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New procedure for timber in heritage buildings - the case study of Castle Friedenstein, Gotha (Germany)

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Abstract

A 370-year-old castle Friedenstein, Gotha (Germany) is expected to get listed on tentative World Heritage List similar to several other Thuringian castles. Timber takes a huge part in its structure and therefore requires additional but also different kind of attention aligned with the current trends. Within the framework of ecological transition, new procedures for the timber assessment are developed as reflection of new values given to the preservation of structure. Ecological transition added importance to preservation of as-much-as-possible-of the available material, not only for the sake of authenticity but, even more, for ecological reasons. Nowadays it is preferred to preserve timber if possible, instead of replacing it with concrete or steel. In the past two decades, the general assessment of existing timber constructions and the determination of material quality increasingly have become the focus of research and standardization at the international level. Unless the state of material is known, it cannot be used any further. The goal is to achieve more precise determination of the material properties using as little invasive methods as possible. In this case, the method was tested on timber for the floor of castle Friedenstein. We described the procedure which reveals dedication to ecological transition with particular attention to details of timber structure.

Keywords: Timber Structure, World Heritage, Assessment, Strength Grading, NDT/SDT

1. Introduction

Rule of minimum interventions nowadays in the light of ecological transition refers also to the amount of new material which is used, even when that material is identical with the existing. Built World Heritage is expected to serve as an example regarding values which must be cultivated in the future, therefore, also in this specific context WH should carry the torch.
In this paper we demonstrated new procedure for the assessment of timber as precondition for further use of the same material. This procedure is designed to meet new contemporary standards which must be respected on all buildings, even when they are listed as World Heritage, for the sake of safety of visitors. We used example of Castle Friedenstein which is expected to be listed in the time ahead.

2. Architectural Aspects of UNESCO World Heritage

Castle Friedenstein is approximately 370 years old castle located in Gotha (Germany). More precisely, it was built between 1643 and 1656 on behalf of Duke Ernst I "the Pious" of Saxe-Gotha-Altenburg. The palace complex was planned by the Erfurt master builder and architect Caspar Vogel (born ca. 1600, died in 1663).
The actual palace is one of the biggest palaces of its kind (Fig. 1). It was constructed as huge, a four-winged building and four-stories high. It consists of the main building situated in the north wing, the adjoining three-story, east and west, wings, and the gate building in the south. The length of the north

wing is 100 meters and the length in the east-west direction is 140 meters. There are two outer buildings on the north side. The side wings end in two four-story tower-like head buildings. The castle was built at the end of 30-year old war and therefore carries symbolic name meaning a peace-rock.
It was designed not only for living and representation, but also for administrations, economic areas, military and church purposes. With its extensive gardens and parks, the palace forms an impressive complex.
Till 1894 it was the residence and administrative center of the Duchy of Saxe-Gotha, which is situated at the heart of Germany. The ruling family had important role in European history, in particularly due to its most famous members of newly established Sachsen-Cobourg and Gotha line – Queen Victoria and Prince Albert. It was not damaged during the WW II and it has been excellently maintained overtime. Since the last heir passed away, it has been opened for public and hosts several museums, the Thüringen State Archive, the Gotha Research Library and Ekhof Theater with original baroque support for mizenscen,and more.

Figure 1: Aerial photograph of the Friedenstein palace complex source: [STSG, 2017]

Eventually, Friedenstein is one of the first baroque castles in Germany, and because of the role of the Cobourg-Gotha family in European history, it attracts a lot of public attention. It belongs to the Thüringen Palaces and Gardens since 2004. The federal government and the state of Thuringia are co-financing renovation which was initiated in 2017 and should be completed in 2031. A big part of its structure is made of wood.

3. In-situ strength grading of timber members

3.1 Regulations for the assessment of existing timber structures

The redevelopment, preservation and future use of existing structures is of increasing economic, ecological and social importance. In order to ensure professional, substance-careful and economic interventions in existing constructions, a comprehensive assessment of the building condition is required. In the recent past, the latter has increasingly become the focus of research and standardization. For example, Italy, Switzerland and Austria published national codes for the assessment of existing structures - especially timber structures - in the period 2004-2013 (see [1]).
In 2015, the Joint Research Centre of the European Union published a first draft of a unified guideline for the assessment of existing structures, which is in line with the regulations of the Eurocodes (see [1, 2]). At the same time, the COST action IE0601 "WoodCultHer" developed a guideline for the assessment of the structural condition of historic timber structures (see [3]). Both guidelines have since been transferred into European standards (see [4, 5]). The essential procedure includes not only

