Assessment matrix for timber structures : basis for standardized building checks

DOI:
10.6100/IR712624

Document status and date:
Published: 01/01/2011

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Beurteilungsmatrix für Holzkonstruktionen

Grundlage eines standardisierten Gebäudechecks

Published by
Bouwstenen Publicatieburo
Postbus 513, 5600 MB Eindhoven
The Netherlands
Telephone: +31(0)40 4442293

[CIP Gegevens Koninklijke Bibliotheek Den Haag]

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Die englische Version
Assessment Matrix for Timber Structures
Basis for Standardized Building Checks
ist unter der gleichen ISBN- und Bouwstenen-Nummer erhältlich

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Proefschrift – Doctorate Thesis – ISBN 978 -90-6814-633-2
NUR code 955

Schlüsselbegriffe (Trefwoorden, Keywords): Beurteilungsmatrix, Gebäudecheck, Nachhaltiges Bauen, Formblatt, Checkliste, Datenbank, Objektbuch, EU-Richtlinie

Cover design: Bert Lammers, Tekenstudio, Faculteit Bouwkunde

Assessment Matrix for Timber Structures

Basis for Standardized Building Checks

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus, prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op woensdag 11 mei 2011 om 16.00 uur

door

Michael Abels

geboren te Grevenbroich, Duitsland

Dit proefschrift is goedgekeurd door de promotoren:

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Acknowledgement

This PhD-Thesis would not have been possible without the support of various people whom I would like to thank at this point.
First of all, I would like to name Dr.-Ing. Hans Löfflad, who in 2004 provided the most important contact for me to my first promoter, prof. mag. arch. ing. dr. h. c. Peter Schmid. Peter, in turn, referred me to my second promoter, prof. dr. ir. André Jorissen. I would now like to thank both of them very kindly since they have contributed greatly to my dissertation now being complete.

I especially want to thank Peter Schmid for his profound insights and excellent directions in allowing me to develop my first thoughts into a scientific dissertation. His method of dealing with the most varied circumstances is exemplary.
Thanks also go to André Jorissen for his perfect knowledge of timber and for suggesting many interesting contacts, both in the scientific field and in different timber companies.

Furthermore, I would like to thank the other members of the examination committee who also supported me and gave me valuable advice during the editing of my thesis.
Here, I would like to first name my Copromoter dr. ir. Ad Leijten of the Eindhoven University of Technology, who, in addition to his knowledge of timber, provided valuable support in the translation of the German version into the English version.
I would like to thank Prof. Dr.-Ing. Karl Rautenstrauch of the Bauhaus University Weimar for his very nice support and confirmation of my ideas during the final stages of my work. My exchange with Prof. Dipl.-Ing. Wolfgang Winter of the Vienna University of Technology was also very beneficial in terms of rounding out the overall dissertation.
I received additional kind support from prof. dr. ir. Wim Schaefer of the Eindhoven University of Technology and prof. dr. ir. Michiel Haas of the Delft University of Technology.

I would like to thank my former high school teacher, Mr. Klaus Weiler, for the unlimited use of his home as a very interesting case study. I also want to thank my mother in her capacity as sexton for providing me with her church key for a further very interesting case study.

I would also like to thank my colleagues at the office who supported me in whatever way they could: Sabrina, Ingo, Hannah, Steffan, Andrea and Nele.

Finally, I would like to thank my entire family very much because they had to go without seeing me quite often in the past few years; here I am reminded of our last holiday in South Tyrol. I hope to soon have more time for my children, Amélie and Magnus. I also want to give a big thanks to my wife Helga. She not only provided continual support but also motivated me again and again in bad times to finish the PhD-Thesis I had started when there seemed to be no end in sight. Thank you!

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0. Introduction - Structure of the PhD-Thesis

In the following first section of this PhD-Thesis the objective of this research is explained and the scientific approach is briefly described.

0.1 Basic Problem

The self-conception when entering a building, from our own home to a large place of gathering such as a historical church, is unfortunately upset on a regular basis when buildings show severe damage and are thus closed for use, or which even collapse.
In most cases this is caused by constructional/structural deficiencies which could have been detected earlier.
How can this deficiency of our modern society be corrected using its large portfolio of technical capabilities?

0.2 Research aim

The objective of this thesis is to provide an instrument and to define a procedure to ensure that in the future people everywhere will be able to enter and utilize buildings, where they can safely stay, live and work. Furthermore, damage could be detected earlier and thus be corrected with less effort.
The focus of this thesis is on load-bearing timber structures, which are evaluated using an assessment matrix developed and presented here, and finally released by a still to be established inspection authority after possible strengthening or reconstruction.
The author of this PhD-Thesis intends to close an existing gap in our society by providing this new assessment matrix. In the future, this can enable timber appraisers, who so far have worked according to their own concepts, to use a strategy allowing them to compare their assessments and to conclude with a common evaluation. Thus, a sustainable process can be established.

What is the benefit to society if individual timber appraisers find typical damage patterns and correct them on one project only when this danger is not detected in thousands of other, similar constructions?
Besides the safety for users (=social relevance), the suggested inspection approach (=matrix), which applies to all buildings independently of materials used, age and size, is used to preserve structural cultural assets (= societal relevance) - with respect to sustainable development as well.

0.3 Scientific relevancy - state of-the-art of science

The tragedy in Bad Reichenhall (Germany), on January 2^{nd} 2006, when the wooden roof construction of an ice pavilion collapsed and 15 people lost their lives, shocked the entire nation.
It was quickly determined that structural deficiencies caused the tragedy. This could have been prevented, if the building had been sufficiently inspected. Active discussions started to take place not only in Germany, if public buildings should be inspected on a regular base in the future. During random inspections initiated by the German TÜV (Technical Supervisory Association) after the tragedy, significant deficiencies were detected on several hall roof constructions, which emphasized the need for regular inspections.

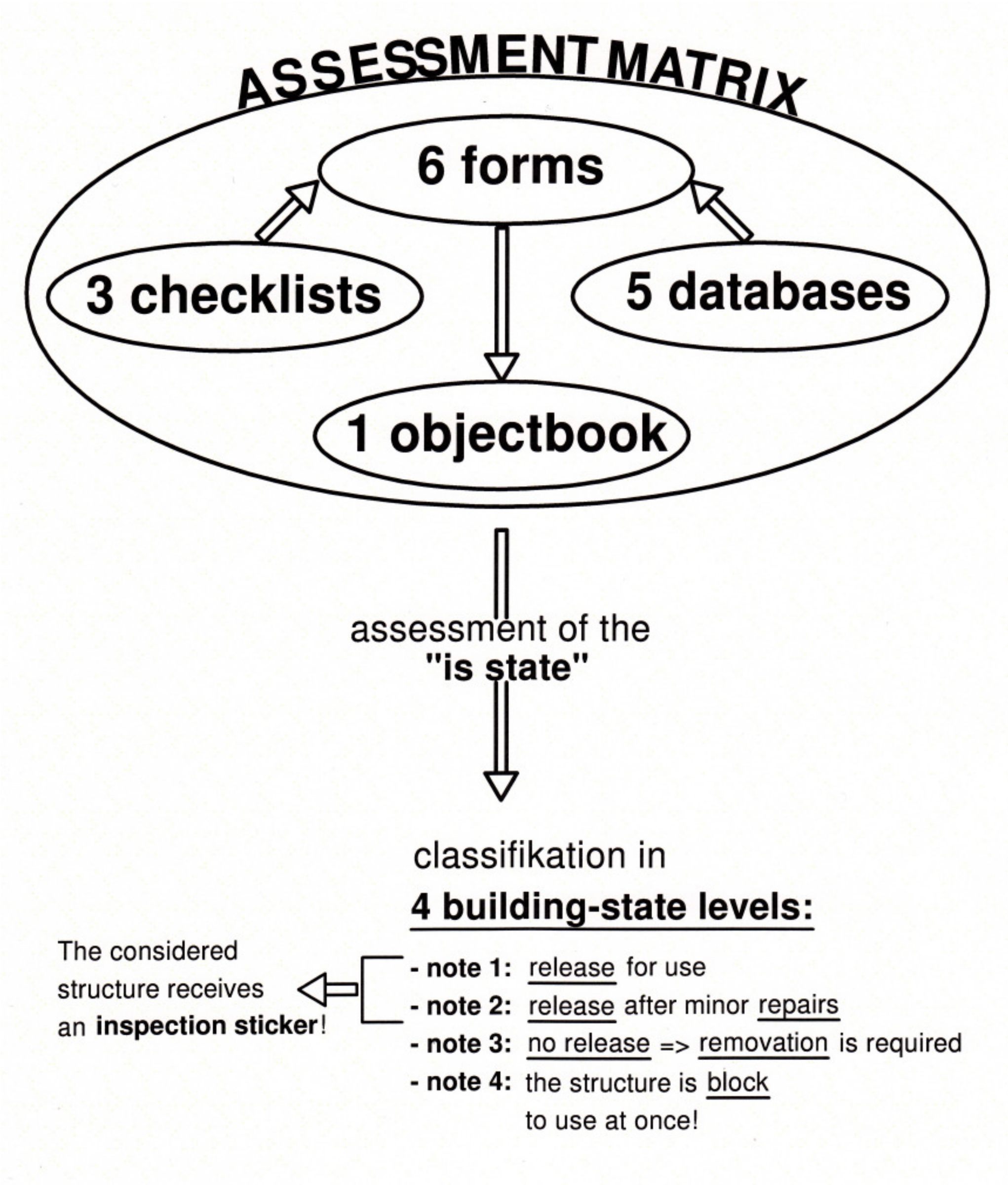
Amongst other things this PhD-Thesis takes up the approaches of the study group Wood Glue Constructions [10] and attempts to establish a unambiguous procedure, in order to stop multi interpretation, as on the one hand so far no standard assessment procedure exists for timber structures and on the other hand, all buildings are basically left alone after their completion.

In the present thesis a sustainable process sequence is developed, how a still to be established inspection instance checks usability and structural integrity of any building on a regular base. For this purpose the buildings are divided into building categories, based on which monitoring effort and cycles will be determined.
Thus, the scientific framework of this work has been established.

The described course of procedure is based on the assessment matrix, which will be developed in the 2^{nd} **chapter** and applied in the 3^{rd} **chapter** of this work. Among others, the current status of all common construction types, common inspection methods, handling of possible damage and material characteristics knowledge was incorporated into this assessment matrix.

Greatest importance is given to a uniform procedure structure independently of the construction type investigated in detail. For this purpose forms, databases and check lists are used, in order to allow to conclude an assessment. The following graphic shows the structure of the Assessment Matrix (see figure 0.1).

Figure 0.1: Structure of the Assement Matrix



As scientific basis of the topic areas addressed in this PhD-Thesis, literature references to other directly related scientific publications are provided at respective locations or sections. In the 5th chapter of this dissertation, in sections 5.3 to 5.7, more references web pages, mentioned rules and standards are given. For that a chapter assignment is made.
At this point a previous dissertation at Technical University Eindhoven, prepared by Jalil H. Saber Zaimian [27], must be mentioned, who in his "Model for structural transformation" uses different terminology, which is used in the present thesis as well.
Furthermore, additional research work, among others by Professor Peter Niemz from ETH Zürich, will be mentioned at certain locations throughout the course of this PhD-Thesis, which addresses individual aspects of timber structures important within the framework of appraisals of existing timber constructions.

0.4 Research scope

In the **1st chapter** the author collects information for individual important aspects of timber constructions from already existing research papers, which in the future could be useful to the user of the assessment matrix, if he faces a similar problem.
The entire thesis should be understood as a collection of literature references to many different timber construction divisions, for which timber construction assessment is of interest, to generate a large network in the future, which will be able to answer any question of the matrix user. This thesis cannot deliver this very advanced version. Most likely this version will only exist in several years in a programmed IT version after multiple applications by multiple users.
A final version will never exist, as the matrix should be continuously updated with the latest development in timber construction.
Besides expert knowledge in timber construction, long-term experience is necessary to actually apply the assessment matrix. In the **1st chapter** of this PhD-Thesis a theoretical knowledge base is presented as well as a large amount of literature references to in-depth information to allow not only timber expert access to this dissertation. The chapter is mainly for interested parties and participants in and on construction processes, who merely have basic knowledge. Due to the complexity of

the discussed topic only such terms can be defined in the **1st chapter**, which are important in the later matrix and its proposed building-law related applications. For all sub-topics addressed in this chapter, information and relation to later topics should be provided or established. It is important to mention with respect to **chapter 1**, that only well understand and reliable information is briefly presented, corresponding to the state-of-the-art of technology. Often reference to technical regulation or literature reference are provided, which will communicate the outlook to the interested party already having great expert knowledge, to apply the later introduced assessment matrix in the future by himself.

0.5 Processing method

By means of literature and Internet research, expert discussions and attendance at expert conferences, congresses and seminars, the topic of timber construction was and is comprehensibly developed addressing all angles. Furthermore, current European timber construction provisions and their predecessor standards were researched. Different tasks in the professional day-to-day work of the author continuously delivered and deliver concrete points of references with respect to timber constructions, covering historical construction methods up to modern engineered timber constructions. The author was able to collect the experiences mentioned above throughout his professional carrier of 15 years as engineer and architect.

The matrix exactly described in the previous section of scientific relevancy, has already been tested over a longer period of time on different buildings within the scope of engineering appraisals. These concrete projects are the reason for the basic idea of the matrix and the prerequisite for its step-wise development.

In the **3rd chapter** of this PhD-Thesis the matrix is applied to three concrete buildings. These case studies are used to test and finally validate the matrix.

In order to present the large spectrum of existing timber constructions, three very different buildings were intentionally selected:

1. Church building with historical Gothic church tower construction (including bell frame), dated 1551, and nave from the late baroque period, dated 1783, with new engineered framework roof-construction, dated 1951.
2. Protected timbered house dated 1653, with framework inner walls, wood-beamed ceiling and double-layered historical roof truss.
3. Triple gymnasium with modern engineered roof construction with glued-laminated girders, erected 1979.

In the following a societal application is presented.
For this purpose the assessment matrix is awarded a possible legal framework. The target should be to define a new EU standard based on this thesis, which regulates regular building monitoring with respect to usability and structural safety depending on defined building classes.
An awarded inspection sticker visibly attached to the building, similar to the known German TÜV stamps, indicates the release for a certain time frame, and could soon be integral part of all buildings in order to awaken respective awareness within the population.

0.6 Result as solution and/or answer to the basic problem description

The present dissertation covers a wide field of detailed topics.
The basis is the previously described development of a matrix enabling comprehensive and objective assessment of the structural condition of all timber constructions. Before that different terms of this matrix are presented and explained.
When preparing the assessment matrix which should be applied in Europe, it is necessary to limit to efforts to one country at the beginning. The focus is on Germany; otherwise the research topic would be too extensive. Subsequent to this work a transnational study could be performed. The matrix form was consciously selected as it is very well suited for the discussed topic. In the following several scientific considerations are presented justifying this assumption. The processing sequence is defined to ensure that all relevant aspects are handled. For faster and simpler processing so-called checklists and databases are provided to the users for frequently occurring problems.

As the later application of the matrix developed in this dissertation should be based on a computer program, the programmer can directly access a clear structure, which highlights relationships and dependences between all sub-aspects.
As already described above, the focus of this work is on timber constructions. The consideration of massive constructions (made of ferroconcrete and/or brickwork) and metal constructions (steel and/or aluminum light constructions) would go beyond the scope of this thesis. However, this dissertation provides a good template, how to include such constructions into the developed approach in the future. Separate assessment matrices of these building materials could be developed in future scientific papers. Besides that, the following considerations apply to all buildings independently from the material used.

In the **4th chapter** of this PhD-Thesis it is discussed, how the topic of this dissertation can be used in future scientific work even by different University Faculties, such as from a legal or technical-philosophical point of view.

Summarizing it can be stated

- That there is a need for systematic checks of timber structures.
- That so far no comprehensive assessment matrix exists for timber constructions taking into account all aspects and considering the social relevance of user safety and societal relevance of preserving structural cultural assets.
- That the matrix can be optimized and adapted to technical developments based on area-wide application and regular user assessments.
- That the approach developed in this work can present the basis of a new EU standard, according to which all buildings must be subjected to regular standardized monitoring.
- That based on previous considerations and studies scientific relevance is given, as the developed sustainable approach should close a gap still existing within the building laws.

1. General Information and Basic Knowledge for the Assessment of Timber Building Structures

As an entry point into this dissertation, different timber structure terms are listed in this chapter.
In preparation of chapter 2, the focus in chapter 1 is mainly on diverse basic knowledge. Continuative literature references are provided for the interested reader and/or later user of the matrix. Thus, to facilitate certain correlations, the later structure of the matrix is already considered in this chapter.

1.1 Explanation of terms

The technical terms often used in this dissertation are briefly explained in this chapter 1. Besides that, technical basic knowledge is briefly presented to address not only a professional audience of architects, engineers and wood experts, who intensively deal with timber constructions and their conservation on a professional base. People interested in timber constructions, but not having the necessary scientific background, should have the opportunity to access this thesis and get an understanding, which aspects are important for the assessment and conservation of timber constructions. These persons for example include employees of monument protection services or other institutions, which accompany and document building monitoring. They usually do not have the in-depth technical knowledge in the timber area.
References and literature references provided, offer the interested reader the opportunity to independently deal with individual topics in detail. It would go beyond the scope of this PhD-Thesis to explain all technical details, such as mechanical and physical timber characteristics. However, the matrix user must know them.
Only qualified persons can actually apply the assessment matrix at a construction site and/or to the building object.
In chapters 2, 3 and 4 this will be discussed in more detail. The instructions of chapters 5.3 to 5.7 are very important.

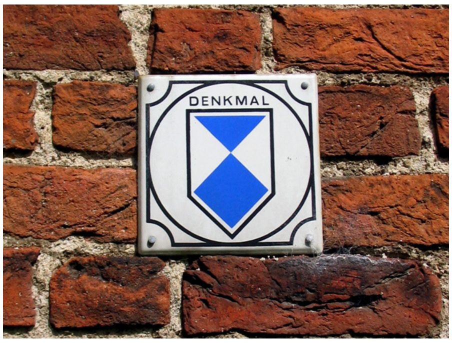
1.1.1 Definition of terms

When dealing with timber constructions, which appear in different shapes in buildings, then experts as well as laymen use terms, which may be differently understood by different people. In the following, different designations are listed and briefly explained to ensure that every reader will understand the same content when using these terms.

Architectural conservation: Older buildings are entitled to architectural conservation from a building law point of view. This means that the original rights from the time of construction and/or the building approval from that time are still valid, although now more strict regulations may apply. Care should be taken in case of larger remodeling or reconstruction measures. Architectural conservation is often voided and the current building laws must be applied to the entire construction object within this building measure.

Monument conservation: The goal of monument conservation is to secure monuments as cultural heritage for future generations. It is important to any society to inform about its own history by means of cultural monuments and nature monuments. A vital image of the architecture and the way of living of previous times is preserved. In Germany it is common to attach a visible label to the outer facade of landmarked objects according to the Hague Convention for the protection of cultural assets in case of armored conflicts (UNESCO 1954 [112]).

Figure 1.1: Monument conversation label of former GDR



Furthermore, different labels are common in individual German areas. (As an example the current monument conservation label for North Rhine-Westphalia is shown in figure 1.2).

Figure 1.2: Current monument conservation label in the German area North Rhine-Westphalia (NRW).

As already described at the beginning of this thesis, it is a very important task of our society to preserve structural cultural assets, often called monuments, for future generations. Here a saying from the Old Testament should be mentioned.
In the sayings of Salomon the following rule is listed as 24.3, which is of crucial importance for monument conservation:

"By wisdom a house is built,
and through understanding it is established"
(Salomon' sayings; 24.3)

Due to the large number of buildings in our modern society worth preserving, more attention will be focused in the future on conservation and strengthening (see definition below) of these constructions.
New timber building constructions will be built in the future as well. The modern methods of engineered timber constructions described before have almost no limits with respect to architectural designs.

In Germany monument conservation authorities exist, controlling compliance with monument conservation laws. Here the monument conservation laws of the German States North Rhine-Westphalia and Brandenburg are mentioned as examples.

Old building: This term is often used for buildings, which do not comply with current building designs due to their condition. In Germany the architecture up to World War II is often addressed by this. Residential constructions mostly consisted of brickwork walls, wood-beamed ceilings and box-type windows. The following architectural style with major use of ferroconcrete components (walls and ceilings) as well as coupled and insulating glass windows concludes the old building era in Germany. Larger clear room heights of more than 3 meters are typical for old buildings. Old buildings are always subjected to architectural conservation mentioned above.

Redevelopment: Redevelopment describes the partial renewal or completion of a building, which after the redevelopment should regain its function functional again. Modernizations are often included in redevelopments, in order to improve the living standard. Prior to a redevelopment it must be coordinated with the responsible building control authority, if architectural conservation is voided due to the redevelopment.

Redevelopment goes beyond maintenance and/or repair and/or strengthening, as the building substance should often be adapted to a new utilization (= change of utilization).

Maintenance and/or strengthening: Unfortunately, continuous monitoring and/or maintenance are not performed for many older timber constructions. For this reason, different deficiencies and even damage can already be detected on younger timber constructions, which must be repaired in order to save these buildings long-term. The modern methods of chemical and constructive wood preservation, which are described later on, already offer good possibilities requiring minor effort to retroactively protect constructions. However, as a retroactive measure is often associated with greater effort, these wood preservation measures should always be a priority when planning new wood constructions.

Wood construction damage has often progressed so far, e.g. due to fungus or insect infestation, that larger maintenance is necessary in order to secure long-term conservation and possibly short-term stability of the building.

This is one of the main subjects of this PhD-Thesis. In the later course of this paper, typical repair methods (see different databases, sections 2.6.2 ff) are presented for different wood construction damage.

Change of use: During their useful life, buildings are often reconstructed or extended. For this reason, occurring stress and loads (especially service loads = traffic loads), caused by more people traffic in the building, may be impacted. Changes of utilization from pure residential use to commercial use, e.g. as store area, are of great importance as well. Besides increased loads on the construction, possibly structural-physical demands, such as new refrigeration/cooling rooms for food stores must be observed.

Structural safety: A building is structurally safe, if the chance of collapse is very small and if its load-bearing construction is designed to transmit all possible external loads (wind, snow, permanent and service loads + possible dynamic loads, e.g. caused by earthquakes) during the construction and utilization duration, without any damage and permissible smaller deformations into the ground. Within the scope of a structural safety demonstration, the structural engineer determines all possible loads and performs stress and deformation analyses.

Usability: In the decisive German regulation is stated:

"A building must be designed and realized to ensure that besides its load carrying capacity it will maintain its usability and stability throughout its provided service duration and requiring appropriate maintenance efforts"

Typical requirements for usability are crack width limitations, water tightness and deformation or vibration restrictions.

It may occur that the pure structural stress analysis is sufficient; however deformations reach an unacceptable value. Thus, the following requirements must be met with respect to the usability of a building:

- Proper function of the entire building.
- Well-being of the persons belonging to the planned building use.
- The traffic safety of all building users must be ensured. For example, railings must be installed at possible dangerous locations.

If one or several of the points mentioned are not met, then usability is not or not any more provided.

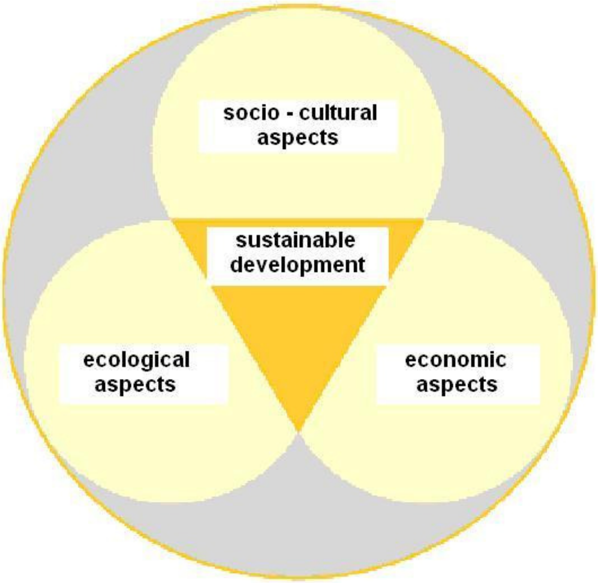
Sustainability [21]: This term is used several times throughout the thesis. It should express, that a system is established and/or installed within our society, which sustains itself and (specifically using the example of this thesis) contributes to the conservation and protection of the entire building inventory. This system is based on a process, which is explained in detail in this thesis and which is based on an assessment matrix.

Different aspects of sustainability are differentiated (see [21]). The present dissertation addresses ecological sustainability by suggested legally obligatory maintenance and protection of all buildings in their original design.

Social sustainability is targeted as well. Usable and structurally safe building substance is the main requirement for a sustainable society worth living. The assessment matrix is developed for this purpose.

To complete the 3-column model of sustainability (see figure 1.3) economic sustainability must be discussed now. If this aspect is used in the PhD-thesis, then it can be stated that regular building checks are more cost-effective (= economic) in the long run than costly redevelopments caused by damage being detected too late. In case of severe building damage, it must often be decided whether demolition is the most cost-effective option.

Figure 1.3: 3-column sustainability model



1.1.2 Wood construction regulations

Starting with the development of human life in shelters, wood was used. Thus, experiences in handling this material were communicated from generation to generation. Today traditional trade rules are often mentioned, which still righteously have a high value in our today's society. Many old trade rules have spiritual aspects containing concrete practical results: *"If you process wood, do not forget the tree"*, indicates for example, that growth direction and thus fiber orientation of the wood must be considered.

Based on former trade rules and empirical values, the DIN standards (German Institute for Standardization) were established in Germany at the beginning of the 20th century.

Any well-founded findings in science, technology and experiences up to the respective publication date are included in these standards. The application of standards is often referred to as working according to the state-of-the-art of technology. However, standards often do not contain current regulations and/or technical developments, as a rather long period of time may pass until an updated standard is published. However, if these not yet standardized advanced developments have already proven themselves, then these improvements apply as **"state-of-the-art of technology"**.

If a European certification is available (within the European Union) for a construction product, then this is documented using the CE symbol (see figure 1.4). This is a freely negotiable process, which today is not automatically applied to all construction products.

Figure 1.4: CE mark („Conformité Européenne")

In the meantime standardized dimensioning rules exist in civil engineering throughout Europe. These European standards were compiled by accredited scientists, engineers and users - similar to the German DIN standards.
In the German standardization, DIN 1052 was always crucial for the calculation and execution of wooden constructions. These measurements and constructions are now regulated in Euro Code 5.
The structural safety analyses executed in the present thesis for the purpose of technical discussions up to wood construction assessments are based on the currently valid regulation. This is especially important, as in the future the topic discussed in this thesis should be applied throughout Europe.
As the assessment matrix presented in this dissertation should in the future be practically applied to wood constructions in our society, it is necessary to address current wood construction regulations, which must be obligatorily applied during any wood construction assessment. The matrix also remains valid after possible law and regulations changes.
Although the goal of this PhD-Thesis is to apply the matrix across Europe, it is necessary to limit initial efforts to one country only. The focus is on Germany. Otherwise the research topic would be too extensive. A transnational study will be suggested in the further course of this thesis.

The topic of this section clearly indicates that a wood expert must permanently adapt his knowledge to the current state of knowledge. This not only applies to new materials and construction methods, but mainly to their proper realization. Structural safety and usability analyses must always be based on the currently applicable regulations, even if an expert never learned them during his vocational training/study. In order to counter this problem, all experts in the building and construction area are subjected to advanced education, which is monitored by the respective chambers of architects and engineers.

1.2 Wood characteristics and different wood materials (= checklist 1 basics)

In the further course of this thesis, different wood characteristics are often discussed. It is important to mention that this includes mostly used natural construction timber, such as pine, spruce, oak, etc. Frequently used glued laminated timber and the increasing product portfolio of wood composites are covered as well.

In this chapter 1 the basics are established, which are of importance for later important sections of this thesis.
The core of this PhD-Thesis is the already briefly described assessment matrix, which will be elaborated and described in detail in chapter 2. Auxiliary tools should be provided to the matrix user, to facilitate its application. This includes three different "checklists", which check the construction to be investigated. Checklist 1 should be helpful in determining the type of wood product (solid wood art, glued laminated timber or wood composite panels).
In the present section, several points belonging to the characterization of wood and other wood composites should be addressed. They thus belong to the topic of checklist 1.

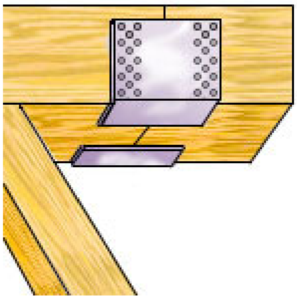
1.2.1 Materials and their selection

When talking about timber constructions, then all commonly used wood types and wood materials are combined. These usually are common soft woods: Spruce and Pine (see section 1.2.1.1). Glued laminated timber (see section 1.2.1.2) belong to today's common materials. The increasing product portfolio of wood composites (see section 1.2.1.3) completes today's offering.

Hardwood (mainly oak) is very often used in older constructions. Hardwood provides better mechanical characteristics than soft wood. For cost reasons however, it is rarely used today.

As the maximum natural available solid wood dimensions (see section 1.2.1.1) are not sufficient for larger spans or constructions, they can be extended using joints (see fig. 1.5). Another option is the use of glued laminated timber (see section 1.2.1.2).

Figure 1.5: Timber purlin joint with cantilever bracket



In the following sections important material alternatives for wood constructions are investigated in detail.

1.2.1.1 Solid wood products

Solid wood products are offered at the wood market in the commercial forms described above. They are installed in design dimensions required according to the structural design and/or structural-physical requirements.
Untrimmed round timber can often be found in older buildings. They were installed in almost untreated condition, but assumed the load-carrying function for a very long time and are still assuming this function.
So-called solid construction timber is increasingly used at the modern wood market. It differs from normal round wood by the fact that the surfaces are shaped and that they were dried in the range of 15% +- 3%.

Common wood products used today in constructions are solid wood or glued laminated timber. Most rectangular timber can be obtained as standard merchandise in different dimensions.

From a tree trunk are made: bars, boards, shelves, squared timber and beams. What form originates from which part of the tree trunk profile can be seen in the following figure (see fig. 1.6).

Figure 1.6: Cut lines in the tree trunk

The strength class is of utmost importance for the wood quality required. As can be seen in the following table (see fig. 1.7), different classes are applied with respect to visual and automatic grading.

Figure 1.7: Strength classes allocation to DIN EN 338 and the assignment of visual and machine grading automatic sorting classes

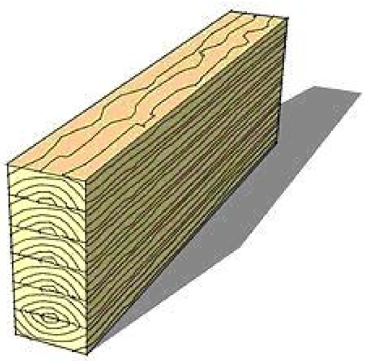
softwood hardwood	C16	C20	C24	C30 D30	C35 D35	C40 D40	C45	C50 D50	D60
visual sorting classes	S7	-	S10	S13 LS10 (oak)	LS10 (beech)	LS13 (beech)	-	-	-
old automatic sorting classes	MS7	-	MS10	-	-	MS17	-	-	-
new automatic sorting classes	C16M	-	C24M	C30M D30M	C35M	D40M	-	C50M	D60M

Different visual sorting characteristics exist. Based on them, timber is assigned to different strength classes. This includes for example the following criteria: cracks, discolorations, insect damage, dull edge, warping, etc.

1.2.1.2 Glued laminated timber = gluam

As the length and cross section of natural timber are limited and, for structural reasons, larger timber dimensions are required for larger spans, glued laminated timber was developed. Here layers of dried timber are artificially glued to each other. (See figure 1.8.)

Figure 1.8: Glued laminated timber (=gluam) in rectangular design



In longitudinal direction the timber is connected via finger jointing (see fig. 1.9). Finger jointing has been described and investigated in detail in several scientific papers.

Figure 1.9: Finger jointing in longitudinal beam direction

◄ Finger jointing

Using this approach, theoretically all dimensions are possible. However, the transport to the usage location, together with the assembly, limits the dimensions of glued laminated limber.

Manufactured glued laminated timber components are not only produced in rectangular profiles. The architecture or the selected roof pitches often require an asymmetrically glued laminated timber design. In those cases single-pitch or ridged roof girders are used. There are almost no limits regarding the shapes (see e.g. fig. 1.10).

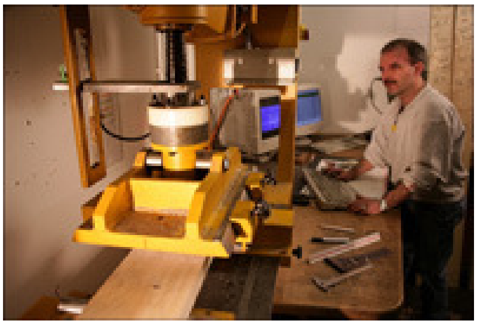
Figure 1.10: Glued laminated timber as ridged roof girder with curved underside in an indoor riding ring.

Glued laminated timber may only be manufactured by approved specialist companies. In Germany this timber can be recognized by its monitoring symbol (see fig. 1.11).

This ensures that only suitable timber is selected with matching glue connections, and that all finger joining connection must pass an inspection (see Fig. 1.12). In general, selected timber manufacturing companies ensure that all specified requirements are met.

Figure 1.11: German glued laminated timber approval symbol

Figure 1.12: Finger joining inspection



The importance of the glue connections is investigated in detail in several scientific papers. Thereby several influences (e.g. climatic) on the glue connection are detected.

The later section 1.5.8.3 provides further information regarding glued connections.

Depending on the usage class of the analyzed building, Euro Code 5 defines minimum requirements for the corrosion protection of metal components and connections, which are mostly used in the discussed engineered wood constructions. Using an investigation device (see fig.: 1.13) the coating layer thickness can be checked.

Figure 1.13: Zinc layer thickness using a leptoskop measuring device (=thick layer scale)

For the glued laminated timber discussed in this section, all requirements for glued connections apply, which will be described in detail in a later section of this PhD-Thesis (see 1.5.8.3). In addition, further professional literature references are provided.

1.2.1.3 Timber products

The increasing range of timber products completes the possible product portfolio of timber to be used in timber constructions.

Depending on the degree of crushed wood pieces, which are manufactured by adding bonding agents, the following groups of wood composites are differentiated:
Plywood (see fig. 1.14), chip boards (see fig. 1.6) and wood fiber boards (see fig. 1.18).
The very frequently used flat pressboards (see fig. 1.20) belong to the wood composites (chip boards).

Plywood consists of wood composite boards, which are glued onto each other in layers respectively rotated by 90°. The number of layers is often odd.
In case of laminated wood the individual boards are parallel.

