

## EVALUATION OF EXISTING TIMBER STRUCTURES – CURRENT STANDARDS FOR THE ASSESSMENT AND EVALUATION IN GERMANY AND EUROPE

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### Abstract

*In Germany, general building regulations regarding planning and execution of structures in compliance with public safety requirements are valid for both, the erection of new and the preservation of existing structures. However, the regulations within current Eurocodes have been developed for new structures. The evaluation of load-bearing capacities of existing structures necessary due to alterations or damages must be performed based on current codes. Especially for existing structures, the application of these standards can cause difficulties and safety issues. What is more, the evaluation of load-bearing capacities in compliance with codes and standards developed for the erection of new structures requires detailed knowledge regarding the technical characteristics of the historical construction at hand. Thus, a comprehensive assessment and evaluation of the actual state to investigate the load-bearing capacity of an existing structure are necessary requirements.*

*Codes and regulations for the assessment and evaluation of existing structures have been developed on an international – especially European – level within the last 15 years. Switzerland can be seen as a pioneer since a whole series of standards for the evaluation of existing structures has been introduced in 2011. These standards belong to the first ones containing regulations for the evaluation of existing structures. Further developments to be considered are current Italian standards, ISO 13822:2010 and the JRC Science and Policy Report 2015.*

*The following contribution summarizes these developments. Besides, the state of the art and of the standardization in Germany is analysed regarding their applicability on the evaluation of existing timber structures. The comparison between the international and national state of the art shall contribute to the development of a common approach for harmonized European standards for the assessment and evaluation of existing structures.*

## 1 INTRODUCTION

The application of codes for new structures – for example EN 1990:2010-12 [1] and EN 1995-1-1:2010-12 [2] – for the evaluation of the structural stability of existing structures must be viewed as critical. The partial safety factors (PSF) which cover uncertainties that occur while planning new structures have to be applied on existing structures. These uncertainties are caused by the variabilities of the loads and the material properties as well as the planning itself. The consideration of the predominant part of these uncertainties is not or at least not entirely necessary for existing structures. Therefore, the strict application of these design rules can lead to uneconomical, unprofessional and not substance-careful redevelopment measurements. Especially on historic structures under preservation order this must be avoided.

With the help of probabilistic methods, modified partial safety factors can be calibrated, and load-bearing reserves can be exploited, see e.g. [3, 4]. Thus, an improved evaluation of the structural stability of the existing structure is possible [5]. This provides the opportunity to plan substance-careful and professional redevelopment measures.

In order to modify the partial safety factors, the conservation state of the structure has to be examined and assessed as detailed and exactly as possible. It is the only way to quantify the present uncertainties in a reliable manner.

An essential part of such an examination is the determination of the material quality of the timber members and the variation of their material properties. This is achieved by strength grading. 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 [6, 7]).

Several codes and regulations for the assessment and evaluation of existing structures have been developed on an international – but here more important on a European – level within the last two decades. Nevertheless, up to now there are no standards or regulations available in Germany.

The following contribution aims to summarize the current developments. Furthermore, the present state of the German regulations concerning the assessment and evaluation of existing timber structures is systemized and compared to international developments.

## 2 CURRENT STANDARDS IN GERMANY FOR THE ASSESSMENT AND EVALUATION OF EXISTING TIMBER STRUCTURES

The redevelopment of existing timber structures usually requires an evaluation of its structural stability. This requirement can result from different circumstances as listed below (see also [8, 9]).

- Change of the planned use (change of the applied loads)
- Damage of the construction, e.g. due to insects/fungi or fire
- Mechanical damages or deformations due to adversely interventions in the load-bearing structure, e.g. due to overloading or structural changes
- Deviations of the primary planning and the eventual execution
- Securing the structural stability in the case of fire or seismic activities

Irrespective of the cause, the assessment and evaluation of existing structures must be conducted according to the valid regulations and design rules for new structures [1, 2]. This can lead to several problems since the uncertainties of new construction projects which are covered by the partial safety factors are mostly not present in existing structures. Therefore, the load-bearing capacity of existing structures is often underestimated. The strict application of the design rules can lead to uneconomical, unprofessional and not substance-careful redevelopment measurements.

