

# REHABILITATION OF HISTORIC HALF-TIMBERED WALLS WITH COMPOSITE MATERIALS BASED ON HIGH-STRENGTH

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## ABSTRACT

The major requirements for present day cultural heritage conservation include the minimization of interventions in historic structures, non-invasiveness and, last but not least, reversibility of rehabilitation and strengthening interventions. Due to these requirements, composites based on high-strength fibres and epoxy resin are increasingly applied during the rehabilitation, renovation and strengthening of building structures. The article points out potential applications of these materials in the renovation, rehabilitation and strengthening of half-timbered constructions.

## KEYWORDS

rehabilitation, strengthening, historic half-timbered walls, FRP fabrics

## INTRODUCTION

The origins of half-timbered buildings (Fig. 1a) most likely go back to the ancient world as evidenced e.g. by Vitruvius in his Ten Books on Architecture [1]. The origins of half-timbered and timber-framed buildings which were built in the Czech lands from the 14th to the late 19th century can be traced to Germany and Scandinavian countries, but also France, Switzerland and Austria. Numerous modifications and shape patterns of wooden elements of half-timbered walls are typical and expressive architectural and decorative elements of these buildings. The buildings preserved on the territory of the Czech Republic, mainly in the northwest border regions, largely represent houses with half-timbered constructions on the upper floor and in the gable and a timbered or masonry ground floor (Fig. 1b) [1].



Fig. 1: Examples of half-timbered houses a) Doubrava; b) Kytlice

The term half-timbered construction denotes a wood post-frame, timber-framed or skeleton frame construction with articulated, partly rigid joints of timber elements (logs, partially squared sections, prisms) with infill panels (wattle and daub, laths, brick nogging) usually about 200 mm in thickness, inserted, in most cases, within the thickness of the wooden post-frame (half-timbered) construction. The main structural elements of half-timbered houses are the lower plate, the upper plate, posts, horizontal noggins, struts and braces. A simpler type of half-timbered framing is only composed of three horizontal beams – a plate, noggins and a ledger. In the oldest buildings, joists were always mounted on the posts to which they were directly jointed by tenons. The very construction of the half-timbered frame did not undergo any substantial changes during its historical development, except for gradual workmanship simplifications, reduction in the number of posts and diagonals and the overall robustness of the whole half-timbered construction [2,3].

## DEFECTS AND FAILURES OF HALF-TIMBERED BUILDINGS

Because of its availability and ease to work with, wood, together with stone, has belonged to the most common materials used in our country in construction since the Early Middle Ages. The advantages of wood include its low weight, high compressive and tensile strength, good workability, a low coefficient of thermal expansion, good thermal insulation properties and good durability (if stored in environments with a relative humidity of 70% and protected against direct effects of water). The disadvantages of wood are heterogeneity, local defects (knots), variable mechanical properties, drying and swelling due to moisture effects (shrinkage cracks), flammability (self-ignition), low resistance to wood-destroying fungi, insects and rot and water absorption (Fig. 2), wood deformations due to compression and drying, which are greater in the direction perpendicular to grain [4].