the assessment of the structural geometry, the present loads and influences and any possible damage, but also the determination of the existing material quality. However, the currently available international codes [4, 5] only specify general requirements. The material quality should usually be determined using the strength grading methods developed for new timber.
However the strict, unrestricted application of these methods is usually not possible in-situ (see [6]). In practice, therefore, in-situ strength grading is rarely carried out and then only visually and to a limited extent. Usually, the material capacity is only estimated and static calculations are carried out assuming an average load-bearing capacity. A reliable assessment of the material quality is thus not possible. Therefore, alternative approaches are necessary. The combination of a visual examination and non-destructive/semi-destructive testing methods is currently the general consensus. However, concrete specifications for the application of an in-situ strength grading are still not available in the existing regulations.

3.2 Methodology for in-situ strength grading

The determination of the material quality is of central importance for the evaluation of existing constructions. On the one hand, it can reveal load-bearing capacity reserves that can be used in the verification process of the structural stability. This applies in particular if an increase in load is to be expected in the course of the future use. On the other hand, the detection of load-bearing capacity deficits enables targeted, professional redevelopment measures.

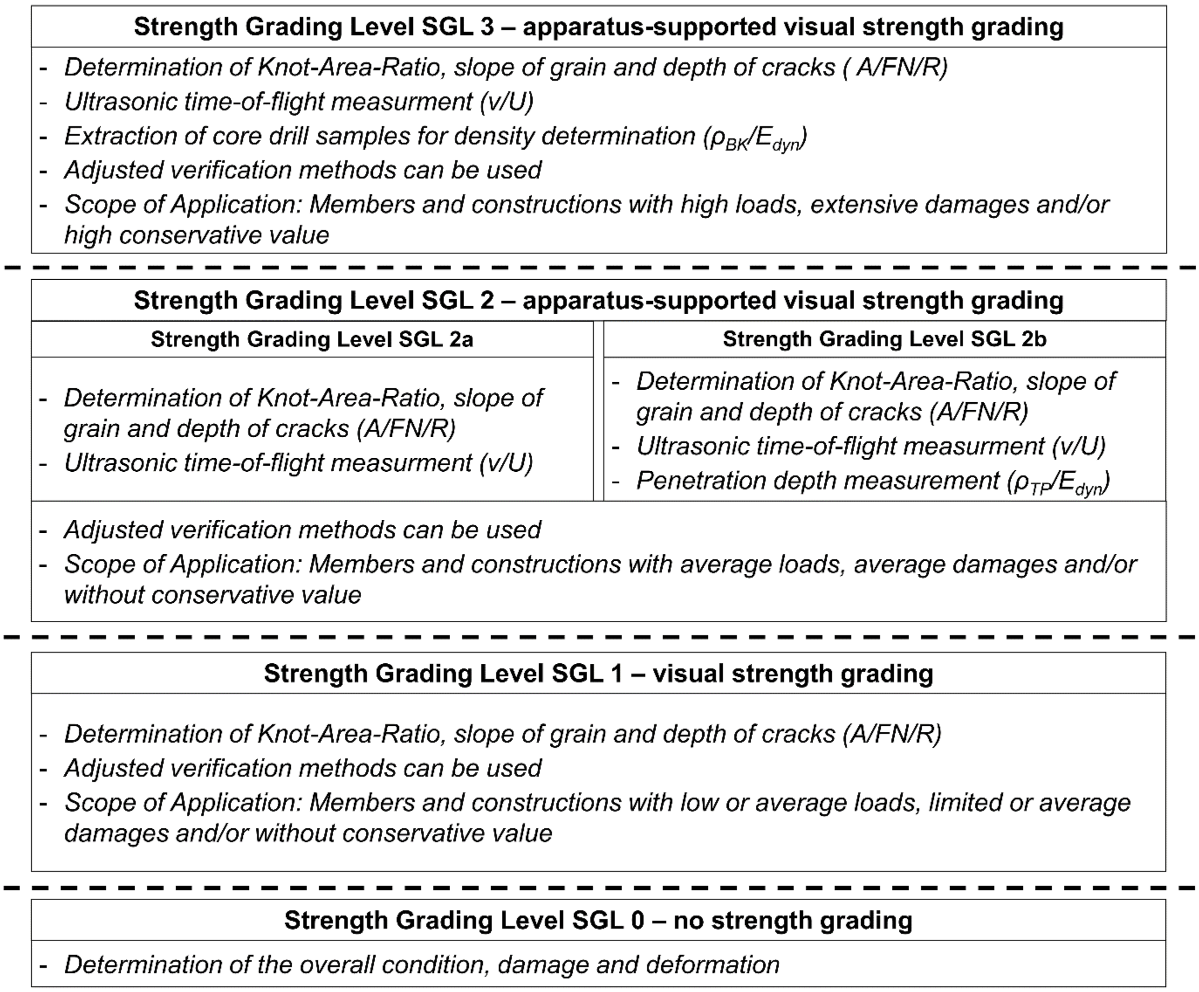

Figure 2: Schematic representation of the methodology for in situ strength grading.

Currently, investigations in this regard are mainly limited to visual examination and grading. However, this is limited in its informative value, as studies on new timber have already shown (see [7]). For timber members in existing constructions, the reliability is additionally reduced by the limited visibility. On the other hand, the combination of visual grading with non-destructive and semi-destructive test methods leads to a significant improvement (see [7]).
