REDEVELOPMENT OF A WOODEN ROOF CONSTRUCTION UNDER PERESERVATION ORDER

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Abstract

The built environment is of great importance for our modern society. It is our responsibility to preserve, rehabilitate and use our existing structures. Within the CEN member states, the so-called Eurocodes form the basis of design and verification of load-bearing capacities of structures. Current Eurocodes do not contain special recommendations for the evaluation of existing structures. Thus, the principles for new structures are also applied in the case of a verification of the load-bearing capacities of an existing structure.

However, the holistic redevelopment of existing timber structures requires a high standard of care and accuracy in all phases of planning and execution. In order to enable a substance-careful redevelopment, a detailed structural survey is required. In addition to the structural geometry, this also includes an exact assessment of the stability. Such an assessment can only be carried out if the load-bearing capacity of the timber members is determined as accurate and reliable as possible beforehand. Purely visual evaluations are usually insufficient, since visually detectable features only correlate slightly with the actual strength and stiffness. The additional use of non-/semi-destructive test methods can significantly improve the accuracy and reliability of the grading process.

This contribution presents the in-situ strength grading of timber members in existing structures using the example of a listed roof construction. Within a qualified survey as being done, detailed information concerning load and material parameters of the structure has been collected. A structural member is chosen exemplary to illustrate the effect of enhanced knowledge on the evaluation of the load bearing capacity. The applicability of DIN EN 1990:2010-12 on the evaluation of the load-bearing capacities of existing structures is discussed and a stepwise evaluation procedure for the evaluation of load-bearing capacities of a structural member using updated information is presented.
1 INTRODUCTION

Our built environment is a central part of our modern society. It is our responsibility to preserve, maintain and use our existing structures. They are part of our history, often of our cultural heritage, and objects to learn from for future constructions. What is more, our planetary boundaries remind us to act responsible with resources and energy. Hence, building with existing structures is an important social task and already a great part of the project volume in civil engineering. Especially timber constructions play an important role within the frame of existing structures. A significant share of historic structures has been built with timber, e.g. roof structures, timber beam ceilings, half-timbered houses and bridges, just to name a few. Due to its positive energy balance, its carbon dioxide neutral production and its pleasant appearance the use of timber already increases within the building industry.

Within the CEN member states, the so-called Eurocodes form the basis of design and verification of load-bearing capacities of structures. Current Eurocodes do not contain special recommendations for the evaluation of existing structures. The principles for new structures are applied on existing structures, too. In some countries, special rules for existing structures are available. To be named here are the Swiss standard SIA 269:2011 [1] and Italian standards such as UNI 11119 and UNI 11138 [2, 3] (see also [4]). A common approach does not exist yet. Hence, the potential of a qualified survey in situ is not fully used and load-bearing capacities are often underestimated. It must be analyzed which changes in the design concept are necessary for the evaluation of existing structures and how it is possible to include data gained in situ in the evaluation.

For concrete structures, recommendations to adjust the partial safety factor depending on the coefficient of variation (COV) to be measured in situ are part of a German recommendation [5]. What is more, in fib Bulletin no. 80 [6] the Design Value Method based on ISO 2394:2015 [7] is described to update partial safety factors for existing concrete structures. These are guiding developments for the evaluation of existing structures.

Such an evaluation can only be carried out as long as a comprehensive and detailed investigation of the existing structure is conducted. This includes the structural geometry and possible defects as well as an exact and reliable determination of the present load-bearing capacity of the timber members.

This is achieved by strength grading according EN 14081-1 [8] which allows a visual and mechanical grading procedure. The visual grading is focused on superficial visible and measurable growth characteristics whereas the mechanical grading uses non-destructive methods to determine material properties (see [9]). These grading techniques which were developed for new structural timber cannot or at least with large restrictions be applied on timber members in existing structures (see [10]).

Therefore, an in-situ strength grading of timber members is carried out only in very rare cases. The present load-bearing capacity of the timber members is assessed intuitively in most cases. The evaluation of the structural stability is then carried out considering the load-bearing capacity of “average-quality timber”—i.e. C24/D30 acc. EN 338. Reserves and deficits in the load-bearing capacity cannot be detected by this procedure. This leads to possibly less conservative and unprofessional redevelopment measurements.

The strength grading of timber in existing structures in connection with the application of non- and semi-destructive test methods allows the exact and reliable determination of the material properties. A purely visual evaluation of the timber members is in most cases not sufficient due to the weak correlation between the visually determinable material features and the present strength and stiffness properties [11, 12]. With the additional application of non- and
semi-destructive test methods a significant improvement of the accuracy and reliability of the in-situ evaluation of timber members can be achieved [9].

