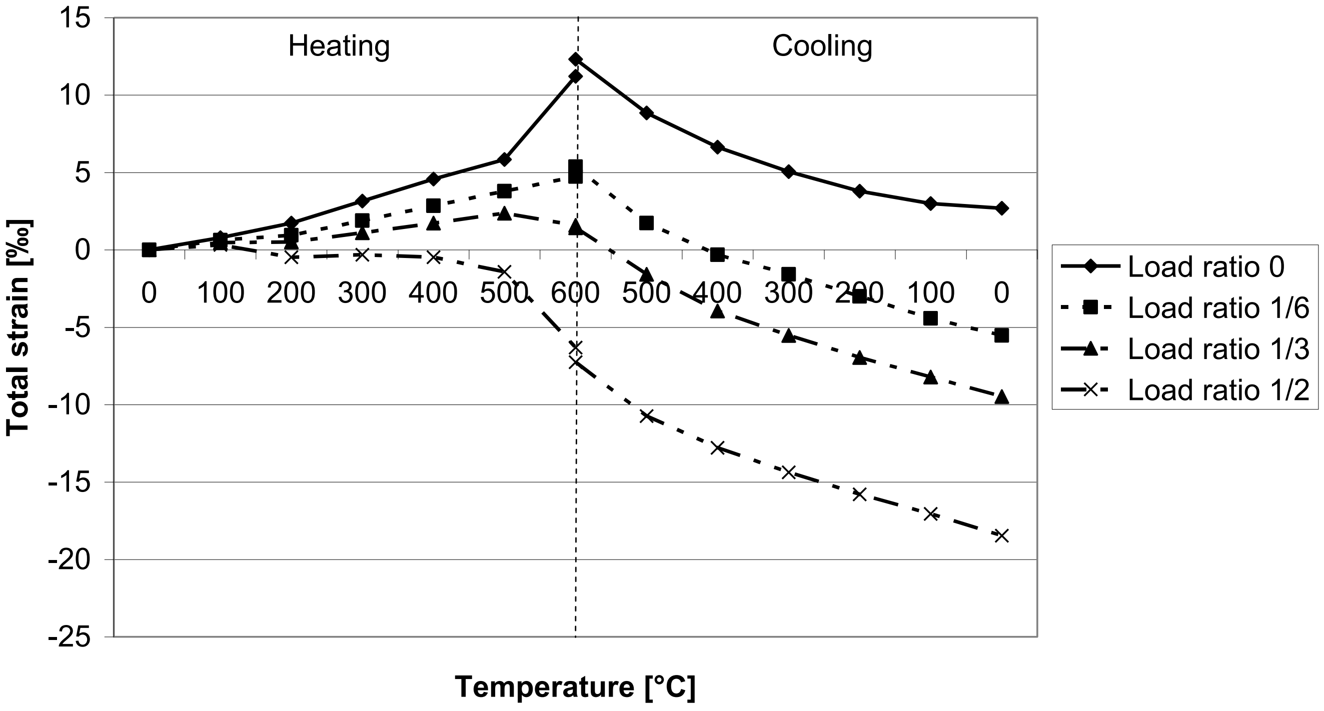
Targets

- Parameter study for determination of residual behavior after fire damage
- Behavior of composite slap during and after fire
- Refurbishment of fire damage

Parameter study



Parameter study



Experiment

- Variation of:
  - concrete C25/30, C35/45
  - mortar sealing
  - gypsum board
  - plastic pipes between reinforcement and cover
  - Cooling
  - Joint and bond in composite slap

FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Experiment – composite slaps

Experiment – store (90 d) and preparation

FIRE EXPERT

Interreg SLOVENIJA – AVSTRIJA SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Experiment – fire test

