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TIMBER CLADDINGS AS FIRE PROTECTION FOR STEEL COLUMNS: EXPERIMENTAL STUDY AND PRACTICAL DESIGN RULES

Jakob Blankenhagen[1], Patrick Dumler[2], Constantin Schwendner[3], Hedi Boukraa[4], Josef Saller[5], Stefan Winter[6], Martin Mensinger[7],

ABSTRACT

Timber claddings offer a sustainable alternative to conventional fire protection for steel columns in hybrid steel–timber structures, but design rules and the influence of detailing remain insufficiently quantified. This paper presents an experimental and numerical study on the fire behavior of timber-cladded steel columns. Furnace tests on thermally loaded, mechanically unloaded columns with varying profile factors and different cladding systems (single-layer box claddings, double-layer claddings with staggered joints, and claddings on timber battens with cross-screws) were conducted under ISO 834 fire exposure. Steel temperatures and characteristic cladding failure modes were evaluated. A 3D heat-transfer model with a simplified cladding-failure representation was calibrated and used for parametric studies. Results show that timber claddings can provide effective protection, but performance depends heavily on joint layout, supports, and fixings. Simple box claddings often exhibit early joint opening and internal hot-gas flow, while claddings on battens with cross-screws demonstrate robust behavior across a wide range of fire resistance levels. The model reproduces steel temperatures with sufficient accuracy for design purposes and enables simplified relations between cladding thickness, profile factor, and fire duration. The findings support preliminary design rules and identify priorities for further research.

Keywords: cladding, steel columns, fire resistance, furnace test, heat-transfer modelling, hybrid construction

1 INTRODUCTION

Hybrid steel–timber systems are increasingly used in multi-storey construction, for example, steel frames combined with timber slabs, walls, or timber-based floor and façade systems. In such structures, both structural

[1] M.Sc., TUM School of Engineering and Design, Chair of Metal Structures, Technical University of Munich
e-mail: jakob.blankenhagen@tum.de, ORCID: https://orcid.org/0000-0001-6954-6421
[2] M.Sc., TUM School of Engineering and Design, Chair of Timber Structures and Building Construction, Technical University of Munich
e-mail: patrick.dumler@tum.de, ORCID: https://orcid.org/ 0009-0009-9498-1674
[3] M.Sc., TUM School of Engineering and Design, Chair of Metal Structures, Technical University of Munich
e-mail: constantin.schwendner@tum.de, ORCID: https://orcid.org/0009-0008-9171-0644
[4] M.Sc., Dlubal Software GmbH
e-mail: boukraahedi@gmail.com , ORCID: https://orcid.org/0009-0001-9053-764X
[5] M.Sc., Mensinger Stadler Ingenieure, Eduard-Schmid-Straße 20, 81541 München
e-mail: saller@mensinger-stadler.de
[6] Prof. Dr.-Ing., TUM School of Engineering and Design, Chair of Timber Structures and Building Construction, Technical University of Munich
e-mail: winter@tum.de, ORCID: https://orcid.org/0000-0002-5825-0710
[7] Prof. Dr.-Ing., TUM School of Engineering and Design, Chair of Metal Structures, Technical University of Munich
e-mail: mensinger@tum.de, ORCID: https://orcid.org/ 0000-0001-5210-5400

and architectural considerations often lead to timber coverings around steel members, raising the question of whether these claddings can also provide primary fire protection.

Conventional protection of steel columns, such as fire protection boards or intumescent coatings, is well established and covered by standards, whereas the fire performance of timber claddings has been studied in only a few projects and lacks general design rules. Existing research indicates that their behaviour depends not only on charring but also on profile factor, cladding material, fire duration, and the fastening systems used. [1-4]

The BraStaHo project [5] was initiated to create a systematic basis for fire-safe hybrid steel–timber construction, including the investigation of timber-cladded steel columns. Its aim was to quantify the influence of cladding configuration and detailing on steel temperature development and to derive design-oriented recommendations.

This paper presents selected results from the column tests and accompanying numerical simulations, focusing on global behaviour and robust configurations suitable for practical application. More detailed parametric studies and refined design models will be provided in a subsequent publication; here, the scope is limited to essential engineering insights and key mechanisms.