In this contribution, the potential of a qualified survey in situ to consider updated information within the evaluation of load-bearing capacities of an existing structure is analyzed. First, the case study and the main results of the evaluation steps are described. This includes the procedure of the in-situ strength grading. The effect of this update within semi-probabilistic and probabilistic evaluation is studied in the next section.

2 CHURCH OF ST. NIKOLAI IN BAD WILSNACK

The protestant St. Nikolai church (also “Wunderblutkirche”) in Bad Wilsnack (Brandenburg, Germany) has a building history of approximately 730 years. The first building was erected between 1286 and 1300. It was destroyed by fire in 1383. In 1384 the re-erection of the new church began. In the course of the destruction the legend of the “blood wonder” occurred so that the new church became a pilgrimage site. This rapidly led to the necessity of a larger church to master the constant flow of pilgrims. Therefore, around 1450 the extension of the existing church began. The mostly continuous construction phase lasted well into the 16th century until the reformation brought it to an end. In the following centuries the construction was constantly reconstructed and redeveloped.

![Figure 1: St. Nikolai church, Bad Wilsnack – left: exterior view (from [12]), right: view on the roof structure above the main nave (Source: Linke, 2018)](image)

The ground plan of the church is cross-shaped with three naves (see Figure 2). The main nave is connected to the side naves by a two-bay cross-vaulting. This runs in between the main nave and the choir and includes a chapel on the east side. Further chapels as well as the sacristy are located in the south and north part of the church. The exterior walls are erected in the style of the North German Brick Gothic. They are interrupted by several stained-glass windows and buttresses.
The eventful history of the St. Nikolai church as well as the representation of several centuries of cultural history and development in structural engineering led to the decision to set the whole building under preservation order.

In 2015 a survey concerning the conservative state and the planning of redevelopment measurements began (see [13]). The predominantly part of the planned measures concerns the timber roof structure.

3 INVESTIGATIONS ON THE LOAD-BEARING CAPACITY

In the course of the redevelopment of the roof structure an exemplarily investigation concerning the quality and load-bearing capacity of the timber members was carried out in 2018. The aim of this investigation was the testing and validation of an in-situ strength grading procedure. The results were also used to show the possibilities of a structural evaluation based on updated information and partial safety factors. The actual investigation of the roof structure concerning the planning of redevelopment measures was carried out beforehand (see [13]) and is nor part of this contribution.

The conducted investigation included several non- and semi-destructive test methods, as listed below:

- Visual strength grading according EN 14081-1 [8] and DIN 4074-1/-5 [14, 15] based on the in situ measurable criteria (i.e. knots, wane, slope of grain, cracks)
- Determination of the moisture content according EN 13183-2 [16]
- Ultrasonic time-of-flight measurements
- Determination of the density and compressive strength of extracted core drill samples
The investigation concentrated on the roof structure above the main nave (see Figure 2, No. 1). Overall 19 timber members in four trusses have been made of pine and oak were examined. The results of the visual strength grading are depicted in Figure 3. Two thirds of the examined pine wood members are classified to class S10 acc. DIN 4074-1 (average load-bearing capacity). The remaining pine wood members met the requirements of class S13 acc. DIN 4074-1 (high load-bearing capacity). The examined oak wood members showed a comparable yield, whereas 57% were classified into class LS10 acc. DIN 4074-5 (average load-bearing capacity). Another member was classified into class LS13 according DIN 4074-5 (high load-bearing capacity). The remaining two oak wood members had to be classified as LS7 (low load-bearing capacity). The decisive criteria were knots and slope of grain.

![Figure 3: Yield of the visual strength grading](image)

The examined members have also been graded based on the measured ultrasonic velocity. This was achieved by applying the limiting values proposed in [9]. The resulting grading yield is shown in Figure 4. The comparison of the results of the visual and the ultrasonic grading shows that the predominantly part of the examined timber members could be assigned to a higher class. Approximately 20% of the timber members were assigned to the same class. Only one member (≈ 5%) had to be classified in a lower class.

![Figure 4: Yield of the ultrasonic grading](image)
The results of the ultrasonic grading are verified by the results of the laboratory tests. For approximately 90% of the examined timber members can be assigned to the same class based on the ultrasonic velocity and the determined density and compressive strength. This proves the fact, that a solely visual grading underestimates the load-bearing capacity [11, 12]. Furthermore, the improvement of the grading yield by applying multiple test methods which was already proven on new construction timber could be verified in this exemplarily investigation.

2 ASSESSMENT OF THE STRUCTURAL STABILITY (LOEBJINSKI)

3 SUMMARY & CONCLUSION

The results of the insitu strength grading have shown that a detailed survey concerning the material quality adds to the accuracy of the structural evaluation. The investigation also showed that it is possible to use partially high load-bearing reserves. Simultaneously, deficits in the load-bearing capacity can only be detected accurately by a detailed investigation.

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REFERENCES