Figure 1.14: Plywood

Figure 1.15: Typical use of spruce plywood sheets as formwork for a wooden-beam ceiling

Laminated chip composites are manufactured from wood chips, synthetic resin glue and additives under heat and pressure application.

Figure 1.16: Chipboards (= flat pressboard)

Figure 1.17: Typical use of chipboards as cladding for timber frame constructions

Wood fiber boards are made from wood, sawing by-products and wood waste (based on wood fiber containing plants, such as flax or canola). Cohesion is based on entangled wood fibers as well as bonding forces within wood. It is also possible to use adhesives as bonding agents.

For wood fiber boards the following types are differentiated:

- Manufacturing using wet processing:
    - Insulating wood fiber board
    - Medium-hard fiber board / density 350 to 800 kg/m³
    - Hard fiber board / density > 800 kg/m³
- Manufacturing using dry processing:
    - Medium-density fiber board
    - High-density fiber board

Figure 1.18: Wood fiber boards

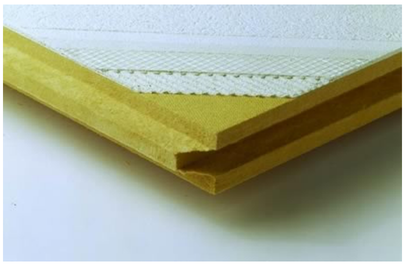


Figure 1.19: Typical use of wood fiber boards as insulation material for rafter insulation = insulating wood fiber board

Figure 1.20: Flat pressboards, e.g. OSB boards (= oriented strand board)

Figure 1.21: Typical use of OSB boards as windproof (= outer) sealing level of a passive house

The boards can assume different tasks, such as load-bearing cladding of ceiling and wall elements, heat and/or noise protection linings of walls and ceilings, and many more.
The large assortment of plasterboards (with and without fiber reinforcements) does not belong to the wood composites. However, they should be mentioned, as they can not only be used as ceiling and wall lining, but can also assume structural functions (only with fiber reinforcement) as cladding. Thus, plasterboards and/or gypsum fiber boards can be partially compared to wood composite boards.

This area of wood composites clearly shows that new products continuously enter the market. A wood expert must continuously inform himself about their characteristics to ensure that all his assessments correspond to the state-of-the-art of technology.

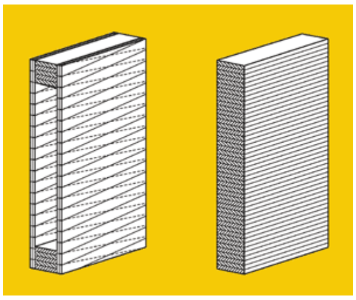
1.2.1.4 Box beams and hybrid products (= composite components)

Another form of composite wood elements is the so-called box beams. They represent a combination of the previously described solid woods and wood composite boards. If, from a structural point of view, very large girder depths are required, then composite boxed-in sections can be used as alternative to heavy glued laminated timber structures. The transitions between the individual boards can be glued or mechanically mounted.

This design type, which was developed in the seventies of the last century, must be critically assessed, as cladding glue connections are very important.

Measured cracks must be carefully examined, because they may quickly negatively impact the load bearing capability.

Figure 1.22: Boxed-in section and rectangular glued laminated girder



Composite wood profiles are often used. Similar to the I profile in steel construction, the material-saving and structurally effective I girders are very often used in wood construction.

An I girder functions according to the same principle as a steel girder, however is made of wood composites. Two belts of glued laminated wood (laminated veneer lumber) are connected by an OSB longitudinal girder (oriented strand board) via special bonding, and present a rigid girder. This girder is very lightweight and still exhibits high load bearing capacity.

Figure 1.23: I girder

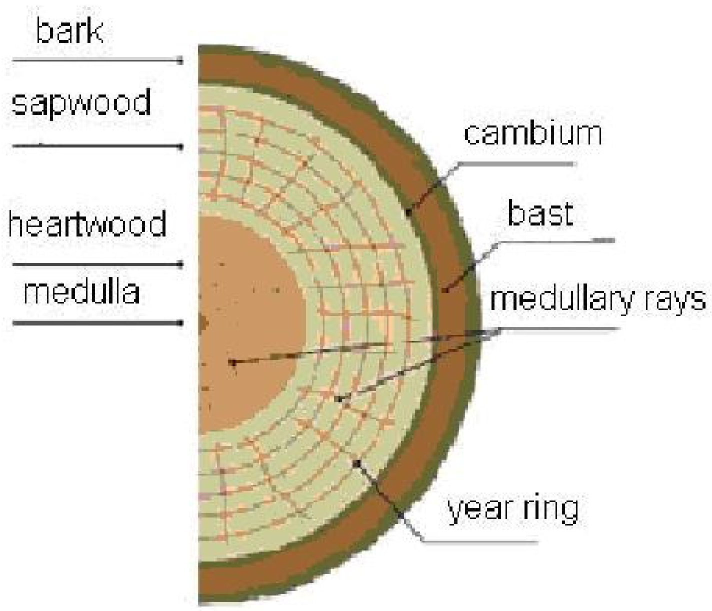
The topic of composite wood profiles is very important for the further development of this thesis. Older wood constructions must often be structurally strengthened, if e.g. existing wood profiles are not structurally sufficient due to usage changes and corresponding load increases.

This strengthening form is addressed several times in chapter 2 in the sections regarding the different databases (see sections 2.6.2 ff).

1.2.2 Mechanical wood characteristics

In order to understand the problem of different wood damage in the further course of this dissertation, a short overview about the physical and mechanical wood characteristics is provided for the inexperienced reader.

Figure 1.24: Wood structure – Cross section through a tree trunk



The wood fibers of a trunk run in the growth direction and thus vertically.
As can be recognized in the cross section through a tree trunk (see fig. 1.25), the structure is heterogeneous, as a year ring is added each year. This heterogeneous structure has a large impact on the mechanical (+ physical) wood characteristics, as they show significant differences depending on the wood fiber directions (see fig. 1.28) (tangential, radial or longitudinal). It is important for a later wood installation, if this cross section is subjected to tensile, pressure, torsional or bending load.

1.2.2.1 Young's modulus - Deformation computations

When subjected to a load, wood behaves almost completely elastically up to a certain load.
For all structural analyses, where the existing stress of a construction is compared to permissible stress, and existing deformations to permissible deformations, the elastic parameter of Young's modulus is very important. Young's modulus can greatly vary for the same wood type and is affected by the moisture content in the wood. With increasing wood moisture, Young's modulus decreases. It is differentiated between Young's modulus perpendicular and parallel to the fiber.
In different tables [4] different Young's modules are listed for different timber building materials.
Young's modulus is decisive for deformation computations of wood constructions, which are very important in the further course of this thesis.

1.2.2.2 Strength and permissible stress types

Similar to Young's modulus, different permitted stress types exist depending on the load in the fiber direction (parallel or perpendicular), the age and the wood type. These must be checked within the scope of structural safety analyses (structural computations) and are listed in tables already mentioned several times in this thesis.
Usually the following stress types are differentiated:

- Compression strength (perpendicular or parallel to the fiber)
- Tensile strength (perpendicular or parallel to the fiber, e.g. timber exists in timber framing subjected to tensile load).
- Bending strength (stress during common loads)
- Shearing resistance (e.g. for offsets, if a longitudinal force impacts parallel to the fiber. The sill of the presented offset is subjected to shearing.
- Shear caused by shearing force (shear stress parallel to the fiber also occurs during bending loads)
- Torsion (= distortion around the own axis)

These values are listed in tables [4] for solid woods, glued laminated timber and wood composites (laminated veneer lumber and flat pressboards).

For all stress analyses, which must be performed by the wood expert according to the requirements of the inspected wood construction, the permitted wood stress limits must be met depending in the wood type, age and moisture content.

1.2.2.3 Wood age impact on mechanical characteristics

As this thesis is focused on the assessment of existing wood constructions, for which an assessment matrix is first developed and later applied within the scope of this dissertation, the impact of the wood age on different mechanical characteristics is very interesting.
Diverse scientific investigations of the last 40 years discuss this very important topic for all existing wood constructions.
Material characteristics, such as the dependency of the compression strength from gross density, pressure, and bending, shear and impact resistance, are tested for 100 to 500 years old structural wood.
According to the investigations mentioned above, it can be summarized that in the comparison of old and new fault-free structural wood no systematic difference in wood structure and strength exists.
For the assessment of older wood constructions, this knowledge should now be applied to the main topic of this PhD-Thesis.

For the structural safety analysis of an existing construction the structural engineer performs stress analyses as described in section 1.1.1. For this purpose, the static system must be determined first (if not already known). Next, all possible loads/stresses must be determined, the building is subjected to. The limiting values are described as allowable stress according to the older regulations, and as characteristic rated values according to the current European regulations. They always depend on the existing wood quality. The quality depends on the sorting characteristics, which were described in previous section 1.2.1.1. For the wood expert, the standard assignment of older wood in installed condition represents a main challenge. In installed condition, visual sorting can often only incompletely be performed.

According to Ehlbeck [113] it is common to assess hardwood according to the permitted values of previous quality class II. However, the necessary sorting according to S10 does not belong to the tasks of a structural engineer.

The specified wood requirements (= sorting characteristics) cannot be checked in installed condition or only with significant efforts, as the wood cannot be visually inspected from all sides and cannot be removed for inspection purposes for economic and monument preservation reasons. Modern investigation methods, which are presented in more detail in section 2.4.7, offer different alternative non-destructive strength determination options.

In addition, the wood expert’s experience is important to assess, if in the concrete case smaller wood damage in rather oversized profiles is harmless, and highly stressed parts must be inspected in more detail and possibly strengthened.

1.2.3 Physical wood characteristics

1.2.3.1 Density

In the further course of this thesis, load determinations for different profiles are often discussed. Thus, the term of density is of great importance. Wood density is the ratio of mass and volume. It is different from wood type to wood type. The density for all materials can be obtained from different tables (see fig. 1.26). As the density of wood depends on the moisture content, the moisture content must always be provided. In the following table wood densities in totally dry condition are measured.

Figure 1.25: Table excerpt: Density of different wood types [4]

European hardwoods:	Mean value of **Density** **(absolutely dry condition)** [g/cm³]:
Spruce and Fir	0.43
Pine	0.49
Larch	0.65
Softwoods:	
Beech	0.68
Oak	0.65

As described in the previous section 1.2.2.3, the gross density of installed wood is directly related to the strength of the wood.

Information on how to determine the cross density for wood in installed condition is provided in section 2.4.7.

1.2.3.2 Thermal characteristics

The importance of thermal protection is continuously increasing. In Germany and/or Europe this is expressed by regular tightening of the Energy Conservation Regulations and the EU Directive regarding renewable energies.

Existing thermal bridges as well as moisture penetration within the construction, cause different wood construction damages. The coefficient of thermal conductivity λ [W/mK] is decisive for the assessment and the comparison with other building materials. In order to assess the heat insulation quality of these building materials, other materials are listed as well for comparison purposes.

Figure 1.26: Table excerpt: Thermal conductivities of different materials [4] (measured in darr-state)

Material:	λ**value [W/mK]:**
Spruce / Pine / Fir	0.13
Beech / Oak	0.20
Plywood	0.15
Chipboards	0.13 ÷ 0.17
Insulation, WLG 035	0.035
Concrete	2.10
Steel	60
Aluminum	200

In the later section 1.7.4 "Thermal protection - energy saving measures", additional important aspects regarding this structural-physical area will be provided.

1.3 Wood moisture: Swelling and shrinkage (= checklist 2 basics)

In the previous section different basic knowledge required for the assessment matrix checklist 1 in chapter 2 was presented. Now the topic of checklist 2 should be prepared. Using his guided checklist, cracks and deformation detected in wood should be assessed. In this context wood moisture will be presented in more details, as it is responsible for swelling and shrinkage, and associated cracks and deformations in wood and wood composites.

Moisture of all wood components and composites has a significant impact on most of the mechanical and physical characteristics. Wood is a hygroscopic building material. The wood moisture will always adapt to its environment. The moisture content can be determined using the standardized procedure, which is described in more detail in section 2.4.7. Another option is the use of different electronic wood moisture measuring devices. Hygroscopic moisture with a moisture range below the fiber saturation point mainly impacts the compression strength.

Wood should always be installed in the condition corresponding to the later moisture situation.

German DIN 1052 [S5]provides the following values:

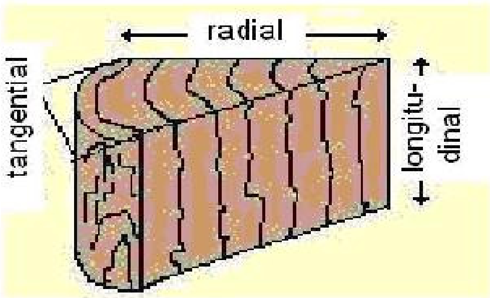
- Completely closed buildings with heating:	(9 ± 3) %
- Completely closed buildings without heating:	(12 ± 3) %
- Covered, open buildings:	(15 ± 3) %
- Building exposed to atmospheric conditions on all sides:	≥ 18 %

It should always be verified on site, if these moisture ranges actually exist, as the previous values are important for wood preservation. Thus, wood preservation may not be met.

Moisture changes in the wood cause dimensional changes. An increase caused by increased moisture is called swelling. A dimensional reduction caused by decreased moisture is called shrinkage.

Due to the heterogeneous structure described above, wood behaves differently in different direction during swelling and shrinkage.
The largest dimensional changes occur tangentially. Radial changes amount to approx. half of tangential changes. Changes in the fiber direction are negligible.

Figure 1.27: Directions in the wood profile



This knowledge is often of enormous importance for damage assessment on wood constructions.
The following table clarifies these different swelling and shrinkage dimensions in % per 1% moisture reduction.

Figure 1.28: Wood shrinkage depending on the fiber direction [4]

	Main direction		
Wood type:	Tangential	Radial	Longitudinal
European hardwoods	0.24	0.12 (range of wood moisture 6÷20%)	0.01
Oak / Beech	0.40	0.20	0.01

The drying process often causes smaller to larger cracks in the wood. Checklist 2 contains information on what types of cracks are harmless. It also indicates, starting from which crack width depth the load bearing capacity is affected. Checklist 2 will be described in detail in section 2.5.3..

1.4 Wood preservation (= checklist 3 basics)

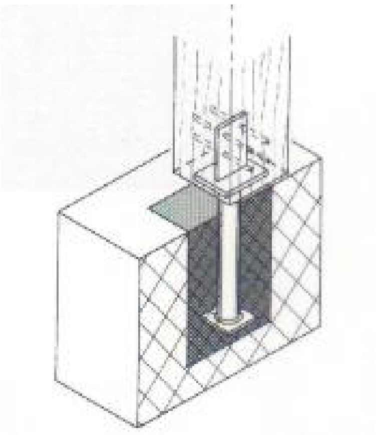
In the previous sections basic knowledge regarding the first two checklists was presented. Now the focus will be on the extensive and thus very important spectrum of wood preservation. The topic of the third and last checklist described in chapter 2 will be highlighted.

1.4.1 Moisture protection: Structural-constructive and chemical wood preservation

As mentioned in the previous sections of this thesis, each wood structure must be protected against excess moisture. Depending on the wood type, short- or long-term damage may occur caused by fungus infestation, mildew-rottenness (soft rod) or similar. The fire detection aspect, which is very important in wood construction as well, will be discussed in chapter 1.7 "Building Physics".
It is differentiated between structural/constructive wood preservation (see e.g. fig. 1.29) and chemical wood preservation. In the later, a wood preservative is inserted into the wood using the boiler pressure method. This form is much more effective than dip preservation.

When applying structural-constructive and/or chemical moisture protection measures to a wood construction, several points should be met.
During any wood construction planning, preventive structural-constructive measures should be applied.
If structural-constructive measures are not possible or not sufficient, chemical wood preservation measures should be applied as well. However, focus should be on the reduction of chemical wood preservatives usage. Furthermore, it must be ensured that this application is properly performed according to strictest specifications and monitoring.

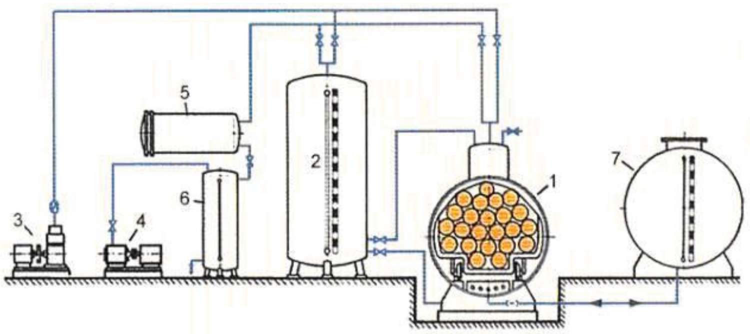
Figure 1.29: Example of constructive wood preservation applied to a column base



1.4.2 Protection against insects, fungi and other influences

The previously mentioned aspects of structural and chemical wood preservation against moisture are also applied for the protection against fungi and insects, as "moisture infestation" is the basis of fungus infestation. Chemical wood preservation prevents insect infestation. In checklist 3 described later in section 2.5.4, wood preservation against insects and fungi will be discussed in detail. Using this checklist, it is possible to diagnose a fungus and/or insect infestation of a wood construction on site.

Figure 1.30: Boiler pressure preservation system



1 Preservation boiler
2 Measuring vessel
3 Compressor
4 Vacuum pump
5 Condenser
6 Vacuum master
7 Storage tank

In most cases redevelopment is necessary, if a wood construction is already infested by insects and/or fungi. It always makes sense to visually inspect constructions on a regular base, as smaller damage can often be repaired with minor effort.
The databases in chapter 2 (see sections 2.6.1 ff) discuss this topic in detail and show common redevelopment methods for different wood constructions.

1.5 Wood constructions (= database basics)

In the previous sections different basic knowledge regarding the 3 checklists was communicated, which are very important for the further course of this paper. Now additional auxiliary resources, the so-called "databases" of the already mentioned assessment matrix, which will be described in detail in chapter 2, will be discussed.
The exact structure of the total of 5 databases can be found in section 2.6.1. Generally speaking, these databases discuss different, most common wood constructions.

In the following sections different basic knowledge will be communicated for these 5 groups:

- Wooden-beam ceilings
- Carpenter-made roof constructions
- Framework plus timber frame construction
- Connections + junction points
- Engineered timber structure

with respect to their historical development and design principles.
Furthermore, literature references will be provided in the different areas, which may be important during the later assessment of specific wood constructions.
Thus, the current reference to the later databases makes also sense in the reverse direction to this chapter 1, as different references to respective scientific publications are already provided.

1.5.1 Historical development of wood constructions

The most important human effort has always been to secure living quality and security. Warmth and living comfort have always played an essential role. Since primitive times wood as regenerating raw material has offered protection and living space to people. Not only shaped using an ax, but by evolving means of growing industrialization, this forest material is one of the most important building materials of today's and future generations.
It is one of our basic needs to make a home. In primitive times without any auxiliary tools, this was a cave or similar shelter (see fig. 1.31).

Figure 1.31*:* Reconstruction of an historical wood shelter in the open-air museum Molfsee in Schleswig-Holstein

Based on inspiration and smartness of our ancestors and by means of simplest tools, this form of accommodation quickly advanced. Even sustainability was already considered in the past.
Today, state-of-the-art connection methods leave all options open to realize wood constructions.
Wood can be used in load-bearing building enclosures and as main building material in sectional construction. In the area of interior fittings, such as lining, floor coverings, etc., the use of this material has not limits.

1.5.2 Wooden-beam ceilings and wooden panels (=basics of database 1)

If floor ceilings are realized as load bearing wood construction, then this is referred to as wooden-beam ceiling [1]. This wood, first only axed and later sawed, is placed on supporting walls or other wooden beams. The beams have a distance of approx. 50 cm to 1.00 m to each other.

Figure 1.32: Bottom view of a wooden ceiling (left); Beam joint to an inner wall after removal of the top formwork (right)

The walls can be framework constructions or masoned (=massive) designs. Above the load-bearing wooden beams, continuous wooden lagging is applied. In older buildings these are mostly wooden floor boards, which were used as top layer in living quarters as well.
Up to approx. 1940, floor ceilings in multi-family houses were realized as wooden-beam ceilings, in single-family houses even up to approx. 1960. Later on, the originally light wood constructions were mainly replaced by massive ferroconcrete constructions.
Wooden-beam ceilings can be found (see fig. 1.33) in modern architecture. In the meantime and in combination with different expansion measures, they comply with current structural-physical requirements of fire protection and noise and heat insulation (see section 1.7). Bottom linings with fire protection panels, compartment insulation for improved heat protection and floating floor structures for improved sound insulation are mentioned as examples.
Wood can be found at any current construction side. The percentage is different from previous decades and/or centuries; however wooden-beam ceilings are still very popular with architects and builders.

Figure 1.33: Wooden-beam ceiling in visible implementation

In database 1 "Ceiling constructions / supporting components / stairs / balconies" described in section 2.6.2, different design variants of wooden-beam ceilings are presented in detail.

1.5.3 Carpenter-made roof constructions (= basics of database 2)

As each building is equipped with a steep or flat roof, whose upper ending is mostly designed as load-bearing wood construction, wood is an essential part.
In database 2 "Roof constructions (carpenter-made)", which is described in more detail in section 2.6.3, common constructions are described in more detail.
The name "carpenter-made wood constructions" [1] refers to the carpenter profession, who builds these constructions. In Germany this is still common.

Figure 1.34: Purlin roof construction of a single-family house in Bedburg -
It was built on site from individual timber (= structural members): rafters, purlins, tie-beams, etc.

In the Netherlands the trend is now to pre-manufacture roof panels in the factory (panel construction) [1] to ensure short building times on site (see fig. 1.35).

Figure 1.35: Assembly of a pre-manufactured heat-insulated roof element

1.5.4 Framework, connections and wooden beams (=basics of database 3)

From the ancient world up to the 19th century, framework construction was one of the dominant construction types, and spread in Central Europe from North of the Alps up to England.

The timber-framed house has a load-bearing wooden frame, where the compartments are mostly filled with a wood-clay mixture or brickwork.

Framework constructions are frame constructions. The individual elements and their designations are shown in the presented system sketch (see fig. 1.37).

Figure 1.36: Assembly of a timber-framed wall

Figure 1.37: Construction elements of a timber-framed wall, source [2]

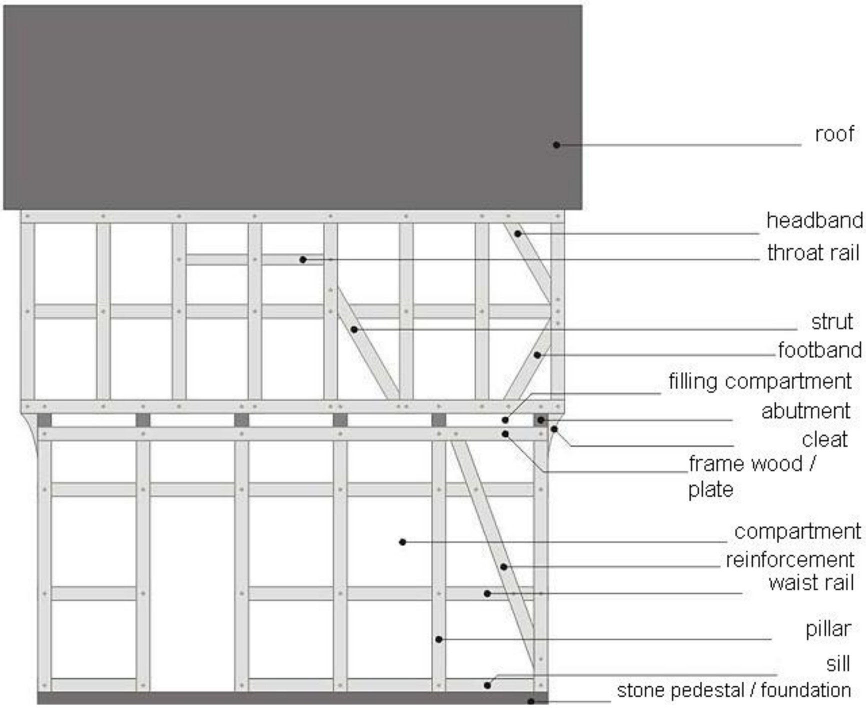


Figure 1.38: Timber-framed house in Elsdorf (Rhineland)

Up to the seventies of the last century it was possible to determine the age of framework constructions simply based on stylistic characteristics. Using dendrochronology (= scientific method of wood age determination), it has been possible since the last decades to more accurately determine the age of framework constructions. The oldest preserved framework constructions in South Germany originate in the 13th century, in North Germany in the 14th century.

Determining the exact age of a wood construction allows the investigation with respect to typical design characteristics. This knowledge can also be important for mechanical wood characteristics (see section 1.2.2.3).

Further development of historic timber-frames houses up to modern prefabricated houses, is explained in more details in section 1.5.5. Throughout the last century up

to today, the modern prefabricated houses were developed based on historical timber-framed buildings. They are manufactured using so-called the timber frame construction.
The different reinforcement systems, which are explained in more detail in section 1.6.5, were and are mostly designed as timber framework. Thus, for the purpose of this thesis, they will be combined with classic timber framework.

In database 3 "Wall constructions / reinforcement systems / framework / wooden columns" described in chapter 2.6.4, different design variants of timber-framed walls are presented in detail.
When in the past large support spans, e.g. for large roof constructions, had to be managed, timber truss was proven early on to be a very good structural system. The junction points of older frameworks were carpenter-made. The variety of roof constructions presented in more detail in database 2 in section 2.6.3, is often equipped with a truss as supporting or stiffening element. The majority of these trusses can also be identified as framework.

Figure 1.39 Oak framework constructions with carpenter-made connections of a roof construction, dated 1772

Simple wood columns should be mentioned in this section as well. Due to their similar design principle, when compared to pillars or posts within framework constructions, they are also added to this section and are also part of the already mentioned database 3 (see section 2.6.4).

1.5.5. Timber frame construction (= panel construction) - prefabricated houses (= basics of database 3)

As the share of prefabricated houses is continuously increasing in Germany, the design principle used should be explained in more detail (refer to [1] as well).
In order to "just" assembly and/or install prefabricated wall, ceiling and roof elements at the construction site, they must be manufactured upfront in the factory. The design principle of framework construction was more or less adapted. As an example, the wall structure should be briefly explained. It consists of a sill, posts (the distance is defined according to the structural specifications and/or lagging dimensions) and one or several bay rails. The structural stability of this wall panel is achieved by installing continuous wooden lagging. This lagging, which can be installed on the inside and the outside, is also called cladding and replaces the original rails, straps and struts of classical framework. In order to achieve good noise and heat insulation, the compartments are filled with mineral wool. These tasks can be recognized on fig. 1.40.

Figure 1.40: Manufacturing of a prefabricated wall in timber frame design

The dimensions of the finished elements must ensure safe transport by truck to the construction site, and there handling using a crane (see fig. 1.41).

Figure 1.41: Installation of a prefabricated wall in timber frame design

Wall, ceiling and roof elements are manufactured as so-called panel elements using timber frame construction already described.

Figure 1.42: Installation of a prefabricated roof element of a prefabricated house

1.5.6 Modern timber engineering constructions: Board stacking systems and board plywood construction

Modern timber engineering constructions must be mentioned as well within the context of this thesis.
Board stacking construction contains massive two-dimensional components (wall and roof elements) (see fig. 1.43).
Adjacent boards or planks are arranged next to each other and joined using nails or hardwood dowels.

Figure 1.43: Inside view of a board stacking ceiling and wooden plank wall

Crossed layer wood or board plywood (see fig. 1.44) is a construction kit similar to the previously mentioned board stacking constructions, made from massive spruce fins glued crosswise.

Figure 1.44: Residential house built using the board plywood construction method

These modern timber engineering constructions meet today's building requirements for several reasons. In the following a selection is provided:

- Building elements can be prefabricated in the factory and must "only" be installed on site.
- Massive wooden elements can be visibly used.
- Smaller component thicknesses, especially in ceiling systems, are possible.
- Comfortable surface temperatures provide a comfortable room climate.

For their moisture-adaptive characteristics, these construction systems allow diffusion-open construction. Peaks in room air humidity can be compensated. No vapor barrier is necessary on the inside of the room.

Although this PhD-Thesis is mainly focused on the preservation of existing, mostly older wood constructions, the short overview of modern timber engineering constructions should consciously point out the required long-term application of the assessment matrix for wooden constructions presented in this thesis. Similar to already existing historic buildings, current modern constructions should be inspected in the next decades as well. The wood expert must permanently be involved with new developments in order to know their specifics in the positive as well as negative sense and to consider them in his future assessments.

1.5.7 Engineered timber structure (= basics of database 4)

Besides the carpenter-made wood constructions previously mentioned, "engineered wood constructions" are differentiated. Originally the carpenter could simply use his trade rules, in order to build structurally safe buildings. The technology development in civil engineering in the last century was mainly focused on incorporating new mechanical knowledge into structural analyses. By this means exact forces could be proven in connection points, which could not be executed using common carpenter-made connections or only with very high material consumption. Further development of wood-processing machines and the use of the previously described glued laminated timber allowed increasingly larger wood constructions. Constructions with a wide span, such as wooden bridges or large roof constructions over halls were and are executed using timber engineering. Examples of different engineered wood constructions are presented in the following.

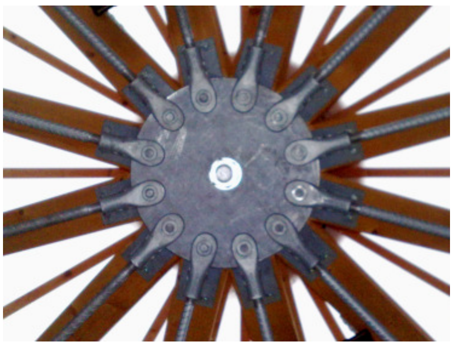
Figure 1.45: Roof construction (= 3-dimensional mullions) over indoor swimming pool in Eurodisney, Paris (France)

Figure 1.46: Wooden pedestrian bridge (= truss construction) in Bedburg (Germany)

Figure 1.47: Indoor tennis courts in Bedburg (Germany) with glued-laminated girders (= three-legged frame) and coupling purlins as supporting (load-bearing) construction / outside and inside view

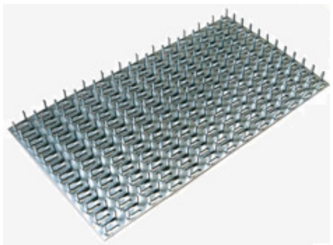
Figure 1.48: Inside view of a lunging hall in Unken (Austria) with supported three-dimensional wood construction

Figure 1.49: Bottom view of the supporting structure (see figure 1.48) with an engineered connection



Wooden framework is used in today's constructions as well. As an example the saddle roof constructions of different supermarkets can be mentioned. For this purpose, prefabricated lattice girders are installed. The connection points are implemented using nail plates (See figures 1.50 and 1.51). They are examples of engineered wood constructions as well.

Figure 1.50 Lattice girder as nail plate construction in a saddle roof construction (see also section 1.5.8.2)



Individual nail plate

See also engineered connections in the following section: 1.5.8.2.

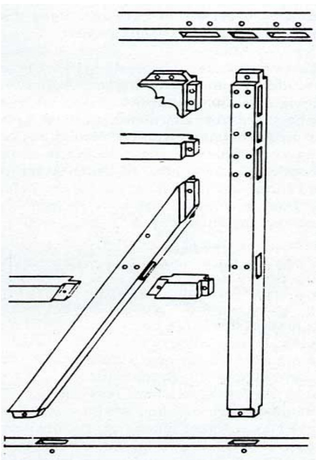
Figure 1.51 Lattice girder as nail plate construction in installed condition

In database 4 "Engineered wood construction with a wide span" shown in section 2.6.5, further typical engineered constructions belonging to this section are described in more detail.

1.5.8 Connections and connection techniques (= basics of database 5)

Throughout the last centuries the original manual connections (see e.g. fig. 1.52), which were only based on empirical values and limited tool use, were increasingly replaced by connections, which require more complex tool use and special material usage. In these engineered connections (see e.g. fig. 1.54, 1.55, and 1.56) metal parts made from galvanized steel or non-oxidizing stainless steel are used.
Within the scope of structural stability analyses (structural computations) (see section 1.6) the exact forces in the junction points are determined, which must be absorbed by the selected connection resources.

Figure 1.52: Traditional manual connections: Framework construction by means of tenons or notches, source [2]



1.5.8.1 Carpenter-made connections

Original carpenter-made connections are connections, which forgo almost all additional metal parts, such as offsets in different designs, e.g. face and heel offsets.

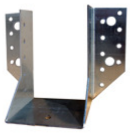
Figure 1.53: Headband connection with a face offset within a historical roof construction

In database 5 "Connections / junction points" shown in section 2.6.6 common carpenter-made connections are discussed in more details.

1.5.8.2 Engineered connections

Engineered connections often use so-called sheet metal parts, as well as wood screws, fitted and pin bolts, special design dowels etc. (see the following figures 1.54, 1.55, and 1.56).

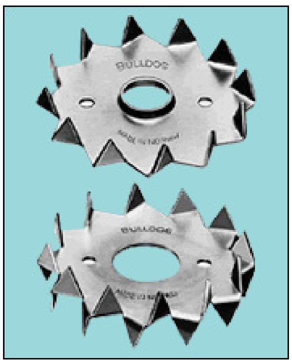
Figure 1.54: Different engineered connections with sheet metal parts



Individual joist hanger

These engineered connections are discussed in more detail in database 5 "Connections/ junction points" in section 2.6.6.

Figure 1.55: Mechanical connection resource: Special dowel design



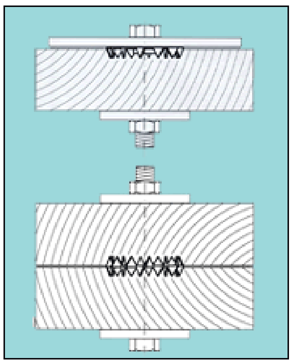
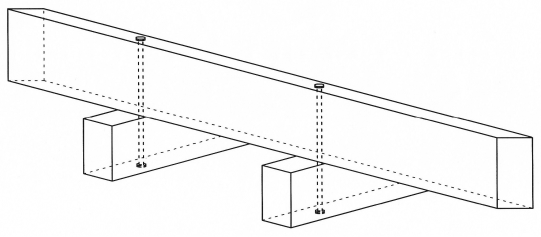
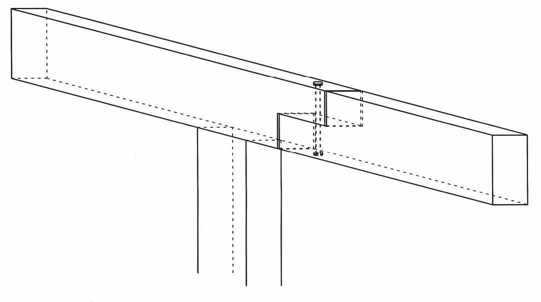


Figure 1.56: Mechanical connection resource: Bolts



secondary girder suspended on main girder



jointed connection of a girder

1.5.8.3 Connections with adhesives

Wood connections (joints) also include connections with adhesives, which are mainly used in manufacturing of the already described glued laminated timber. The adhesives used must meet certain requirements. The adhesives can for example be found in the adhesive list of Stuttgart University.