The lack of concrete specifications for determining the material quality of timber components in existing buildings has led to numerous non- and semi-destructive tests methods being investigated

and put to test with regard to their applicability for in-situ strength grading over the past two decades. A summary of the current state of the art can be found in [6].
In the period 2017-2021, systematic investigations into the strength grading of timber components in existing structures were carried out at Brandenburg University of Technology in Cottbus/Germany in cooperation with the Laboratory for timber construction and ecological building technology in Eberswalde/Germany (see [8]). The aim of the investigations was to develop a methodology for in-situ strength grading based on non- and semi-destructive test methods. For this purpose, specimen made of new spruce, pine and oak timber were examined in comparative material tests. The investigations included visual grading, ultrasonic time-of-flight measurements, density determination and destructive bending tests.
On this basis, a methodology for in-situ strength grading was derived. This is based on the determination of a so-called grading parameter with the help of a multi-level, multi-parameter regression model. Results from several non- and semi-destructive methods are taken into account in the grading process. The multilevel nature of the grading methodology allows the scope of the investigation to be specifically adjusted to the respective conditions on site and the objectives of the investigation as a whole (see Fig. 2). Thus, less extensive investigations are required for subordinate structural components. The main structure and critical components, on the other hand, require a more detailed investigation. Furthermore, depending on the grading level the methods for the verification of the structural stability ca also be adjusted, as shown in [9].
The application of the grading method on specimen made of new timber showed a high reliability of the method. The method described in [8] was adapted and further developed on the basis of further investigations on old timber members in order to further reduce existing uncertainties (see [10]).

