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Development of joining details for timber components using long fully threaded screws

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Abstract

Since their appearance, self-tapping fully threaded screws have been used extensively as reinforcements and fasteners in state-of the art timber construction. Especially where the wood is weak due to its anisotropic and inhomogenious material behavior, the screws are used to reinforce the material locally and thus safely transfer the forces. However, the areas of application also include the reinforcement of existing structures [1] and the joining of timber components. Especially in these applications (joining), where screws with long lengths are necessary, the problem of exact positioning of the screws becomes apparent and limits the conceivable application possibilities. In an ongoing research project, the principle of pyrolytic pre-drilling with laser radiation is being developed in order to ensure exact positioning. This opens up new application possibilities.

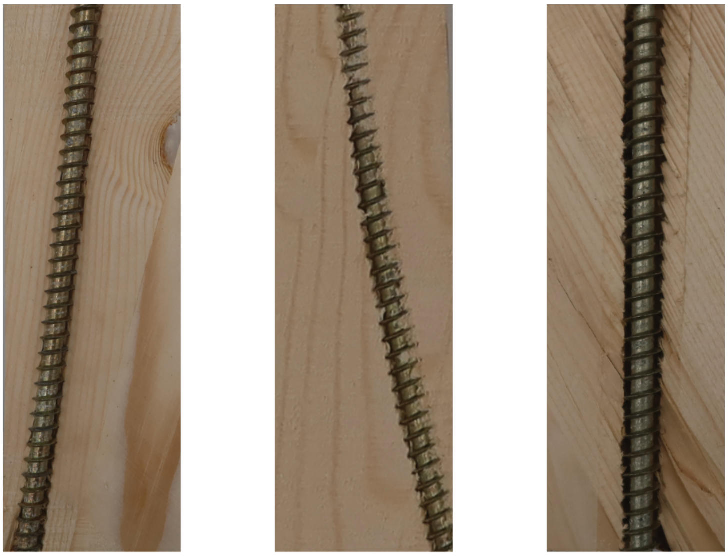
The paper describes the principles of the predrilling process and presents the new applications developed where long fully threaded screws are for joining timber components. Detailed solutions are presented for using self-tapping fully threaded screws to gain load-bearing and stiff connections. The solutions presented offer a wide range and can be used for multi-storey timber construction as well as for complex curved shell structures.

Keywords: Timber construction, self-tapping screws, fully threaded screws, joining details, predrilling, laser, glulam, CLT

1. Introduction

Self-tapping fully threaded screws have become established in timber construction and are currently used widely in many timber structures [2]. Their purpose is generally to reinforce the timber locally and thus to safely absorb the stresses that occur, particularly in the orthogonal direction of the fiber orientation. The advantages of using self-tapping fully threaded screws are their ease of use and good performance in terms of force transmission. Compared to other established metal fasteners in timber construction, such as nails or dowels, the fully threaded screws are stressed along their longitudinal axis, and the force is transferred into the wood via the bond between the screw and the wooden matrix. This means that no bending stresses occur in the fasteners, resulting in optimal utilization of the screws' high tensile strength. In addition to being used as reinforcing elements, the screws can also be used to join components. This opens up a wide range of possible applications for load-bearing and stiff connections. While the screw-in angle (angle between the screw-axis and the fiber direction) was initially limited to at least 15°, fiber-parallel (0°) screw connections are now also possible, which further increases the range of applications.

The force to be transmitted in a connection can be controlled not only by the number of fasteners but also by the length of the screws. When designing and dimension a connection, the length of the screws can be selected in such a way that a bond behavior as close as possible to the steel failure of the screws is achieved. This also ensures the type of failure usually desired (ductile failure due to the screw being pulled out) with the maximum transmittable force. Screws are available in lengths of up to one meter and even longer, but the long screws are usually not used, as it is not possible to position them straight into the wood section. Due to the inhomogeneous structure of wood with its changing densities of early and late wood and other discontinuities like enclosed knots, the screws are deflected and stray from their intended position while screwing in. Despite various technical devices such as guide rails or angle brackets offered by the manufacturers, the problem cannot be solved as the cause of the screws straying during the screwing-in process lies primarily within the wood section.