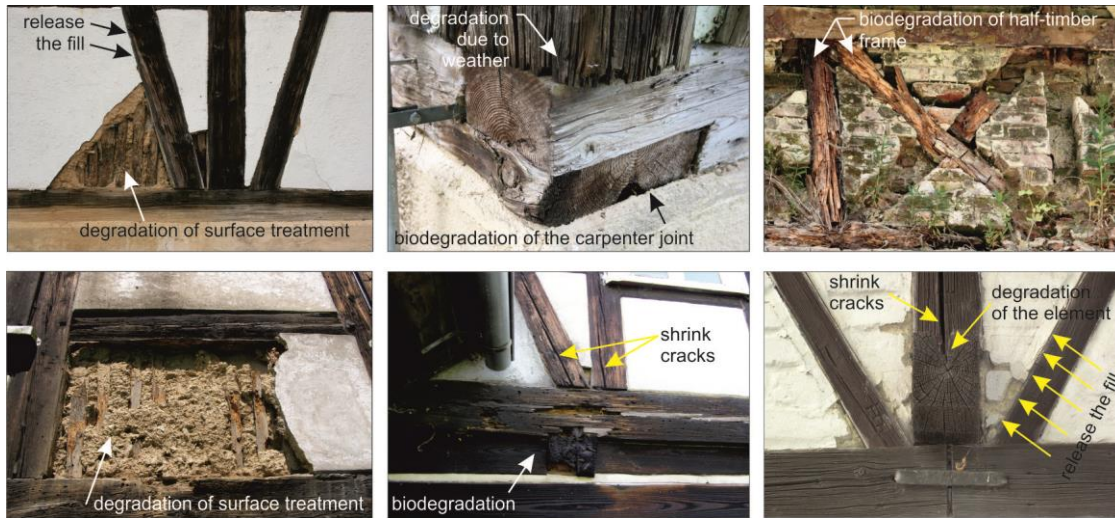


Fig. 2: Degradation of half-timbered houses

A preliminary construction and technical survey of selected historic half-timbered constructions showed that the most common defects of timber-framed constructions were insufficient thermal insulation properties of perimeter half-timbered walls, defects and poor quality of wooden elements, workmanship defects (faulty placement of the ground plate on the plinth, poor execution of carpentry joints of wooden elements, mounting wood with high moisture, mechanical degradation of wood, excessive shrinkage and creep of wood), inappropriately applied wood treatment, absorbent material of the plinth and a generally rigid connection between internal masonry constructions (masonry walls, partitions, chimney, etc.) disabling free pushing, strain or swelling and deformations due to loading by the timbered or half-timbered construction.

The survey revealed that the main causes of failures of half-timbered buildings were inadequate foundations (settlement and deformation of foundations), deformations and strain of the timber construction due to the shrinkage (or swelling) of wooden elements, insufficient rigidity and stability, roof truss deformations, loosening of joints of wooden elements and their degradation by wood-decay agents and rotting due to elevated moisture levels, high temperatures or aggressive environments, improper use and unqualified interventions. Fig. 3 shows examples of degraded carpentry joints and wooden elements of half-timbered constructions.

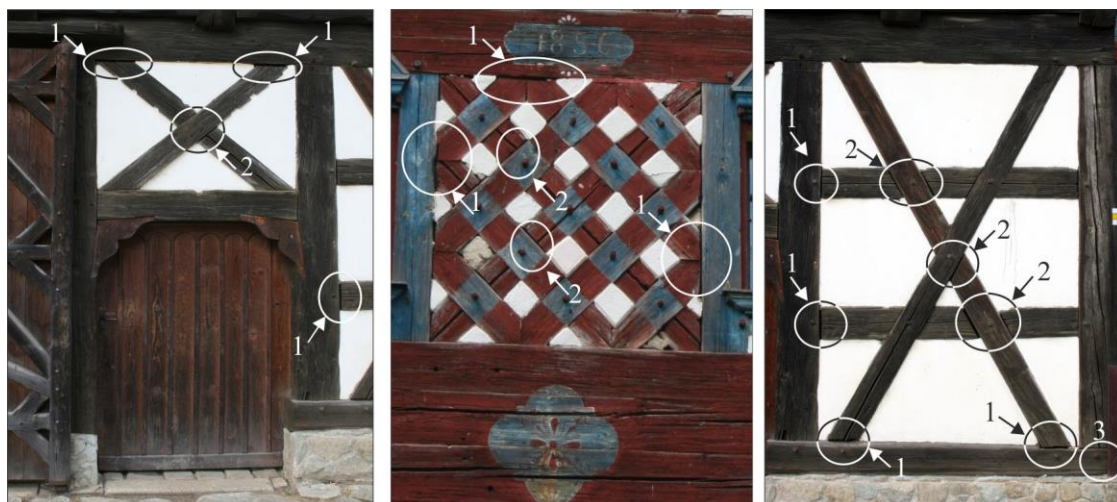


Fig. 3 Examples of failures (loosened connections) of different carpentry joints (legend 1 – tenon jointing (struts, noggins, posts), 2 – dapping (struts, noggin), 3 – halving (foundation plate))

The compression of the half-timbered frame due to wood shrinkage may reach values of up to several millimetres per meter of the wall height. This compression is prevented e.g. by the brick nogging, which, if properly wedged out, takes up part of the load transferred by the wooden frame. The loading of the joints of wooden elements due to this effect may cause the failure - loosening of connections of the half-timbered frame (Fig. 3). The joints thus created successively allow easy penetration of moisture accelerating the aging or rotting of wood.