This can be avoided when the structural stability is evaluated based on the present conservation state of the structure. In order to enable such an evaluation, the required information has to be gathered on site [6, 8]. In doing so, the material quality as well as the corresponding uncertainties to be considered can be assessed. Load and material models can be updated based on this assessment what gives the opportunity to modify the partial safety factors and use possible load-bearing capacity reserves. Thus, a reliable and realistic evaluation of the structural stability is possible [10, 11]. Additionally, redevelopment measures can be planned and executed more substance-careful, economical and professional.

The principal approach is not regulated by standards or codes in Germany. Solely the Technical Committee for Structural Engineering of the conference of Ministers of Building (ARGEBAU) released general instructions for the verification of structural stability of existing structures in 2008 [12]. These instructions are independent of materials and construction methods. According to this guideline it is possible to assess and evaluate the structural stability of existing structures based on codes and design rules which were valid at the time of the constructions erecting. However, when deficits in the load-bearing capacity are revealed or a change in the construction is intended, the static calculation for the eventually necessary redevelopment measurements must be carried out according to codes and design rules valid nowadays. The application of probabilistic methods as well as the update of the required information are neither recommended nor considered.

The modification of partial safety factors is allowed for reinforced concrete structures in [13], whereas these recommendations are not part of the current standards. The necessary requirement for the modification is a detailed survey on-site which includes the determination of the material properties and their variation. Here, a modification of the PSF is possible, if the coefficient of variation (COV) of the material property can be determined. What is more, in Switzerland the PSF  $\gamma_G$  for permanent actions can be reduced if permanent loads and the geometry is assessed carefully on site.

The on-site investigation respectively the assessment of the conservation state is not regulated by standards in Germany yet. The guideline of the VDI [14] which was released in 2010 aims at the regular inspection of structures and buildings. They are also mostly independent of materials and construction methods. The special characteristics of timber structures are considered more in general. Furthermore, this guideline is originally aimed on the assessment of the general state of the construction. The results of an inspection which is strictly conducted according to this guideline are insufficient for a reliable evaluation of the structural stability.

Within research activities and based on practical experience, a widely accepted approach on the assessment and evaluation of the functional capability of timber constructions has been developed in the last 25 years. This approach is depicted in Figure 1.