2 EXPERIMENTAL PROGRAM

2.1 Specimens and cladding configurations

The test program comprised steel columns of typical hot-rolled sections commonly used in building construction. The sections were chosen to cover a representative range of profile factors, A_p/V. The 1-meter-long columns were protected by timber claddings with different configurations.

The main cladding variants were:

a) single-layer box claddings directly screwed at the corner of the timber box,
b) double-layer claddings with staggered panel joints, and
c) claddings mounted on timber battens with cross-screws penetrating the cladding into the battens.

The claddings were made from industrially manufactured timber panels (e.g., three-layer panels). Different panel thicknesses were selected to address target fire resistance classes typically required in practice. In all cases, the claddings formed a closed rectangular box around the steel section. Figure 1 shows the different cladding variants.

In total, 29 specimens were tested.

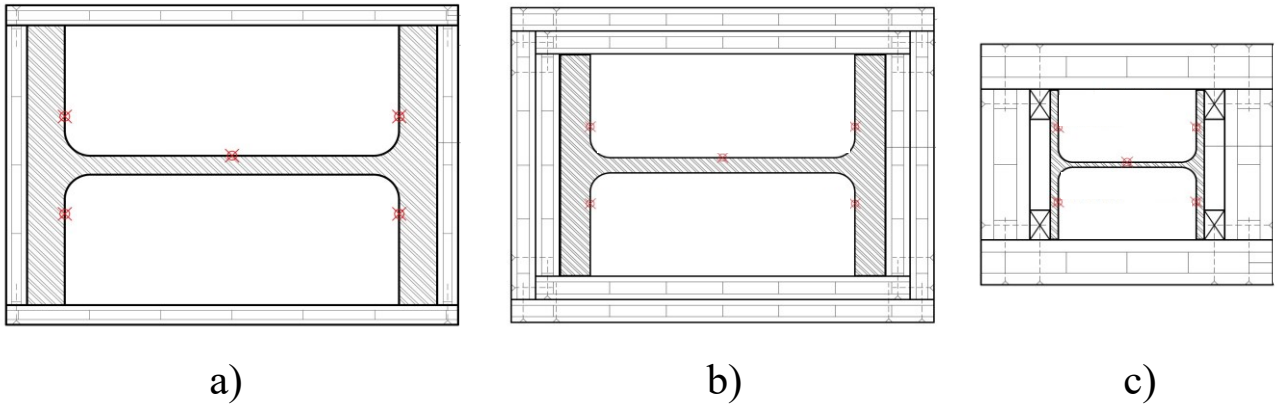


Figure 1: Overview of the different column cladding variants investigated.

Table 1: Overview of test configuration, X: cladding separation on both sides; O: cladding separation one side; ✓: intended fire resistance reached

Specimen	Section	Cladding variant	Thickness of cladding in mm	(A_p/V) in m^{-1}	Failure type*	Intended Fire resistance in min	Time till failure in min
S1_90	HEM 400	a	42	45	O	90	37/67
S4_90	HEB 240	a	60	91	O	90	47/-
S5_90	HEA 300	a	60	104	O	90	47/98
S6_90	HEA 200	a	60	145	O	90	49/96
S7_90	IPE 200	a	60	211	X	90	84
S8_90	IPE 100	a	60	301	X	90	49
Sgroß_90	HEB 300	a	60	80	X	90	43
S9_90 V	IPE 100	a	60	301	X	90	49
S10_90 V	HEB 300	a	60	80	✓	90	102
S2_90	HEM 280	a	42	50	X	90	30
S3_90	HEB 450	a	60	69	X	90	34
S9K_90	IPE 100	a	60	301	X	90	29
S10K_90	HEB 300	a	60	116	X	90	30
S1_60	HEM 400	a	32	45	X	90	34
S5_60	HEA 300	a	50	104	O	60	23/34
S8_60	IPE 100	a	50	301	X	60	25
S6_30	HEA 200	a	32	145	X	30	28
S7_30	IPE 200	a	32	211	✓	30	31
S1_30	HEM 400	a	22	45	✓	30	35
S2_30	HEM 280	c	22	50	✓	30	34
S3_30	HEB 450	c	32	69	X	30	29
S4_30	HEB 240	c	32	130	O	30	26/-
S5_30	HEA 300	c	32	104	X	30	26
S8_30	IPE 100	c	32	301	✓	30	35
S1_60	HEM 400	b	2 x 16	45	X	60	42
S4_60	HEB 240	b	27 + 22	130	✓	60	62
S6_60	HEA 200	b	27 + 22	145	X	60	55
Sgroß_60	HEB 300	b	27 + 22	116	X	60	47
S5_30	HEA 300	c	32	104	✓	60	66
X: cladding separation on both sides; O: cladding separation one side; ✓: intended fire resistance reached							