### REHABILITATION AND REINFORCEMENT OF HALF-TIMBERED BUILDINGS WITH COMPOSITE-BASED MATERIALS

While restoring and renovating historic half-timbered buildings, especially listed ones, it is necessary to preserve the original historical value of the building, prevent its further damage and the degradation of its historic construction. Permissible interventions include the restoration, conservation and stabilization of the current condition of half-timbered constructions and components – e.g. preservation of the nature and wear of a “deformed” wooden construction, including tilted floors, cantilevered ceiling parts, door framing and frames of door and window openings, only partial sealing of shrinkage joints and cracks, etc.

Loosened joints are currently wedged out during the rehabilitation or strengthened by means of suitably placed prostheses, stiffening elements, partial resin grouts, reinforcement (e.g. glass fibre connections, special steel bars), etc. Classic rehabilitation methods of timber members are used for the rehabilitation of parts of wooden or joint elements, e.g. placement of prostheses, replacement of parts of elements, etc. New and original parts of the construction are most frequently connected by carpentry joints, or joints complemented by steel bolts, pins, etc. (Fig. 4).

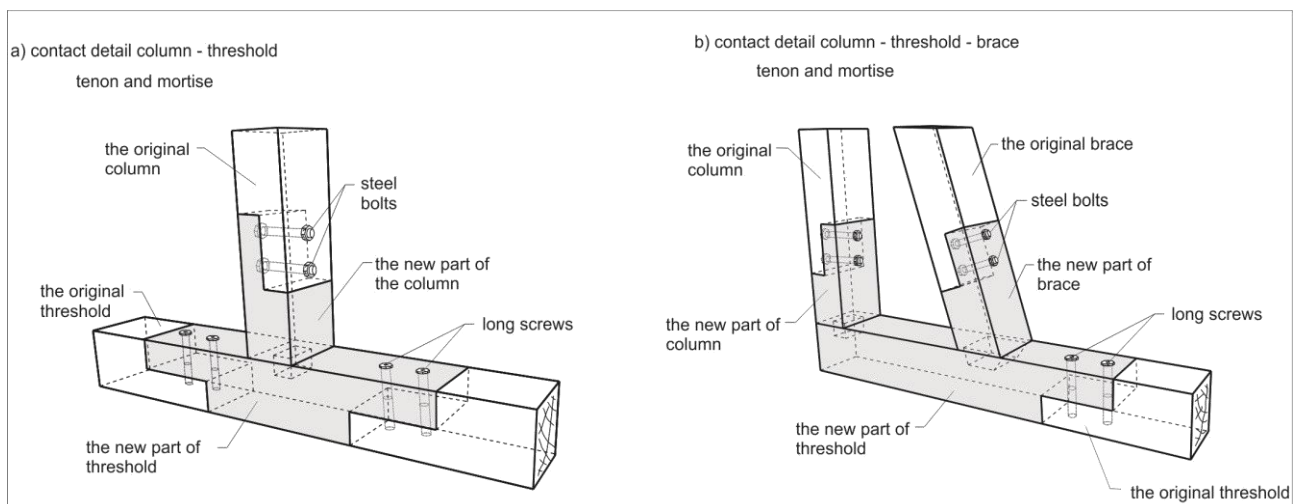


Fig. 4 Existing rehabilitation techniques of joints of elements

New possibilities in the rehabilitation of wooden elements and their joints are e.g. the surface application of diffusion-permeable fabrics based on high-strength fibres and nanofibres, or the use of lamellae based on high-strength fibre composites and epoxy resin. If the requirement for the preservation of the original appearance of the construction is raised, transparent fabrics represent a viable option. Inserting prepared lamellae or bars of composite materials in holes or grooves in wooden elements is advisable if the surface application of fabrics cannot be performed for aesthetic and heritage conservation reasons (Fig.5). While inserting strips or bars in grooves a desirable solution in this perspective may be the closure of the groove with a “splinter” of wood of the same or similar structure as the surrounding wooden part of the construction (Fig. 6). The

advantage of this solution is also enhanced fire protection of reinforcing composite strips, without the necessity of additional panelling or another modification of the construction.