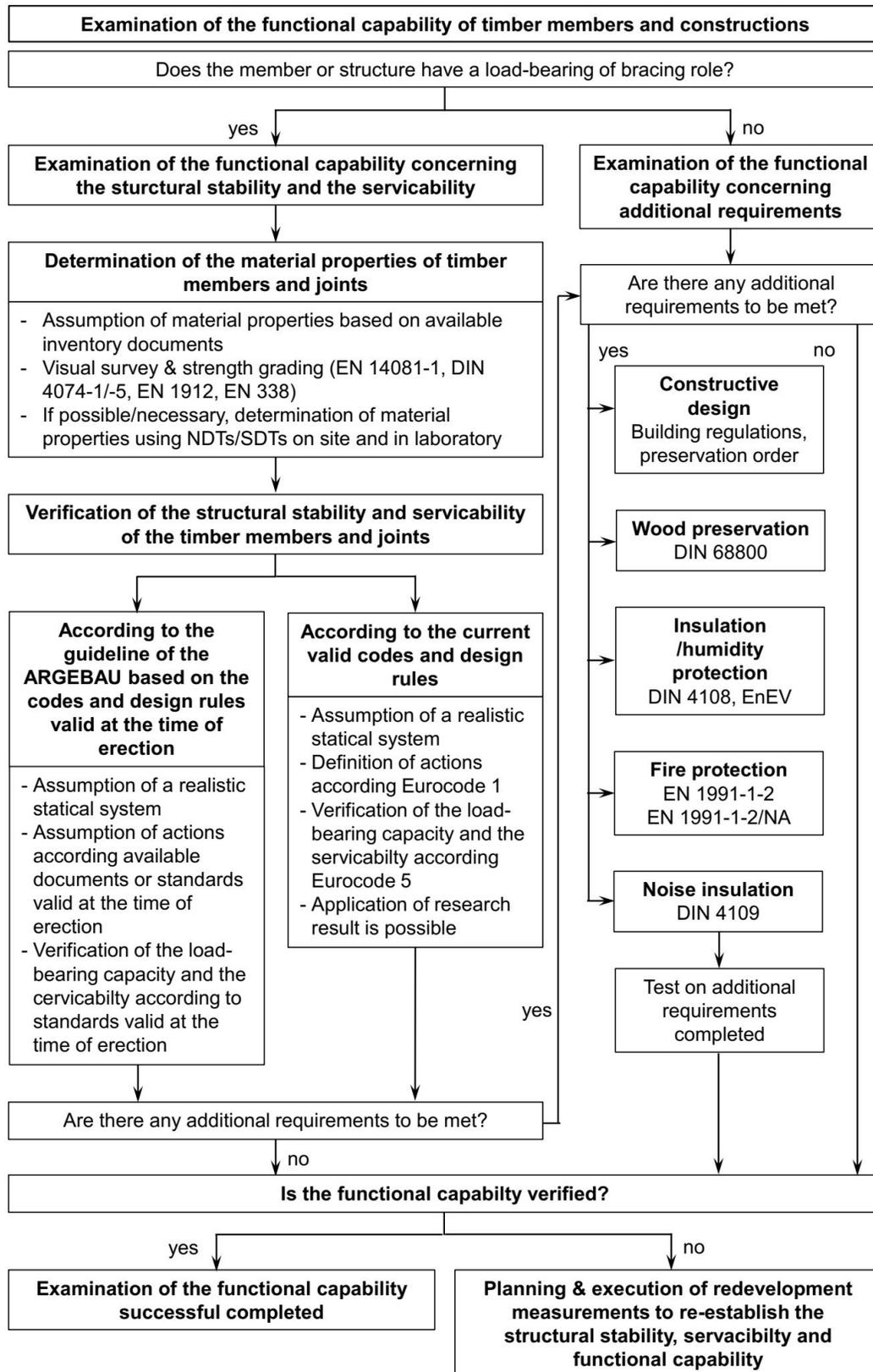


Figure 1: Functional capability test for load-bearing timber members in existing structures (out of [6], amended by the authors).

### 3 CURRENT STATE OF INTERNATIONAL STANDARDS CONCERNING THE ASSESSMENT OF THE CONSERVATION STATE OF EXISTING TIMBER STRUCTURES

Within the last two decades an international trend aiming for the development of codes and guidelines for the assessment and evaluation of the conservation state of existing structures could be observed.

In 2004 the Italian UNI 11138:2004 [15] was published as the first standard containing rules for the evaluation of the structural stability and planning of safety and redevelopment measures for existing timber structures. There, the determination of the present material properties is postulated as the fundamental requirement for the evaluation of the structural stability. This should be carried out according to UNI 11119:2004 [16]. The purpose of this standard is to define aims, methods and evaluation criteria of structures under preservation order. Besides, fundamental measures – such as the determination of the wood species, the structural geometry and eventually present damages – strength grading of the timber members is demanded.

Strength grading can be carried out globally for the whole structure or locally for separate segments or members. Since grading methods which were developed for new structural timber cannot be applied on timber members in existing structures, UNI 11119:2004 [16] establishes exemptions and clarifications concerning the on-site strength grading. On principal, the grading process should be a combination of a visual survey respectively grading and the non-destructive determination of at least one physio-mechanical material property (see [16], chapter 7.5). In exceptional cases, strength grading can be carried out exclusively by applying non-destructive test methods.