Non-pre-drilled

Mechanical
pre-drilled

Pyrolytical
pre-drilled

Figure 1: Deviations of self-tapping screws without and with mechanical and pyrolytical predrilling

In order to position a screw precisely, a straight pilot hole is required, as only in this case the screw follows a prescribed axis and can be positioned exactly. However, conventional mechanical pre-drilling using metal drill bits does not provide a solution, as the drill bits are also deflected by the structure of the wood and tend to stay even more than the screws. The pyrolytic pre-drilling process presented in [3] and [4] and summarized below enables the exact positioning of self-tapping fully threaded screws. Compared to mechanical predrilling, it allows to position self-tapping fully threaded screws precisely in a cross-section without the risk of collision or the screw of an escaping from the cross-section. With this possibility, the scenarios for the use of self-tapping fully threaded screws are expanded and can be rethought. Detailed solutions are shown for how the screws can be used to make connections that have not typically been realized yet.

2. Pyrolytical Predrilling for self-tapping screws

Together with the Chair of Laser Technology (LLT) and the Institute for Building Materials Research (ibac) at RWTH Aachen University, a pyrolytic process for predrilling self-tapping fully threaded screws is being developed. Different laser beam sources were investigated and suitable process parameters for creating deep drill holes were determined.

After an exploratory phase, a QWC laser process was chosen, which is being further developed in an ongoing project. The QWC laser process uses a pulsed drilling process with a collimated laser beam. The laser beam is collimated to a diameter of approx. 2 mm by setting up a spiral drilling optic, whereby an almost constant diameter of the laser beam is achieved over the depth of the hole. The laser beam single pulsed with a pulse duration of 0.2-10 ms. The drilling speeds vary depending on the parameters used and the fiber angle tending to be faster than mechanical predrilling. Drilling depths of up to 300 mm are possible with this setup. In the current project, the extension of the drilling depth is being implemented through the development of a new type of laser drilling optics.

The process enables the production of straight guide holes, as the laser beam is not deflected by the discontinuities in the wood. Figure 1 shows cut-open test specimens with screwed-in screws in the non-predrilled case (left) and with a mechanical (center) and a pyrolytic predrilled guide hole (right). In comparison to the non-predrilled installation, if a drill hole is present, the screw follows it and is positioned according to the direction of the drill hole. With mechanical predrilling, the drill itself tends to stray more strongly than if the screw is installed without prior predrilling due to the lower stiffness of the drill, so that even larger deviations accure. The pyrolytic process, on the other hand, enables straight predrilling and therefore exact positioning of the screw. Due to the different burning behavior of early and late wood, the drill hole diameters vary over the drilling depth (see figure 2. Despite these irregularities, the pyrolytic pre-drilling does not have a significant influence on the bonding behavior of the screws. This was demonstrated in several series of pull-out tests on test specimens with different fiber angles and screw diameters [5], [6]. Further investigations into the bonding behavior of fully threaded screws in pyrolytically predrilled holes and their influence on, for example, the disassembly properties are currently being investigated.

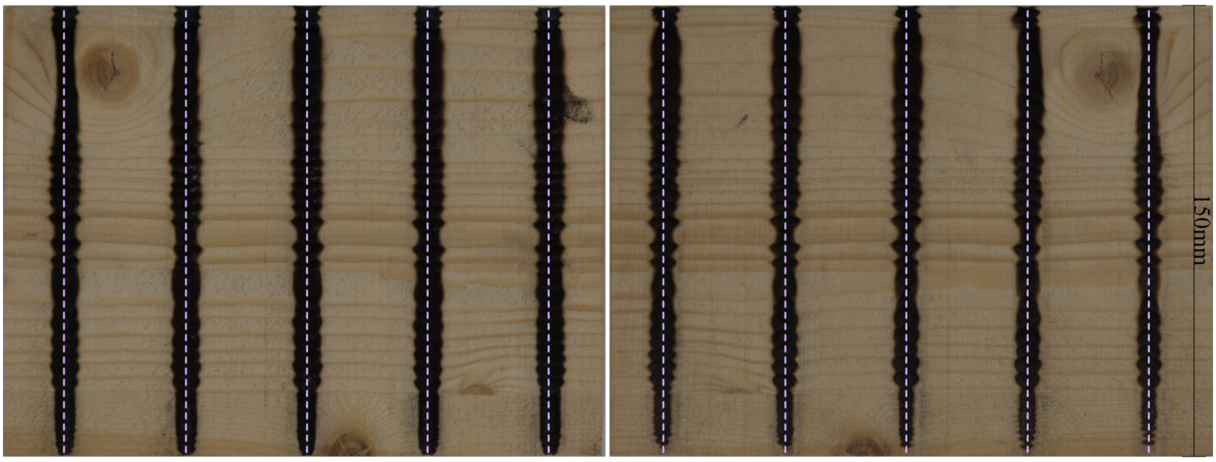


Figure 2: Cut specimen with pyrolytic predrilled boreholes

3. Joining details for long self-tapping screws

As part of previous projects, the realization and investigation of a rigid frame corner showed that fully threaded screws can not only be used for local reinforcement of transverse compressive or transverse tensile stresses, but also have the potential to systematically join components [7]. The following examples show further possibilities for the design of component joints as well as considerations for their implementation.