If the wooden half-timbered construction acts as a spatially rigid “frame” with rigid joints (as a construction with semi-rigid joints), or as a “latticed” construction braced by diagonals and struts (spatially stable half-timbered structures without infill panels), a complex repair of the masonry infill can be performed with only partial securing of the supporting half-timbered construction during the repair. In the case of non-rigid joints and insufficient bracing of the supporting frame, the masonry infill simultaneously has a significant structurally reinforcing function. While replacing and restoring the masonry infill, this function can be substituted by using prestressing lamellae based on a composite of high strength fibres and epoxy resin, both in the vertical and horizontal direction (Fig. 5). The prestressing of the timber construction with lamellae, together with the quality assessment of the condition of joints of supporting wooden elements, the amount of bracing and the degree of rigidity, allows the removal of infill panels of the half-timbered construction and its subsequent rehabilitation.

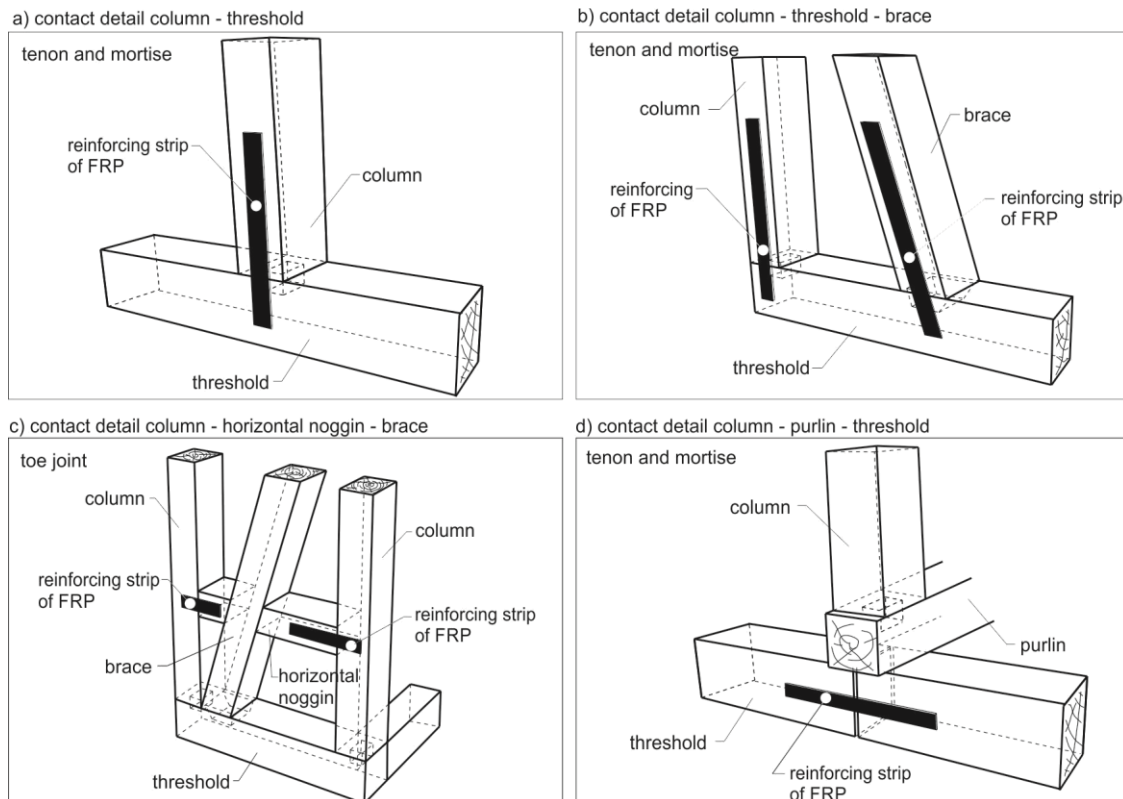
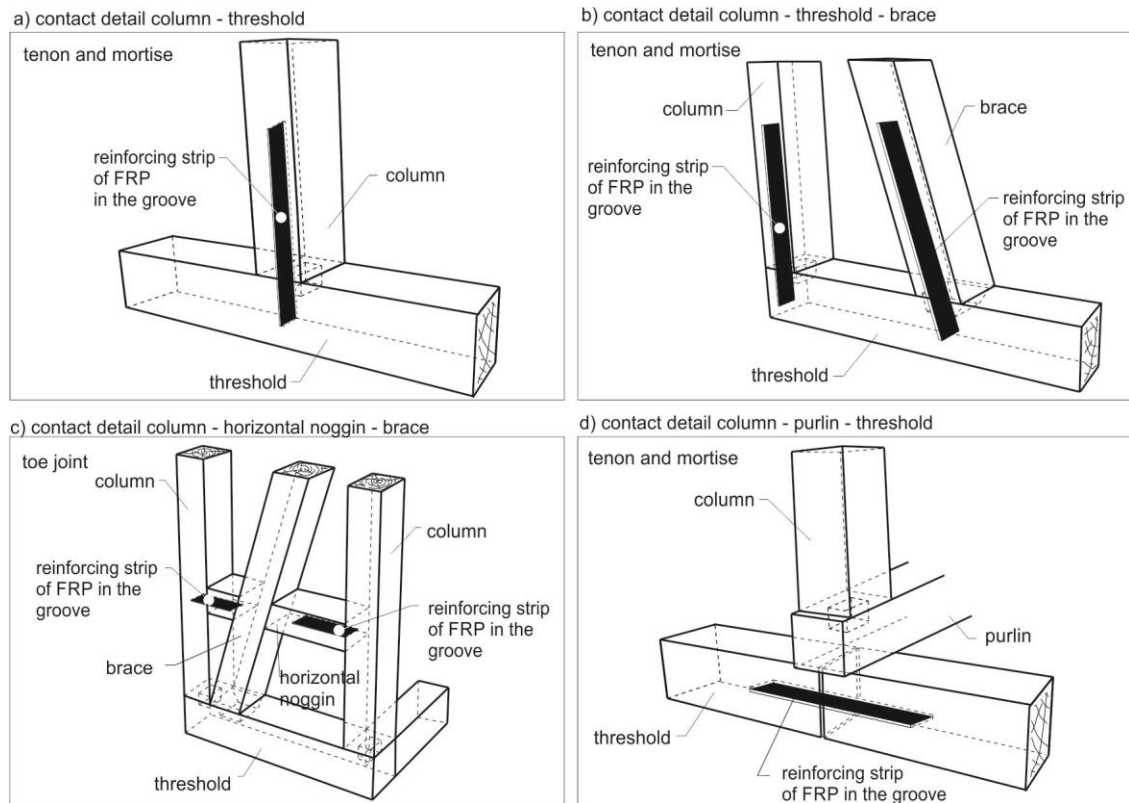