The Swiss standard SIA 269 [17] which was published in 2011 is a whole series of standards for the assessment and evaluation of the conservation state of existing structures. The standard SIA 269-5:2011 [18] deals with existing timber structures in particular. There, the update of information – i.e. actions and material properties – is explicitly demanded. Similar to the Italian standards this should be done in a visual survey combined with non- and semi-destructive test methods. In contrast to the regulations of UNI 11119:2004 [16] the grading methods for new structural timber can be applied without exemptions. The extent of the survey is dependent on the required level of knowledge of the timber structure. In this context it is differentiated between a “limited”, an “average” and a “comprehensive” level of knowledge. The corresponding extent of the survey is given in Table 1.

**Table 1:** Required survey extent for the update of information according to SIA 269-5:2011 [18].

<b>Knowledge Level</b>	<b>Required survey extent</b>
„limited“	Specifications based on project plans and service specifications or based on assumptions according to usual construction methods at the time of the erection
„average“	Specifications based on construction plans, invoices and other inventory documents or based on an investigation of about 50 % of the members and joints in the highly endangered areas under consideration of the climate conditions
„comprehensive“	Specifications based on updated construction plans together with corresponding reports or based on an investigation of about 80 % of the members and joints in the highly endangered areas under consideration of the climate conditions

When a “limited” knowledge is sufficient for the evaluation of the structure, the specifications of inventory documents can be used according to SIA 269-5:2011 [18]. If a “comprehensive” knowledge is required it can only be acquired by accurately archived inventory documents. Such documents are seldom available. In that case, the updated information must be acquired in an extensive on-site survey with the help of “special” methods. These “special” methods are a series of non- and semi-destructive test methods which are as well listed in SIA 269-5:2011 [18].

In 2013 another national code, the Austrian guideline ONR 24009 [19], was published. This guideline for the evaluation of the structural stability of existing structures can be applied on all major construction methods and building materials. Although there are no special rules for timber structures, this guideline also follows the principle that the structural evaluation should be based on the previously assessed conservation state.

The standards and guidelines outlined above are essentially identical match the regulations of ISO 13822:2010 [9]. Though it is recommended that the structural evaluation should be carried out based on inventory documents available, it is also recommended to use updated information on the structure if possible. This approach allows the consideration of the influences of present damages due to biotical harmful organisms, environmental conditions of past incidents – e.g. fire or earthquake –. Thus, an on-site survey with a specific focus on the present material quality is required. Besides, non- and semi-destructive test methods as well as destructive methods can be used.

In the past decade several other standards for the assessment and redevelopment of existing structures have been published across Europe – e.g. NEN 8700 (Netherlands, 2011), Code of Interventions (Greece, 2013), CTE DB SE Annex D (Spain, 2009). In general, all the existing national standards and guidelines show a broad consensus in the principal approach on the evaluation of existing structures. However, harmonized European standards have not been published yet.

Preliminary approaches on the development of a consistent European standard have been undertaken in the past ten years. In this course, the publications of the COST Action E55 (“Modelling of the Performance of Timber Structures“, e.g. [20]), COST Action IE0601 (“Wood Science for Conservation of Cultural Heritage – WoodCultHer“, e.g. [21]) and COST Action FP1402 (“Basis of Structural Timber Design – from Research to Standards”) have to be named as pioneers. The reports which have been published by these committees are strongly oriented on the international state of the art and the standardization. The proposed policies and procedures are in general identic with the regulations of ISO 13822:2010 [9] and the already outlined Italian, Swiss and Austrian standards and guidelines (see [15-19]).

A first proposal for a European standard has been developed by the Working Group WG2 of the CEN/TC250. This proposal was summarized and published in the report of the Joint Research Centre (JRC) „New European Technical Rules for the Assessment and Retrofitting of Existing structures“ [22]. The aim of the proposed standard is the harmonization of the deviating requirements and methods of the evaluation of the structural stability of existing structures with the principles of the Eurocodes [1].