In addition, this testing laboratory maintains a list of companies, which are qualified to modernize wooden components using adhesive procedures in Germany.
Further information regarding glued connections can be found in section 1.2.1.2.

1.5.9 Special constructions

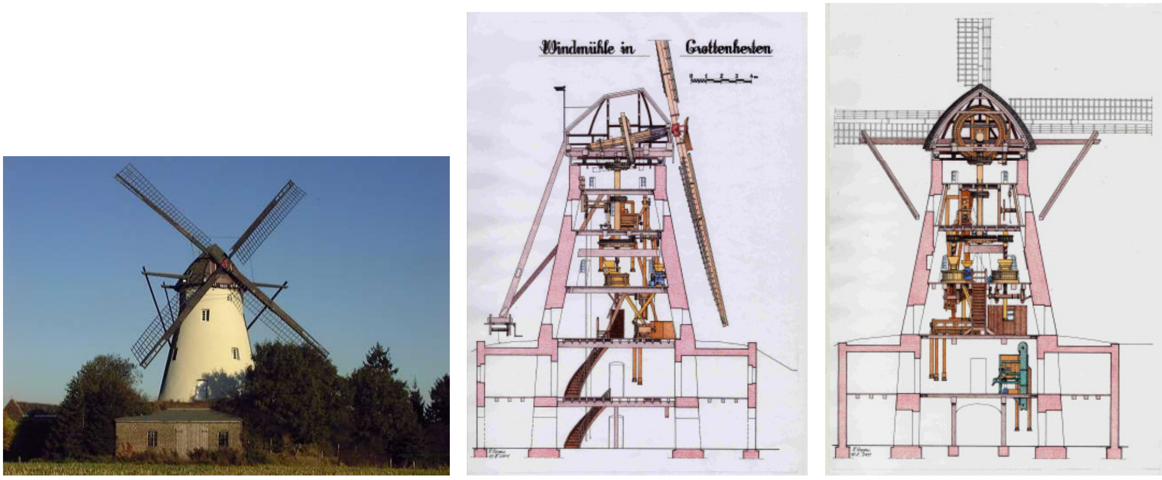
In section 1.5 different wood constructions were briefly presented regardless of their dimensions and age. Now constructions should be presented, which do have a long history as well, but are named special wood construction due to their mostly dynamic stress.

One example is bell frames (see figure 1.57), which are implemented as wood construction in all historical churches as well as in newer religious buildings.

Figure 1.57: Bell frame in St. Georg, Alt-Kaster (Bedburg)
[see Case study 1, section 3.3]

Another example of a special wood construction is windmills (see figure 1.58).

Figure 1.58: Windmill in Bedburg (exterior view and sectional system drawing)



The special constructions presented in this section only represent a very small selection.
A variety of wood constructions exist, which were built in previous years (decades and/or centuries), and which are for a multitude on reasons not built anymore or were only built for a short period of time. In addition, regional structural specifics exist, which a wood expert may face, when he works for the first time in this region.
Another example of special constructions is the Zollinger architecture for roof construction.

Figure 1.59: Roof panel in Zollinger construction, source [2]

In all cases the wood expert must always independently familiarize himself with constructions unknown to him. In the further course of this thesis, this topic will be addressed. Suggestions are provided, how wood experts can access the technical knowledge of other colleagues. For information refer to later sections 3.6 and 4.2.

1.6 Structural computations (= database basics)

The static system is of great importance for any assessment of load-bearing (supporting) structures. In the databases already mentioned several times, the static systems and the corresponding structural analyses of all investigated wood constructions are of fundamental importance. For older buildings without any planning documentation, the wood expert's experience is required. He must record the static system via visual inspection of the construction, and verify it using comparison computations.

The following sequence is used for new buildings. The actual structural analysis procedure described is generally applicable to all analyses.

1.6.1 Structural safety analysis and usability analysis

Based on the design, the structural engineer prepares the structural safety analysis. Term definitions can be found in section 1.1.1. This analysis is also called structural analysis.

First, all internal and external loads affecting the building, are collected. Here it is differentiated between permanent loads (tare weight of installed materials) and traffic loads. This includes all varying loads (= not permanent), mainly of persons staying in the investigated building. Wind and snow loads are very important as well. They are determined based in the geographical location and the geometry of the building. Finally, the importance of earthquake protection is increasing. In other words, the building must withstand the vibrations of an earthquake.

In Europe standardized loads exist, which are compiled in Euro Code 1/ EN 1991 (= impacts on supporting structures) [S7]. According to this provision, all outer and inner loads of a building must be determined. The structural engineer in Europe analyses earthquake protection according to the requirements of Euro Code 8 / EN 1998. This analysis is called the dynamic analysis of the building.

Within the scope of a structural analysis, the engineer proceeds as follows. He starts the building measurements with the top (highest) components. Then, all loads are determined from top to bottom. At the end, the foundation loads are determined. For this purpose, previously described densities are often required (see section 1.2.3.1). Outer loads cause forces on individual building components. These different outer forces (lateral, normal, bending forces etc.) cause inner stress in the profiles, which must be withstand. The structural engineer analyses this stress using a stress analysis. Besides structural safety analyses, usability analyses (refer to section 1.1.1 for term definitions) are very important. This analysis describes the compliance with maximum deformations. Wood has the best elastic characteristics. However, they must be referenced to the entire building. For example, a rafter with insufficient height may be able to safely transfer all occurring outer loads to the components arranged below. A stress analysis would be approved. However, if the deformation is too severe, then this may e.g. negatively impact the interior fittings. In this case plasterboards installed at the underside may show cracks sooner, as their elasticity is not sufficient.

A degree in civil engineering with specialty "construction engineering" is necessary in order to be able to perform structural analyses, and to be officially permitted to perform them in Germany. Architects and construction technicians are usually capable to perform smaller structural analyses.

1.6.2 Historical development

While the construction of historical buildings was only based on empirical values, today all buildings to be constructed are structurally analyzed. Not infrequently structural engineers must solve the riddle, why constructions, which become visible within the scope of reconstructions, were structurally safe for decades or even centuries. Today, the present stress is compared to the maximum design stress in all stress analyses. Different timber often under designed. However, theses should not be carelessly exhausted. In addition, most structural analyses are based on idealized two-dimensional static systems. However, buildings have three-dimensional load bearing capabilities, which mostly lead to better load bearing capability.

1.6.3 Load bearing (supporting) and non-load bearing (nonstructural) Components

Within the scope of a structural safety analysis of a new construction, the structural engineer defines a load bearing system in the analyzed building. In the system continuous force flow to the foundations must be ensured. If components, such as e.g. walls, do not contain vertical loads, then they are called non-load bearing (nonstructural) elements. Care should be taken, if builders would like to independently remove "obviously" nonstructural components within the scope of a reconstruction.

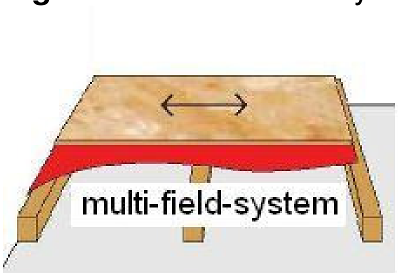
Applied to the topic of this thesis, these could for example be wooden construction parts infested with fungus and/or insects, which are not used for vertical load propagation (e.g. framework wall parallel to the wooden-beam ceiling stress direction). Besides vertical loads caused by tare weight, snow and traffic loads, a multitude of horizontal loads exists. This includes wind loads, impact loads, handrail loads, etc. Dynamic loads of standing machines or earthquake loads also cause horizontal loads. These must also be absorbed by the building construction. It may occur that a nonstructural wall must not absorb any vertical loads; however it must be used as stiffening element for the dissipation of horizontal loads. The analysis of sufficient building reinforcement (stiffening) is another task of the structural engineer.

The wood expert's experience is especially required for the analyses of existing wood constructions performed in this PhD-Thesis. He must identify load bearing and nonstructural elements on site.

1.6.4 Static systems

The idealized presentation of the static system of a building as single-field systems and/or multi-field systems (see fig. 1.60) is the simplest solution. Spanned free rooms are defined as fields.

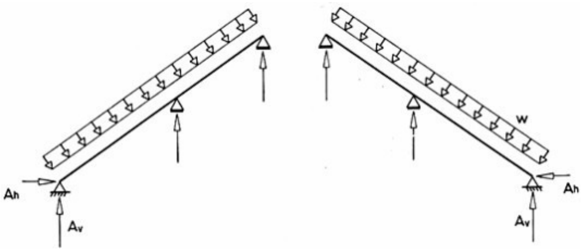
Figure 1.60: Multi-field system, here a 2-field system



For the analyzed systems it is investigated, on which supporting components (= supports) they rest and how many fields they pass. From a structural point of view, multi-field systems are usually better than single-field systems. The flow effect across the inner supports is beneficial with respect to stress and deformation in the mostly unfavorable field center.

A multitude of static systems of roof supports (flat and three-dimensional), reinforcement (stiffening) systems (roof and wall systems) etc. exist.
For angled rafters (according to the roof pitch) the supporting components, such as e.g. purlins, are added to the static system. Fig. 1.61 illustrates such a system.

Figure 1.61: Static system (2-field system) of a continuous rafter, which rests on an eaves, center and ridge purlin



The next two figures show 2 additional possible roof construction designs. The collar beam roof (see fig. 1.62) still common today, and truss and strut frames often found in older roofs (fig. 1.63).

Figure 1.62: Static system of a collar beam roof

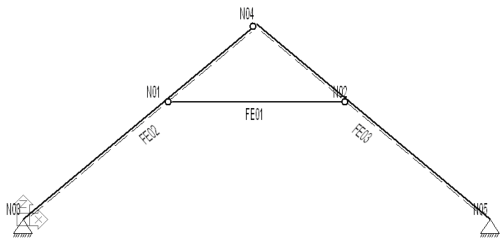
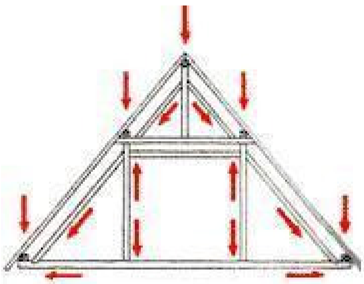


Figure 1.63: Static system of purling roof with strut and truss frame

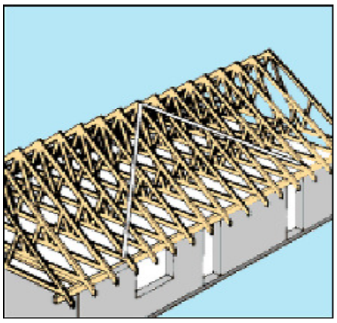


Different static systems can be found in chapter 2, section 2.6.1 ff, databases 1-5 of this thesis.
The literature references in section 1.6.1 provide different information as well.

1.6.5 Reinforcement (stiffening) systems

As described above in detail, besides dissipation of vertical loads for all structural systems, dissipation of horizontal forces applies as well. The systems here are called reinforcement systems. Each roof construction must safely transfer wind loads to components arranged below. For this purpose, the roof area should be implemented as so-called structural panel. Today this is e.g. ensured by the application of wind bracing tape (see fig. 1.64).

Figure 1.64: Wind bracing tape on a roof construction



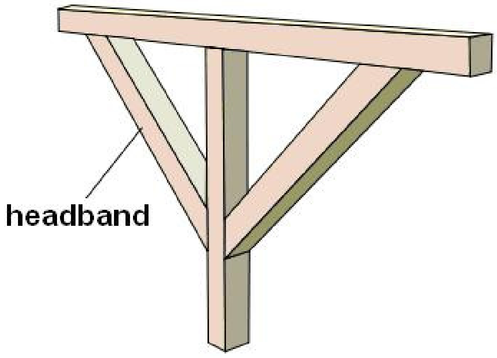
Wind bracing tape on the roll

For older roof constructions wooded wind braces were attached (nailed) (see fig. 1.65).

Figure 1.65: Wooden wind brace on bottom side of the rafter

Typical for older wood constructions are headbands (see fig. 1.66) attached to the column head, which also support the stability of the supporting structures.

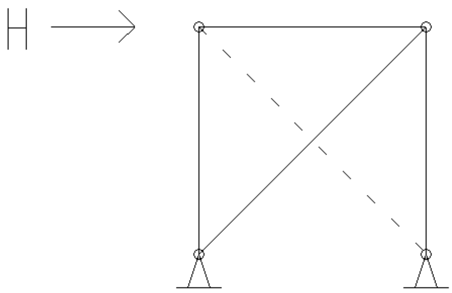
Figure 1.66: Headband on a column



In combination with the column and the horizontal purlin, these headbands have the same effect as a bending-resistant frame corner, which represents the classic form of a reinforcement element in steel construction.

By installing continuous wooden lagging, the floor ceiling level is made into a structural panel, which can dissipate horizontal forces.
The diagonal elements in old framework walls were also used for reinforcement. In modern timber frame construction, which is briefly described above in section 1.5.5, the wall is transferred into a structural disk by cladding installation.
All reinforcement systems can also be recorded as static system. For this purpose, flat (level) framework systems are often used. A stationary (not moving) triangle can be used as simplest reinforcement system in a static system.

Figure 1.67: Static system of a wall bracing



1.7 Building Physics basics (= database basics)

Building physics includes the following divisions: moisture, heat, fire and noise protection.

As the basic knowledge described in the previous sections already contains building physics aspects for the 3 checklists (material characteristics, cracks and deformations, wood preservation against fungi and insects) as well as the 5 databases, it must not be repeated. The actual databases in chapter 2 (see sections 2.6.1 ff) address further building physics aspects, as they often cause different damage patterns in wood constructions.

A missing or insufficient chemical and/or constructive moisture protection, insufficient heat insulation of wood constructions of the thermal building enclosure, or missing fire protection of the load-bearing construction of a residential building, mostly cause damage to the wood construction, which must be repaired and/or strengthened for old buildings. When planning new buildings these aspects of building physics should be considered from the beginning.

Next, the building physics divisions are briefly discussed. The goal is to mention the most important aspects of assessing a wood construction in general, regardless of dimensions, age and usage.

References included to scientific papers and/or literature references should provide the possibility of researching an aspect in detail, possibly taking into account the entire current state-of-the-art of technology.

1.7.1 Sound insulation

Faulty sound insulation rarely leads to construction damage. However, to retroactively improve impact sound and structure-borne sound for wooden ceiling and wall constructions is usually very difficult. Especially for new buildings, a sound insulation analysis must be performed and consequently implemented during the planning phase. This should silence the preconception that only massive buildings can achieve good sound insulation.

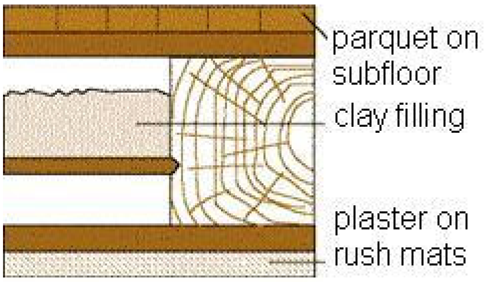
As it is difficult to assign older constructions to available reference constructions with respect to sound assessment, only sound level measurements can provide reliable values within the object.

In section 2.6 databases are collected, which besides additional assessment criteria, show common redevelopment measures for detected deficiencies for the different wood components and/or wood constructions.

The following system sketches (see figures 1.68 and 1.69) show options, how to improve the sound insulation of a classic wooden-beam ceiling.

Figure 1.68: Common wooden-beam ceiling with clay inserts and parquet floor

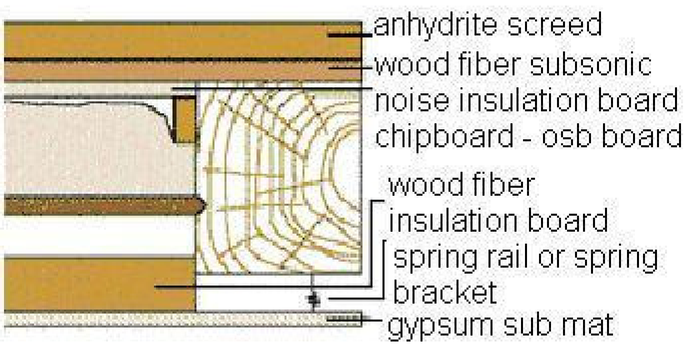
(achieves minimum sound insulation in most cases)



When subsequently introduced or lifting loads that are intended to improve the sound insulation, must necessarily be a static pre-review.

Figure 1.69: Improved structure with insulating wood-fiber boards

(achieves sound insulation of 70 dB)



The wood expert must usually decide, which measures improve sound insulation. For this decision the impact of adjacent components is important and structural safety verification must show, which load reserves are available in the analyzed construction. This is necessary, as additional ceiling superstructures and/or suspension significantly increase the tare weight of the roof construction.

1.7.2 Moisture protection

Due to its great importance and the corresponding negative impact of water and/or moisture on wood constructions, moisture protection was already discussed in detail in the previous section 1.4.1.
In summary, it can be stated that each construction must be protected against moisture using building physics means. If this natural protection is not sufficient and/or not possible, then necessary chemical wood preservation must be applied according to hazard and usage class (see sections 1.4.1 and 1.4.2).
A planned usage change of a building may cause increasingly necessary chemical wood preservation. The wood expert must decide on the implementation on a case-by-case base.
With respect to moisture protection for wood constructions, not only outer influences of weather and ground moisture must be considered, but also handling of too high air humidity in kitchens and bathrooms. A water pipe leakage not being detected for a long time, not infrequently causes significant damage to adjacent wood and wood composites. Thus, this aspect is not only important when planning new wood constructions. When assessing older constructions, greatest attention must be paid to the generation of wet areas in bathrooms as well as water pipe routing.
In sections 2.4.6 and 2.4.7 investigation methods are presented, which can be used to localize different weak points and already existing damage, which are often caused by have building physics.

1.7.3 Fire protection

Wood is a flammable material, which must be protected against fire. When protecting wood against fire, it is of fundamental importance to understand, which requirements must be met by the load-bearing wood components. For this purpose fire ratings were defined.

They indicate how long (in minutes) a construction must remain structurally safe in case of a fire to enable the rescue of persons by the fire brigade.

F30 (fire retardant)

F60 + F90 (fire resistant)

These requirements are clarified within the scope of structural fire protection. Depending on the building dimensions and usage, fire ratings are defined.

There are 3 possibilities to protect wood in the case of a fire. It is possible to line components with fire panels (see fig. 1.73). Depending in the fire rating, cladding provided by different suppliers may be used, which must demonstrate the respective permits in form of test certificates.

Figure 1.70: Fire protection cladding of wood profiles in a roof construction

[The left pillar (with headband) is already protected. The right is without plater]

Furthermore, chemical wood preservatives exist, which generate a heat insulating foam layer in case of a fire (see figure 1.74).

Figure 1.71: Heat-insulating foam layer of chemical fire protection cladding

Foam layer on a wood profile, generated during a fire

The third option is to increase the wood dimensions, as the charring zone represents natural fire protection of the remaining profile. Tables exist for this constructive fire protection specifying the minimum wood profiles as a function of present stress, fire rating and fire load (three or four sides).

Fire protection is of special importance for the assessment of older and/or already existing wood constructions, which are the focus of this thesis.

If deficiencies in the other building physics divisions, such as moisture, sound and heat protections, cause wood damage, the damage must be detected as soon as possible and successively professionally corrected. In case of fire protection assessment of wood constructions, the focus is on personal protection in case of a fire.

For this reason, wood experts should be urged not to compromise in fire protection questions, when monitoring buildings. With respect to this point, the often mentioned argument of architectural conservation may not be applied either (see section 1.1.1). What may have worked for several decades may tomorrow cost a person’s life.

The actual building usage must be considered for the definition of escape routes/options in the case of a fire within the scope of structural fire protection. The above mentioned fire ratings must be defined depending on the building dimensions, height and usage. The quality of installed fire panels or similar must be verified and/or specified, if this had not been done yet.

If for reasons of monument conservation, wood must remain visible, chemical fire protection is an alternative.

If above described constructive fire protection is applied, then structural safety analyses of the investigated constructions must be available or must be performed to ensure that stress reserves are available. In case of a fire, the remaining profiles underneath the generated charring zone, must ensure structural safety for a certain time (= fire rating in minutes).

1.7.4 Heat insulation - Energy-saving measures

The importance of this last building physics area is increasing - especially for the assessment of existing and/or older wood constructions.

As already described in section 1.2.3.2 "Thermal characteristics", societal awareness is well developed due to regular tightening of heat insulation and energy saving provisions in the past years and decades.

For example, the heat insulation provision in 1995 still pursued the realization of so-called low-energy houses. Future provisions are increasingly focusing on the requirement to build zero-energy houses. The current energy saving provision provides specifications, which must be met in case of redevelopment as well as partial replacement of outer components of the thermal building enclosure (= all outer components bordering against ambient air, the ground or unheated rooms).

In the following, individual aspects are listed, which are important for the energy assessment of older buildings. A wood expert should always think about these aspects, while he applies the assessment matrix using all previously mentioned auxiliary tools: forms, checklists and databases described in detail in chapter 2 of this thesis.

If the wood expert does not have sufficient knowledge in the area of heat insulation, then he should involve a respective expert as needed. Databases are available in the German region of North Rhine Westphalia, providing officially recognized experts for sound and heat insulation.

The new energy saving provisions combine the original heat insulation provisions and heating system provisions. Thus, not only structural-constructive characteristics of the building enclosure, but also building services are important for the energy assessment of a building. In order to meet these higher requirements, a new occupational field was created for architects and civil engineers. These experts are called "energy advisers". Energy advisers are capable to completely assess a building with respect to energy (including the area of moisture protection). They point out weak points and list necessary and/or recommended remodeling measures, such as e.g. additional insulation of outer components. The result of an energy consultation is an energy pass (certificate) (refer to section 3.9.6). This label will be addressed at the end of this thesis, as the result of a building investigation, which will be described in more detail in the further course, should also be documented in the form of a label (see section 3.9.5).

Each wood expert should be familiar with the basics of building energy assessments.

The quality of the outer enclosure has the highest priority. In energy saving analyses, the heat transfer coefficients (= U values) are determined for individual outer components or against unheated rooms or areas adjacent to the ground. This is necessary for component comparison and in order to maintain the limiting values defined in the energy saving provision. If observed in the context of the general analysis procedure, all qualities of the thermal enclosure target a value, which is the decisive parameter of energy saving analyses, the so called "specific transmission heat loss (= H'T value). The 2nd parameter is the annual primary energy requirement (= Q"p value). For both parameters specified limiting values must be met. Building service conditions are decisive for the annual primary energy requirement.

Besides the previously mentioned aspects within the scope of building energy assessments, the points possibly causing damage to wood constructions, are very important in this building physics area.

During the inspection of the thermal building enclosure described above, greatest attention must be focused on possible and/or obviously existing heat bridges. These are the classical locations, where warm inner air condenses on a cold inner wall (mostly a corner) due to insufficient or missing outer insulation. This moisture causes short- or long-term mold damage, which may cause significant damage to wood constructions as already described in section 1.4. When heat bridges are detected, the wood expert must provide useful improvement measures.

In the case of heat bridges, retrospective insulation measures may be unavoidable. In case of facades subjected to monument conservation, retrospective insulation measures may only be installed on the inside. In any case, for any retrospective insulation measures it must be investigated upfront, if condensation may be generated within the construction. This water condensation could cause known damage to wood constructions. Using for example the Glaser approach, this condensation risk within the construction can be estimated.

The window condition as well as roller shutter casings (if available) should be inspected during every building inspection. Window quality, including frames and roller shutter casings, has been significantly improved during the last decades. However, replacing old windows with new highly insulated designs, which are air-tight, can also cause problems. Until now, air could be exchanged through leaks in the old frame. Humid room air may have been able to escape. After a window replacement this may not be possible anymore and lead to mold in the room corners. This must be investigated prior to installing new windows.

In this context the term "leak-tightness" is used, whose importance is increasing with respect to energy assessments. In new buildings the leak tightness required in the energy saving provision, is more frequently tested using a "blower-door" test to ensure the controlled air exchange rate.

Wind and air leak-tightness are differentiated for buildings.

The air-tight layer (on the interior side) in outer components is mainly used to avoid condensation due to room air convection into the component. The air-tight layer is also used to prevent heat loss and to ensure comfort (= prevention of draft effects).

For insulated wood constructions a vapor barrier must be installed on the inside, which should exclusively prevent or reduce water vapor diffusion through the component.

When investigating air tightness, the transitions from walls to ceilings and/or roof pitches as well as window connections must be inspected with greatest care. The airtight implementation of openings (e.g. chimney, pipe penetrations, electrical cables etc.) must be inspected as well.

Wind tightness describes the layer on the outside of an outer component to prevent ambient air flow through the heat insulation.

The aspects mentioned last, indicate the complexity of this building physics subject. It should be highlighted that a building must always be analyzed as a complete entity. An energy pass / certificate should be issued for serious building assessments (if not existing already).

If no information is available, then the quality of outer components, especially of insulation layers, should be inspected on site. This is also important, as not visible damage to wood constructions can cause enormous remodeling costs, if not detected early on.

Besides energy losses causing financial damage, the focus should be on the harmful aspects (dangerous to health), e.g. in the case of mold infestation.

The aspects mentioned in this section should sensitize the reader, who may perform building inspections himself, which points are of great interest during a building assessment.

Next, an example is presented experienced by the author within the scope of his appraisal activities. The green flat roof of a new construction had to be completely replaced after one year of utilization. The reason was a planning mistake causing the generation of condensate in the layer structure of the construction. Significant damage can already be caused after shortest time. This example should emphasize that care should not only be taken, when inspecting older buildings, and that moisture impact on wooden constructions is in any case destructing.

1.8 Intermediate conclusion and outlook into the following chapters

As already described at the beginning of chapter 1, this chapter should merely provide an introduction into the subject matter of this dissertation. Thus, sections 1.1 to 1.7 are limited to important facts. The goal was to address the contents of the following chapter 2, which as the core of this thesis, presents the development of the assessment matrix. Thus, chapter 2 is based on the basic knowledge in chapter 1. In chapter 2 additional cross-references and/or literature references are provided enabling in-depth self-study as needed or as desired.

The collection of the different aspects of this first section indicates that wood is very versatile and that the buildings constructed from early times, up to today's modern society, must be analyzed with respect to this aspect.
The importance of the subject discussed in this thesis, the assessment of buildings with a load bearing wood construction, must be highlighted for each sub-aspect.
This was and is the greatest challenge: collect the different aspects of wood constructions and summarize them in a matrix, in order to analyze the condition of wood constructions regardless of their dimensions, age, location or consistency, and to finally assess them.
This challenge is gradually addressed in the next chapter, where an assessment matrix of valuable timber constructions is compiled.
Everything communicated in chapter 1 is already known and corresponds to the current state-of-the-art of technology. This chapter does not have any scientific relevance, as no new findings are presented. These should be delivered in the following sections of this PhD-Thesis.

2. Development of an Assessment Matrix (= Main Matrix)

After presenting different aspects of timber structures in the previous chapter, the current chapter seeks to present and develop step-by-step an assessment framework with the help of which timber structures can be inspected in the future.
A user manual for the use of the matrix is presented at the end of this 2nd chapter.

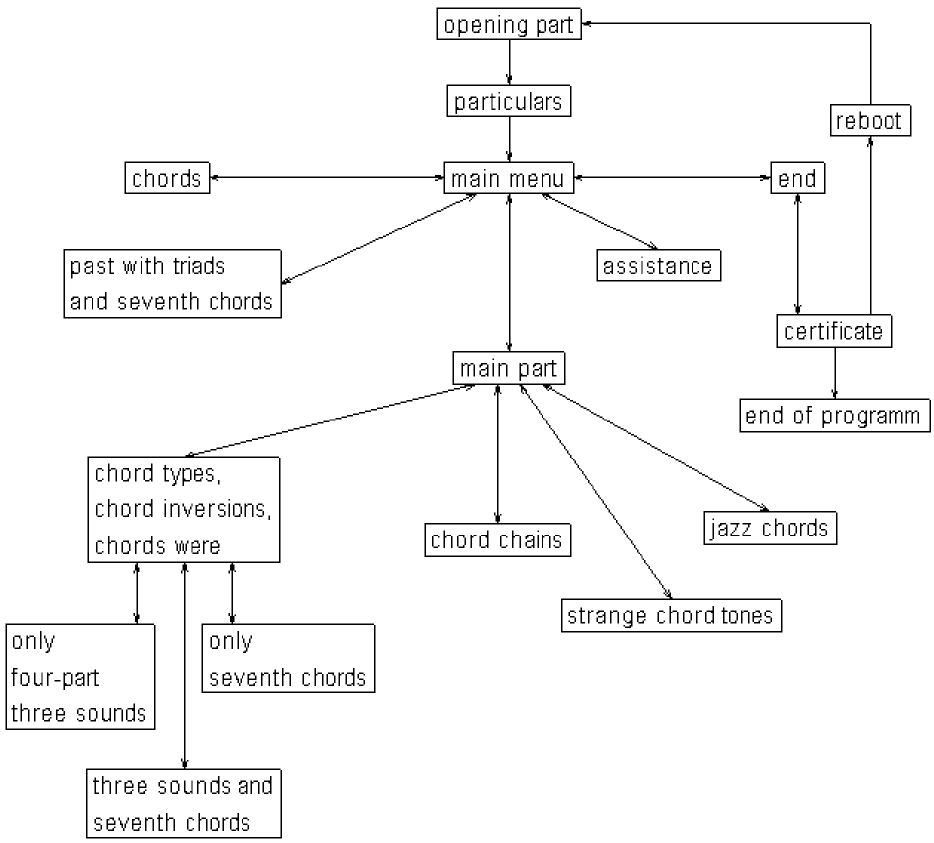
2.1 Definition of terms - matrix

A matrix is referred to as a fact that is arranged in the form of a technical table (see Figure 2.1) or presented graphically, for example, in the form of a structured chart (see Figure 2.2), or in a combination of the two. This form is most suitable for tackling or illustrating a previously described technical question. The processing sequence is predefined with all aspects or subitems to be observed. Thus all important parameters are examined.

Figure 2.1: Representation of a technical fact in a tabular form,
e.g. properties of various types of wood

Wood-species	Moist wood % fiber saturation	Shrinkage % axial	Shrinkage % radial	Shrinkage % tangential	Dry density
pine	26 – 28	0,2 – 0,4	3,7 – 4,0	7,7 – 8,3	0,49
fir	30 – 34	0,2 – 0,4	3,6 – 3,7	7,9 – 8,5	0,43
oak	22 - 24	0,3 – 0,6	4,6	10,9	0,65

Figure 2.2: Example of a structured chart of piecework



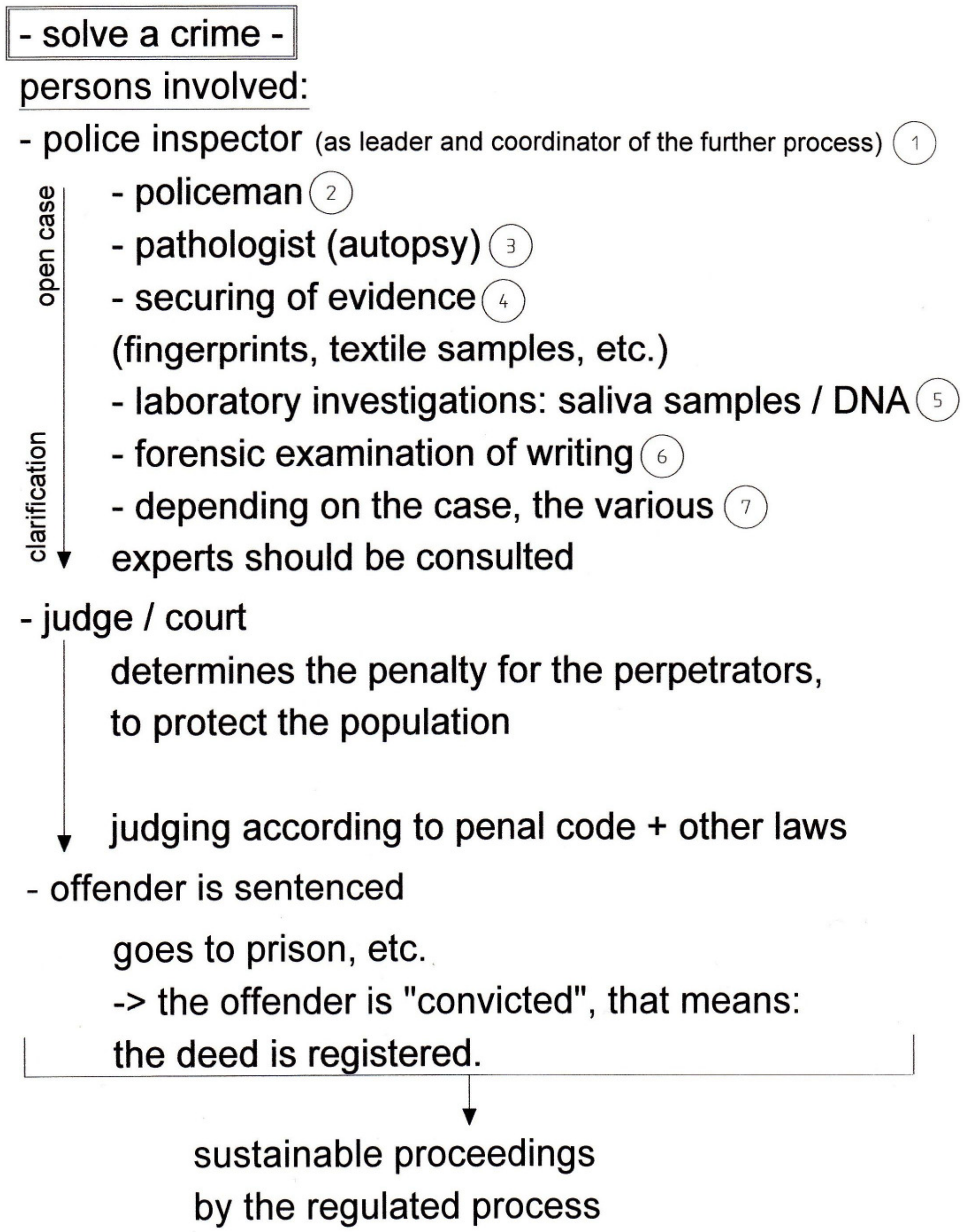
2.2 Complexity of Tasks

Because a timber structure that can be inspected from countless perspectives is so complex, it is also important to refer to experts who posses a great deal of knowledge, for example, in the area of building biology as well as the necessary equipment, which allows them to conduct more precise investigations and, therefore, make more decisive declarations about their findings. The timber expert is at the forefront of an investigation. He oversees the complete assessment procedure and conducts an evaluation upon completion.