2.2 Test setup and boundary conditions

All tests were carried out in a furnace operated with oil under ISO 834 [6] standard fire exposure. The columns were subjected to thermal loading only, without mechanical loading, to isolate the thermal behaviour of the claddings and the resulting steel temperatures. The column ends were protected by fire protection boards. Thermocouples were installed on the steel surface. The furnace temperature was controlled to follow the ISO curve, while gas temperature, furnace pressure, and column temperatures were recorded throughout the test. Figure 2 illustrates the furnace setup and thermocouple arrangement.

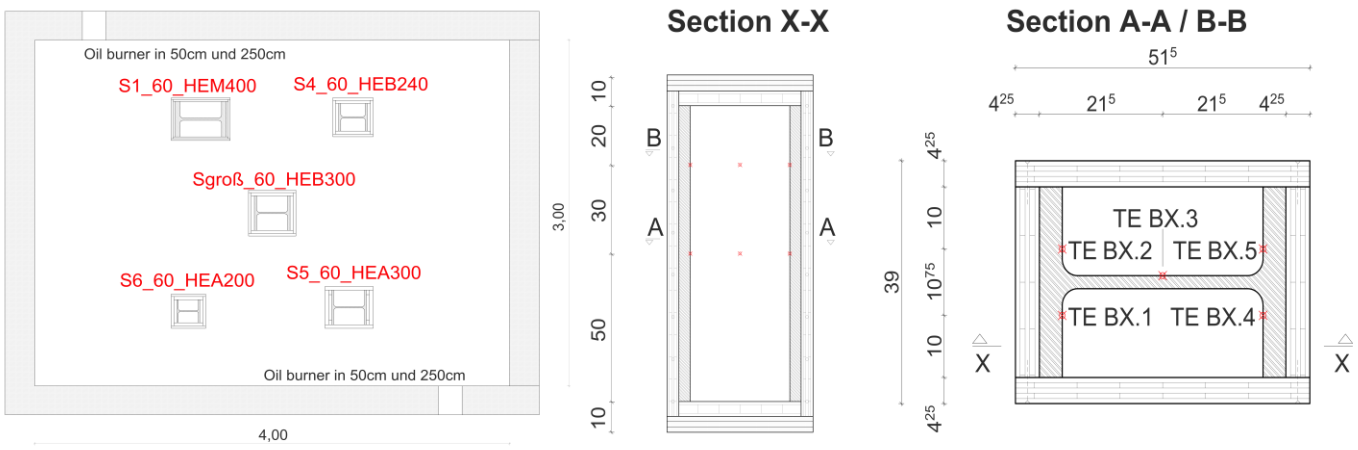


Figure 2: left: arrangement of test specimen in the furnace, right: placement of thermocouples

2.3 Evaluation criteria and target fire resistance

The evaluation focused primarily on the time-dependent steel temperature. For each specimen, the maximum steel temperature was derived from thermocouple readings, with additional measurements at key locations (e.g., flange and web center) to capture potential multi-sided exposure effects. A uniform critical steel temperature of 500 °C was adopted in line with common design practice, so the experimental fire resistance time corresponds to the point at which this value is reached. Beyond temperatures, the deformation and integrity of the cladding were also assessed qualitatively during the tests, with particular attention to:

- opening of corner joints
- detachment or loss of cladding parts,
- delamination of panel layers, and
- charring patterns

These observations are discussed in Section 4 and are illustrated in Figure 3.