4. Castle Friedenstein, Gotha (Germany) – A case study

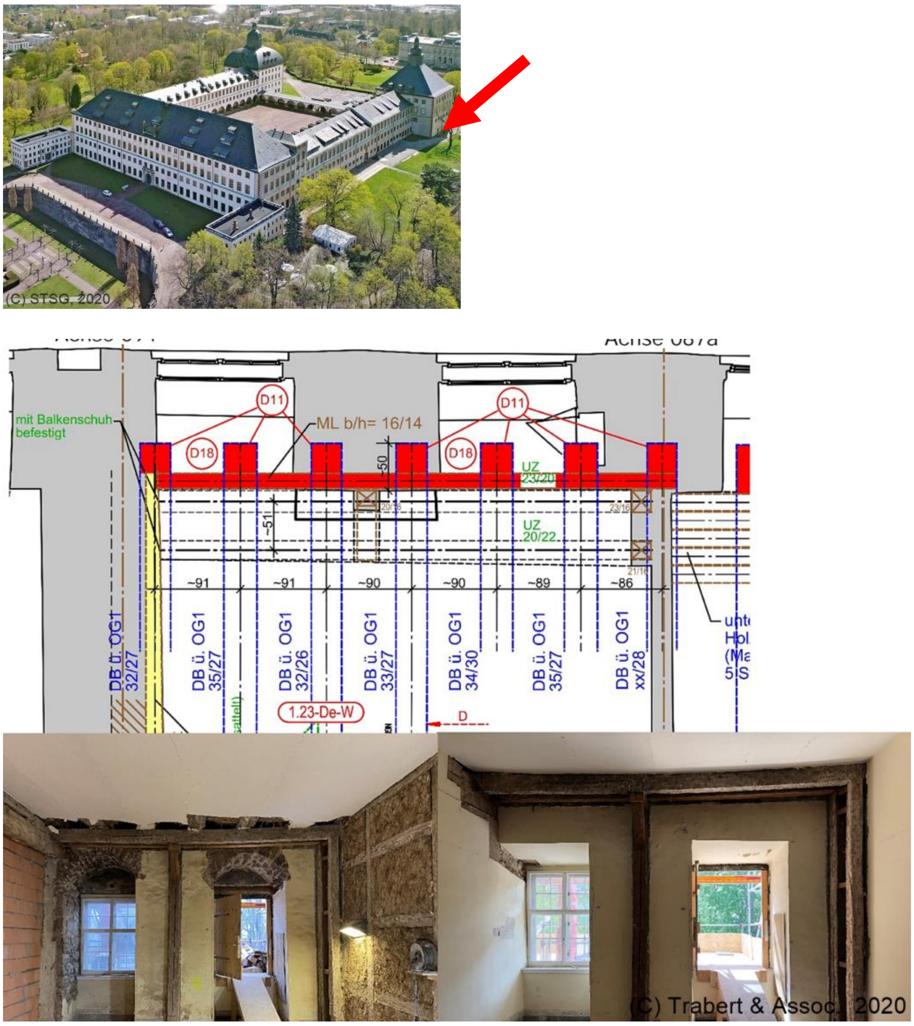

Figure 3: Top; the location of investigated ceiling is marked in red, Middle: mapping of organic damages and Bottom: interior view on the ceiling.

4.1 Scope of the study & methodology

Since 2018, extensive redevelopment work has been carried out on the west wing. In addition to repairing the foundations (masonry pillars), the wooden roof construction and the historic stucco ceilings, a barrier-free access is also being constructed. In the course of this, parts of the historic ceiling constructions between the first and second floor of the west wing have been dismantled (see Fig. 3).

The investigated ceiling showed partial damage due to wood destroying funghi along the exterior wall (see Fig. 4). In the course of previous redevelopments the ceiling beams were already supported with additional joists and columns (see Fig. 3, bottom and Fig. 4).

The ceiling beams (spruce timber) were made available for the performance of material test in order to enable a more precise evaluation of the timber structures in the context of future redevelopment measures. They were cut into specimen and underwent comparative material test. The material tests carried out for this purpose corresponded to the comparative study described in [8] and were subdivided as follows:

- Visual grading
- Ultrasonic time-of-flight measurements
- Density determination
- Destructive bending test to determine bending strength and modulus of elasticity

The results of the material tests were then used to strength grade the sample material using the methodology described in [8]. On the one hand, the sorting methodology was to be tested in this way with regard to its practical applicability. Furthermore, the grading served as a basis for the evaluation of the remaining timber constructions in the west wing of the castle.

Figure 4: Illustration of state of the timber beams

4.2 Results & Discussion

The visual grading showed that about three quarters of the sample material examined could not have been used as construction timber according to the current grading regulations. The main reasons for this were pronounced shrinkage cracks and the disadvantageous slope of grain. In addition, individual test specimens also showed longitudinal curvatures and locally restricted damage caused by wood-destroying fungi. The remaining test specimens had an average or above-average load-bearing capacity.

Taking into account the fact that the floor beams did not fail due to overloading, severe deformation or even the present organic damage and that their load-bearing capacity was still as given after nearly 370 years, the results of the visual grading show that a strict application of the grading rules developed for new construction timber is not suitable for assessing the material quality of timber components in existing constructions without a more detailed assessment and the use of additional measuring and test methods. This becomes particularly clear when comparing the results of visual grading with grading based on destructive bending tests (see Fig. 5).