Solving a criminal case is shown here for comparison (see Figure 2.3) because such acts are already anchored in society's collective awareness.

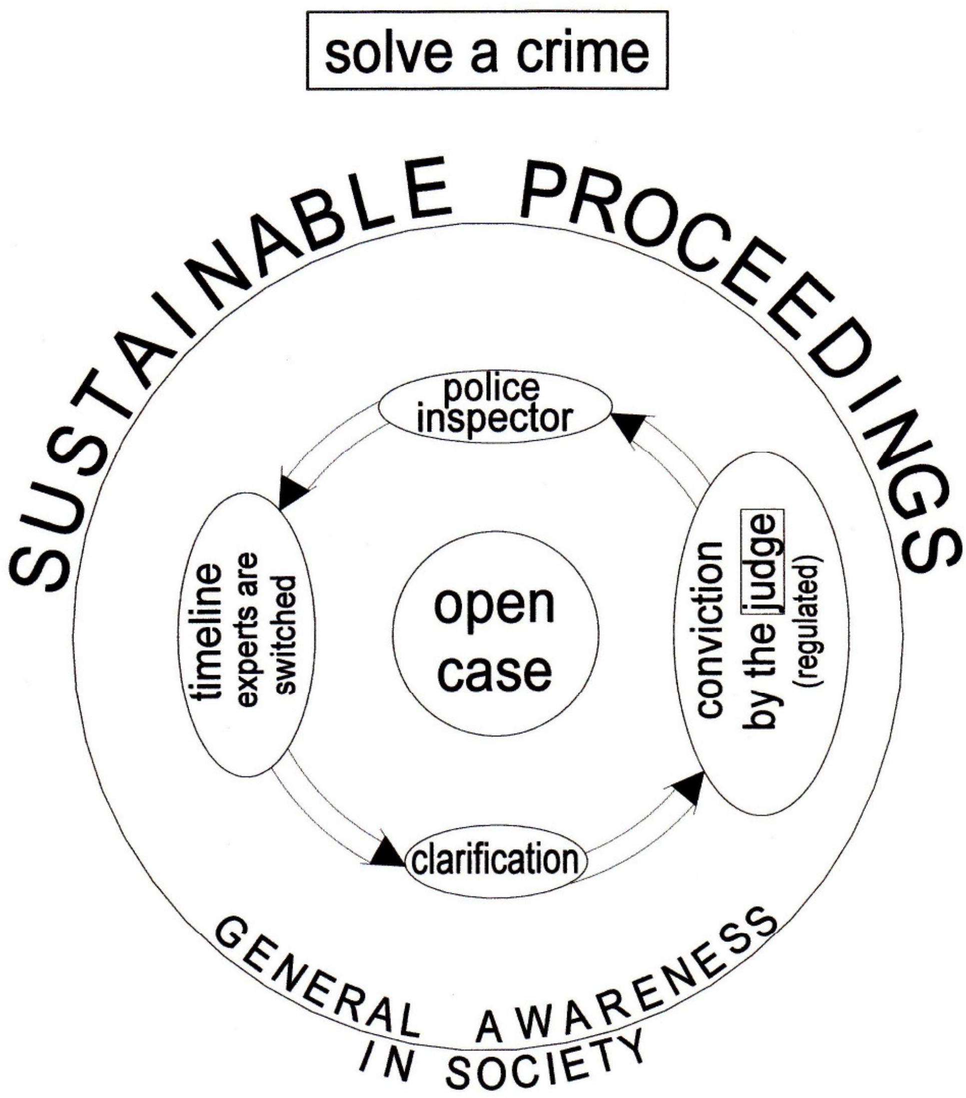
The chief inspector is the director and coordinator of a criminal case that involves for example, a manhunt. The inspector's analytical procedure at the beginning of a still highly complex case resembles, in principle, a timber expert's evaluation of a timber construction, which he will be able to conduct in the future with the aid of the matrix developed here.

Figure 2.3: The proceedings of an inspector solving a criminal case – Schematic representation



The inspector usually involves diverse experts until the case is solved.
If the possible offender is found, he is brought before a judge who convicts him according to the laws (e.g. the penal code, etc.)if he is guilty. From now on, the offender has a criminal record and, therefore, registered in order to protect the public from further criminal acts. This legal process (or proceeding), which is conveyed to the youngest of children and thus made known early on, achieves long-term impact that is of great importance for the public good.
These proceedings can also be represented graphically. Figure 2.4 is a graphic that presents the chronology of the inspector's proceedings.

Figure 2.4: Matrix of an inspector's sustainable proceedings for solving a criminal case



During the construction state analysis [2], which is described in detail in Section 2.4, the timber expert (= appraiser) undertakes, as the leader and coordinator of a timber structure assessment, the role of inspector in the analogy described above. The open case is a specific task here, for example, the evaluation of a timber structure's stability. After the execution of various on-site analyses and the possible inclusion of experts, which will be explained in greater detail in the following Section 2.3, the timber expert produces a construction state analysis. Based on this, he establishes the additional procedures, such as strengthening, restoration, etc., that should be implemented. All works are conducted on the basis of current timber regulations (e.g. EN 1995 [S8]) or, as the case may be, the state-of-the-art.

At the end of the state of the construction analysis, the timber expert can classify the construction under consideration into different “construction state levels.”

At this point the assessment usually ends momentarily. The idea of this PhD-Thesis is to achieve sustainability in these common construction jobs by pursuing a coherent process similar to the one described for solving the criminal case. For this purpose, a concept is developed over the course of the thesis, which is described concretely at the end of chapter 3. As a result, catastrophes such as the 2006 collapse of the ice pavilion in Bad-Reichenhall, Germany can be prevented.

If the system presented later in this thesis were to be introduced into European society, it can be argued that such catastrophes could be made nearly impossible.

In Germany, the laws only obligate the property owner to maintain his property. The following excerpt from the German Civil Code [S24] serves this purpose.

German Civil Code Article 836: *If a human being is killed or the health of a human being is injured or a thing is damaged by the collapse of a building, then the possessor of the building is liable to make compensation to the injured person, to the extent that the collapse is a consequence of inadequate upkeep.*

Therefore, most owners are overextended on one hand due to their lack of technical knowledge and on the other hand, no official control function exists that verifies the usability of buildings let alone authorizes their use.

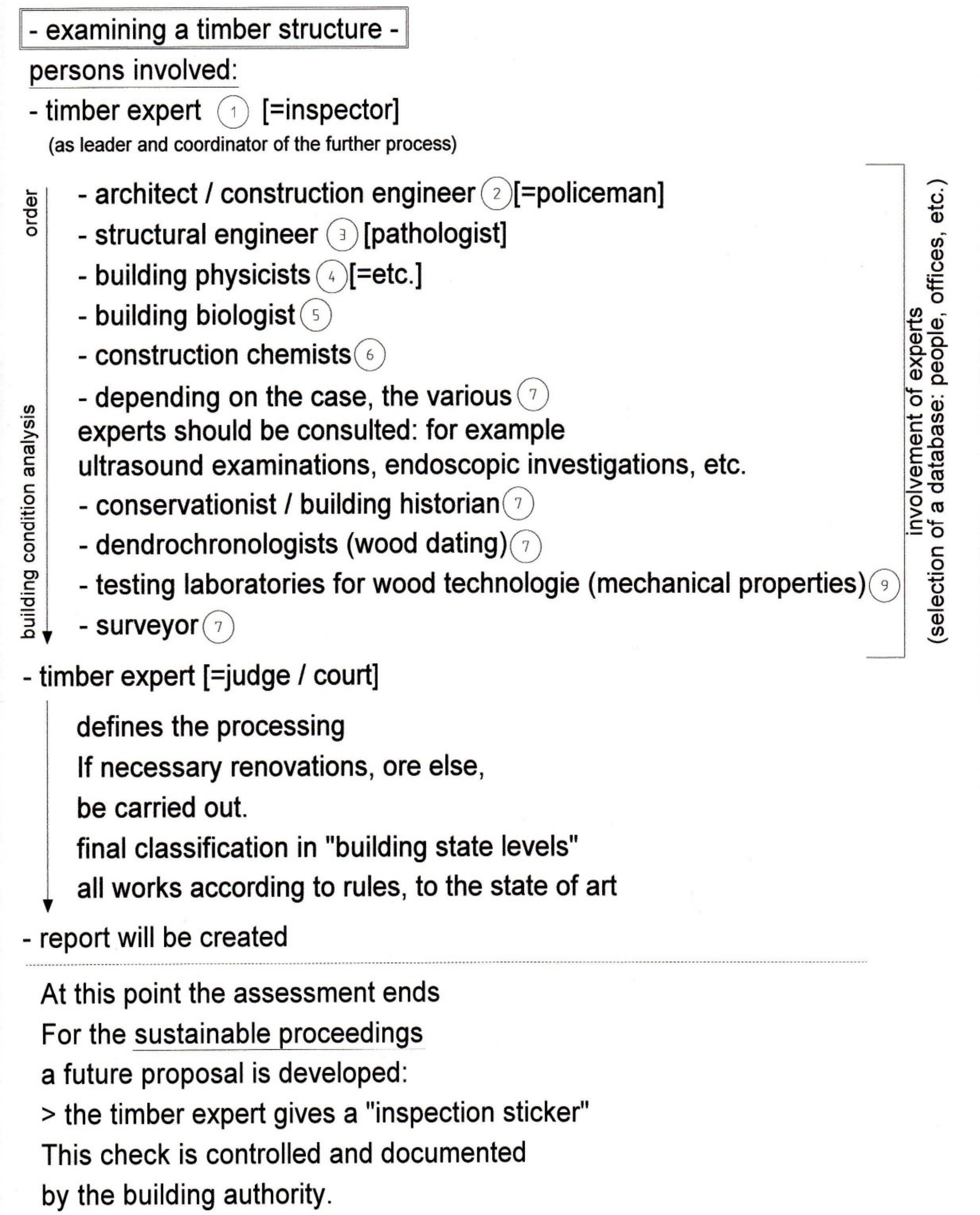
The German TÜV (= Technical Inspection Association) can serve as a model. No vehicle is allowed on public roadways without a TÜV sticker. This model is described in detail in chapter 3.

German building laws (e.g. regional building laws) require an official, government-issued building permit with a final inspection before use. Afterward, all buildings are left to their “fate”, reminders of the Bad-Reichenhall tragedy.

This complex fact, which is effective in improving the sustainable safety of the user, is the goal of this PhD-Thesis. For this process an instrument is necessary initially. The matrix represents this instrument.

To narrow down the scope of this thesis, “only” timber structures are covered and included in the evaluation matrix. In old buildings these are mostly the supporting structures (roofs, ceilings, stud walls, etc.). As damages in the recent past have shown, however, not only older timber structures must be more closely inspected since devastating damage can occur in newer (engineering) timber structures in a short amount of time.
As described in the previous section, timber experts use different expertise knowledge to conduct a condition analysis depending on the specific task in order to evaluate the considered timber structure as well as possible or necessary. Various experts are presented in the following graphic (= Figure 2.5).

Figure 2.5: Assessment of a timber structure with different (external) experts – Schematic representation



The timber expert is usually an architect or engineer with verifiable minimum credentials predominantly in the timber sector. Due to the complexity described above, these days it is nearly impossible to cover all industries.

2.3 Involvement of Experts

The timber experts listed in the above graphic (see number 1) can be consulted or involved if knowledge is lacking or necessary measuring and testing equipment is unavailable. In Section 2.4.7, the creation of an expert database will begin, which can be expanded or individually arranged by the respective users (= timber experts) at any time.

Subsequently, the main areas that the timber expert must cover during the construction state analysis are named. Additional experts may become involved according to the specific needs of each respective situation.

The verification of forces and stresses in the supporting cross-sections and fasteners often requires verification by a structural engineer (= stress analyst).

Often the cause of damage lies in the structural-physical realm. Strengthening or reconstruction, etc. usually concerns the improvement of the structural-physical aspects of moisture, sound and fireproofing and heat insulation. For this purpose, building biologists and chemists can be just as involved in the state of the construction analysis as timber experts if protecting the timber from fungus and inspects is required as part of the bigger picture.

As far as the inspection of landmarked structures is concerned, it can be potentially advantageous to receive technical knowledge from monument curators and architectural historians. The dendrochronological age determination of wood provides an exact age determination. This can only be conducted by testing laboratories.

Mechanical stresses, such as for example, acceptable bending stress and shearing stress can only be investigated in testing laboratories equipped for such a purpose once one or more wood samples has been taken from the structure under consideration.

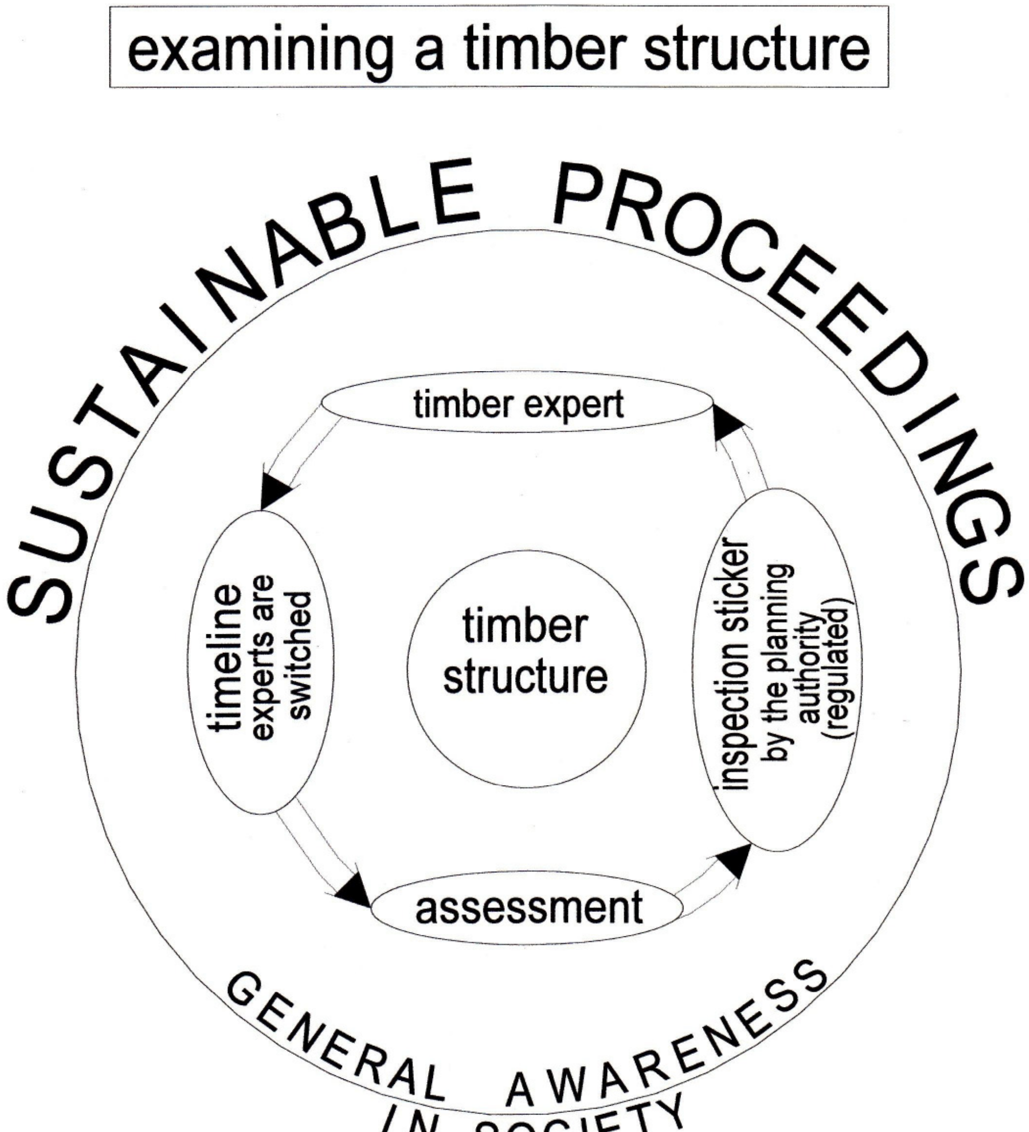
Once in awhile, precise surveying equipment is necessary in order to verify exact deformations, for example. In this case, external surveyor's offices can be contracted.

In the continuing process, various inspection methods are named in Sections 2.4.6 + 2.4.7, which are usually only carried out by experts who possess the necessary equipment, such as for example, a device for endoscopically inspecting a wooden-beam ceiling, among other things.

This was a selection of experts that the timber expert involved in the construction state analysis where required.

This procedure can also be represented graphically as shown previously in figure 2.5. Figure 2.6 shows a graphic that illustrates the chronology of a timber expert's proceedings.

Figure 2.6: Graphic of a timber expert's sustainable procedures for examining a timber structure.



2.4 Methodology of the construction state analysis

In the future the total assessment of timber structures should occur with the aid of a matrix. Top priority is the simplification of work through the specified forms that are processed consecutively. A further advantage would be the potential improvement resulting from evaluations that could be conducted within the scope of a QM system (= quality management system) [17] in the timber expert's office, which could then recall the matrix in the future. The goal is to use the matrix in the form of an IT program (= computer program) in the future. This is discussed in greater detail in Section 4.1.

The simple structured design of the matrix should simplify the assessment of timber structures through the predetermined processing sequence,
The matrix consists of a total of **6 forms**, which are presented in greater detail in Section 2.4 et seq. All forms are presented in the **object book**. This is described in detail in Section 2.7.2.
Furthermore, there are **3 checklists** that simplify the work, which are shown in Section 2.5.1 et seq.
The selection of forms that are laid out, especially for the assessment of timber constructions of any kind, is rounded out through **5 databases** described in detail in Section 2.6.1 et seq.

The aim of this matrix for the assessment of timber structures is to achieve the same conclusion for the same construction among different timber experts. This standardization would stop assessments from facing criticism of any kind. When the assessment of the timber structures should be carried out and the associated consequences will be described in greater detail in chapter 3 of this thesis.

2.4.1 General information about the design + content of the "forms"

The forms, which are henceforth introduced and described in greater detail, present the guidelines of the entire assessment matrix. The open points on all forms are completed in chronological order. The aforementioned checklists and databases, which will be described in greater detail later on, serve to ensure that the forms are filled out completely and that a subsequent full summary of the undertaken assessment is conducted. The last form 6 serves this purpose in that it documents the final acceptance report (see Section 2.6.7).

All completed, filled out forms are compiled together in the object book (see Section 2.7.2). The purpose of this assessment, which at first seems time-consuming, is described in detail in chapter 3. If this sustainability strived for in the assessment process of timber constructions "merely" saves a human life, the costs will have already been worthwhile.

2.4.2 Form 1: Basic evaluation and structural parameters

All general information regarding the considered timber construction is first compiled in Section 1 of Form 1. The reason or the motive for inspections is requested in Section 2. Concepts that will be explained later on in chapter 3 are already included here (forms of monitoring, building categories, etc.).

Form 1: ***date ……………..*** ***(enter date)*** **(1/3)**

*The completely filled out Form 1 is to be filed in the **object book**!*

The yes / no / unknown – fields are to be marked.

*Additional **appendices** are to be referenced!*

1. General project information:

General: General project information and the reasons for inspection can be specified in advance.

On-site meetings: All conducted on-site meetings are listed.

Accessibility of the timber construction: The accessibility of the regarded on-site timber constructions is described here in short.

no.:	**term:**	**entry:**	
1.1	**building – description**		
1.1.1	**examined structure**		
1.2	**builder / ownership:**	**name:** **adress:** **tel.:** **fax:** **e-mail:**	
1.3	**responsible for building-check:**		
1.4	**leading office** **(complete adress):** **[= timber-expert]**		
1.4.1	**clerk:**		
1.5	**date of check:**		
1.6	**place (street, village):**		
1.7	**geographical location, altitude (above see level):**		unknown ☐
1.8	**direction / cadastral extracts available:**	yes ☐	no ☐
1.9	**age of the building or of the structure:**		unknown ☐
1.10	**date of setting-up:**		unknown ☐
1.11	**design drafters / architect:**		unknown ☐

Form 1: ***date …………….. (enter date)*** **(2/3)**

1.12	**exporting company:**			unknown ☐
1.13	**responsible building-office:**			
1.14	**planned use in the planing:**			
1.15	**Is the building listed?**	yes ☐	no ☐	unknown ☐
1.15.1	**responsible conservation authority:**			
1.16	**Is the building used or unused? (unused since?)**			
1.17	**classification in a building style:**			
1.17.1	**determined building style or construction era:**			

Form 1: ***date …………….. (enter date)*** **(3/3)**

2. Occasion or reason of the building check:

2.1	**first check of the structure after completion**	yes ☐	no ☐
2.2	**commission per building check (= official normed building check)**	yes ☐	no ☐
2.3	**monitoring form 1**	yes ☐	no ☐
2.4	**monitoring form 2**	yes ☐	no ☐
2.5	**classification of the building in a building category: BC 1 / BC 2 / BC 3 (see chapter 3.9.1)**		
2.6	**Is a structure defect noted?**	yes ☐	no ☐
2.7	**Is a building-measure planned? (enlargement, extension, use change, expansion, etc.)**	yes ☐	no ☐
2.8	**Is a repair planned? (modernization, reconstruction, renovation, etc.)**	yes ☐	no ☐

continuation: see form 2

2.4.3 Form 2: construction state analysis

Once the (first) general information and the motive for the inspection has been clarified and listed, then Form 2 serves the purpose of closely inspecting the constructions. Records shall be closely reviewed and the previous, current and planned use is established. Subsequently, classification into **usage classes** (according to EN 335) is conducted. The age with possible historical classifications should also be collected within the scope of Form 2.

Later in this thesis these usage classes are used for the classification of any building in so called **"building categories"** (see Section 3.9.1).

This beginning to the in-depth inspection within the scope of the construction state analysis is carried out in the office and represents, with the information from Form 1, the prerequisite for the on-site meetings to follow. The information from Form 3 (see Section: 2.4.4) comes partly from the reviewed documents, yet is checked on-site, finalized, and subsequently documented.

Form 2: ***date …………….. (enter date)*** **(1/11)**

Beginning of an "in-depth inspection" in the office:

Notes/ Comments:

The completely filled out Form 2 is to be filed in the **object book**!

Copies of the reviewed documents, such as building designs, static calculations, etc., are to be made and also filed in the object book.

*Additional **appendices** are to be referenced!*

1. Documents for classifying timber constructions:

Notes:

- The documents listed below are to be requested from the builder or authorized party and accepted by the building authority and land registry (= department of the appropriate district court) with a corresponding power of attorney (see page 13 on Form 2).

- The potentially available planning documents are to be compared at the following on-site meeting with the actual construction state. In doing so, the static span widths, the verified connections, and the indicated materials are inspected above all.

no.:	**term:**	**present:**	**checked on site or performed:**
1.1	Building an civil engineering drawings available	☐ yes / ☐ no	
	if 1.1 negative answered:		
1.1.1	allowance necessary		☐ yes / ☐ no
	if 1.1 positive answered:		
1.1.2	building-application plans = approval plans scale = 1:100	☐ yes / ☐ no	
1.1.2.1	ground plans	☐ yes / ☐ no	☐ yes / ☐ no
1.1.2.2	sectional drawings	☐ yes / ☐ no	☐ yes / ☐ no
1.1.2.3	building-views	☐ yes / ☐ no	☐ yes / ☐ no
1.1.2.4	site map or cadastral extracts	☐ yes / ☐ no	☐ yes / ☐ no
1.1.3	execution plans or detailed plans scale = 1:50	☐ yes / ☐ no	☐ yes / ☐ no

Form 2: ***date …………….. (enter date)*** **(2/11)**

1.1.4	Detail drawings scale = 1:25 / 1:20 / 1:10, etc.	☐ yes / ☐ no	☐ yes / ☐ no
1.1.5	Joinery drawings of the timber structures	☐ yes / ☐ no	☐ yes / ☐ no
1.1.6	Installation plan of the roofing, etc.	☐ yes / ☐ no	☐ yes / ☐ no
1.2	Statics available ?	☐ yes / ☐ no (if yes, go to 1.3)	
	if 1.2 is <u>negative</u> answered:		
1.2.1	Is the statical system important?/ The statical system is treated on the form 3.		☐ yes / ☐ no
1.2.2	Statical calculation	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3	Check the constant load on the building	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.1	Maximum snow-load	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.2	Maximum wind-load	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.3	Structure of the components with the load-determination of the net weight	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.3.1	Cover plates	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.3.2	Walls	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3.3.3	Roofing	☐ yes / ☐ no	☐ yes / ☐ no
1.2.3	Specification of the used materials (=wood-species)	☐ yes / ☐ no (if yes, go to 1.3)	☐ yes / ☐ no
	if 1.2.3 is negative answered:		
1.2.3.1	determination of the wood-species	see <u>*Checklist 1*</u> (2.5.1)	
1.2.4	Execution plans of the statical calculation, e.g roof construction plan, etc.	☐ yes / ☐ no	☐ yes / ☐ no

Form 2: ***date ……………..*** ***(enter date)*** **(3/11)**

1.2.5	test report of the statical calculation of the auditor-structural engineer	☐ yes / ☐ no	
1.2.5.1	special structure	☐ yes / ☐ no	
1.2.5.2	license in individual cases	☐ yes / ☐ no	
1.3	physical evidence existing?	☐ yes / ☐ no	
1.3.1	heat protection certification	☐ yes / ☐ no	☐ yes / ☐ no
1.3.2	constructive fire-protection certification	☐ yes / ☐ no	☐ yes / ☐ no
1.3.3	constructual fire-protection certificate = fire protection concept	☐ yes / ☐ no	☐ yes / ☐ no
1.3.4	sound-protection certificate	☐ yes / ☐ no	☐ yes / ☐ no
1.3.5	information to the moisture-protection	☐ yes / ☐ no	☐ yes / ☐ no
1.4	montage-information	☐ yes / ☐ no	
1.5	glue-book of the timber structure company	☐ yes / ☐ no	

Form 2: ***date …………….. (enter date)*** **(4/11)**

2. Establishing the use of the building:

Notes:

- Use of the building is coordinated with the builder or authorized party, which is to be inspected in each case at the following on-site meeting!

- Multiple uses are possible in one structure.

- The indicated loads are determined.

- The classification into **usage classes** is conducted. Different assignments are possible from room to room or in general depending on the situation within the building.

Form 2: ***date …………….. (enter date)*** **(5/11)**

2.1	**<u>Use</u>** of the building as:	present:	Checked on site or performed:
2.1.1	residential building	☐ yes / ☐ no	☐ yes / ☐ no
2.1.2	public building	☐ yes / ☐ no	☐ yes / ☐ no
2.1.3	commercial used building. Which crowds are possible?	☐ yes / ☐ no	☐ yes / ☐ no
2.1.4	special loads on the structure of building. The load is be specified in kN.	☐ yes / ☐ no	
2.1.4.1	point loads from machines, water bed, safe, watertank, bulk materials, bells, or other	☐ yes / ☐ no	☐ yes / ☐ no Load in kN=
2.1.4.2	roof construction: solar system/ photovoltaic system	☐ yes / ☐ no	☐ yes / ☐ no Load in kN=
2.1.4.3	trafficability of areas by vehicles, or similar	☐ yes / ☐ no	☐ yes / ☐ no Load in kN =
2.1.4.4	existing horizontal-loads by impacting of vehicles, handrailloads, etc.	☐ yes / ☐ no	☐ yes / ☐ no Load in kN =
2.1.4.5	existing dynamical loads	☐ yes / ☐ no	☐ yes / ☐ no Load in kN =
2.1.4.6	statement of other loads	☐ yes / ☐ no	☐ yes / ☐ no Load in kN=

Form 2: ***date …………….. (enter date)*** **(6/11)**

3. Classification of the considered building into usage classes:

Notes:

- The considered timber construction will be subsequently assigned a usage class. Different assignments are possible from room to room or in general depending on the situation within the building. The usage classes define the requirements of installed timber with regard to resistance and durability.

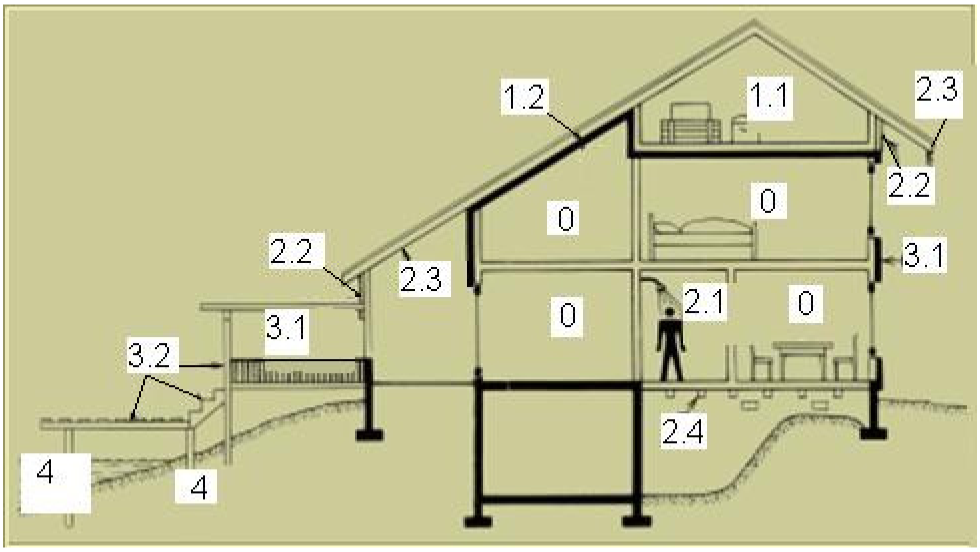
- The specified timber moisture and room humidity as well as the required wood preservative will be determined within the scope of exact diagnosis techniques or detection methods (see Form 5).

Form 2: ***date ……………..*** ***(enter date)*** **(7/11)**

3.1	**Classification in use-classes** (according to EN 335)	**Classification possible:**	**Checked on site:**
3.1.1	**use-class 0:** Inside built wood, completely dry (wood moisture <20%); no wood preservatives required	yes / ☐ no	☐ yes / ☐ no
3.1.2	**use-class 1:** Internal components with an average room humidity ≤70%; requirements to the wood preservatives: insect-preventive	yes / ☐ no	☐ yes / ☐ no
3.1.3	**use-class 2:** Internal components with an average room humidity>70%, internal components in wet areas, external components without direct weather stress; requirements to the wood preservatives: insect-preventive, fungus-retardant	yes / ☐ no	yes / ☐ no
3.1.4	**use-class 3:** External components with weather stress without permanent ground- an/or water contact internal components in wet rooms, wood exposed to the weather or condensation, but no ground contact; requirements to the wood preservatives: Iv, P, W= insect-preventive, fungus-retardant, weatherproof	yes / ☐ no	yes / ☐ no
3.1.5	**use-class 4:** Timber with permanent ground- and/or fresh water contact, even with sheath, there are special conditions for wood on sea water; requirements to the wood preservative, insect preventive, fungus-retardant weatherproof, soft rot retardant (timber used in the ground)	yes / ☐ no	yes / ☐ no

Form 2: ***date …………….. (enter date)*** **(8/11)**

Figure 2.7: use-classes for timber (according to EN 335)



Class	Term of use, area of application	Woodmoisture	Art of risking
0	Living rooms/machine rooms, components in heated rooms	about 10%	no
1	Without ground contact, covered (dry)	10-18%	
1.1	Controllable construction timber in roof and basement		insects
1.2	Difficult to controll construction timber		insects
2	Without ground contact, covered (risk of humidification)	Sometime >20%	
2.1	Wet rooms: bathrooms, indoor swimming pools		Moulds, wood-destroying mushrooms not exclude
2.2	Outdoors under roof, small cross sections, protected facades, roof spans		Blue stain
2.3	Outdoor under roof, medium to large cross sections		Blue stain and moulds
2.4	Unvantilated basements: structure, cover, floors		Rot, insects
3	Without ground contact, not covered	often >20%	
3.1	Small cross sections (thickness <25mm): façade unprotected, thin balcony parts		Low risk of rot, if water can drain off, blue stain, weathering
3.2	Medium to large cross sections: windows, shutters, open balconies pergolas		Rot, insects, blue stain, weathering
4	In contact with ground or fresh water: masts, swells, poles, wood in foundation	constantly >20%	Rrot by wooddestroying mushrooms (also soft rot)

Form 2: ***date …………….. (enter date)*** **(9/11)**

4. Determination of the age of the considered construction with a comparison of typical historical constructions:

Notes:

- *As taken from Section 1.2.2.3, the exact age is not necessary for continued assessment of the timber construction.*
- *Below a table is shown for 2 epochs. The table contains: typical structures, constructions and connections.*
- *Like all other templates of this matrix, the table can be extended gradually by the matrix user.*

Form 2: ***date ……………..*** ***(enter date)*** **(10/11)**

4.1	**History of building classification:**			**Classification possible:**
4.1.1	**Middle Ages/ Romanesque** (1020 – 1250) Sample-building 	**Sample-constructions:** roof construction on the outside brickwork (roman influence) -each beam was assigned to a couple of rafter (roof trusses) -no supporting blanket (family and church buildings) -formation along with panicle -roof pitch ≥ 28°	**Sample-connection:** -the solid wood structure still betrays the ax blows of the carpenter	yes / ☐ no
4.1.2	**Middle Ages/ Gothic** (1140 - 1470) Sample-building 	**Sample construction:** -wood often already laid on edge -stiffening the rafters with collar beams -related trusses manufacturers: sparring with aim = cross-linking, head bands + head rail = formation along -development of the horizontal roof	**Sample-connection:** Simple leaf, shear stud, tap, comb, stowing (hardwood nail for deposit insurande)	yes / ☐ no

- The following periods may be supplemented.

Form 2: ***date ……………..*** ***(enter date)*** **(11/11)**

Power of Attorney

Regarding: Inspection and copying of building files

Construction project designation: ……………………………………………

As owner of the property: ……………………………………………

I hereby authorize: ……………………………………………

to review and prepare photocopies of the construction documents and land register of my property.

Name: ……………………………………………

Date: ……………………………………………

Signature: ……………………………………………

Continuation: see Form 3

2.4.4 Form 3: Load-bearing system / structural analysis / structural elements / connections (building parameters)

*The completely filled out Form 3 is to be filed in the **object book**!*
*Additional **appendices** are to be referenced!*

Because all possible damages to timber constructions resulting from cross sectional weaknesses, for example, due to faulty wood preservation, overstraining or the like, (can) induce short or long term adverse effects of the bearing structure, they play a meaningful role in the construction state analysis. It is often difficult to statically investigate interior, supporting structural elements (e.g. in lower levels) if the complete system is unknown. In order to investigate present strains in a weak or cracked timber cross-section, the complete load-bearing system of the considered timber construction must be measured. The structural engineer (= stress analyst) always begins at the highest point of the building because the loads function from top to bottom.