Fig. 5 Surface application of FRP fabrics for strengthening carpentry joints of half-timbered constructions



*Fig. 6 Application of FRP fabrics in grooves for strengthening carpentry joints of half-timbered constructions*

In less significant, unlisted buildings, major structural interventions may be designed, apart from the above specified rehabilitation measures – e.g. replacement of extensively damaged elements, strengthening of joints by means of prostheses, bolts and reinforcing sections, strengthening of elements, partial replacement of damaged parts of components, levelling deformations, stiffening the supporting structure, adding (inserting) reinforcing and supporting elements, strengthening or an extensive reconstruction of the damaged frame construction, wooden floor construction, roof truss, etc. to restore the full functionality of the construction while preserving the original nature and architecture of the building.

## CONCLUSION

The application of composites based on high-strength fibres and epoxy resin for the remediation of the wooden frame of half-timbered buildings is significantly limited by the requirements for the surface quality to which they are anchored during the application of these materials. The second, no less important characteristic of these materials is high diffusion resistance limiting overall surface applications of composites on wooden structural elements of half-timbered buildings. Local rehabilitation of defects and failures of joints of wooden elements of the supporting wall construction, particularly the slippage of individual elements from the joint, is the appropriate surface application of these materials. Inserting FRP-based composite strips and epoxy resin in the grooves of wooden elements increases the fire resistance of the reinforced construction. It is advisable to use composites based on high-strength fibres and epoxy resin to improve the mechanical properties of bent elements of half-timbered constructions, mainly joists, rafters and reinforcement of roof truss joints.

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