3.1. Fixed column support

The construction of fixed column supports in timber construction is challenging and only possible to a limited extent due to the greater elasticity of the material compared to, for example, steel. In general the connection is realized with inner steel plates, which are inserted into the timber cross-section and then fastened with rod dowels. When the node is subjected to a moment load, the rod dowels are under bending stresses and determine the connection significantly in terms of load-bearing capacity and stiffness. The suggested alternative in figure 3 shows a a connection with fully threaded screws. A steel head plate is attached to the end of the column, with holes drilled at the appropriate intervals so that the fully threaded screws can be screwed through the plate into the timber. The rigid plate can then be screwed to the foundation. With an appropriate floor design, the steel plate can be covered to create an overall invisible connection. The fact that the connecting elements lie completely in the cross-section not only has a visual advantage, but also has a positive effect on fire behavior.

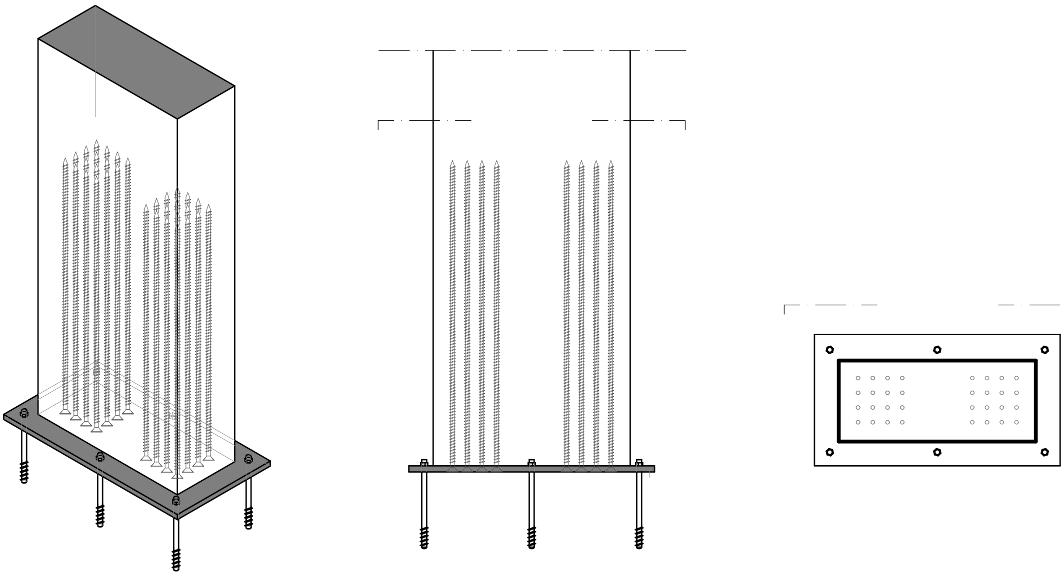
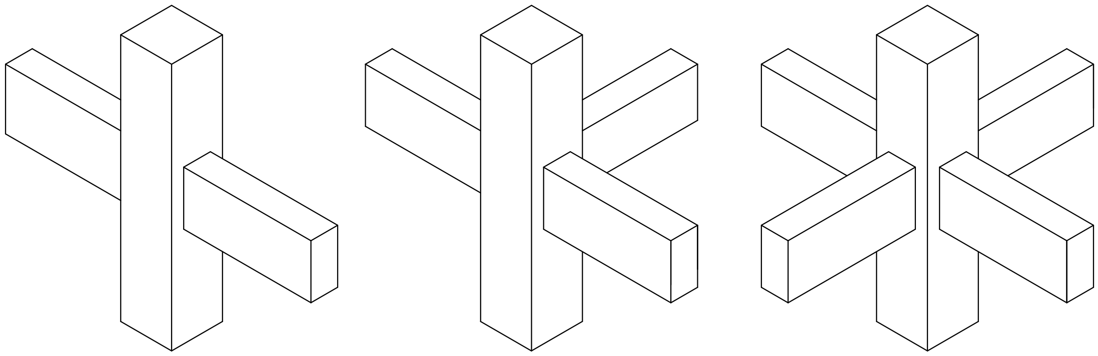