Form 3: ***date ……………..*** ***(enter date)*** **(1/3)**

- **General information about static computation: (explanations regarding stability can be listed here)**
- **Finished static layouts that are created or available for the considered construction can be inserted here as alternatives to the prescribed input structure of Form 3.**

1.) Construction of the load-bearing system:

- **1.1 Supporting structural elements for vertical loads**

  (Dead weight, live/payloads, snow, etc.)

→ **1.1.1 Roof Construction:**

Roof crossbars, rafters, purlins, binders, containers, frames, etc.

Sketch(es) (possibly use further sheets or refer to Form 4):

Insert here

→ **1.1.2 Horizontal supporting elements:**

Beamed ceilings, beams/coatings, roof bracings (wind braces, plates, etc.)

Sketch(es) (possibly use further sheets or refer to Form 4):

Insert here

→ **1.1.3 Vertical supporting elements:**

Stud walls, posts, columns, wall bracings

Sketch(es) (possibly use further sheets or refer to Form 4):

Insert here

Form 3: ***date ……………..*** ***(enter date)*** **(2/3)**

- **1.2. Supporting structural elements for horizontal loads**
  (Wind, beam loads, reinforcement loads, LF: earthquakes, impact loads, dynamic loads (e.g. vibrations from church bells)

→ **1.2.1 In the whole structure:**

Framework, latticework structures, bracings (roof and wall bracings), wind braces

Sketch(es) (possibly use further sheets or refer to Form 4):

Insert here

2.) Identification / determination of all loads:

- **2.1 Outdoor loads:**
  - Wind
  - Snow / rain
  - Earthquake zones
  - Soil characteristics
- **2.2 Dead weight of the construction (construction and expansion loads):**
  - Roof cladding:
  - Collar beams framing
  - Collar beams over the …floor: (insert flat floor)
  - Collar beams over the …floor: (insert flat floor)
  - ……………………….
  -………………………..
  - Wall construction (outside):
  - Wall construction (inside):
  - Balcony or projections (if present):
  - Other loads:

Form 3: **(3/3)**

3.) Connections:

Weak points are often the connections within a structure that can no longer sufficiently bear the existing weight as a result of various circumstances (cross-sectional weaknesses, gaping joints due to shrinkage and swelling, corrosion of metal connecting devices, overstraining due to changes of use, etc.).

For this reason they must also be documented in the form of sketches (photos, etc.) and the visible cross-sections, connecting devices, and materials documented. Here the difficulty is often present that internal connecting devices, such as e.g., studs of specific constructions types cannot be secured from outside. In this case, the inspecting timber expert must decide on a case-by-case basis which methods (see Sections 2.4.6 + 2.4.7) to implement for a more detailed and continued analysis.

Sketch(es) (possibly use further sheets or refer to Form 4):

Insert here

4.) Cross-sectional dimensions of the supporting structural elements:

→ In the sketches of the static system(s) shown above (from top to bottom), the on-site measured cross-sectional dimensions are recorded. The wood type is also documented [potentially use checklist 1 (2.5.1)].

Continuation: see Form 4

2.4.5 Form 4: Condition mapping of the "actual state" (1/3)

*The completely filled out Form 4 is to be filed in the **object book**!*
*Additional **appendices** are to be referenced!*

Conducting the construction state analysis is initially a matter of determining the current status and documenting it in a suitable form. In the ideal case, planning documents would have been reviewed in the previous process, which could be used for this purpose (see Form 2).
If original documents are not available, measurements are to be made and presented in a suitable (if possible, to scale) form. Digital photographs also present a good option these days for documentation. The drawings in Form 3 (see 2.4.4) can also be used.

Concerning the targeted standardization of form entry described in the previous sections, a legend is also provided here so that all future timber experts can use the same symbols, abbreviations, etc. for certain phenomena, such as pests (e.g. house longhorn beetles, dry rot, etc.) and types of damages (e.g. strong moisture penetrations, distortion, decay, etc.) to more precisely examine timber constructions or timber structural elements (e.g. ceiling beams, rafters, purlins, etc.) within the scope of a construction state analysis for the mapping of conditions described here.

As can be derived from the concept that was just explained, not only the condition of the timber construction's supporting elements should be mapped, but also visibly obvious damages should be identified and additional required areas of inspection specified. With this, a rough assessment of the construction is conducted within the scope of mapping, Form 5 (see Section 2.4.6) to follow contains, together with the expert database (see Section 2.4.7), the possible inspections to be undertaken later when mapping conditions.

2.4.5 Form 4: Conditions mapping of the "actual state" (2/3)

Proposed design of a mapping with different information:

State Mapping [= form 4]

[official normed building check]

object-details:

- building: ____________________
- components: ____________________
- builder: (adress, tel./fax, E-mail) ____________________
- place: (street, postcode, village) ____________________
- name of the timber expert: (with complete address) ____________________

photo of the building:

(insert here)

Note all details of form 1!

insert drawing(s): ground plan (possibly sectional drawings and / or building views)

please specify: (see form 1) [please cross]

☐ original drawing ☐ allowance drawing ☐ photo

- plan-signification (with nr. + flat name): ____________________

drawing(s)/sketch(s)

(insert here)

- Referring to other (associated) drawings: ____________________
- referring to photos with appropriate numbering: ◯ ____________________

Indentification of the examined points (withe numbering) [blue, orange, brown, red]

☐ **green marking** if complete studied structure is intact (if so - cross)

Continuation: see Form 5

2.4.5 Form 4: Conditions mapping of the "actual state" (3/3)

Symbols and designations for recording the construction state – suggestion for a legend (based on [2])

Legend

comment to the method:

The appropriate boxes must be numbered + these boxes (with numbers) must be inserted in the drawing. Colormap: see below

□✓ = Investigation was already carried out □! = Investigation wil carried out in future

To Describe or in order to induce certain investigations the shortcuts shouls be used.

note all details of form 5!

• Conducted local investigations

blue marking:

- apparent damages □
- hammer test (tap) □
- pocket knife or hatchet □
- drill to take cores □
- wood-moisture-meter □
- deformations □

May consult the

expert database:

• special test

orange marking

- ultrasonic method □
- drill resistance □
- penetration resistance measurement □
- thermography □
- electromagnetic / radiographic measurement methods □
- endoscopic examination □
- microscopic □
- infrared spektoskopie □
- ultrasonic echo □
- X-ray □
- acoustic tomographic measurements □
- dendrochonological investigations □
- mechanical load test □
- chemical and biological investigations □
- darr-method □
- load test □
- expert-database □
- ______________________ □

note all details of form 3!

structure description

(timber / massiv structure / steel structure)

- Indicate bearing direction!
- Specify dimensions: b/h [cm]!

brown marking:

- beams □
- purlin □
- collar beam □
- pillar / stalk □
- beam head □
- spar □
- roof □
- strut □
- wind panicle □
- diagonal □
- threshold □
- bar □

-> Bearing on:

- truss-wall □
- masonry wall □
- concrete wall □

→ Short description of the wall structure (from the inside out):

- ______________________

(statical system / connections / dimensions, etc.):

→ Description which parts virsible / not visible / as achievable:

- visible □
- not visible ✕
- as achievable: ______________

→ Stability proof required: ◎

note all details of form2!

• Observed damages

red marking:

• Using the checklist:

-CL2: cracks + deformations

damages □yes□no

- strong moistrure □
- brown rot □
- white rot □
- mildew fungi □
- break □
- missing components □
- strong deformation □

• use of the checklist:

-CL3: Fungus and / or insect-attack

harmful organism □yes□no

- hb = house borer □
- cb = common furniture beetle □
- dh = despite head □
- pb = pied furniture beetle □
- dr = true dry rot □
- bs = brown cellar or wart sponge □
- ws = white porous sponge □

• Check the wood protection:

- cop = constructive wood protection
- chp = chemical wood protection

risk in distortion!

The futher use should be directly prohibited.

If so => □ (please cross)

Announcement to the relevant building-office + reffering to cover letter:

____

signature of the timber expert:

____

place, date

• use of the checklist:

-CL1: wood species □yes □no

[behind the cross-section specify the wood species]

• softwood:
  - spuce:
  - pine:
  - fir:
  - larch:
  - douglas fir:
  - other:

• hardwood:
  - oak:
  - beech:
  - other:

• glued timber:
  - softwood:
  - hardwood:

• wooden material: (specify type)

____

2.4.6 Form 5: Examination methods for different material parameters (1/3)

[Only approximate “on-site controls”] [7], [18]

*The completely filled out Form 5 (including the expert database) is to be filed in the **object book**!*
*Additional **appendices** are to be referenced!*

Whether the timber expert personally performs a detailed inspection of the construction within the scope of a building inspection very much depends on his experience. A trained eye already sees a lot, yet a timber expert directly examines the critical areas.
For an approximate “on-site control” of different material parameters, tools are hardly necessary.
Subsequently, the first established inspections that the timber expert completes at the first on-site appointment are specified.

- Visual appraisals + photographic documentation:

Required tools: Digital camera, magnifier, hammer, nails, pocketknife, chisel, wood moisture meter, spiral and core drill, measuring tools (measuring tape, calliper + crack gauge, water level, wire for depth measurements of cracks)

Procedure:	**Parameter(s):**
- Visible damages that are recorded with hand drawings or digital photos.	- **General building state:** **type, place, and extent of damage**
- Hammer test (tapping) of suspicious areas.	- Positioning of: **cavities and weak spots.**
- Test with the pocketknife or chisel.	- **Timber strength**
- Drilling of suspicious areas with a core drill for core extraction (see also 2.4.7)	- A wide variety of inspections can be conducted in the test laboratory with the core drill.
- Wood moisture meter	- **Wood moisture**
- Measuring or locating big deformations with a water level.	- **Deformations**

2.4.6 Form 5: Examination methods for different material parameters (2/3)

[Only approximate "on-site controls"]

Procedure:	Parameter(s):
- Determination of wood type, e.g. with the help of pictures for comparison (= Checklist 1, see 2.5.1)	- **Wood species**
- Measuring or locating cracks with a crack gauge (= Checklist 2, see 2.5.2)	- **Cracks**
- Locating fungus and/or insect infestations, e.g. with the help of pictures for comparison (= Checklist 3, see 2.5.3)	- **Fungus and/or insect infestation**
- Drilling of suspicious areas with a spiral drill (mainly abutments)	- **Rot + cavities** **(= physical condition of the timber)**

Were experts from the expert database (see 2.4.7) consulted?

☐ yes / ☐ no

If yes, show the result:

……………………………………………………………………………………………

……………………………………………………………………………………………

Figure 2.8: Wood moisture meter with electrodes

2.4.6 Form 5: Examination methods for different material parameters (3/3)

[Only approximate “on-site controls”]

Figure 2.9: *Crack gauge*

The timber expert determines the next approach_based on previous inspections.
He can decide, using the forms (1 to 4) competed thus far, which additional inspections must be conducted. In addition, external experts are often included unless he has other additional measuring tools, etc., at his disposal.

Figure 2.10: Core sampling on a roof structure

An expert database is subsequently consulted, where offices, institutes and individual persons can be found and activated for the various problems that have come to light within the scope of the initial appraisal. Each user of the assessment matrix introduced here can, over time, compile his own expert list that satisfies, for example, his regional, financial, and personal requirements, etc.
Therefore, no business addresses are shown in the expert database.
Continuation: see Expert Database + Form 6

2.4.7 Specifying an Expert Database for specific inspections (1/3)

(= Appendix to Form 5)

As already explained in the previous section, an expert database should now be compiled that can be consulted for all (current) potential timber inspections.

Parameter	**Procedure** According to [114]	**Expert =** **Business Address**
- Hidden, unexposed structural elements	- X-ray examination (= electromagnetic / radiographic measuring procedures)	(the timber expert enters his preferred address/es in this column)
- Timber density	- Echo-tomographical measurement	
- Timber age	- Dendrochronological inspection	
- Stability (= mechanical properties)	- Mechanical load test on core drill	
- Fungus and/or insect infestation	- Chemical and biological inspections of timber: - Vitality test - Proof of penetration	
- Timber moisture	- Gravimetric method of measuring moisture in timber	

2.4.7 Specifying an expert database for specific inspections (2/3)

(= Appendix to Form 5)

- E-Module	- Ultrasonic method (= Acoustic measuring method) in-situ or in laboratory?	(the timber expert enters his preferred address/es in this column)
- Cavities and stability	- Drilling resistance measurement with the help of resistographs	
- Stability and gross density	(- Penetration resistance measurement with a Polidyn measuring tool 6J) - Measurement of specimens	
- Identifying covered lattice work structures	- Thermograpy (= Thermal procedures)	
- Fungus infestation	- Electromagnetic / radiographic measuring procedures	
- Hidden, unexposed structural elements	- Endoscopic inspection (= optical measuring procedures)	
- Determining wood species	- Microscopic - Infrared-spectroscopy	
- Interior cracks + cavities	- Ultrasound-Echo	

2.4.7 Specifying an Expert Database for specific inspections (3/3)

(= Appendix to Form 5)

- Loading capacity (e.g. of existing wooden beamed ceilings)	- Load test	(the timber expert enters his preferred address/es in this column)

The NDT building compendium of the Federal Institute for Materials Research and Testing in Berlin, Germany, provides a listing of modern non-destructive inspection methods on timer, or rather, timber structures. The “German Society for Non-destructive Testing” offers more information. The expert database can be continuously updated using these references.

There are numerous scientific tests for the different possible inspection methods for timber structures addressed in this current section. These can be consulted as needed, e.g. when preparing and planning certain forms of inspection.

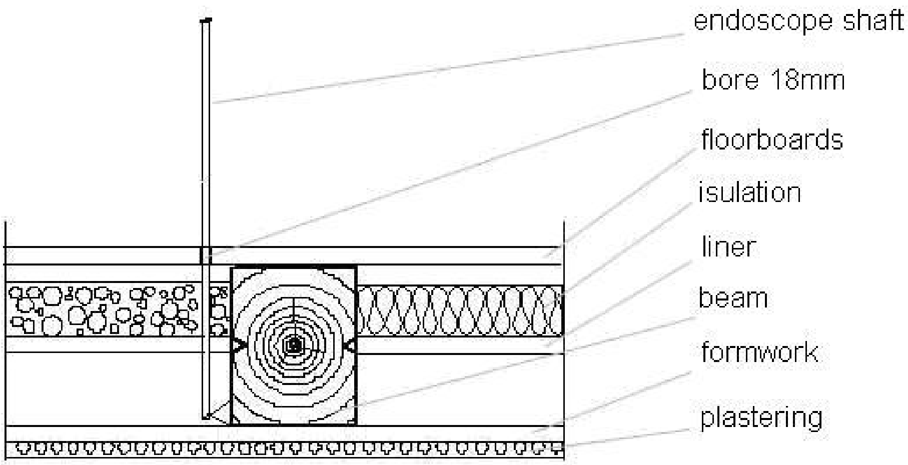
2.4.7 Specifying an Expert Database for specific inspections

(= Appendix to Form 5)

The following pictures show examples of the same expert examinations:

Figure 2.11: Drilling resistance measurement on a damaged supporting structure

Figure 2.12: Endoscopic examination of a wooden beamed ceiling



2.4.7 Specifying an Expert Database for specific inspections

(= Appendix to Form 5)

Various possibilities are presented with these specified procedures for conducting a non-destructive inspection if necessary. This may be required for different reasons (e.g. monument conservation, etc.).

Figure 2.13: Mobile computer tomography on wooden foundation piles

The still absent Form 6 (= end acceptance protocol) is described in greater detail in Section 2.6.7, because this serves as the final evaluation of the considered timber structure.

As previously described, all filled out forms are collected, or rather, compiled in the object book. This object book is introduced in Section 2.7.2.

2.5 General information about the layout and content of the "Checklists"

Now that the first 5 forms have been presented, 3 checklists will be developed in the following sections. As previously described, these should serve to conduct an easier and, above all, faster assessment of the considered timber structures.
The checklists are broken down as follows:

- **Checklist 1:** ***Material Properties (determination of wood species)***
- **Checklist 2:** ***Cracks + Deformations***
- **Checklist 3:** ***Fungus + Insects***

These three topics are of great importance for the appraisal of almost every timber construction.
In the previous sections of this thesis:

- 1.2 "Wood characteristics and different wood materials" (= basis for checklist 1)
- 1.3 "Wood moisture: Swelling and shrinkage" (= basis for checklist 2)
- 1.4 "Wood preservation" (= basis for checklist 3)

different basic knowledge was provided.
Section 2.4.6 referenced these checklists multiple times. The checklists represent great relief for the "on-site controls" described in the previous section. With their help, discovered material can be directly identified, cracks and deformations can be evaluated, and potential fungus and/or insect infestations of the considered timber structure can be eradicated.
If inspections do not produce results using the checklists, experts from the expert database described in Section 2.4.7 can become involved.
The 3 checklists outlined here were also referenced in the conditions mapping of the "actual state" (see Section: 2.4.5).

2.5.1 Checklist 1: Determination of Wood-Species (1/4)

- With the following questions the determination of the wood-species could be carried out.
- Is no clear determination possible, the experts database should be involved (see section 2.4.7).
- The pictures below should be compared with the wood samples. They were created based on the process of Dr. Hanno Sachße [20].
- Required equipment: Knife and loupe.

question 1: Are pores on the brain surface visible?

answer 1: yes → it is a **hardwood**

answer 1: no → it is a **softwood**

hardwoods: Oak or Beech

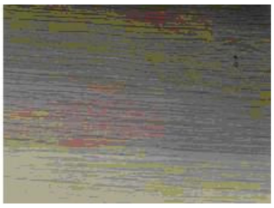
(On the brain surface tree-ring are visible)

question 2: Are large pores existing on the brain surface in tree-ring device (=tangential)?

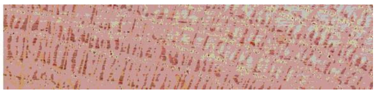
answer 2: yes → it is a **Oak**
(= ring-porous hardwood)

Oak – cross section radial

Oak – cross section tangential



Oak – cross section lateral

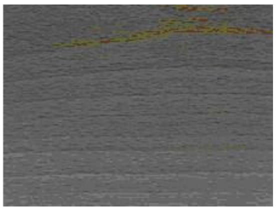


Oak – cross section – stock of a tree

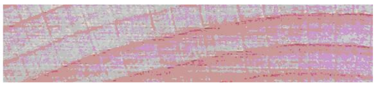
answer 2: no → it is a **Beech**
(= dispersed-porous hardwood)

Beech – cross section radial

Beech – cross section tangential



Beech – cross section lateral



Beech - cross section – stock of a tree

2.5.1 Checkliste 1: Determination of Wood-Species (2/4)

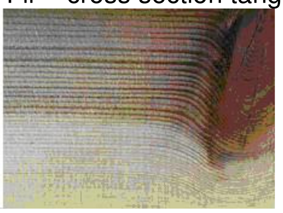
softwoods: Fir, Pine, Douglas Fir, Larch and Spruce

question 3: Has the wood resin ducts (they are sometimes filled yellow white)?

answer 3: no → it is a **Fir**

Fir – cross section radial

Fir – cross section tangential



Fir – cross section lateral

Fir - cross section – stock of a tree

answer 3: yes → The softwoods: Pine, Douglas Fir, Larch and Spruce are possible.

question 4: Smells the wood very aromatic?

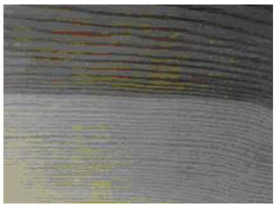
answer 4: yes → The softwoods: Pine and Douglas Fir are possible.

question 5: Ends the early wood selective on the late wood?

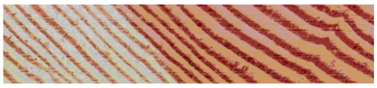
answer 5: yes → it is a **Pine**

Pine – cross section radial

Pine – cross section tangential



Pine – cross section lateral



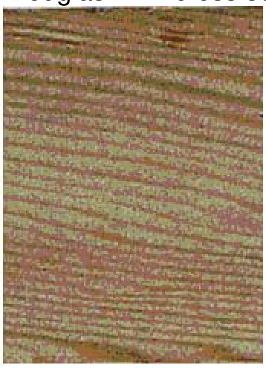
Pine - cross section – stock of a tree

2.5.1 Checklist 1: Determination of Wood-Species (3/4)

softwoods: Fir, Pine, Douglas Fir, Larch and Spruce

answer 5: no → it is a **Douglas Fir**

Douglas Fir – cross section tangential



Douglas Fir – cross section radial

Douglas Fir - cross section – stock of a tree

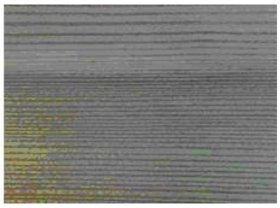
answer 4: no → The softwoods:
Larch and Spruce are possible.

<u>question *6:*</u> Ends the early wood selective on the late wood?

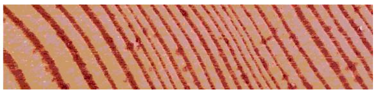
<u>answer *6:*</u> yes → it is a **Larch**

Larch – cross section radial

Larch – cross section tangential



Larch – cross section lateral



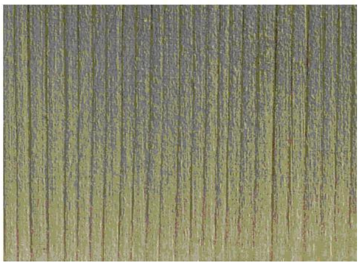
Larch - cross section – stock of a tree

2.5.1 Checklist 1: Determination of Wood-Species (4/4)

softwoods: Fir, Pine, Douglas Fir, Larch and Spruce

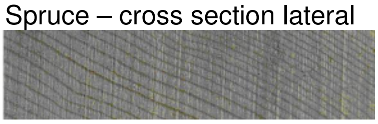
answer 6: no → it is a **Spruce**

Spruce – cross section radial



Spruce – cross section tangential

Spruce – cross section lateral



Spruce - cross section – stock of a tree

2.5.2 Checklist 2: cracks and deformations (1/2)

(see basic information and references in Section 1.3)

General: To assess influence of cracks in wood different limits (depending on the direction of stress) have to observed. These are given in the following charts.

References: „Risse im Bauholz“ [103], „Beurteilungskriterien für Rißbildungen“ [12] and „Alte Holzbauwerke – Beurteilen und Sanieren“ [2]

Local host: Crack widths are measured with crack lessons, **crack depths** can be seen with a wire and/or a crack width drawers.

There are various levels of cracks:

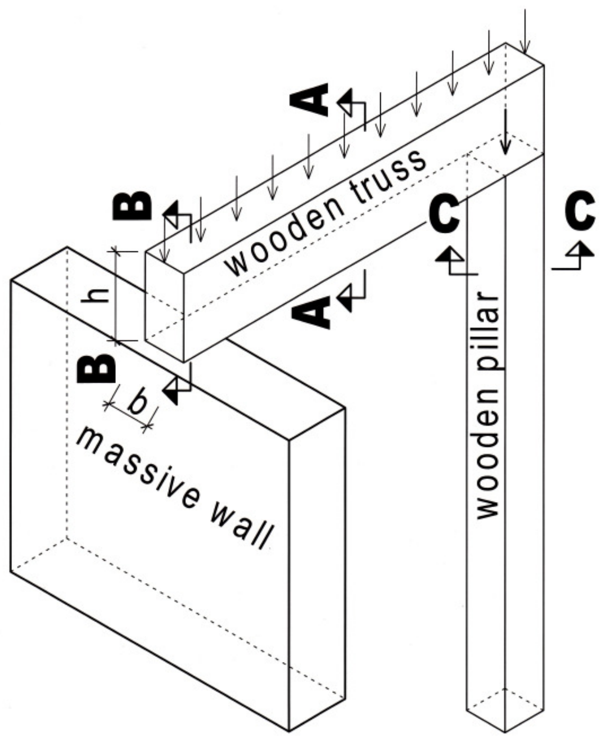
- Development prior to installation (biologically related cracks): heart shakes, frost cracks, skin cracks and ring shake
- Shrinkage cracks: form before and after installation
- Mechanical cracks: tension cracks, shear cracks, splitting cracks (cracks of connections), shear cracks

Cracks in wood often have negative influence on:

- sustainability
- access to moisture
- access to harmful organisms
- fire resistance

Graphics: Sketch of system with different types of stress on a wooden truss:

To bend (in the middle) and shear (at the support points) and a thrust stressed wooden pillar:



2.5.2 Checklist 2: cracks and deformations (2/2)

- Permitted (= acceptable) crack depths in timbers

- Maximum crack width ≤ 0,07 x b (b = relevant section width)

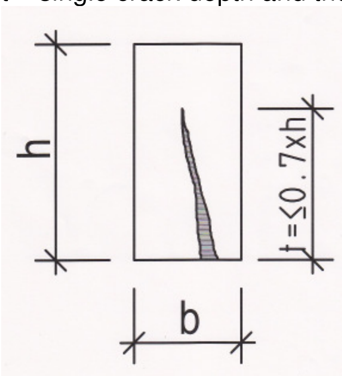
- The safe crack length must be evaluated case by case.

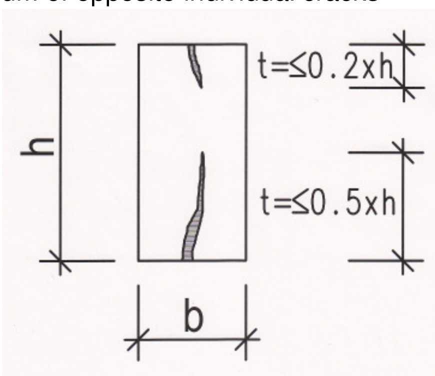
- All crack sizes (depth, width, length) are only valid for non-achievement of the permissible stress!

- Incision: see system diagram on the facing page:

cut: A-A

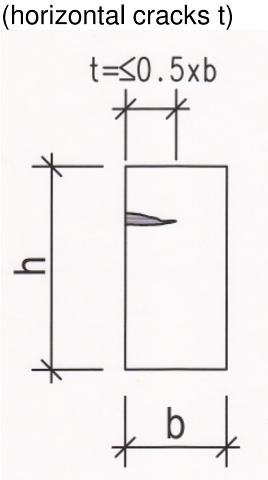
Main stress: **bending**
t = crack depth in the bending direction
t = single crack depth and the sum of opposite individual cracks





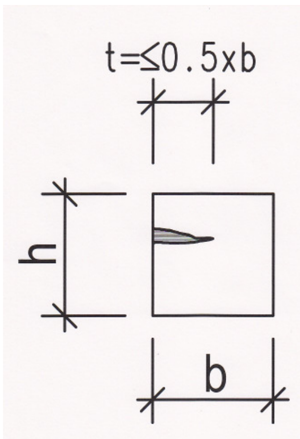
cut: B-B

Main stress: **Shear**
(horizontal cracks t)



cutt: C-C

Main stress: **Thrust**



Deformation: The determined local deformation must also be interpreted by the timber experts.
Here experience of the timber expert is needed again. He must judge, if the deformation have attained a critical level or a negative influence on other components.
He must determine the context in which position stand the actual (= measured on site) to the calculated deformation and permitted (as the case: L/200 or L/300).
In critical cases it may be necessary, to determine the Young`s modulus. For that different details are listed in section 2.4.7.

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (1/7)
(see the associated basic knowledge + references in Section 1.4)

On-site quick analysis using the technique from Björn Dinger, specialist for wood and wood preservation [IN110].
With the following set of questions and the corresponding pictures for comparison, the timber expert can implement a quick on-site analysis of the occurrence of fungus or insect infestations.

1. Which damages exist?
Damage to the considered timber can be evaluated with the help of the following questions and images in just a few steps.
This determination of damage is not only applicable to the initial orientation. In order to eliminate defects and attain a professional analysis, experts should be consulted when needed (see Section: 2.4.7).

Step 1: **The determining step**
The picture that most closely resembles the instance of damage should be selected.
The 3 categories are broken down as follows:

Broown rot fungus (see chart 1)	+	**White rot fungus** (see chart 2)
Furniture beetles (see chart 3)	+	**Longhorn beetles**(see chart 4)
Blue strain fungi (see chart 5)	+	**Mold** (see chart 6)

If none correspond, direct contact with an expert should be made.

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (2/7)

chart 1: Brown rot fungus

Brown rot fungus: True dry rot, brown cellar-sponge (= cellar rot fungus), pore-sponge and bracket fungi

Question 1:

Are destroyed wood (rot, Figure 1)

and / or
fungus fruiting bodies (Figure 2) visible?

Figure 1:

Figure 2:

Question 2:

Is the wood brown, destroyed in a cube-like chunks or broken?

Is any whitish "hyphae" visible on the timber?

Figure 3:

Figure 4:

Answer: The damage described is caused by **brown rot fungus**. Brown rot fungi occur mainly in buildings. They destroy the wood and result in the loss of strength.

The main culprits on wooden constructions are: **true dry rot**, **brown cellar rot fungus**, **pore sponges** and **bracket fungi**.

Because true dry rot means an increased hazard, the fungus type should be determined in case of a brown rot infestation so that the real dry rot can be differentiated from other timber damaging fungi.

Figure 5:

Figure 6:

Figure 7:

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (3/7)

2: White rot fungus

White rot fungus: House spores (= oak spores)

Question 3:

Does the timber have a light, fibrous appearance?
(referred to Figure 8)

Figure 8:

Answer: The damage described is caused by **white rot fungus**.
This fungus destroys wood, whereby the timber becomes whitish, fibrous and soft. This fungus usually needs high wood moisture and is usually found less often in buildings. An exception is the effuse **house spore (oak spore).**

Because the white rot fungus also leads to the loss of stability in timber the attacked areas should be professionally improved.

Figure 9:

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (4/7)

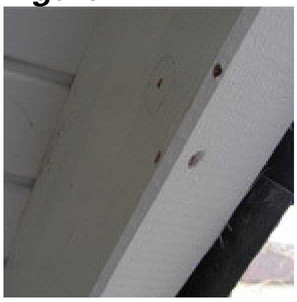
Chart 3: Furniture beetles:

Question 4:

Are burrows (Figure 10) and / or holes (Figure 11) visible in the timber?

Figure 10:

Figure 11:



Question 5:

Can small, round holes (referred to Figure 13) and burrows (referred to Figure 12) up to approx. 4 mm in diameter be seen?

Figure 12:

Figure 13:

Figure 14:

Figure 15:

Answer: The damages described are caused mainly by **furniture beetles**. There are various types of these beetles, which live in dry timber and are relatively small.

The **common furniture beetle** (see Figure 14) is typical and is also called the ***"woodworm"***. This insect lives in dry, constructed timber (e.g. stairs, furniture, cross beams) where it causes great damages. The afflicted timber surfaces exhibit small, round holes.

Another common pest is the **death watch beetle** (see Figure 15). They are mostly found in lattice woodwork. The insect infests timber already damaged by decay.

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (5/7)

Chart 4: Longhorn beetles:

Question 6:

Are oval holes or burrows larger (see Figure 16 and Figure 17) than a few millimeters (> 5 mm) visible?

Figure 16:

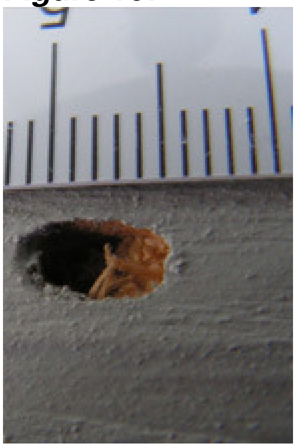


Figure 17:

Figure 18:

Figure 19:

Answer: The damages described are caused mainly by **longhorn beetles**.
Figure 19

The **longhorn beetles** (see Figure 18, Figure 19 shows agrub) comprise numerous species, of which only a few have any direct significance for the timber. As fresh wood insects they can be present in the wood when it is constructed or they may also infest timber as dry wood insects.

Theold- **house borer** beetle has special meaning. It lives in dry soft wood where it causes immense damage. These insects are mainly found in the timber of roofs where they ruin the inside of the beams while leaving a thin outside layer of timber. The extent of an infestation is only identifiable after the removing the surface layer.

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (6/7)

Chart 5: Blue stain fungi:

Question 7:

Are superficial discoloring (Figure 20) or soft films of fungus (Figure 21) without deeper damages noticeable?

Figure 20:

Figure 21:

Question 8:

Is the afflicted material timber? Do the discoloring reach deeper in the timber and cannot be removed with a damp rag?

Figure 22:

Figure 23:

Answer: The damages described are caused mainly by **blue stain fungi**. Blue stain fungi populate damp timber. They penetrate the top timber layer and cause dark discoloring. Despite these appearances, however, these fungi bring about no significant reduction in stability. Thus the blue stain fungi play only a secondary roll for timber usage in the building industry. The fungi mainly destroy coatings on timber (e.g. windows, facades). In the long-term, therefore, moisture can penetrate the cracks that have formed in the covering, which leads to damage (decay).

Blue stain fungi appear mainly in connection with mold. They can only be clearly distinguished from mold in laboratory test.

2.5.3 Checklist 3: Quick on-site analysis of fungus and insect infestations (7/7)

Chart 6: Mold:

Question 9:

Are discolorations (referred to Figure 24)/
fungal films (referred to Figure 25) found on the surface of the material?
Can they be removed with a wet rag?

Figure 24:

Figure 25:

Answer: The damages described are caused mainly by **mold**.
Mold grows on organic materials (e.g. wood, wallpaper) and on soiled inorganic materials.
Mold can arise starting with 70 – 80 % relative humidity (surface humidity), (see “Mold Decontamination Guide” from the Federal Environment Agency, UBA) [308].

Because individual mold varieties can lead to health hazards the infestation should be inspected by a specialist and the causes identified.
On wood, mold often occurs alongside **blue stain fungi**. They can only be clearly distinguished in laboratory tests.

2.6 Concrete, typical damages to structural elements, their detection + causes and professional removal or restoration

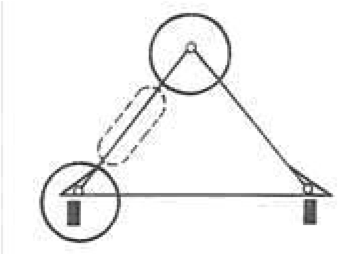
In the past and present, constructions have been used in a great variety of buildings that are befitting of the respective period. Today and in the past, the advantage to this has been that different firms can produce the same quality constructions because they are common knowledge.

The disadvantage on the other hand is that when constructions prove faulty in retrospect, typical damages appear that must be rectified. Figure 2.14 shows typical timber construction damage.

The reasons for such damage can be many. Because timber is an organic material, it can be attacked and corroded by fungi and insects. The cause in this case is often a high moisture content within the structure, which can effectively be minimized through certain constructive and/or chemical protective measures.