3 NUMERICAL MODELLING

3.1 Model description

To complement the experimental program and enable parametric studies beyond the tested configurations, a two-dimensional finite-element model for transient heat transfer was developed. The model includes the steel section, the timber cladding, and, where relevant, intermediate air gaps and timber battens. Transient heat conduction was solved separately for steel and timber using temperature-dependent material properties; the timber was assigned effective properties accounting for charring and moisture effects. The cladding was treated as a continuous material with an advancing char front. Heat transfer at the external cladding surface was

modelled using combined convection and radiation boundary conditions calibrated to measured specimen temperature. Potential gaps and cavities were represented by assigning effective heat-transfer coefficients to their boundary surfaces. The model was implemented in commercial FE software Ansys [7] using 2D solid elements, with symmetry applied where possible to reduce computational effort.

3.2 Representation of cladding failure

A fully coupled thermo-mechanical model of joint opening and cladding failure would be computationally demanding and difficult to calibrate. Therefore, a simplified three-stage failure representation was adopted. In the first stage, the cladding is assumed to remain intact, and heat transfer proceeds as in a closed system as long as joints and fixings maintain integrity and no significant hot-gas flow develops. Once a defined failure time or steel temperature ϑ_1 is reached, the model transitions to an 'opened' state by locally increasing the effective heat-transfer coefficient or, in severe cases, in a third step, removing cladding elements at steel temperature ϑ_2. The timing and affected regions were calibrated for each cladding configuration based on test observations and temperature measurements. This approach provides a pragmatic means of capturing the principal thermal effects of cladding failure without explicitly modelling mechanical joint opening; its limitations are discussed in Section 4.3.

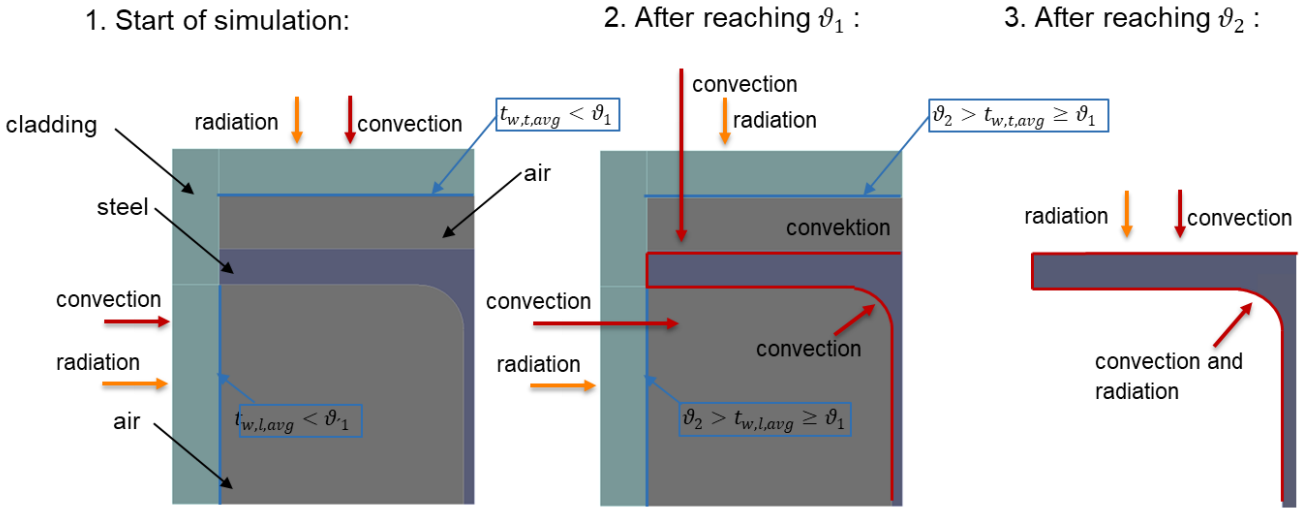


Figure 3: 3-step approach of the numerical model

3.3 Calibration and validation

The numerical model was calibrated against a subset of tests by comparing measured and predicted steel temperature–time curves. Key calibration parameters included the temperature-dependent thermal properties of timber, the external heat-transfer coefficient representing furnace–cladding interaction, and the timing and extent of the transition between the two failure stages. After calibration, the model was applied to the remaining specimens without further adjustment, and the agreement between measured and calculated temperatures validated the modelling approach for all investigated cladding concepts.