Figure 3: Fixed collumn support with self-tapping fully threaded screws

The fully threaded screws are inserted parallel to the fibre direction over the required determined depth. Compared to an oblique screw-in angle, the rather lower bond load-bearing capacity with a parallel screw connection is not a disadvantage, as the required force to be transferred can be ensured over the bonding length of the screws. However, the high rigidity of the connection in the parallel direction has a positive effect, offering the possibility of a stiffer connection overall. The number of screws required and the needed embedding lenght can be determined from the applied internal forces. For this purpose, the occurring moment is divided into a force pair consisting of a tensile force and a compressive force. The superposition of the moment and normal force results in the necessary force to be anchored in the tensile area of the column, which is to be transferred to the foundation via the steel plate using anchors. This normal force is distributed over the installed screws, whereby the transmitted force of each screw is determined by its embedding length. The achieved moment load-bearing capacity of the node can be used, for example, for the design of frame constructions or for building bracing.

3.2. Connection of beams to a column

The node point of columns with adjoining beams poses a particular challenge in timber frame construction, as direct support of the column on the beam or of the beam on the column results in local stresses in the weak direction of the wood. The implementation of continuous columns with 3 or even 4 beams connected on all sides is unusual. To realize such knots special solutions using steel prostheses are therefore used at the junctions. A variant with fully threaded screws would also be conceivable at this point. Figure4 shows a continuous column with two, three and four connecting beams at one point. The connection is made from below through the beam to the column so that the screws are stressed in the axial direction in accordance with their strong axis. To prevent the beam from twisting, additional screws can be arranged from above to create torsional rigidity in the connection. The connection can be assumed to be hinged, so that only the transmission of the transverse forces needs to be ensured by the screw connection.



a) two beams connection b) three beams connection c) four beams connection

Figure 4: Connection of two, three or four beams to a column

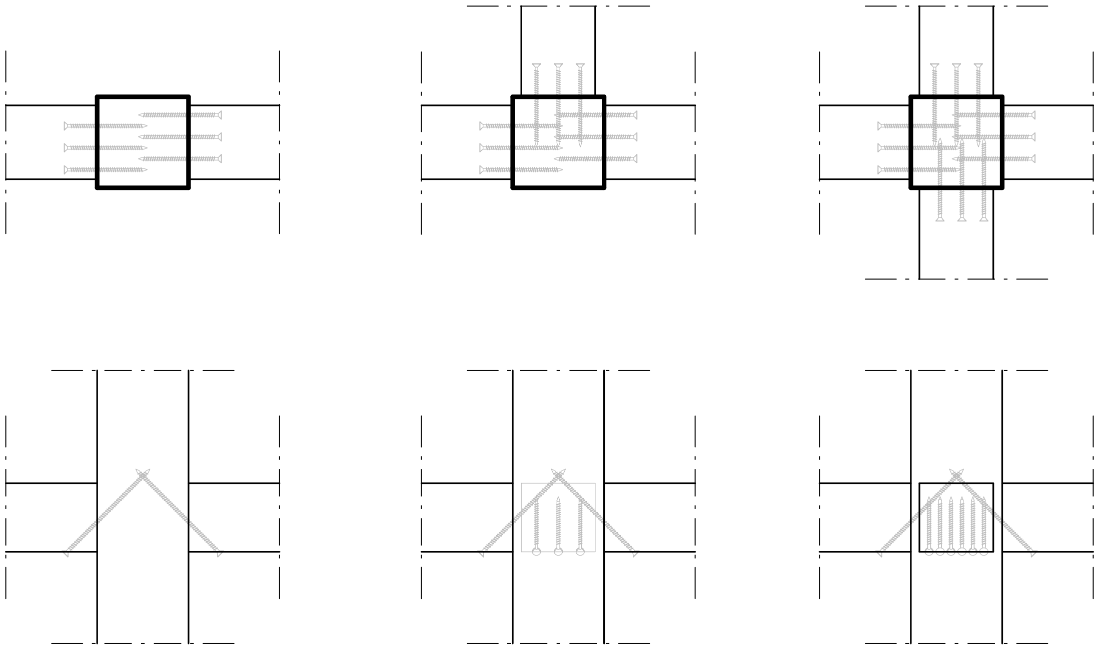


Figure 5: Variant A: Arrangement of fully threated screws with same screw lenghts and angles for one beam

Two different variants for the design of the joints with regard to the arrangement of the fully threaded screws are shown in Figures 5 and 6. In the first variant, the screws of one beam are all inserted at the same angle, which ensures an evenly distributed load. The axes of the bolts are arranged offset to each other with corresponding distances so that the minimum distances of 3d are maintained inside the column cross-section. This determines the external dimensions of the column and must also be taken into account when dimensioning. If there are three adjacent beams, the angle of the fully threaded screws of the additional beam can be steeper. In the case of a column with beams connected on all sides, the angles must also be adjusted.