Fundamentally, the structural evaluation in this report [22] is divided into a so-called preliminary and a detailed assessment. The preliminary assessment should be used to clarify whether immediate safety interventions are necessary and to plan further investigations. This includes the compilation of all available inventory documents as well as a preliminary visual survey of the construction. Based on these preliminary measures the detailed assessment is planned and carried out, which should aim on an exact and reliable evaluation of the construction’s structural stability and the derivation of middle- and long-term measurements. The detailed assessment includes a detailed investigation of the existing structure, the analysis of the

documents available, the update of the actions and material properties, the verification of the construction's structural stability and its approval as well as the development of further redevelopment and maintenance measures. A division into preliminary and detailed assessment can also be found in the Swiss code SIA 269:2011 [17] described above.

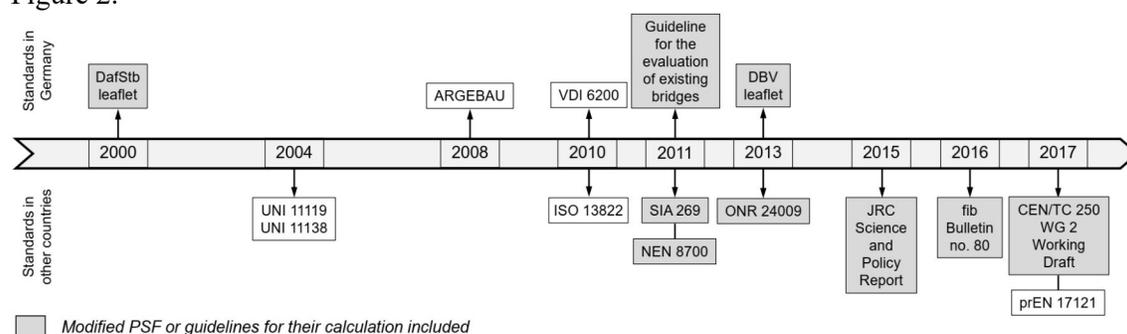
According to [22] the evaluation of the conservation state should be carried out based on updated information. This includes actions, geometrical parameters and material properties. The latter can be determined applying non- and semi-destructive test methods which have been calibrated in destructive material test. If the characteristic material values should be determined, the extraction and destructive test of sample material is recommended.

The guideline which is proposed in [22] summarizes the European and international state of the art concerning the assessment and evaluation of the conservation state of existing structures. It is intended to include it into the current Eurocodes after a sufficient audit and trial. A first draft of such a standard was published in 2017 (see [23]).

The WG 10 of CEN/TC 346 also worked on the development of a European standard concerning the assessment and evaluation of existing timber structures. The first draft was published as prEN 17121:2017 [24]. This standard is part of a whole series of standards which aim on the conservation of cultural heritage – both mobile and immobile property. Although prEN 17121:2017 [24] itself is aimed on historic timber structures under preservation order, its regulations can also be applied on other existing timber structures. The approach is similar to the proposals in [22]. Additionally, precise specifications on the execution of the assessment in general and the determination of the material properties in particular are made. Therefore, prEN 17121:2017 [24] is the first European standard for the assessment and evaluation of existing timber structures.

#### 4 STANDARDS INCLUDING ADJUSTMENTS FOR THE EVALUATION OF THE LOAD-BEARING CAPACITY OF EXISTING STRUCTURES

As described above, some standards and recommendations for the assessment and evaluation of existing structures are available, some on a national, some on a European level. However, some also contain the adjustment of the design concept for a verification of the load-bearing capacity of structures or structural elements including information gained in situ, see Figure 2.



**Figure 2:** Codes & recommendations for the assessment and evaluation of existing structures.

Some documents contain adjusted PSF for practical application. For a comparison of these adjustments of PSF allowed within the standards and recommendations see Table 2. For all modifications the regulations of the requirements according to the documents have to be met.