Figure 4 illustrates this comparison for specimen S5_30.

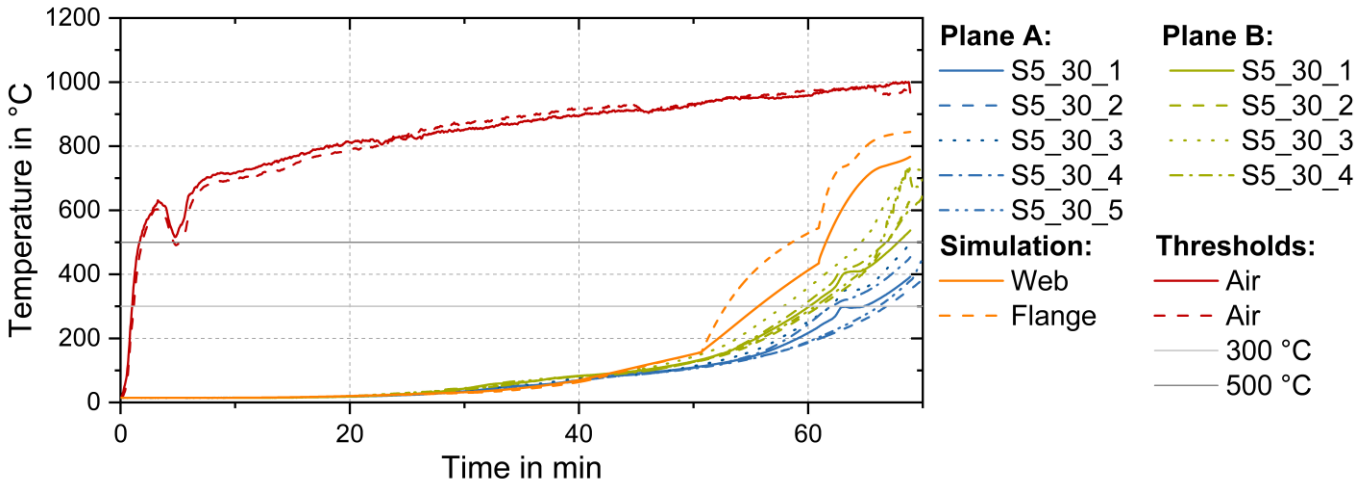


Figure 4: Comparison of test results and numerical model in the case of test specimen S5_30

4 RESULTS AND DISCUSSION

4.1 Global Trends

The tests confirm that timber claddings can substantially delay the rise in steel temperature during standard fire exposure. Across all configurations, steel temperatures remained well below the furnace gas temperature for a considerable period. The delay depends mainly on cladding thickness, the section's profile factor, and the effectiveness of joints and fixings: thicker claddings and sections with lower profile factors result in lower steel temperatures and longer times to reach the critical temperature. Cladding configuration is equally decisive - configurations that maintain a closed box without gaps throughout the fire around the steel perform markedly better than those with early joint opening or cladding loss, particularly at longer fire durations and for higher, larger profile factors.

4.2 Influence of cladding configuration and detailing

The tests underline the decisive role of detailing in the fire performance of timber-cladded steel columns. Single-layer box claddings with screws only on the narrow faces (Figure 1) showed pronounced deformation and early corner-joint opening, leading to hot-gas penetration, internal charring, and a faster rise in steel temperature. Double-layer claddings with staggered joints were initially tighter but exhibited other failure modes, including early lamella delamination due to the smaller lamella thickness and early detachment of the outer layer due to the type of screw fastening at half the cladding thickness. As soon as the charring reaches the screws, the panels lose their connection, which accelerates the charring of the inner layer.