Experiment – fire test

FIRE EXPERT

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Results

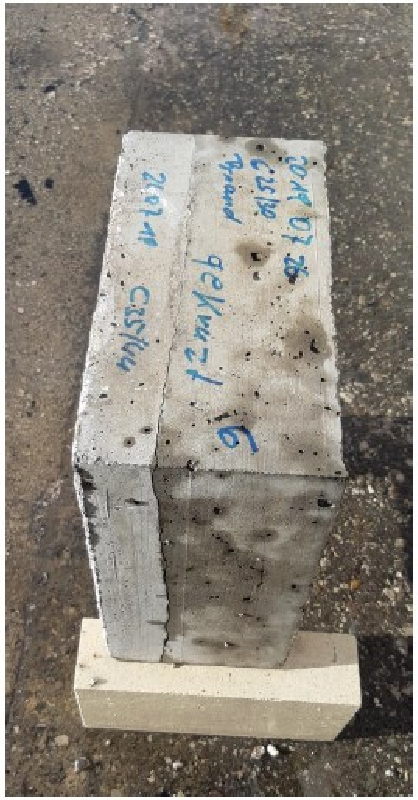
Mortar, small spallings

Gypsum,
no sealing with paper
gypsum is damaged

C25/30,
only carbon black

Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Results – composite slaps



Results – Parameter – Compressive strength

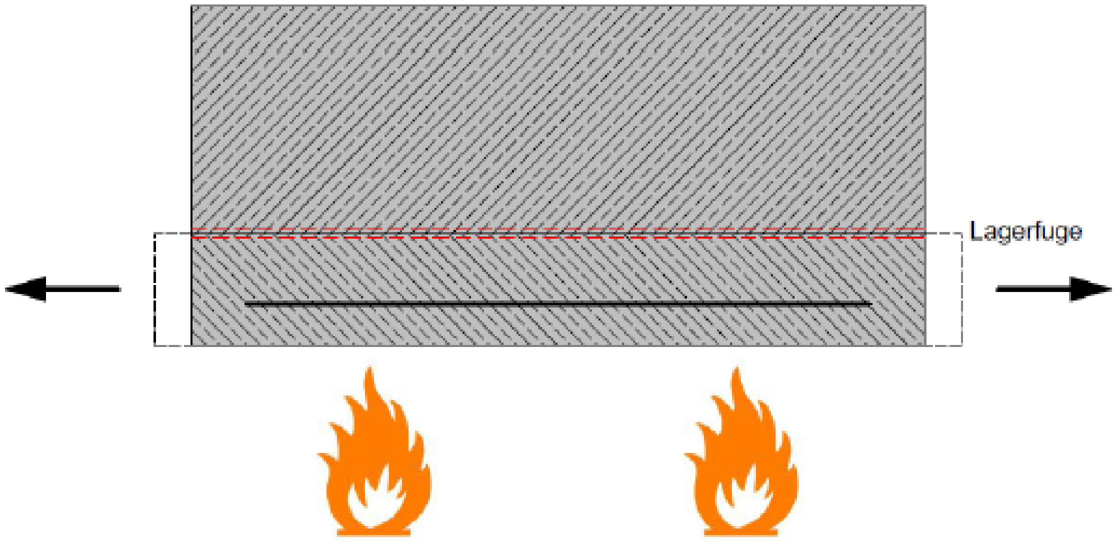
Surface sealing during fire	Decrease in %
Gypsum	20.5
Concrete	35.25
Mortar	32.0

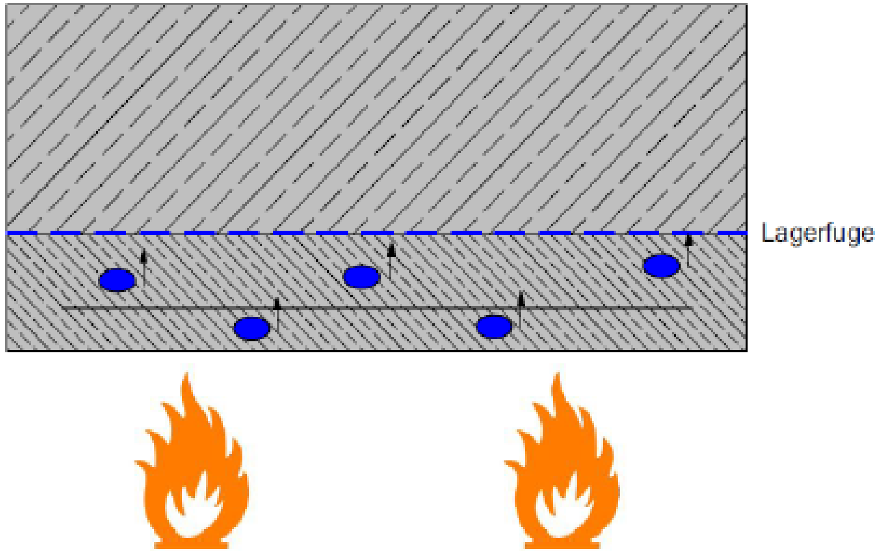
Interreg
SLOVENIJA – AVSTRIJA
SLOWENIEN – ÖSTERREICH
Evropska unija | Evropski sklad za regionalni razvoj
Europäische Union | Europäischer Fonds für regionale Entwicklung

Results – Parameter – tensile adhesive strength

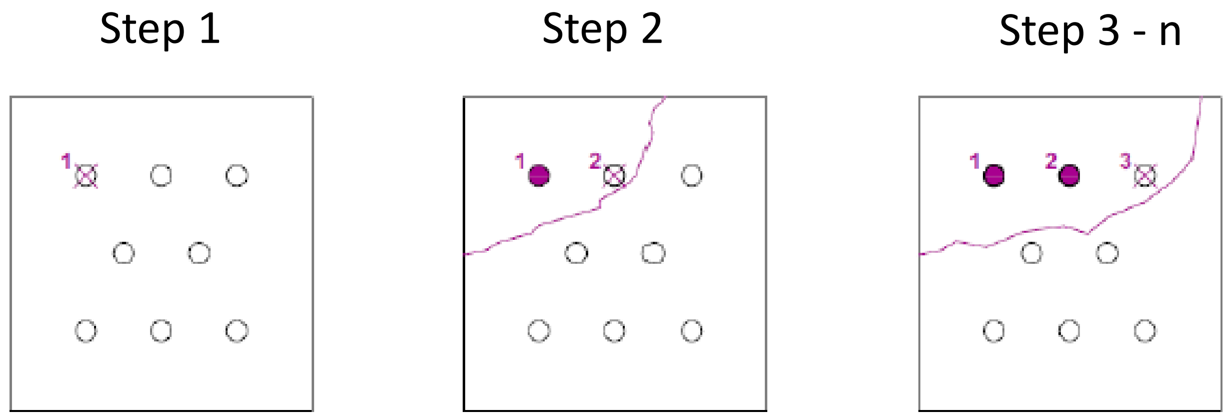
Experiment	Concrete + surface	tensile adhessive strength (MPa)
1	C35/45 plain concrete	1,8
2		1,7
3	C35/45 mortar	2,2
4		1,5
5	C35/45 gypsum	2,0
6		1,7

Discussion composite slaps





Discussion composite slaps



○ Drilling hole between the 2 layers of the composite
⊠ Drilling hole between the 2 layers of the composite with injection tube
● Drilling hole between the 2 layers of the composite closed

Thank you.

- Questions?
- Comments?