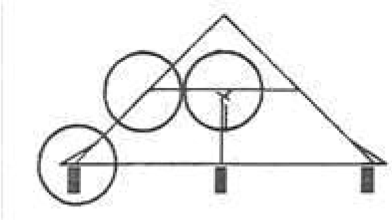
In the case of older structures, it was typical that window connections and passages between horizontal and vertical structural elements, etc., could not be built adequately leak-proof. Various damages occurred based on the respective condition. Through the advancement of wood preservation, damages typical of older constructions have all but been eliminated in newer structures. The older construction methods, however, also had their positive side effects. Due to small leaks, which were indeed unintentional yet not technically different to implement, moist air could be released to the outside. This is often a problem with newer buildings and unfortunately may lead to typical damages in the future. The buildings can be and are constantly becoming denser. Windows are made with sealing strips and the underside moisture barriers of the roof cladding are linked together and connected to all adjoining structural elements so that the required airtight seal is fulfilled (see Section: 1.4.7). The impermeability required by the German Energy Conservation Regulations can be tested with a “blower door test” [36]. If modern buildings are constructed without an automatic ventilating system it should assumed that a mold infestation is developing in the classic indoor areas (e.g. thermal bridges in the upper corners of a room) because the moist air condenses on colder exterior elements.

Figure 2.14: Typical vulnerabilities of timber structures. Taken from [6]



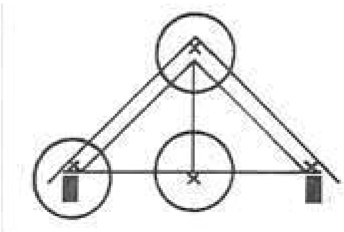
roof rafter with a wooden floor joists:

- recording horizontal forces at the base
- missing or ineffective panicle
- deformation at the first
- deformation in the middle rafter



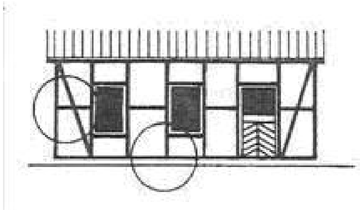
collar beam roof with single roof standing:

- eaves + collar beam connection
- fracture of the collar beam above the head rail



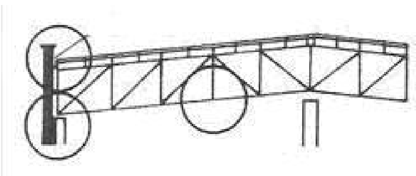
simple truss:

- eaves
- connections: strut and seek head
- connection: joist to hang stalk
- corrosion hanging iron
- connection: hinged beam



stud wall:

- swell + column base
- bolt connection + strut
- infill + eaves



truss beam:

- bearing
- guttering on attika formation
- deformation

binder boarch, cold roof with rainproof and airtight roofing:

- lateral deflection
- tilt
- twist of the boards at high temperatures
- lack of vapor barrier at warm room under roof trusses

The problem in the past was that structural inspections could often not be carried out due to the lack of proper technical equipment.
Today there are many different inspection methods for timber construction that detect problems in the first phase of damage. The inspections indicated in Sections 2.4.6 (Form 5: Examination methods) and 2.4.7 (Expert database for specific inspections) offer today, in comparison to the past, excellent opportunities to inspect timber constructions in various ways.
How these possibilities should be dealt with in the future to avoid the development and testing of certain inspection methods in research facilities or universities will be described at length in Chapter 3 to follow.

Now that the identification of potential timber damages and, in part, their causes have been addressed, this section will describe in detail the professional repair or decontamination of possible damages.
Today there is a large selection of proven decontamination techniques that have been under constant development for the past few decades. The classics are presented in the following databases, for example, various abutment rehabilitations, etc. The timber expert usually works together with the involved specialty company on a case-by-case basis to select one of the many rehabilitation methods that use advanced tool and material inserts.
The question of when exactly the timber expert will schedule the rehabilitation or corrective maintenance is also very important.
This topic will be discussed in greater detail later in the thesis once the different databases have been described and the construction status levels have been assessed, so that an objective assessment can also be made in this case.

2.6.1 General information about the layout + content of the “Databases”

As previously described in this thesis, appraising timber constructions should be made easier by various tools.
The “databases” presented below should represent an additional simplification along with the previously described forms and checklists. Five are distinguished here and are separated into the following types of construction:

- **Database 1:** **Ceiling constructions / supporting elements / stairs / balconies**
- **Database 2:** **Roof constructions (carpenter-made)**
- **Database 3:** **Wall constructions / bracing systems / framework / wooden supports**
- **Database 4:** **Engineering / widespread timber constructions**
- **Database 5:** **Connections / junctions**

In the sections of the first chapter:

- 1.5 Wood constructions (= basics of all databases)
- 1.5.2 Wooden-beam ceilings + wooden panels (= basics of database 1)
- 1.5.3 Carpenter-made roof constructions (= Basis of database 2)
- 1.5.4 Framework, connections, and wooden beams (= basics of database 3)
- 1.5.5 Timber frame construction (= panel construction) – prefabricated houses (= basics of database 3)
- 1.5.7 Engineered wood construction (= basics of database 4)
- 1.5.8 Connections and connection techniques (= basics of database 5)
- 1.6 Structural computations (= basics of all databases)

diverse basic knowledge about the databases was provided. It is important to note that various references have already been provided in the aforementioned sections of Chapter 1, which concern an array of issues such as scientific examinations among others, and may be of interest while using the database.
Common timber constructions should be covered by these databases. Typical types of damage and their professional rehabilitation are presented in all five databases.

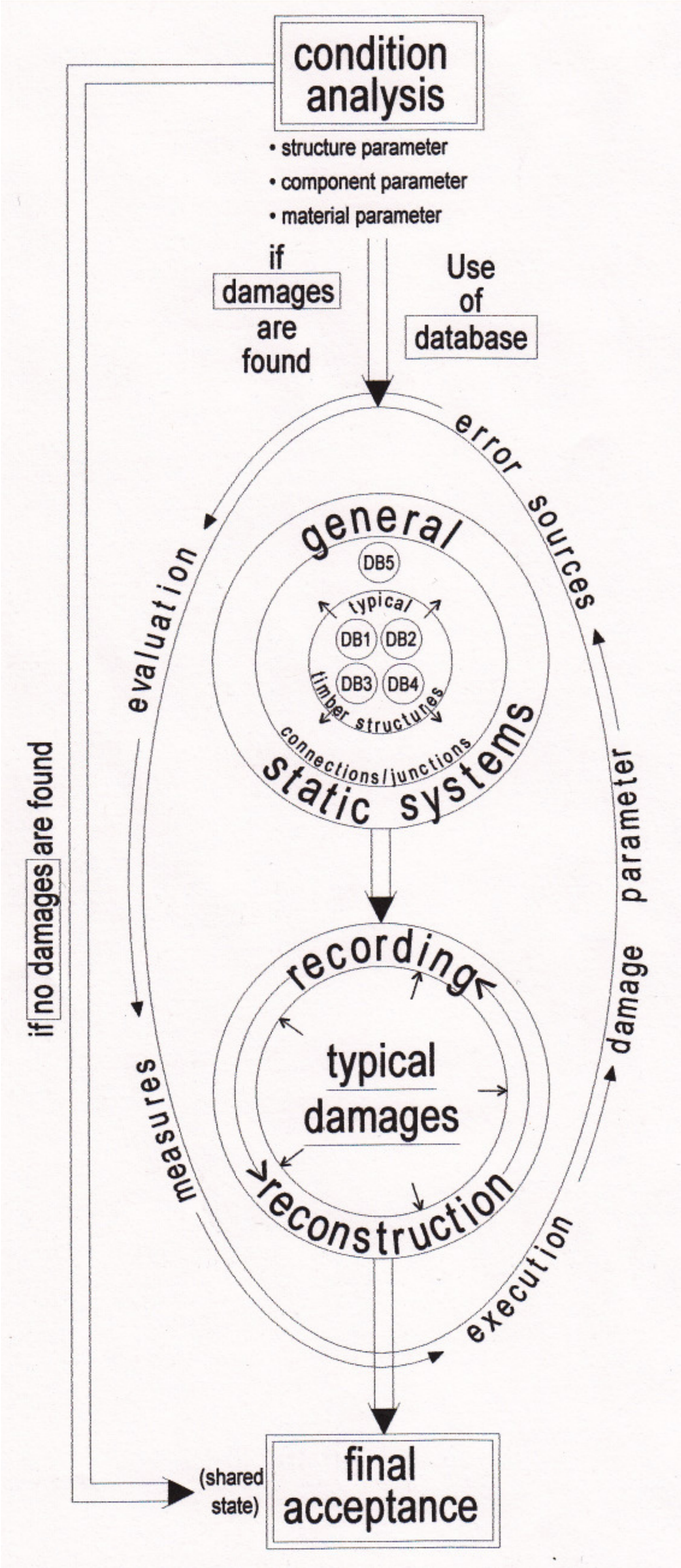
All databases are constructed in the same way and are organized into 5 categories (A to E).
These are explained in brief here:

Category:	Name:	Content:
A	General	- The considered type of construction is briefly described and explained.
B	Damages	- The causes of typical damages are presented and briefly explained.
C	Static System	- Typical concrete constructions are shown and the corresponding static system is explained in order to show the forces to be absorbed.
D	Identification	- Typical methods of compiling or analyzing the above-mentioned damages are presented.
E	Rehabilitation	- Subsequently, modern refurbishment or restoration methods that remedy the previously described damages are presented.

The following graphic shows the importance of the databases in the assessment process of timber structures.

The complete process sequence of the assessment of timber structures is given in the diagrams 2.6 and 2.63.

Figure 2.15: Importance of "databases" in the Assessment Process of Timber Structures



2.6.2 Database 1: Ceiling constructions / supporting elements / stairs / balconies

(see the associated basic knowledge + references in Section 1.5.2)

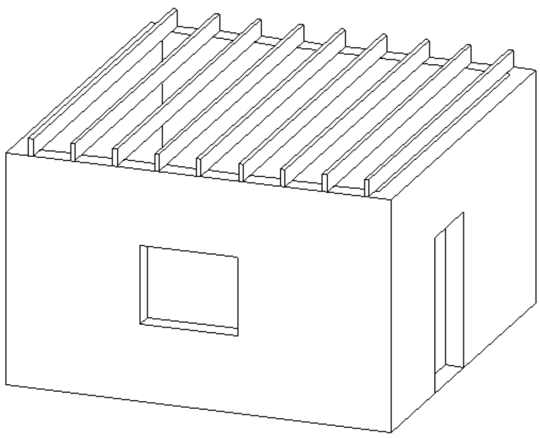
A (General):

Wooden balconies have traditionally been used and often still are used as a supporting ceiling joist over the individual floors. Depending on static requirements, these balconies are used as the living room ceiling, terrace, etc.

Wooden balconies are mostly used as girders for a central support or in general over openings in supporting walls.

Due to mostly similar constructions, the wooden balconies in database 1 are also assigned in the same way as wooden stairs, which in almost all cases are an integral part of a wooden-beam ceiling.

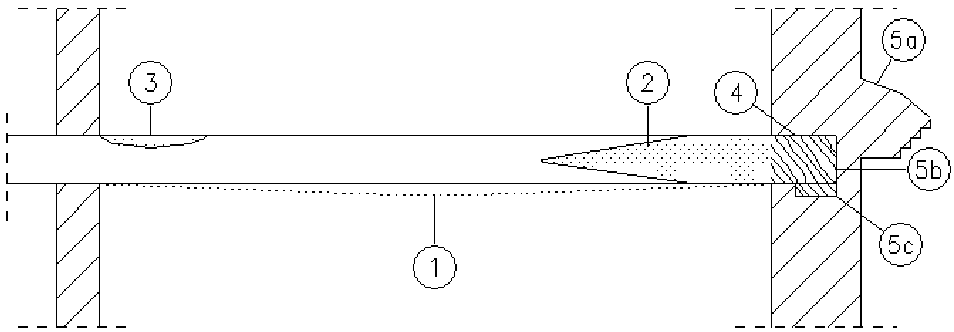
Figure 2.16: Tier of wooden beams over a living space



B (Damages):

The same damages often occur in wooden-beamed ceilings because any exposure of the timber construction to moisture leads to short or long-term damage. Typical damages and their causes are shown below:

Figure 2.17: Typical damage to wooden-beamed ceiling, taken from [2]



Legend to Figure 2.17:

1. *Heavy sagging or swinging of the ceiling*
2. *Insect burrows + fungi decay*
3. *Rot in wet areas (kitchen, bathroom) due to mildew*
4. *Abutment walled-in tight on all sides*

5a. *Defective or unbeveled / stripped cornices*

5b. *Overly thin fore wall frame with lacking insulation*

5c. *Wall slat (sill plate) made of softwood, mostly rotten*

No.:	**Type of Damage:**	**Cause:**
1	Heavy sagging or possible breakage of the beam or swinging of the ceiling	- Decay due to moisture exposure without sufficient ventilation. - Too much pressure (e.g. construction or service loads are too heavy after a change of use).
2	Insect burrows + fungi decay	- Entry of moisture through the exterior wall.
3	Rot in wet areas (kitchen, bathroom) due to mildew	- Improper changes: e.g. renovation measures (= formation of damp areas)
4	Rotting beam ends	- Abutments walled-in on all sides - Due to inadequate ventilation the timber moisture cannot escape and causes the aforementioned damages.
5	Rotting beam ends	- Due to damaged exterior walls (e.g.

unmasked cornices, overly thin fore wall frames without sufficient insulation, etc.), moisture permeates the beam ends and causes the aforementioned damages. The weather side (= west side) is often the most vulnerable area of a building.

C (Static System):
(see the associated basic knowledge + references in Section 1.6ff)

Only singe field or multiple field systems are distinguished for wooden-beamed ceilings. The following **parameters** are important for the static evaluation:

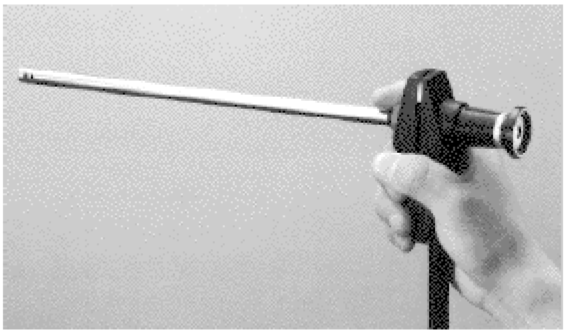
- **Static span** = Usually the distance from the middle of a supporting wall to the middle of a supporting wall.
- **Dead weight**: The beam weight and the total ceiling construction count here: underside sheathing + top side execution (sheathing, construction with top layer lining). For older constructions the fill between the beams is extremely important.
- **Working or live load**: Which loads affect the topside of the ceiling?
  Does it concern living spaces, flat roofs, rooms with large gatherings of people, etc.?
- The **distance between timber beams** with all alternate formations (e.g. for stairway openings, chimneys, etc.) within a tier of wooden beams is standard for the static calculations of beams and wooden lagging (with boards, wood panels, etc.) on the underside, and most importantly, on the top side.
- Takes the tier of wooden beams a important function as a static plate in the stability of the building?

D (Identification): [7]

In order to identify the various damages described above methods of evaluation are needed, which have already been described in detail in Sections 2.4.6 + 2.4.7.
These are reviewed as follows:

- **Optical positioning:** If the top or bottom casing or coating is removed, the critical beam ends can be clearly assessed.
  Without having to remove the casing, the beams can be precisely examined with an endoscope (see Figure 2.18).
  To this end, small holes (DN = 15mm) must be drilled in the casing for the endoscope to be able to pass into the partitions of the wooden-beamed ceiling.

Figure 2.18: Endoscope [7]



- **Acoustic positioning:** The spaces between beams can only be accounted for by testing with a hammer. However, a reliable conclusion cannot be made on this basis.

- **Vibration tests:** If vibrations occur from jumping on the roof, conclusions about the condition of the considered wooden ceiling beams can be made.

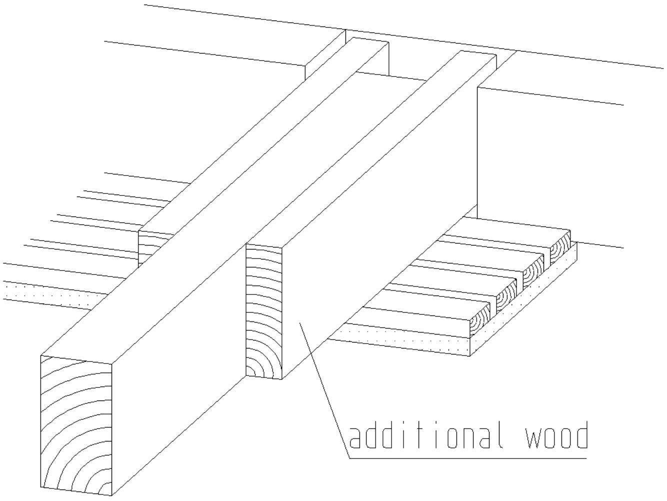
- **Mechanical positioning:** This inspection is more accurate with a drill. The beam ends, for example, can be bored into through the flooring and then inspected.

E (Restoration): [2], [5], [6]

Now that the most common damage to wooden-beamed ceilings and their supporting structural elements, etc., have been defined, a selection of present day refurbishment and restoration methods will now be presented:

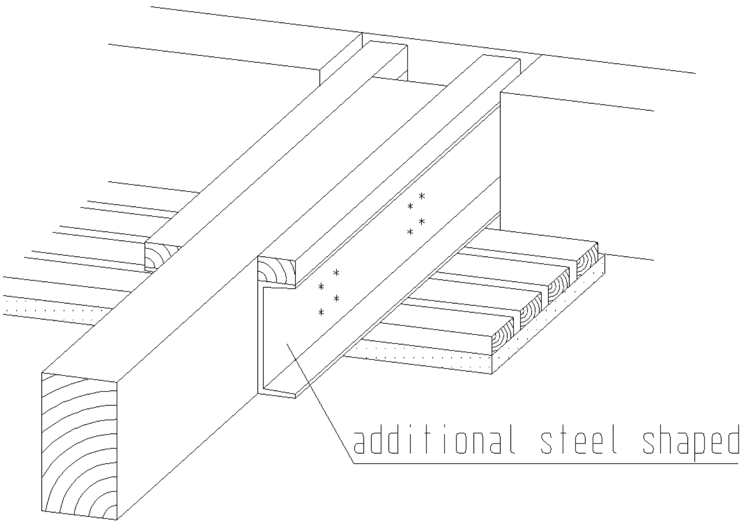
3 Common restoration methods for decaying wooden-beam ends:

Figure 2.19: Lateral joint element with wooden joints



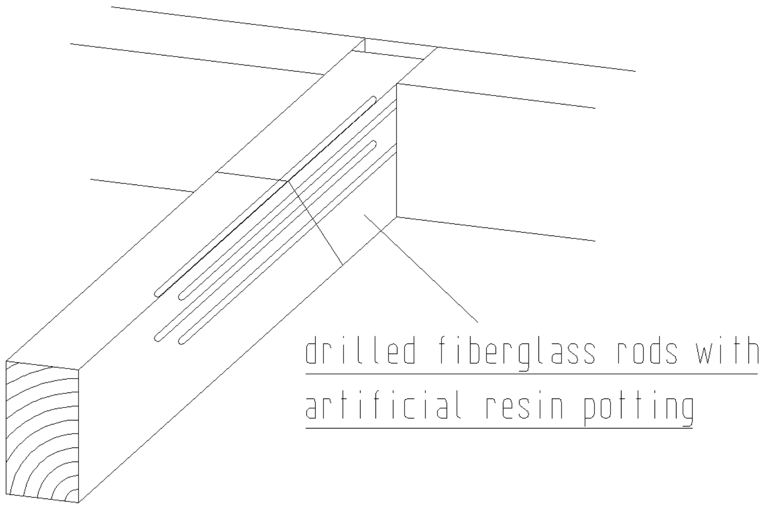
- The connection pieces must be statically proven in each instance.

Figure 2.20: Lateral joint element with steel beams



- The connection pieces must be statically proven in each instance.

Figure 2.21: Abutment restoration using the BETA technique



- The method of restoration must be implemented according to regulation by a specialist company.

The timber expert decides on a form of restoration in line with the appraisal and, in addition, provides more detailed instructions. In order to identify the forces that must be connected, he must first conduct a proof of stability for the affected wooden-beams being restored so as to indicate the joint element connection pieces on the resting beams.

The construction status levels, which will be presented later in the thesis within the scope of Form 6 “End Acceptance Protocol” (= 2.6.7) do not leave the extremely important step between points D (= Identification) and E (= Restoration) found in all databases to the subjective experience of a timber expert in deciding when exactly and how extensive the restorations will be, but rather they provide a precise approach in the matter. These objective decisions, which are derived from Section 2.6.7, have the positive side effect that different timber experts come to the same conclusion when using the assessment matrix.

2.6.3 Database 2: Roof constructions (carpenter-made)

(see the associated basic knowledge + references in Section 1.5.3)

A (General):

Wood materials have been employed since the beginning of time for the assembly of roof constructions. The classic forms of construction are subsequently presented:

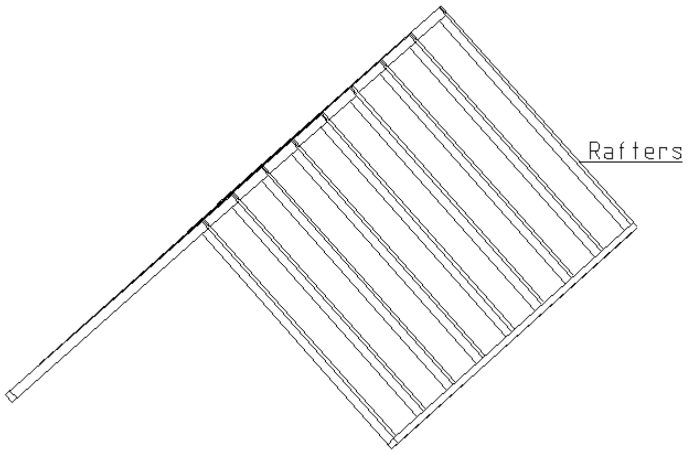


Figure 2.22: *Rafter roof*

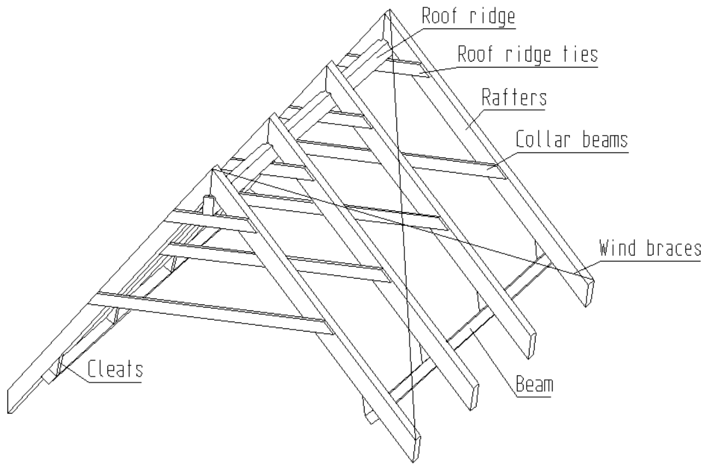


Figure 2.23: *Collar beam roof*

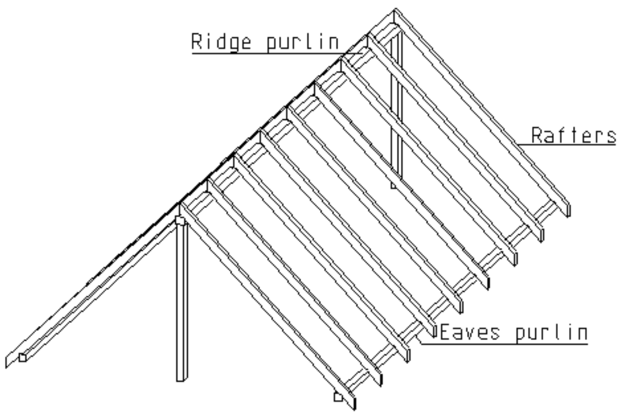


Figure 2.24: *Single standing truss*

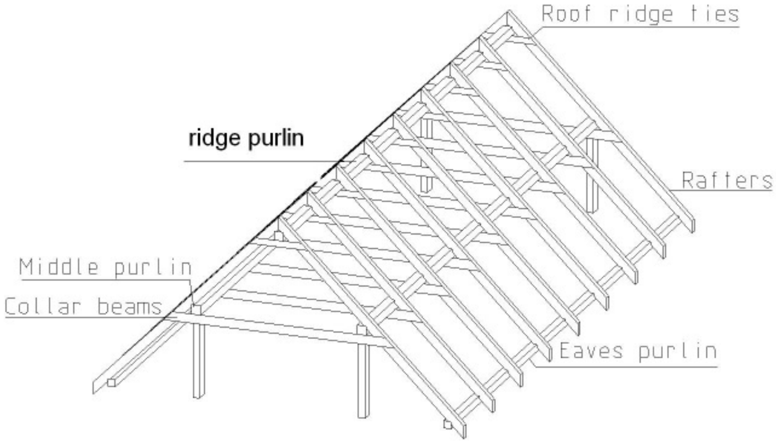


Figure 2.25: *Double standing truss*

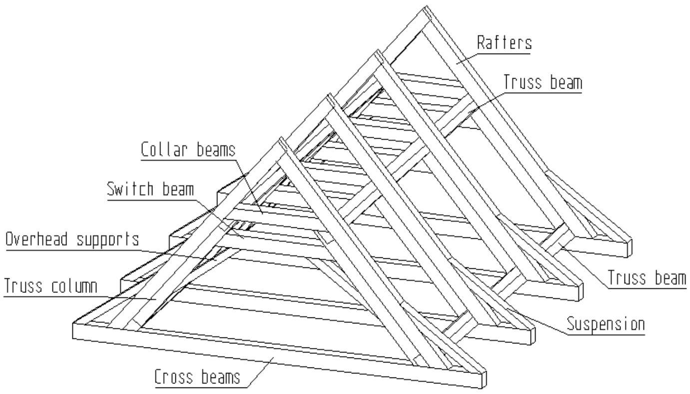


Figure 2.26: *Horizontal truss*

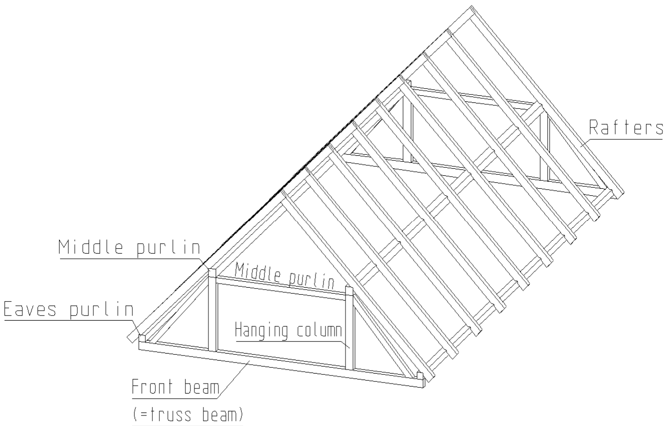


Figure 2.27: *Hanging fixture = truss frame*

B (Damages):

Damages similar to those for the wooden-beamed ceilings described in the previous section also often occur in different carpenter-made roof constructions.

Short and long-term damage can occur through the penetration of moisture if small leaks are present in the roof cladding or due to other structural-physical reasons (e.g. condensation problems in the construction). Different types of damage to roof constructions and their causes are subsequently presented:

No.:	Type of damage:	Cause:
1	Tilting	- Absent reinforcements or reinforcements no longer functioning due to damage.
2	Bent or broken compression struts (often the upper belts of trussed rafter)	- Missing or deficient bracing bonds
3	Broken truss members	- Overstressing - Timber abnormalities - Chemically aggressive influences (= cross-sectional weaknesses)
4	Cracked tension plates or tension rods	- Knottiness - Cross-sectional weaknesses - Load transfers - Inadequately measured
5	Damages to binding supports (e.g. due to decay)	- Increasing moisture - Splash water, condensation - Leaks in roof cladding - Cracks in preliminary timber - Fungus infestation
6	Knot distortions	- Defective (loose, corroded, inadequately measured) fasteners - Bad fit of pressure connections - Timber shrinkage
7	Distortions (shifting, sagging	- Subsequent reconstruction or extension measurements (e.g. resulting from changes

	of roof beams)	of use)
8	Destroyed timber parts	- Insect and/or fungus infestation

C (Static System):

(see the associated basic knowledge + references in Section 1.6ff)

With the carpenter-made roof constructions considered here the static systems look different accordingly. The proof usually occurs through idealized biaxial systems. The following **parameters** are of importance for the static evaluation:

- **Static spans**
- **Dead weight**
- **Live load (= snow load)**
- **Distance between binders, rafters, etc.**

Figure 2.28: Gypsum plasterboard covering on a roof extension

The experienced timber expert, who has more than sufficient knowledge about static systems**,** diverts the load bearing system from a considered construction for which no proof of stability exists. The type of support points that the roof construction has is important here, i.e. if it is directly over an eaves purlin covering the entire surface, or indirectly over a free spanning middle purlin. Each roof construction must secure the flow of forces from the roof ridge to the base points so that stability and usage safety are guaranteed.

Furthermore, it must be determined for the static system whether the transition points from various timbers are flexible or rigid. The lengths or distances between supports and roof pitches can be determined on-site using various measuring tools.

For a better understanding of the aforementioned roof constructions, the biaxial cross-sectional views and the corresponding static systems are drawn here.

Figure 2.29: *Rafter roof (sectional view + static system)*

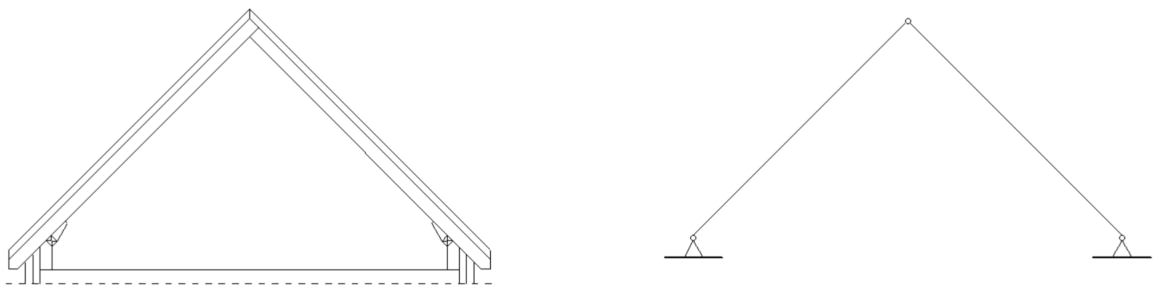


Figure 2.30: *Collar beam roof (sectional view + static system)*

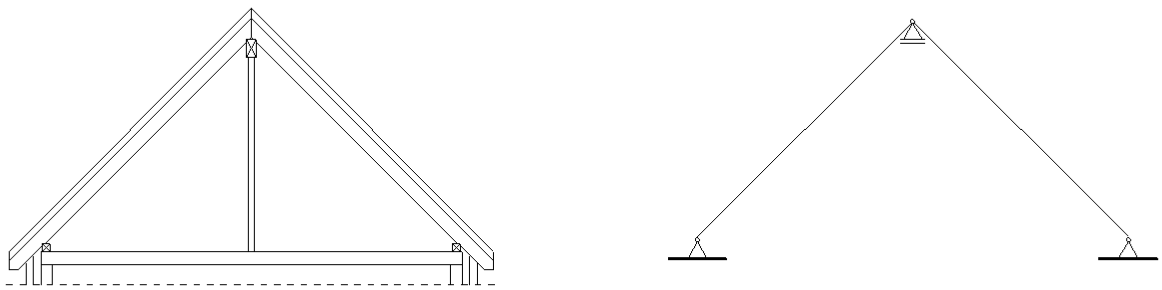


Figure 2.31: *Single standing truss (sectional view + static system)*

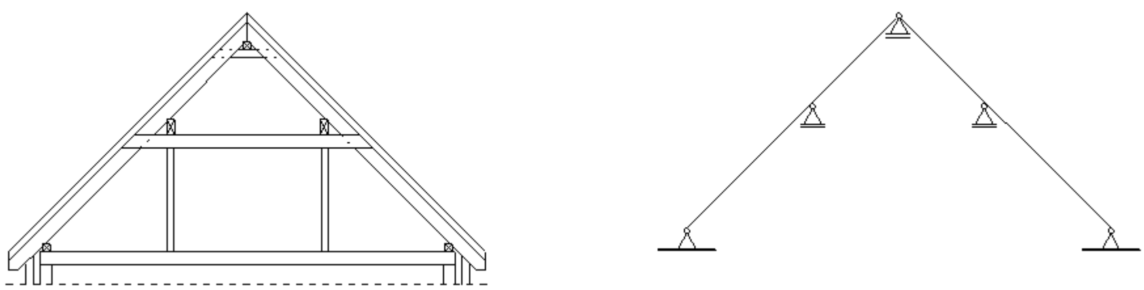


Figure 2.32: *Double standing truss (sectional view + static system)*

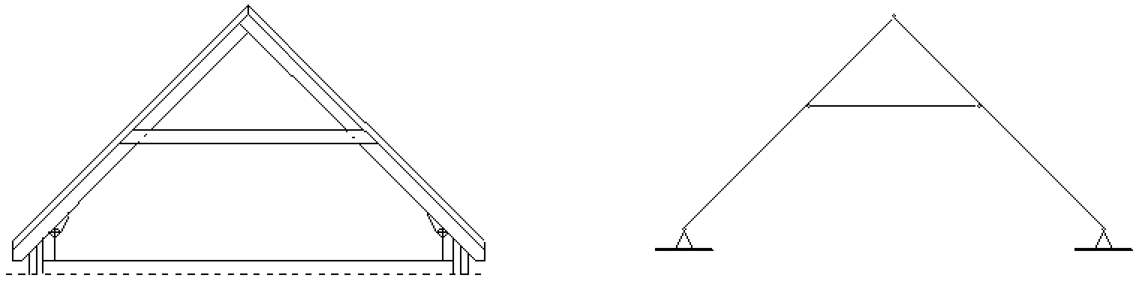


Figure 2.33: *Horizontal truss (sectional view + static system)*

[see case study 2 = Section 3.4]

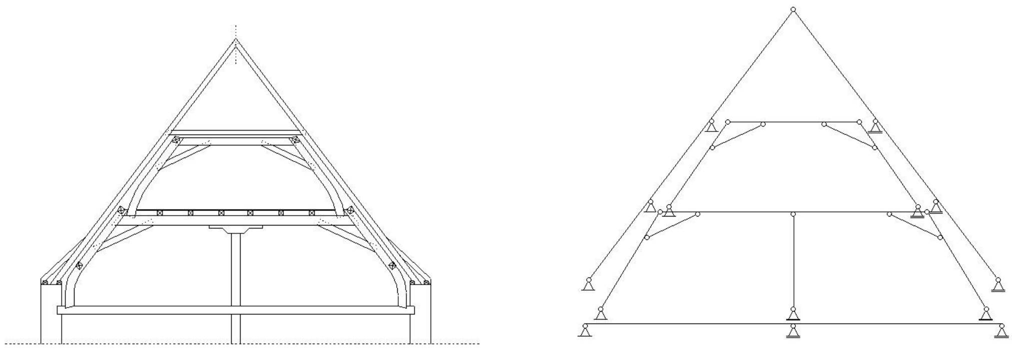
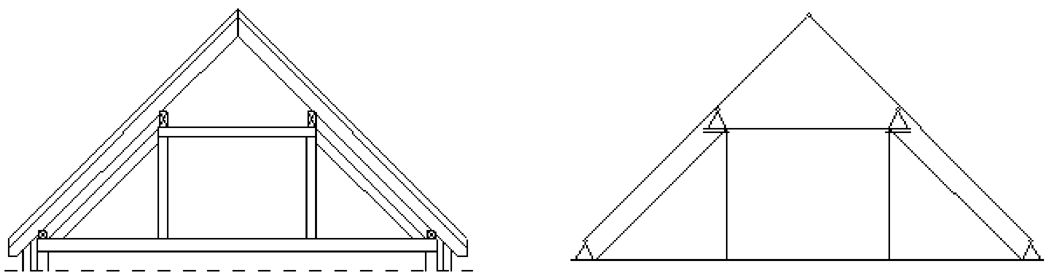


Figure 2.34: *Hanging fixture = truss frame (sectional view + static system)*



The biaxial static systems mainly serve the inspection of all vertical (from dead weight, snow, and proportionate wind loads) and horizontal loads (predominately) from wind in the x and y directions.