In contrast, single-layer claddings mounted on timber battens with cross-screws performed robustly. Continuous support and improved load transfer reduced joint opening, prevented hot gases from flowing behind cladding joints, and resulted in a more gradual increase in steel temperature, enabling the intended fire resistance to be achieved more reliably across the tested sections and cladding thicknesses.

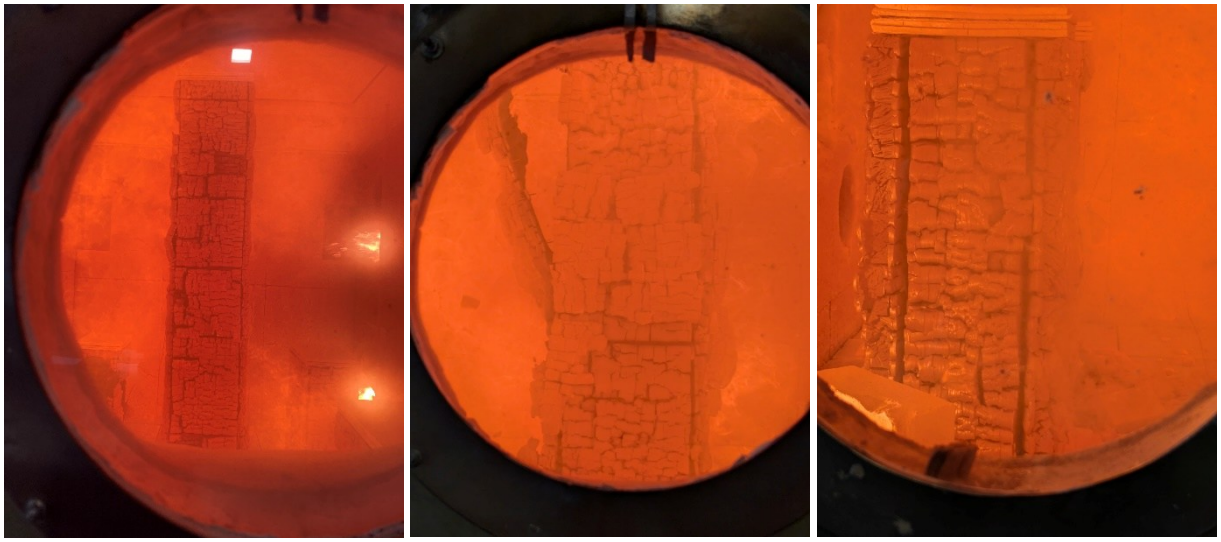


Figure 5: Left: Partial detachment of the first layer of the cladding of test specimen Sgroß_90; Center: Large-area detachment of the inner layer of the cladding of test specimen Sgroß_90; Right: Gap in the joint area of the cladding of test specimen S6_90

4.3 Comparison between tests and simulations

The numerical model reproduced the measured steel temperature–time curves with good accuracy across all cladding configurations. Deviations were small in the early fire stages, when the cladding remained intact, and heat transfer was dominated by conduction through the timber. At later stages, accuracy depended on how well the simplified failure representation captured joint opening and cladding loss.

For robust claddings—such as those on battens with cross-screws—the transition between the two model stages was unnecessary or occurred late, resulting in close agreement with the tests. Configurations with early joint opening or cladding detachment were more difficult to represent, and the model tended to be slightly conservative, predicting somewhat higher steel temperatures. This behavior is acceptable and often desirable in design.

Parametric studies based on the calibrated model produced response surfaces relating cladding thickness, profile factor, and fire duration to maximum steel temperature, forming the basis for simplified design relationships discussed in Section 5.

5 IMPLICATIONS FOR DESIGN

5.1 Qualitative design rules

The first-phase results of the BraStaHo [5] program provide several qualitative design rules for timber-cladded steel columns. Timber claddings can serve as primary fire protection, provided they form a robust, continuous enclosure of sufficient thickness. The most critical factors are joint integrity, fixing layout, and overall continuity: claddings on timber battens with cross-screws proved far less sensitive to deformation than simple box claddings with screws in the narrow face. Double-layer systems with staggered joints may offer initial tightness, but only until the outer layer falls off. Afterwards, the inner layer faces the same problem: joints open due to panel deformation at the corners. The required cladding thickness increases with both the profile factor and the target fire resistance. These findings align with engineering judgement and complement existing guidance for board-clad steel and timber structures [8,9].