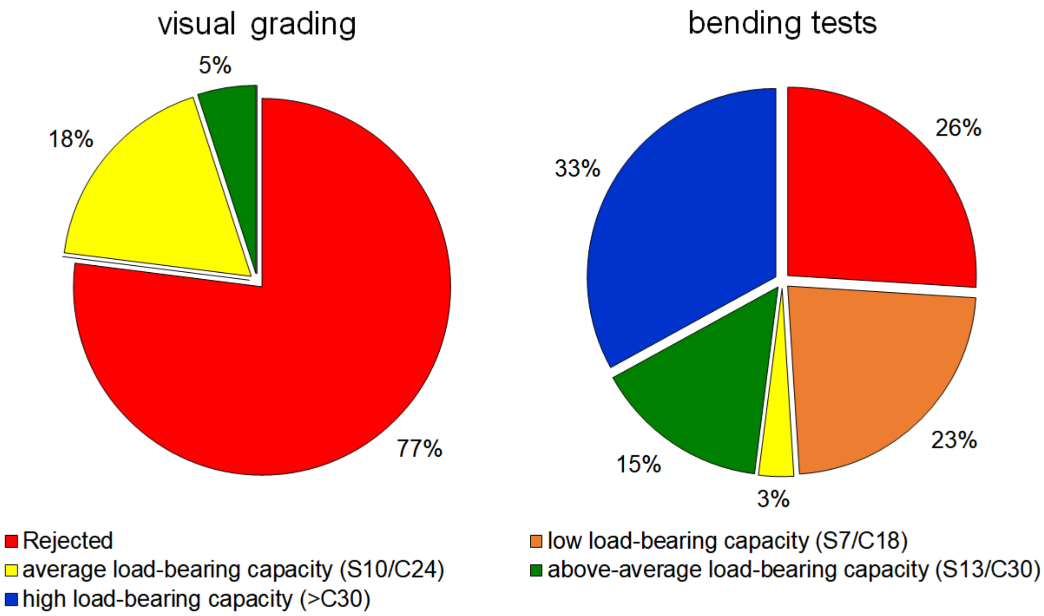

Figure 5: Comparison of the results of the visual grading and the destructive bending tests.

The in-situ strength grading method made it possible to estimate the load-bearing capacity of the sample material more precisely. Depending on the strength grading level, the overestimation of the actual load-bearing capacity determined by testing was (6...15) %. The reliability of the sorting method is therefore given. Furthermore, it has been shown that comprehensive strength grading of timber components in existing constructions can in some cases reveal considerable load-bearing capacity reserves that can be used in the evaluation of structural stability. As already described, an average load-bearing capacity is usually assumed. For softwoods, this corresponds to strength class C24 according to EN 338 or a characteristic bending strength of 24 N/mm². With the help of in-situ strength grading, some of the sample material could be assigned to strength class C40 according to DIN EN 388, which has a characteristic bending strength of 40 N/mm². This results in a load-bearing capacity reserve of 67 %.

At the same time, however, it is also evident that for a reliable assessment of the material quality, extensive technical expertise - especially with regard to the load-bearing and fracture behavior of timber components - is required. Those test specimens that could not have been used as structural timber even on the basis of the destructive bending tests all failed prematurely due to disadvantageous located cracks and preliminary mechanical and biological damage. Such structural features are not reliably detected by the non-destructive/semi-destructive test methods which were applied and must be visually recorded and taken into account when assessing the material quality.

5. Final remarks & conclusion

In huge buildings and extensive use of timber as it is the case with Friedenstein castle, strategy of restoration of one of the dominant construction materials strongly affects flow of the project and its funding. That is why the decision-making process cannot be led by instincts or mere desire. On the contrary, all and every option must be thoroughly reconsidered, and the decision must be based on proper arguments which should preferably be quantified. In other words it should be based on well-established method. The concerns spread into two directions. Firstly, responsible heritage management is expected by all means to reconsider if existing timber can be reused or not, for the sake of authenticity, restoration effort and expenses. It is in the interest of the integrity of heritage building to keep all timber which can serve its purpose even after 370 years as in this case. Secondly, providing such huge amount of timber nowadays and, that is high quality timber, with substantial spans and dimension of section, has obvious ecological footprint. Such action reduces in numerous ways quality of our living environment, due to timber production from living trees, causing degradation, additional energy consumption and transportation needs. Therefore both aspects lead to keeping timber as preferable choice. Both lines of thoughts are eventually concordant, which proves that preservation of built heritage is essentially ecological human activity, whose coordination with ecological transition should develop harmoniously to the great extent. However, in this particular case, the method showed that preserving existing timber is not possible because it cannot serve further its purpose in safe and reliable way according to existing standards. Keeping it would eventually lead to endangering the heritage building and subsequently, it may even cause permanent loss.
Therefore, we proved that decision regarding use of old timber or not should be tested by adequate method. It is highly desirirable that similar decisions regarding heritage buildings are more and more based on proved methods in the future, which should be subject of further research.

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