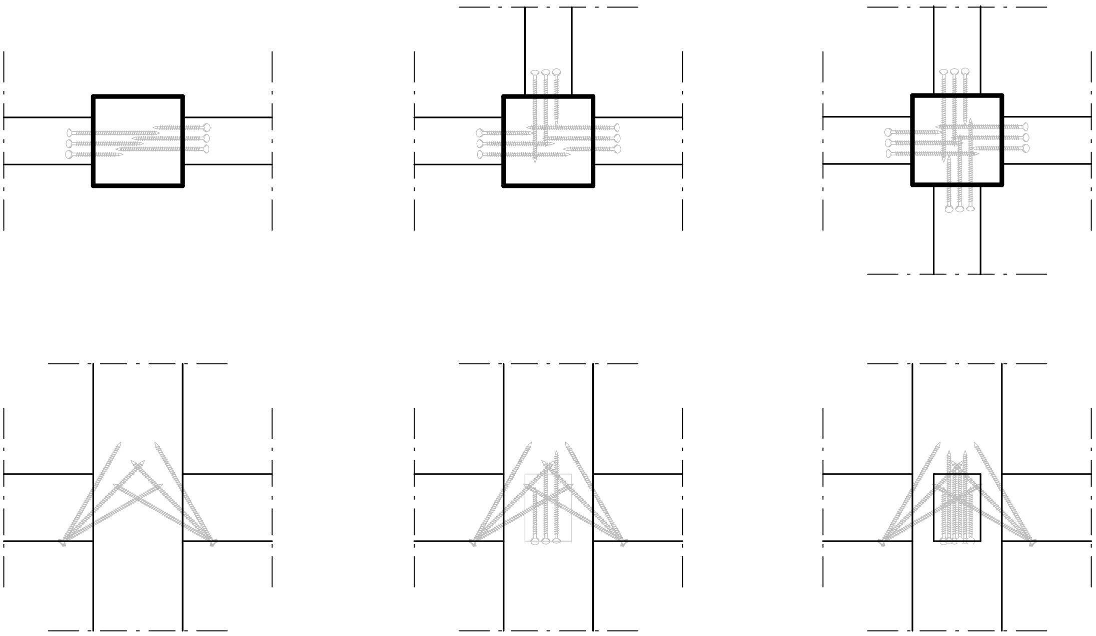


Figure 6: Variant B: Arrangement of fully threated screws with various screw lenghts and angles for one beam

Figure 6 shows the schematic structure of the second variant, in which the angle of the connecting bolts of a beam varies. This means that the space in the column cross-section can be used more efficiently so that the connections can be realized with significantly smaller cross-sectional dimensions. Depending on the force to be transmitted, the number of screws can be adjusted, and it is conceivable to have one in the width of the beam as well as the arrangement of a second row. In both variants, there is a large accumulation of screws inside the column cross-section, with a complex arrangement from different directions. The implementation of the connections is therefore only conceivable if precise positioning of the screws can be guaranteed.

4. Conclusion

The connection presented show extended application possibilities for self-tapping fully threaded screws for joining components and constructing details in structural timber construction. The applications relate to the use of long fully threaded screws. All connections shown require the possibility of precise positioning of the screws, which can only be reached by straight predrilling. This is accomplished with the currently developed pyrolytic predrilling process presented here.

In the case of the shown fixed column support, very long embedded length need to be expected to ensure a sufficient load-bearing effect due to the fiber-parallel installation. This requires a further development of the maximum drilling depth. Furthermore, the extent to which block failure of the screws can occur and what preventive measures can be taken to avoid this must be investigated.

When connecting beams to a column, there is a large accumulation of screws with a high potential for collusion, so that implementation is only conceivable if the positioning is exact. The complex arrangement with different angles from various sides creates further demands on the adaptability of the drilling process. Depending on the assumed variant, the installed screws also results in a reduction in the cross-section of the column. The extent to which this has an influence on the load-bearing capacity of the column must be investigated.

Following a similar principle to the specific solutions presented, fully threaded screws can also be used to join bar-shaped structures at different angles and also plate-shaped materials such as CLT panels. This can be used in the construction of shell structures discretized by straight or plane elements. Depending on the forces to be transmitted, the fully threaded screws can be analog used to ensure the required force transmission and rigidity of the connection. The development of further possible applications is the focus of further work.

In further stages of the project, the solutions shown will be implemented in prototypical assemblies and tested for the practicability of the application of the pyrolytic drilling process as well as for their load bearing properties. In this way, the advantages of the newly developed process for the production of deep boreholes can be assessed holistically.

Acknowledgments

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