5.2 Towards simplified design models

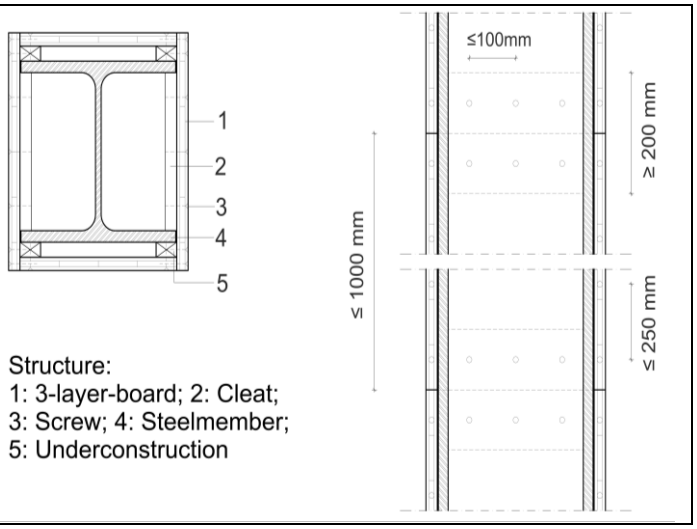
The combined test and simulation results enable simple, design-oriented relationships between cladding thickness and fire resistance for each cladding concept. A practical approach is to express the maximum steel temperature as a function of fire duration t, the section's profile factor A_p/V, and an equivalent cladding thickness d_{eq} that accounts for gaps and joints. For each cladding type, the corresponding coefficients can be derived from the parametric studies and used in preliminary design - e.g., in spreadsheets or design charts - while detailed heat-transfer simulations remain appropriate for configurations outside the calibrated range.

This paper focuses on the qualitative interpretation of these relationships; full formulae and coefficients, including further validation, will be presented in a subsequent publication.

For simplified determination of the required cladding thickness, refer to Table 2, noting that its applicability depends on the accompanying specifications.

Table 2: Simplified design recommendations

Fire Resistance in min (ISO 834 standard fire)	Cladding thickness in mm	
	A_p/V in m^{-1}	
	≤ 60	> 60
R30	22	32
R60	50	50
R90	60	60



6 CONCLUSIONS AND OUTLOOK

This paper provides an overview of the experimental and numerical investigation of timber-clad steel columns carried out within the BraStaHo project. The main conclusions of this first-phase evaluation are:

- Timber claddings can provide effective fire protection for steel columns under standard fire exposure, although the achievable fire resistance strongly depends on cladding configuration, detailing, and thickness.
- Claddings mounted on timber battens with cross-screws demonstrated the most robust performance, maintaining cladding integrity over extended periods and limiting steel temperature rise across a wide range of profile factors.
- Simple box claddings with unfavorable screw layouts and double-layer systems prone to delamination exhibited early joint opening and cladding fall off, leading to hot-gas ingress, accelerated charring, and earlier steel temperature increase. Such configurations require careful detailing or should be avoided for higher fire-resistance requirements.
- A three-dimensional heat-transfer model with a simplified cladding-failure representation reproduced measured steel temperatures with sufficient accuracy for design, providing a valuable basis for

parametric studies and for deriving simplified relationships between cladding thickness, profile factor, and fire resistance.

The first phase of the research program results establishes a solid foundation for qualitative design rules and for identifying robust cladding concepts suitable for practice, while also highlighting the need for clear detailing requirements for joints, supports, and fixings, as well as further studies on mechanically loaded columns and natural fire scenarios. Future work will focus on three aspects:

(1) a more systematic quantification of the influence of load level and boundary conditions on the structural response of timber-clad steel columns in fire,

(2) an extension of the numerical models to incorporate selected thermo-mechanical effects and to support performance-based design under natural-fire scenarios; and

(3) the development and validation of detailed design rules and tabulated data for engineering standards, based on the response surfaces derived in this study.

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