It should not be forgotten to inspect each load bearing system in the third (= spatial) z direction. This means the building reinforcement. Wind braces or sheathings often serve this purpose, which convert a roof or ceiling into an effective plate. Ceiling and wall braces should also be mentioned here. The timber expert conducts the required proofs.

D (Identification): [7]

The inspection methods already described in detail in Sections 2.4.6 + 2.4.7 are necessary for identifying the various damages.
These are subsequently presented again:

- **Optical appraisal:** At this juncture the experience of the timber expert is questioned. Many of the damages mentioned above are obvious in inspections, for example, large deformations. It is still sensible, however, to use appropriate measuring instruments for detecting distortions.
  The endoscopic inspection is also a good opportunity to localize and assess damages to sloping ceilings closed on the underside (or closed collar beam positions).
  It is always sensible to look at the outside condition of the roof because the roof covering must be in flawless condition so that no moisture can pass through.

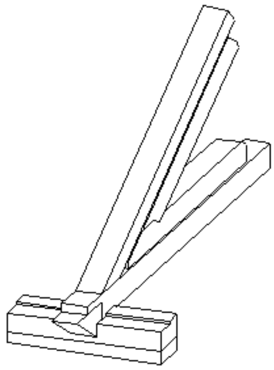
- **Mechanical positioning:** Voids in timber can initially be localized with a hammer test. More precise inspections can be conducted here with a drill like with wooden-beamed ceilings.

E (Restoration): [2], [5], [6]

The previously described damages to carpenter-made roof constructions mostly concern timber beams that are rotted in sections (mostly in the areas nearest to the outside wall) and, therefore, warrant professional replacement.
Various established restoration methods are subsequently outlined.

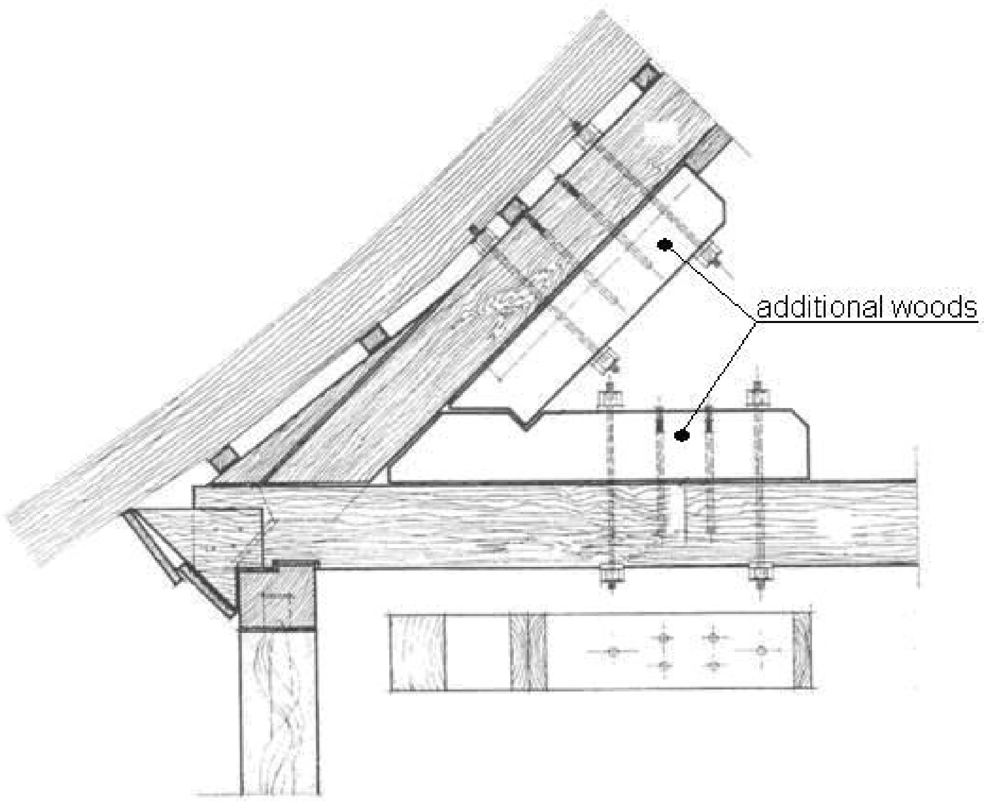
- 3 Common restoration methods for the partial replacement of decayed wooden-beam sections in roof bases:

Figure 2.35: Restoration of a dilapidated rafter base (Version 1): Lumber add-on with sliding dovetail joint



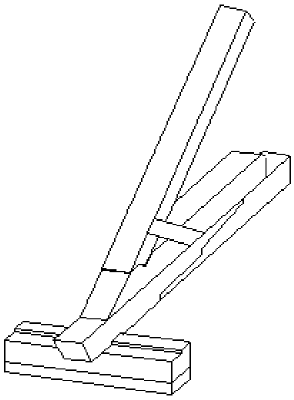
Spatial schematic drawing

Vertical Section, taken from [2]



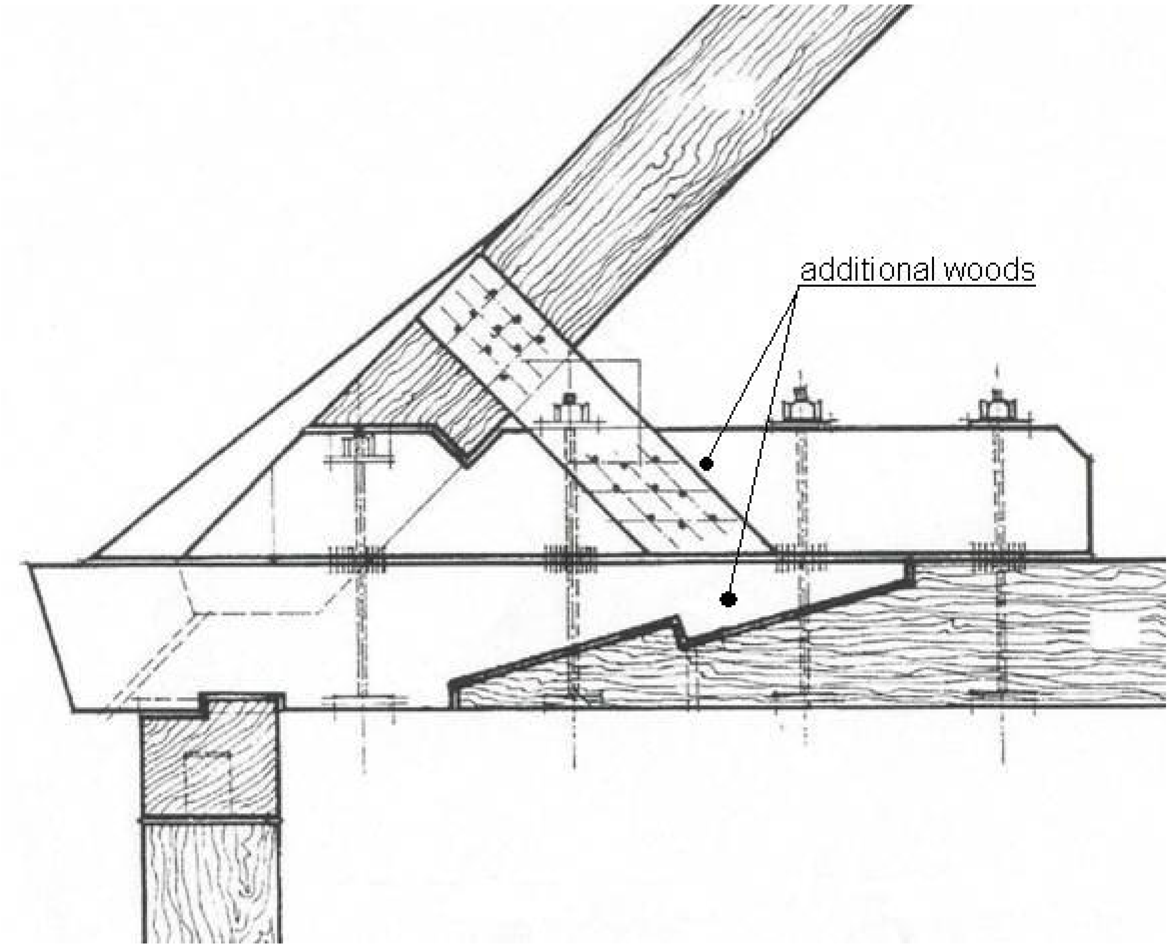
- The connection pieces must be statically proven in each instance.

Figure 2.36: Restoration of a dilapidated rafter base (Version 2): Replacement of timber



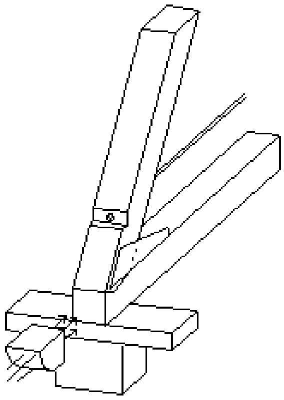
Spatial schematic drawing

Vertical Section



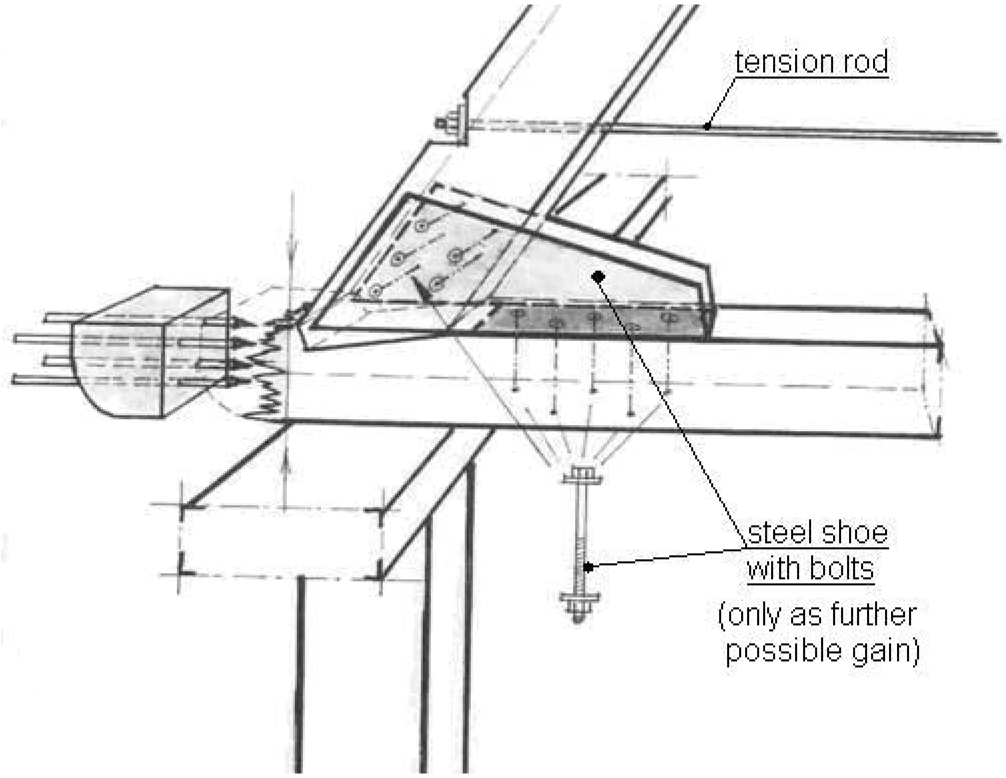
- The connection pieces must be statically proven in each instance.

Figure 2.37: Restoration of a dilapidated rafter base (Version 3): Installation of a tension rod



Spatial schematic drawing

Vertical Section taken from [2]



- The connection pieces must be statically proven in each instance.

The timber expert decides on a form of restoration in line with the appraisal and, in addition, provides more detailed instructions. In order to identify the forces that must be connected, he must first conduct a proof of stability for the affected wooden-beams being restored so as to be able to indicate the connection pieces of the new timber on the existing intact timber construction.

2.6.4 Database 3: Wall constructions / bracing systems / framework / timber supports

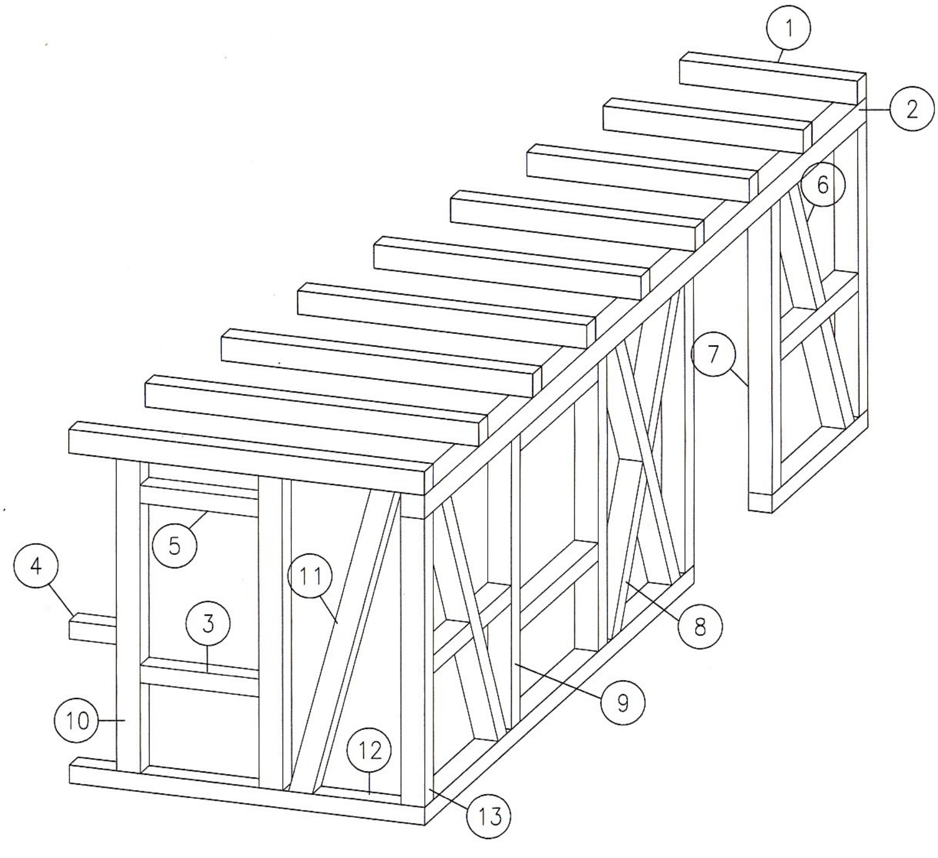
(see the associated basic knowledge + references in Sections 1.5.4 + 1.5.5)

A (General):

The last structural elements - the wall constructions - are now considered alongside the previously considered ceiling and roof constructions in order to construct a complete timber house.

The component drawings of a classic stud wall are presented in the following graphic (= Figure 2.38):

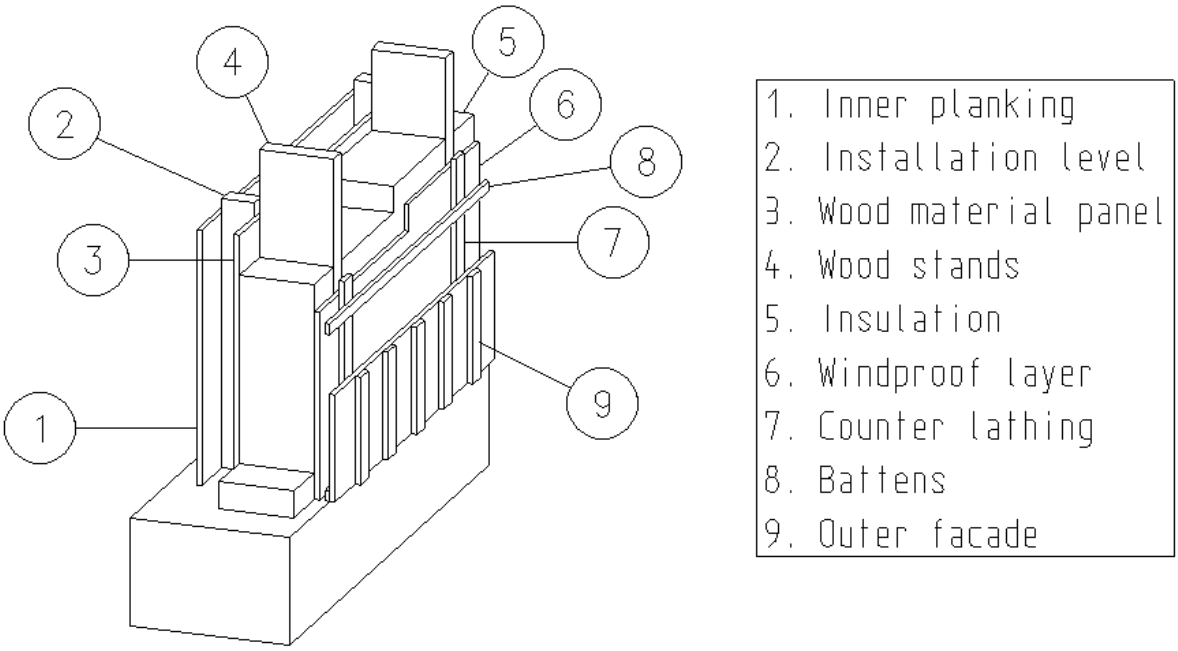
Figure 2.38: Stud wall – system drawing



1	celling beams	2	timber of floor beam
3	parapet transom	4	transom
5	lintel	6	bands
7	door stand or door post	8	St. Andrew´s cross
9	window stands or window post	10	stands
11	support	12	beams
13	corner stands or corner posts		

The original stud walls were replaced with timber frame structures in modern wood house constructions (see Figure 2.39).
The bay rail and St. Andrew’s cross of bracing supports are achieved in the timber frame construction by the inner and/or outer planking.

Figure 2.39: Timber frame construction – system drawing



B (Damages):

The types of damage described in the previous sections regarding wooden-beamed ceilings and carpenter-made roof constructions also often occurs in stud walls.

All exterior walls are exposed to atmospheric conditions and thus moisture. Therefore, potential weak spots in transition zones to roofs, floor slabs, or foundations occur as a result of any potential increasing moisture.
Various types of damages to stud wall constructions and their causes are subsequently listed:

No.:	**Type of damage:**	**Causes:**
1	Rotten beams and posts	- Insufficient insulation of the bottom plate - Missing or deformed vertical and horizontal insulators of the base point.

2	Rotten locking connections	- Frequent moisture ingress on worn windows. - Mostly inadequate heat protection of outer stud walls. - Leaks in the transition points to the roof
3	Slanting outer and inner walls	- Inadequate bending reinforcements of wall parts. - Displacement due to rotten beams (see above) - Stresses are too heavy
4	Damaged infill	- Bracings are too weak
5	No longer functional junctures	- Shrinkage (= fermentation) of timber due to high moisture ingress or moisture fluctuations - Shifts due to inadequate building stabilization (= bracing)
6	Rotten timber	Diffusion resistant (retroactive) color application of the timber

C (Static System):

(see the associated basic knowledge + references in Section 1.6ff)

The timber construction of the stud walls assume the function of load dissipation inside (= interior walls) as well as outside (= exterior walls) of a building's vertical and horizontal loads over the undermost beams and into the groundwork, i.e. foundation or basement.

The fillings have no static duty function.

The vertical loads (dead weight and live weight of ceilings, walls, and roofs) are fed from the top timber beams into the posts where they rest flat on the surface of the beams.

The same statistical information is valid for the timber beams as for the ceiling beams and supporting structural elements handled in database 1. The posts portray the point of support. All diagonally attached timber such as middle crossbars, head, and tail bands, help the bend stabilization of these posts.

These were also assigned to database 3 because of the comparable system of stud posts to conventional timber supports,

Due to wind pressure and elements of live loads, the horizontal loads are carried by the diagonally constructed lumber within the stud walls. Triangles, by way of the St. Andrew's cross, braces, head, and foot bands, rise together with the vertical and horizontal existing lumber cross-sections and can be fed over the horizontal forces downward into the beams.

As long as the stud wall is not plastered, a timber expert can easily use the static system.

D (Identification): [7]

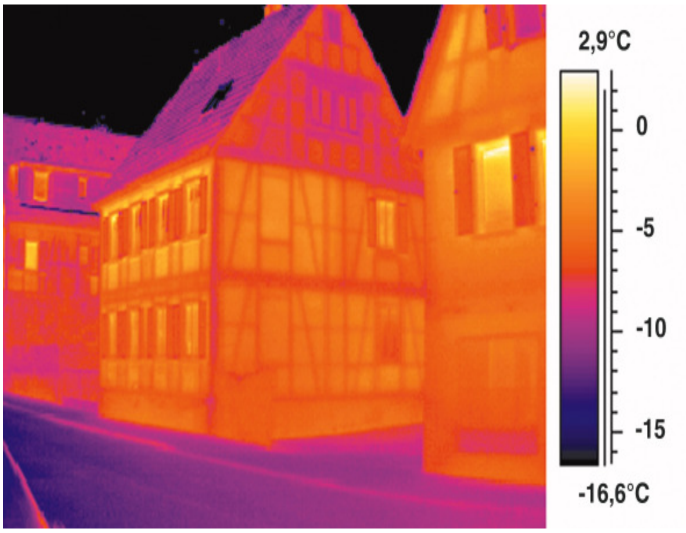
Optical method:

As long as the stud walls are not plastered, no special method is needed to observe the aforementioned damages.

However, in many cases the lumber is plastered over. If a non-destructive assessment is desired, the timber construction can be inspected using thermographs (see Figure 2.45).

The following picture shows the hidden timber structure under the plastered surface. The differing temperatures on-resistances are made visible here.

Figure 2.40: Photo of a plastered building with an infrared camera



Mechanical positioning: With the latticework structures, as with the wooden ceiling beams and roof constructions of the previous databases, a mechanical examination is possible with knocking tests, drilling, etc.

E (Restoration): [2], [5], [6]

If rotten timbers inside of a stud wall are discovered within the scope of an appraisal, they must be replaced with new timber.
Various methods are subsequently presented. Aesthetic reasons or grounds for monument conservation often play a role here in choosing elaborate substitution methods. If no optical standards are provided, a rotten mortise joint of a brace can, for example, be replaced on a plate or a barrier by sheet metal mounted on the outside and the renovation is complete.
Various well-established, present day restoration methods are subsequently presented.

- 2 Common restoration methods for the partial replacement of decaying timber sections of a stud wall construction:

Figure 2.41: Restoration of a dilapidated mortise joint:
False pivot

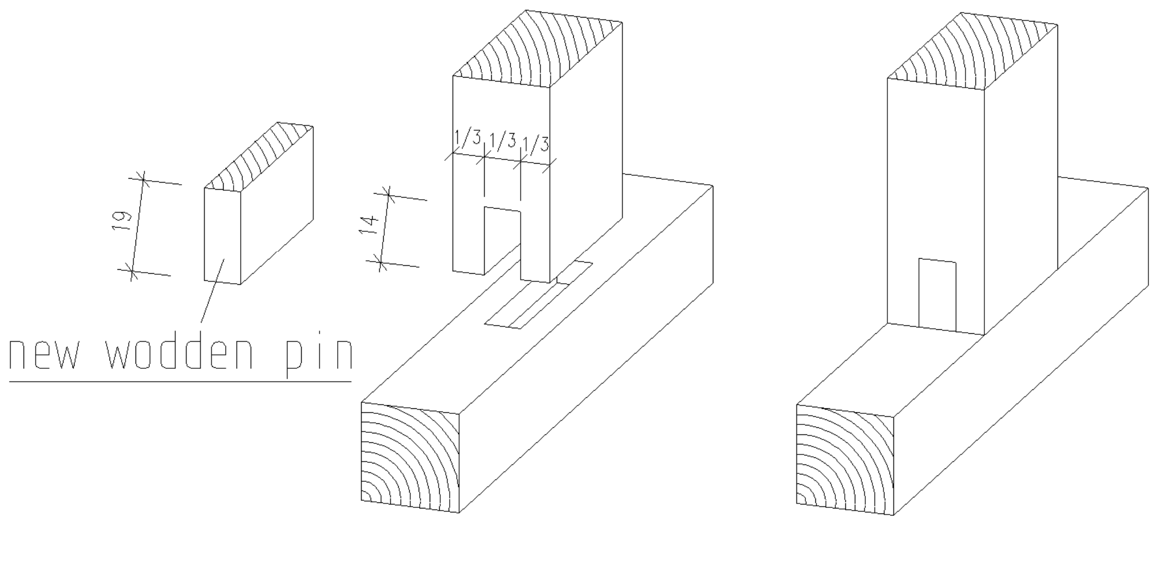
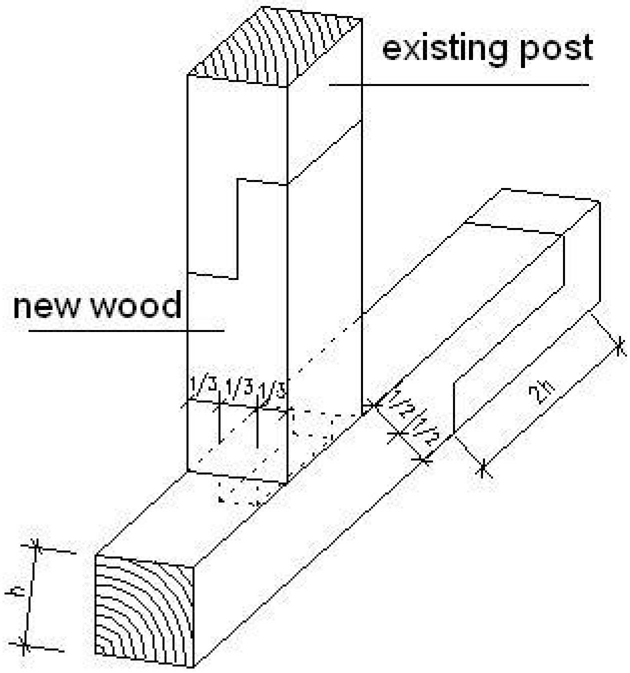


Figure 2.42: Restoration of a dilapidated post base:
New post base with pivot



The timber expert determines a mode of restoration in the context of an appraisal and specifies more precise data to this end. To determine the connected forces, he must conduct the proof of stability for the stud wall construction in order to specify the fasteners of the new timber on the previously intact timber construction.

2.6.5 Database 4: Engineering / widespread timber constructions
(see the associated basic knowledge + references in Section 1.5.7)

A (General):

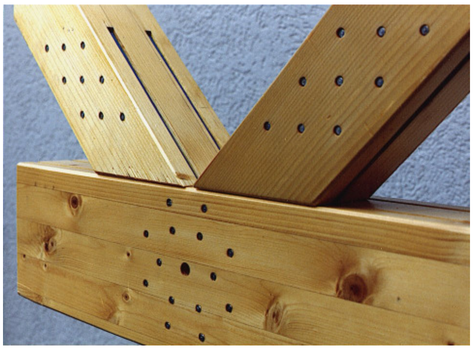
After considering the older or original timber constructions, the newer engineered constructions stand in the foreground of this database.

Through further permanent development of the static appraisal possibilities and the development of glued timber, ever increasing spans can be bridged with timber material.

Besides timber bridges, roof constructions over halls (gyms, public buildings, agricultural buildings, etc.) are especially worthy of mention.
Almost all forms can be fabricated with glued laminated timber.

The connection points in carpenter-made timber constructions essentially *are* the criteria for producing standard and utilizable constructions. Timber engineering has developed a variety of joint connections for this purpose that can withstand much heavier loads. Beside this increased load bearing capacity in the timber construction, a self-contained aesthetic is joined with multifaceted design opportunities.

Figure 2.43: Junction with embedded steel plates and steel dowel pins



Dimensions can be artificially fabricated using glued laminated timber, which makes it possible to bridge large distances between supports.

Stud wall constructions are also fabricated using relatively small timber dimensions with large distances between supports because large strains can be absorbed using the proper structural elements and the described juncture techniques for timber constructions (see also Section 1.5.8.2).

Various german “**Informationsdienst Holz”** books act of these engineered juncture possibilities in a very detailed way, and through a multitude of charts, offer the possibility to examine or newly configure existing connections using information regarding maximum loadable stress resultants.
These books are listed in section 5.6

B (Damages):

With engineer-like or widespread timber constructions there are also typical damages or damage core areas worth inspecting.

As was described in the previous databases, the constructions considered here are also exposed to weather and thus moisture.

Various types of damages and their causes are subsequently presented:

No.:	Type of damage:	Causes:
1	Deformed multifaceted frame supports	- Insufficient buckling safety - Unaccounted for eccentric application of load - Deformations in adjacent fields
2	Slanted frames	- Insufficient buckling and wind bracings
3	Destroyed or displaced column footing	- Pest infestations - Insufficient water spray protection - Unventilated column footings - Missing chemical timber protection - Mechanical destructions (possible missing impact protection) - Insufficient anchoring against wind suction, that is, for position stability
4	Fractures from fasteners and wooden rods	- Chemically aggressive influences - Subsequent static influences (e.g. additional loads, changes in the static system, etc.) - Settling of building
5	Moisture / corroding damages	- Changes in structural physical influences - Changes in climatic relationships
6	Truss support	- Unventilated lumber - Bearing plates not secured against lifting - Corroded loose coating - Additional torque via eccentric support - Changes in mechanical connections: e.g.: studs are loose, gaping jointing with displacements, cracked front timber faces
7	With solid timber purlins	- Insufficient tip and slip resistance

		- Insufficient wind suction anchoring
		- Missing tight-connection bond of purlin face
8	With joint purlins	- Lateral cracks with faulty hinge formation

C (Static Systems):

(see the associated basic knowledge + references in Section 1.6ff)

It is assumed that with previous databases the regarded timber constructions were partly built without proof of stability and it was thus often difficult to provide evidence for these in hindsight. The constructions regarded here were statically examined in each case before their assembly.

In the best case this proof of stability is available, which makes an examination much easier, because the resulting cross sections and connecting specifications can be examined on-site. If no evidence exists, the systems can be evaluated using modern static programs (e.g. as a level, or if necessary, spatial framework).

D (Identification):

The classic examination methods mentioned in the previous databases, rather than various other methods of examination, could be implemented for prevalent glued laminated timber (= glued timber). At this point only the non-destructive inspection methods that were presented in the expert databases (see Section 2.4.7) are referenced.
Those commonly used are listed again below.

Non-destructive inspection methods:

- The inspection of hidden timber components, or rather metallic fasteners, with an **endoscope** belongs to the standard examination.

- The **moisture measurement** with hand tools is conducted using electronic resistance methods.

- The occurring shrinkage cracks in glued timber are of great importance and must be precisely (width, depth and location) identified in order to make further predictions.

The corresponding limit values are taken from Checklist 2 (see Section: 2.5.2)

- The interior timber condition (cavities, firmness) can be monitored with the help of a **drilling resistance measuring procedure**. These inspections of the object can easily be conducted with a **resistograph**.

More precise information about these evaluation methods can, for example, be taken from links in the expert databases (see Section 2.4.7).

- A **drilling core extraction** is essential if the timber expert decides that further inspections should be conducted in the laboratory (e.g. assessment of existing waterproofing, analysis of strength, pest infestation, etc.).

These drilling cores are also essential for the appraisal of glue quality on laminated timber in the laboratory.

Figure 2.44: Core samples (diameter 80mm) from laminated timber beams

- An additional, yet relatively costly possibility for inspection is the integrity check (= test of flawlessness) using the **ultrasonic method** developed by Dr. Andreas Hasenstab [41].

E (Restoration):

Engineering companies specializing in timber construction must professionally restore any damage to engineer-made timber constructions detected by experts.

The timber expert decides on a form of restoration in line with the appraisal and, in addition, provides more detailed instructions. The maximum occurring stress resultants in the affected areas are also of great importance here. They arise, as already described either from existing static details or they must be newly calculated with static programs.

2.6.6 Database 5: Connecting pieces / junctions

This 5th database is not as elaborately examined as the previous 4.

In the other databases various connections were already closely examined, which initially serves to examine and then to mend.

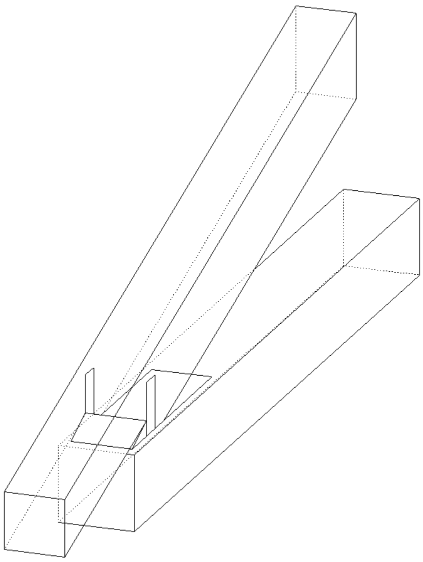
At this point the timber experts should have the possibility to include his already closely examined special connecting pieces (carpenter and engineer-made) and junctions so that he can fall back on these experiences in his future appraisals. These connecting pieces and junctions can also be listed in multiple databases because there is a multitude of connections that occur, for example, in engineer-made roof constructions, stud walls, and wooden beams (e.g. displacements, attachment of headbands, etc.).