Besides, in some standards advice to adjust safety factors based on the Design Value Method (DVM) is given. To be outlined here are *fib* Bulletin no. 80 [25] and SIA 269 [17].

**Table 2:** Modified PSF for existing structures acc. to different codes (German documents in italic) [4].

<b>Standard/ guideline</b>	$\gamma_G$	$\gamma_Q$	$\gamma_M$	
<i>DAfStb (2000) [26]</i>	<b>1.15</b>	-	conc.: <b>1.40</b> ; reinf.: <b>1.10</b>	
<i>Guideline for the evaluation of existing bridges (2011) [27]</i>	<b>1.20</b>	-	reinf.: <b>1.05</b> ; prestr. steel: <b>1.10</b>	
<i>SIA 269:2011 [17]</i>	<b>1.20</b>	-	-	
<i>NEN 8700:2011-12 [22] [28]</i>		Leading, exc. wind	Wind load	-
	<b>1.30</b> (reconstr.)	<b>1.30</b> (reconstr.)	<b>1.40</b> (reconstr.)	
	<b>1.20</b> (disappr.)	<b>1.15</b> (disappr.)	<b>1.30</b> (disappr.)	
<i>ONR 24009:2013 [19]</i>	-	-	conc.: <b>1.45</b> ; reinf.: <b>1.05</b> conc.: <b>1.40</b> <sup>1</sup> ; conc.: <b>1.35</b> <sup>1,2</sup>	
<i>DBV leaflet (2013) [13]</i> (exemplary values)	-	-	conc. $V_{R,C}$ $\leq 0.2$ 0.30 0.40	reinf. $V_{R,S}$ 0.06 0.08 0.10
			<b>1.20</b> <b>1.30</b> <b>1.50</b>	<b>1.05</b> <b>1.10</b> <b>1.10</b>
<i>JRC Science and Policy Report (2015) [22]</i>	<b>1.09</b>	<b>1.40</b> Leading (snow)	<b>1.11</b> Acc. (snow)	<b>1.02</b>

<sup>1</sup> VAR comp. strength min. 30 tests <10%

<sup>2</sup> low geometric deviations or geometry determined on structure

It can be concluded, that in Germany as well as on an international level the development of an adjusted evaluation concept for existing structures on the material side is focused on reinforced concrete structures at state. Within codes and recommendations listed above few special references to existing timber structures is made, an exception is SIA 269/5:2011 [18]. However, the special characteristics of this structural material require a comprehensive and skilled assessment to allow for an accounted evaluation of structural stability.

## 5 CONCLUSIONS

Up to now, in Germany no consistent regulations for the assessment and evaluation of existing structures which are approved by the building authorities are available. Thus, codes and design rules which are valid for new structures have to be applied on existing ones. This often leads to comparatively uneconomically and less substance-careful redevelopment measures. Especially within the redevelopment of historic timber structures this has proven to be a challenge. The essential deficit of the German standards is the assessment of the conservation state and the determination of the present material properties – i.e. on-site strength grading.

A widely accepted approach on the assessment and evaluation of the functional capability of timber constructions has been developed in the last 25 years. Unfortunately, the state of the art is not summarized in a consistent guideline. The methods applied in the course of the evaluation are still at the discretion of the respective experts.

The European development shows clearly, that problems which result from the application of design rules for new structures can be solved by a detailed and professional assessment of the conservation state and evaluation of the structural stability based on updated data. Alt-

though existing standards and guidelines show a broad consensus concerning their regulations and requirements, there is no consistent, harmonized European standard available at state.

Preliminary drafts for standards include precise specifications and clarifications to apply design rules for new structures on existing structures. Besides, a harmonized European standard for the evaluation of the structural stability of existing structures based on the proposals of CEN/TC250 and CEN/TC346 as an additional standard should be developed. This code should emphasize the methodology and technology for the assessment of the conservation state – in particular the on-site strength grading of the structural timber and the modification respectively development of an adjusted design concept for an improved and individual evaluation of load-bearing capacity of structural elements and structures.

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