As with all of the described databases, the stress resultants (in direction and magnitude) for the considered connection must be known. These cannot be determined by a connecting or junction point. The whole system must therefore be examined.

Examples of junction restorations from rotting mortise or offset joints are subsequently shown:

Figure 2.45: Restoration of a dilapidated sliding dovetail joint with a piece of sheet metal (= rafter foot connector):

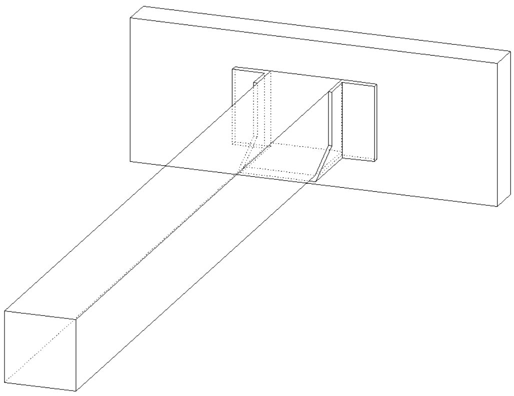
This restoration may represent an alternative to the figures 2.35 ÷ 2.37



The sheet metal part replaced the rotted away heel displacement.

Figure 2.46: Restoration of a dilapidated mortise joint with a piece of sheet metal (= joist hanger):

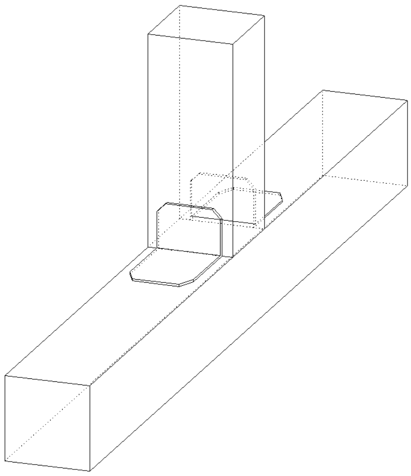
This restoration may represent an alternative to figure 2.19



The later added bar shoe replaced the rotted away cone.

Figure 2.47: Restoration of a dilapidated mortise joint with a piece of sheet metal (= angle joint):

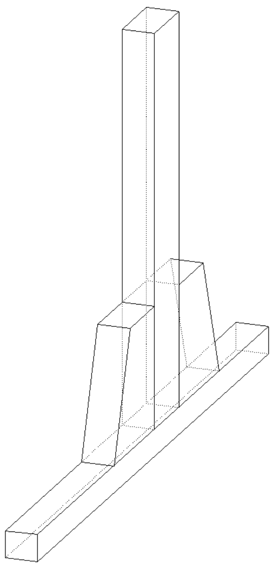
This restoration is an alternative to the figures 2.41 and 2:42



The lateral steel angle replaced the rotted away cone.

Figure 2.48: Restoration of a dilapidated mortise joint with jointed cleats (e.g. with a dilapidated truss support foot):

This restoration is an alternative to the figures 2.41 and 2.42



The lateral cleats replaced the rotted away cone.

As will be described further along in the thesis, the entire assessment matrix is aligned with the fact that an exchange should occur between the operators (see chapter 3.9). It offers this regularly in all 5 databases. Timber experts can share information about completed restorations with the entire sphere of users so they can all profit from the individual knowledge (see 4.1).

2.6.7 Form 6: Final inspection protocol (1/14)

This last Form 6 presents the final inspection protocol of the entire inspection, which should be conducted with the help of the assessment matrix developed in Chapter 2.
At the end of the evaluation the timber expert is asked to compose a neutral final opinion using the collected data and characteristics.
He must consider the whole structure and in doing so follow the main objective if the stability against collapse (= static) and the fitness for use for a specific future time can be secured. He (= the timber expert) consequently undertakes the responsibility for these two aspects: stability and suitability for use.

In the context of the following concluding assessment the term "state of construction level" is used.
This designation was already used in earlier codes from the former GDR (= German Democratic Republic (see [2] + [16]) and it finds a sensible reuse in the assessment matrix of this PhD-Thesis.

2.6.7 Form 6: Final inspection protocol (2/14)

It is important that the timber expert consider the structure permanently and not allow himself to be guided to a positive impression from the beginning. It makes no sense to examine individual components when the initial appearance of trivial damages can lead to bigger damages in a short amount of time. Static supporting and non-supporting structural elements belong to the whole construction. The following **structural elements** should be examined closely:

- **Walls:**
  - Exterior walls
  - Interior walls
  - Facades
  - Moisture barriers
- **Floors/ceilings:**
  - Ceiling construction
  - Stairs
  - Floor construction
- **Roof:**
  - Roof construction
  - Roofing
  - Roof drain

With all components, the structural-physical aspects of noise, heat, fire, and moisture protection should be scrutinized and considered with the complete evaluation.
To this end, the details of Section 1.7 can be helpful.
All of the aforementioned aspects are included in the same assessment table presented.

2.6.7 Form 6: Final inspection protocol (3/14)

In the framework of a construction evaluation, various characteristics and already existing damages are reviewed. In order for different timber experts to come to the same conclusions in the future, diverse assessment criteria are presented in the following table.

For all 5 databases it is specified (see chapter 3.9) when (that is, from the construction status level 3) the timber expert must bring about a refurbishment or restoration of the considered timber construction so that, at the very least, construction status level 2 can be reached, which allows for a harmless use of the building.

This assessment table, which makes up 7 pages with all the annotations, addenda, and appendices is now presented.

A similar approach to the construction assessment, which doesn't cover the extent of this thesis, was delivered by the authors Willi Mönck and Klaus Erler (see [6]).

2.6.7 Form 6: final acceptance-rating table (4/14)

Figure 2.49 a: Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assessment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability	1	statical calculation according to EC1 + EC5 (buildings of BC2) (XX)	fully guaranteed	fully guaranteed (maximum is exceeded by 5%)	partially not guaranteed	mostly not guaranteed		4 (+1) measured strength on site (+1) for accurate detection
stability	2	state of the connections or lanyards	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2 (+1) with an exact proof
stability	3	corrosion protection of the steel components	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		1 (+1) accurate check on site
usability	4	functioning (qualification for the planned use) (XX)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2 (-1) if structure for more than 3 years unused
usability	5	deformation of the structure: (deflections, displacements, tilts) (deflections, shifts, oblique positions, etc.) (XX)	no f <= L / 300	no f > L / 200	no f > L / 150 (localized)	predominant deformation to breaks		2 (+1) for accurate detection with control of e-module

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: final acceptance-rating table (5/14)

Figure 2.49 b: Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
building physics	6	heat protection by energy saving regulations (only relevant components of thermal building envelope)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) withe precise control of the insulating materials
building physics	7	sound-proof (only with statutory requirements, e.g. in apartment builings, but external noise, etc.)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
building physics	8	constructive fire proof (exact requirements as fire resistance according to structural fire protection) 2)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with precise control of the materials (=claddings, chemical wood protection) or structural analysis (for structural fire protection)
building physics	9	cracks (= desiccation cracks / shrinkage cracks) [assessment using the checklist 2]	no	low	partially	mainly		1 (+1) with accurate recording
• All remarks and comments of form 6 (page 8/14) are applying !								

2.6.7 Form 6: final acceptance-rating table (6/14)

Figure 2.49 c: Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assessment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability / building physics	10	damages of the seatings (rot, twisting, wind uplift anchorage, ventilation)	no	low	partially	mainly		1 (+1) with precise control
timber protection	11	structually constructive moist protection (including weather protection)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
timber protection	12	chemical timber protection (according to use class the corresponding chemical wood preservatives are prove)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with precise laboratory verification
timber protection	13	attack by wood-damaging insects [assessment using the checklist 3]	no	low	partially	mainly		1 (+1) with an exact determination
timber protection	14	attack by wood-damaging mushrooms [assessment using the checklist 3]	no	low	partially	mainly		1 (+1) with an exact determination

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: final acceptance-rating table (7/14)

Figure 2.49 d: Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
special aspects	15	special formations (water proofing, etc.) in wet areas and wet rooms	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with an exact determination
	16	roofing (with all transition points + execution of the roof drainage + wind resistance)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
	17	Check the tightness with the "blower-door-Test" (e.g. for prefabricated houses of wood frame construction)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2
	18	check of lime-connections in case of chemical influences (e.g. chlorine, fertilizer, etc.)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		1 (+1) with precise laboratory verification
							total "Building-Stage-Level": decimal: .... / rounded .... (X)	

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: Final inspection protocol – assessment table (8/14)

Averaged final scores:

Evaluation of all assessment criteria: With the help of the important factors, an average score of the construction status is calculated.

=> The whole structure is assigned the "Building Stage Level" (= average -overall score / rounded): ________

The reason for this decision follows in **Appendix 1**.

The definitions of construction status levels are taken from **Addition 1** of Form 6

(see page 10/14 of form 6)

If more serious damage occurs, construction status level 2 cannot be reached!

Notes on the table:

(bracket value) = corresponding increase

1) Increase of the weighting factors with more exact proof or enabled experts.

2) The assessment of structural fire protection is not the purpose of this evaluation. When necessary, an external fire protection plan can be obtained from a fire protection expert.

3) To complete the full evaluation some recommendations could be pronounced by the timber expert. In addition to the requested time the color of the inspection badge is given (see page 12/14 of form 6)

(X) To be able to approve an appraised construction for further use, at least construction status level 2 must be reached. In the case of a worse assignment corresponding repairs and/or strengthening (or others) are to be conducted according to the precise specifications of the timber expert. See: Form 6 _ Appendix 2

(see page 11/14 of form 6)

(XX) Basic requirements for the static examination:

- Well-defined static system of load transfer
- The supporting system consists exclusively of materials approved by the building authorities

☒ = see **Addition 1** to Form 6 (= Definition of construction status levels)

(see page 9/14 of form 6)

2.6.7 Form 6: Final inspection protocol – assessment table (9/14)

Addition 1: Definition of Building Stage Levels (based on [6] + [16])

Building Stage Level (BSL) / Grading	Characteristics of building	Percentage of wear, that is, damaged parts (=damage in %) Brief description
1 very good – good	**- well maintained** - no loss of function whatsoever - negligible defects, which can be removed via maintenance and repairs	0 – 5 - SS fully ensured / secured - no damages
2 Satisfactory - fair	**- minor damages** - repairs are to be carried out in order to remove small disruptions in function and to avoid an expansion to larger damages	6 – 25 - SS ensured - marginal damages - almost secured
3 poor	**- serious damages** - sizeable defects, which compromise the continued existence or the functional efficiency; repairs of large areas are needed	26 – 50 - SS partly not ensured / secured - minor / partial / locally limited faulty
4 deficient	**- unusable** - paramount indemnifications are required for rehabilitation of the functional efficiency	> 50 - SS predominately not ensured / secured - significant damages
SS = structural safety		

2.6.7 Form 6: Final inspection protocol – assessment table (10/14)

Appendix 1:

Reason for the assessment = summary

(At this point the final score is explained briefly)

↑

Insert here
the summary

↓

2.6.7 Form 6: Final inspection protocol – assessment table (11/14)

Appendix 2: (only needed for construction status level 3 and 4)

As a result of the detected defects of the construction regarded here and the resulting grading, the following repairs and/or retrofitting are necessary: (here the various databases can be referenced)

↑

Here could
be proposed
recommended
repairs and/or
exercises!

↓

2.6.7 Form 6: Final inspection protocol – assessment table (12/14)

Appendix 3:

At the end of the assessment the timber expert has the option to provide general recommendations. The period for acceptance is also defined and described here shortly. The inspection badge color is specified.

↑

Here could
be proposed
general
recommendation!

↓

2.6.7 Form 6: Final inspection protocol (13/14)

The assessment table presented earlier, aims to conclusively evaluate the regarded timber structure. This assessment is subsequently illustrated again.
At the end of the appraisal the timber expert provides a final score for the regarded structure.
This corresponds to the “Building Stage Levels”: 1 to 4.
A short explanatory note to the score is also included.
It is also important to say that grade averaging cannot be conducted for buildings where various individual, independent timber constructions were appraised. Almost the entire construction can be classified as construction status levels 1 and 2, whereas a relatively small portion is so defective that the building must be restored at this point for the continued use to be approved.

In Chapter 3 of this thesis, a standardized building check is prompted upon which the appraisal is based. Based on their building category, the constructions are only approved for a certain amount of time. These specifications are also presented in Chapter 3.

Consequences of the Grading:

- If **grade 1 (= Building Stage Level 1)** is given, the construction can **unobjectionably** be **approved** for use.

- If **grade 2 (= Building Stage Level 2)** is given as a result of minor damages, the construction can **still** be **approved** for continued use. The timber expert specifies exactly which repairs are to be conducted to prevent further expansions of damages. He does not, however, have a regular controlling function if the specified work really is conducted. The timber expert can, in his discretionary judgment, reduce the approved time by up to 5 years.

- If **grade 3 (= Building Stage Level 3)** is given, the construction is **initially not approved** for further use. Serious damages are present (usually more than 3).

2.6.7 Form 6: Final inspection protocol (14/14)

The timber expert specifies exactly what must be done. Only **after** a successful approval of the restored or reinforced construction will an **approval** be given.

- If **grade 4 (= Building Stage Level 4)** is given, the construction is **immediately blocked** for further use. Such sizeable damages are present that the construction is useless. Multiple and extensive restorations are required. Therefore a previous cost calculation is needed. A deconstruction (= demolition) may be the most sensible solution before further damages emanate from the construction. Yet it must be considered that the owner in this case is required to undertake the demolition costs, which cannot be insubstantial. It is also important to state that before the demolition of a landmarked object, the agreement of the appropriate monument protection service should be obtained.

As gathered from the previous explanations, the timber expert has a very important assignment to approve the construction for use or to call for the remediation of defects. Yet he also has the authority to block a building from further use. If danger is present and thus a person's life is endangered in any way, the construction must immediately be barricaded!

At the end of the final inspection protocol the timber expert can provide a suggestion, for example, concerning the maintenance of the regarded building. Furthermore, it is sensible to summarize all conducted examinations, which are documented in the forms. The assigned grade can be explained here.

2.7 Assessment Matrix for Timber Structures (= complete matrix)

In the previous sections a matrix was successively created that should serve as a guide during the assessment of timber constructions. As mentioned, this 2^{nd} chapter can serve as a guide for the user of the assessment matrix. Because of the complexity of this task, which was already discussed in Section 2.2, not all areas can be completely covered. With each appraisal the most important task belongs to the timber expert, which is to combine all aspects or characteristics in an objective manner into a neutral report. The matrix should bring the operator to objectively evaluate the regarded construction.

Over time, the operators of this matrix can supplement or change the forms, checklists, and databases according to their own interests so that the benefit (= assistance) is always increasing. This aspect will be addressed in Chapter 3.

The completed matrix is subsequently first illustrated in a schematic outline (see Figure 2.63) and later in a detailed schematic extended version (see Figures 2.64 to 2.66).

Figure 2.50: Assessment Matrix in summary form

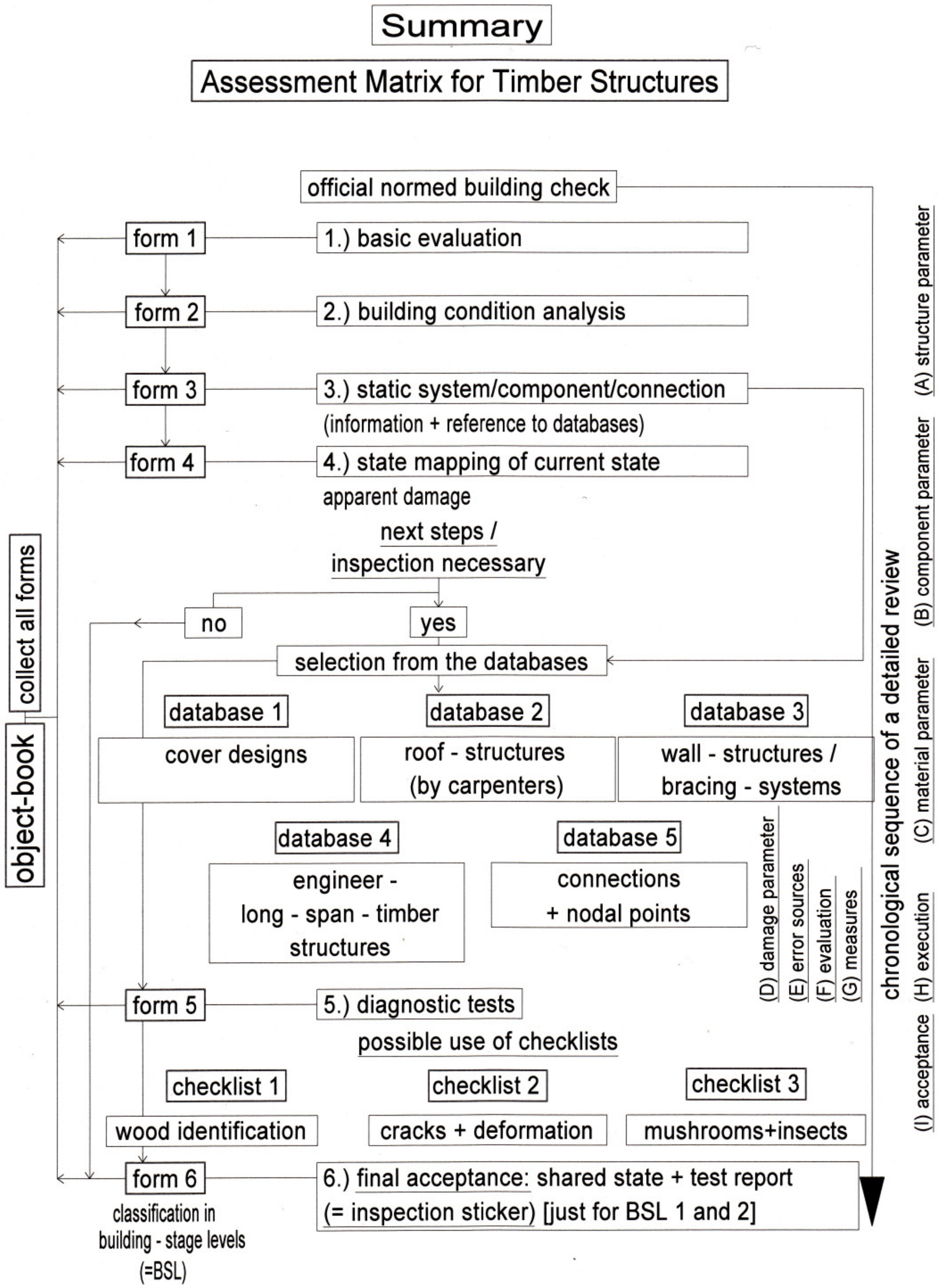


Figure 2.51 a: Assessment Matrix as long – version (1/3)

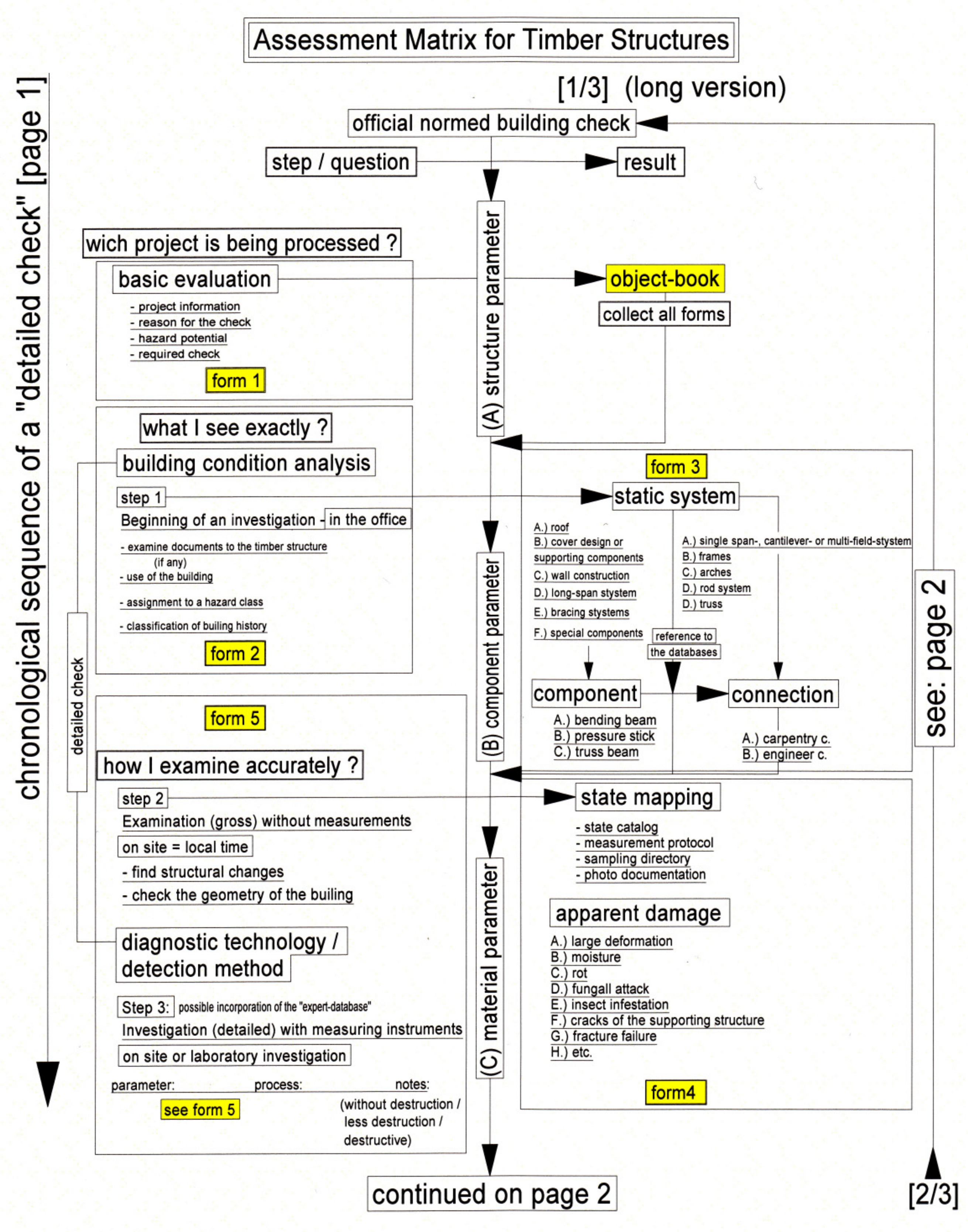


Figure 2.51 b: Assessment Matrix as long – version (2/3)

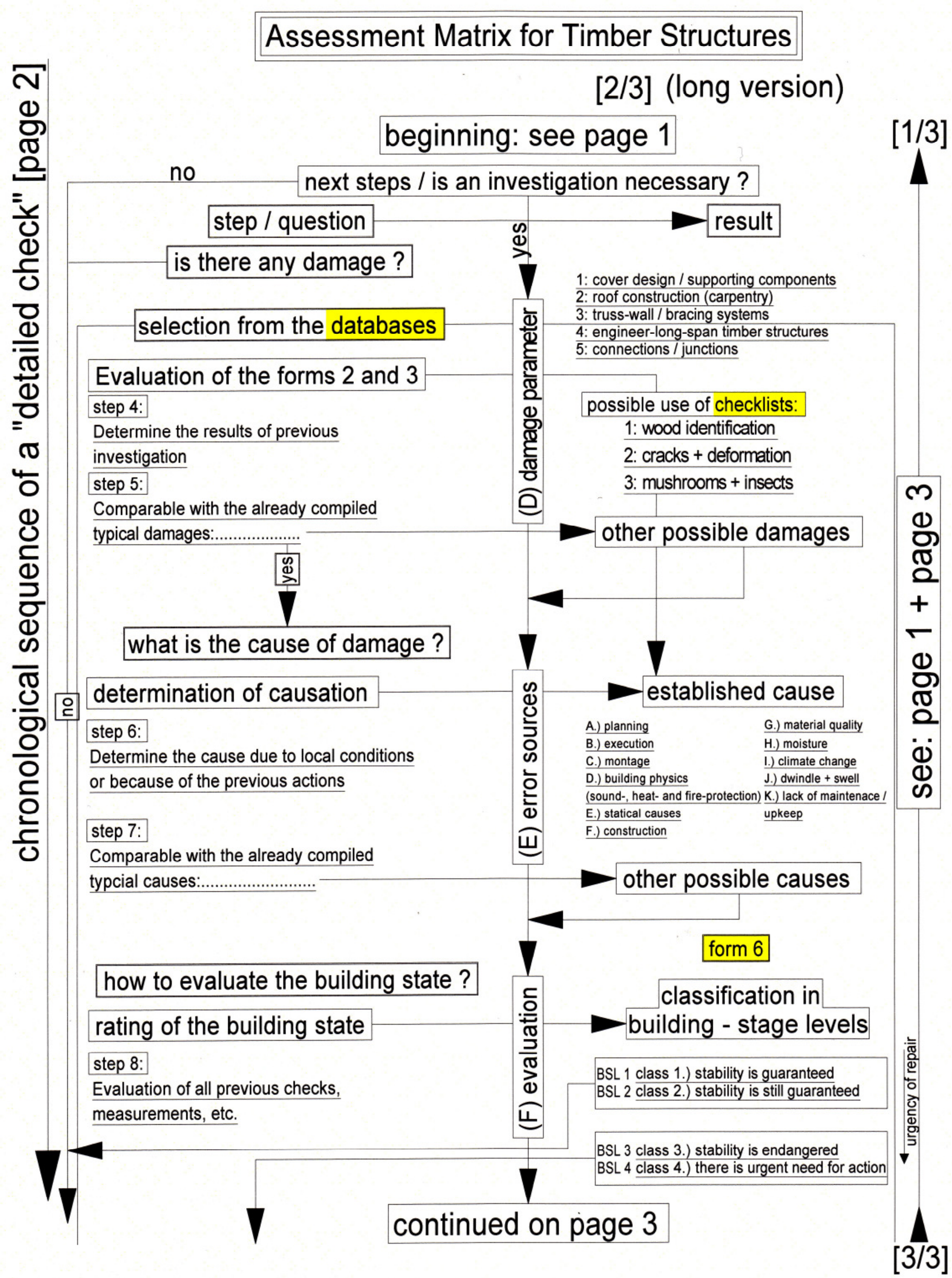
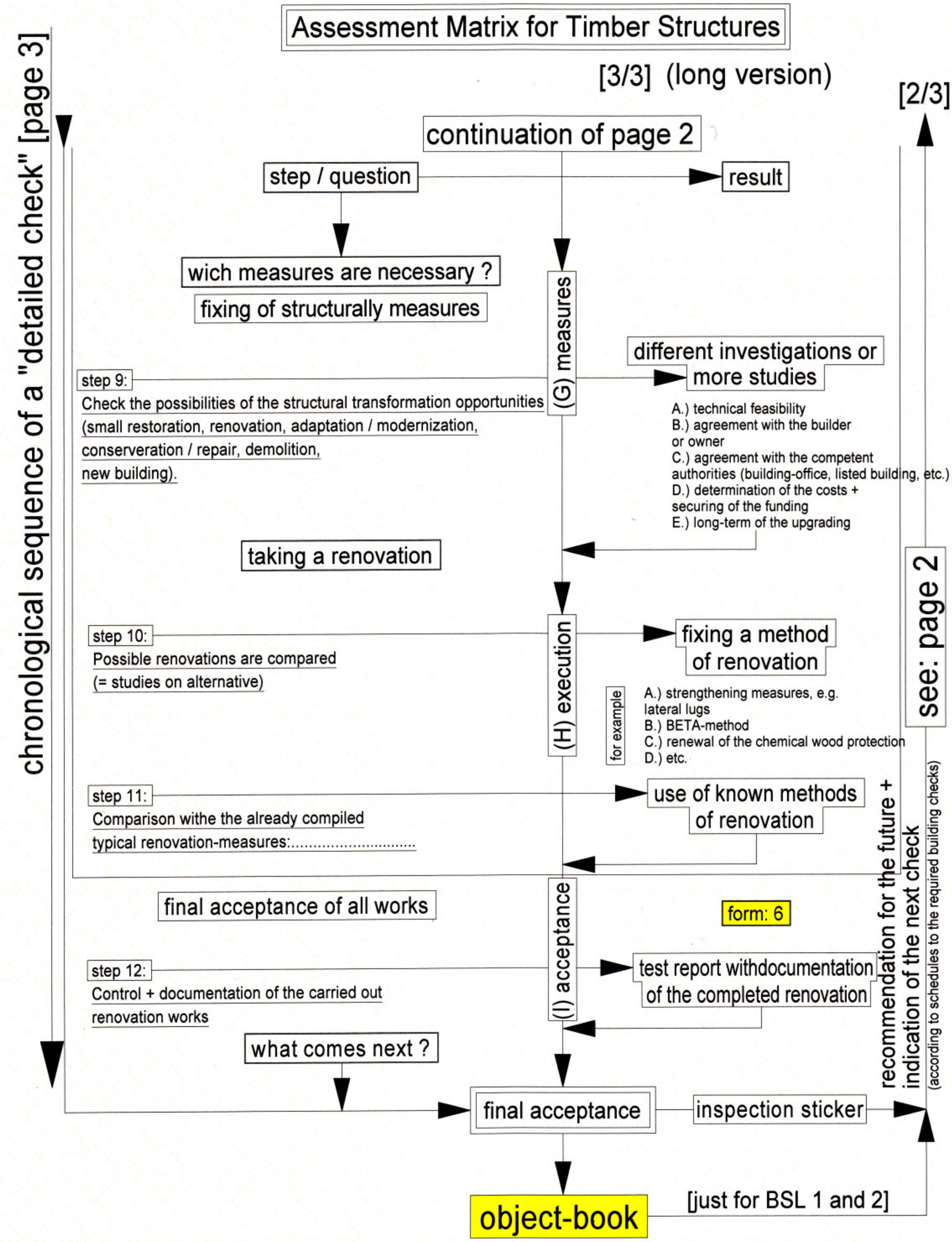


Figure 2.51 c: Assessment Matrix as long – version (3/3)



2.7.1 Application of the matrix: why / how / where / when

The developed matrix is suitable for all timber experts. The main goal, which follows with the implementation of this matrix, is to increase the safety of all users of buildings with load-carrying timber structures. At the same time, the preservation of all buildings and thus objects of our cultural assets are secured. Society must be sensitized to this to begin with if buildings today can be entered without hesitation. Unfortunately, in the past this regularly led to tragedy when buildings, due to serious structural damages, were barricaded and even when buildings collapsed burying many people beneath them (see figure 2.52).

As previously described, our society has the necessary "know-how" and the required "equipment" for recognizing damages to timber constructions early on.

Figure 2.52: Ice pavilion in Bad-Reichenhall, Germany,
before and after the structural collapse on 01.03.2006

The question “how can this instance be avoided in our society in future?” is answered in chapter 3. In doing so, an effective process is developed, which requires the owners of timber constructions to allow examinations to be conducted on all buildings.
By whom, how, where, and when these assessments should or must be conducted will be described in detail in the next chapter.

2.7.2 Object book (for documentation)

The object book presented here contains all of the previously conducted analyses conducted within the framework of an assessment. As already presented in Section 2.4, all forms are integrated in the object book.
Why this is done is described in Chapter 3 of this PhD-Thesis. In this section the author develops an effective process in which the structural examination should be legally required. The control of these evaluations falls in the area of responsibility of the lower building control authority. The object books can be applied here as construction documents.
In order for the person responsible to quickly obtain an overview, the cover sheet of the object book will be configured as follows:

- Object - Book -

Object specified:

- Building: (description) **Photo of the building:**

.... (insert here)

- Components / Investigated Structures:

....

- Builder, Owner: (name, address, phone, fax, e-mail)..............................

- Place: (street, postcode, place, district, landing, parcel, land registry number)

....

....

- Responsible Building Office:

....

- File Number: (if any)

....

Building Information by Building Check:

- Timber Expert: (name, address, phone, fax, e-mail)

....

place, date:..(signature timber expert)

- Building Category: (underline the right one)

BC 1 / BC 2 / BC 3

- Last Monitoring: ....

- Partial acceptance / Professional Company Statement(PCS) no later than:

....

- Next Monitoring: ....

Contained **Forms**:

Form:	**date:**	**index:** (= date of revision)
1		
2		
3		
4		
5		
included experts		
6 = final acceptance		

- Total "**Building Stage Level**" (BSL): (+ explanatory report: see back)

- special features or special reports (date):....................................

- *Inspection Badge* (red / green / blue) awarded on (date):.............../ valid through:.....................

2.8 Temporary conclusion and prospects of the following sections

Now that an assessment matrix has been composed in chronological order in this 2nd chapter, it can be employed in the further course of this thesis. It is important to once again note that the present condition of the matrix cannot or should not be the final result. As the past and present have shown, the field of construction is always in a state of development. In the future this should be permanently incorporated into the forms, checklists, and databases.

In the following 3rd chapter the matrix is implemented in 3 different case studies.

Finally, the societal relevance of the assessment matrix developed here will be addressed in the form that this matrix can illustrate the basis of an officially standardized building check. On the other hand, suggestions are being developed, such as how the previously described development process (of the matrix) can be taken into account.

3. Example Assessment Matrix applications (= main matrix)

Chapter 1 of this PhD-Thesis provided a strong foundation of knowledge followed by Chapter 2, with the development of the assessment matrix now being applied to concrete building objects. In doing so, a few explanations will be noted in advance; the selection of case studies is founded before the 3 matrix applications are presented. The case studies will then be subsequently evaluated [17]. Once these practical matrix applications have been established, Chapter 3 will then present a social application of the matrix and its thoroughly sustainable process.

3.1 General information about the practical matrix application

In Chapter 2 of this thesis, the assessment matrix for appraising timber constructions was developed. In doing so, multiple complexities were described that result from wood that has been and still is being used in a variety of building constructions. Neither the size nor the age of the construction plays a role when applying the matrix. The design of the matrix allows for controlled processing. This means that the described forms allow a chronological appraisal of all constructions. It initially concerns the detection of the "actual condition" of the considered construction. The databanks contained within the assessment matrix provide typical weak points for the most common construction types including options for testing as well as possible restoration methods if required. Otherwise the described checklists can represent a simplification of work for appraisals because they respond to typical circumstances like damages, e.g. from cracks, fungus, insects, and/or material properties.

All common inspection methods are prompted in the forms in addition to the "formal" project properties for construction state analyses right up to condition mapping. In addition to timber experts with knowledge and equipment who take on the most important role in the overall process as the user of the assessment matrix, additional experts (see expert database, section 2.4.7) may be consulted for the assessment of the considered constructions. The forms provide useful information about this topic as well.

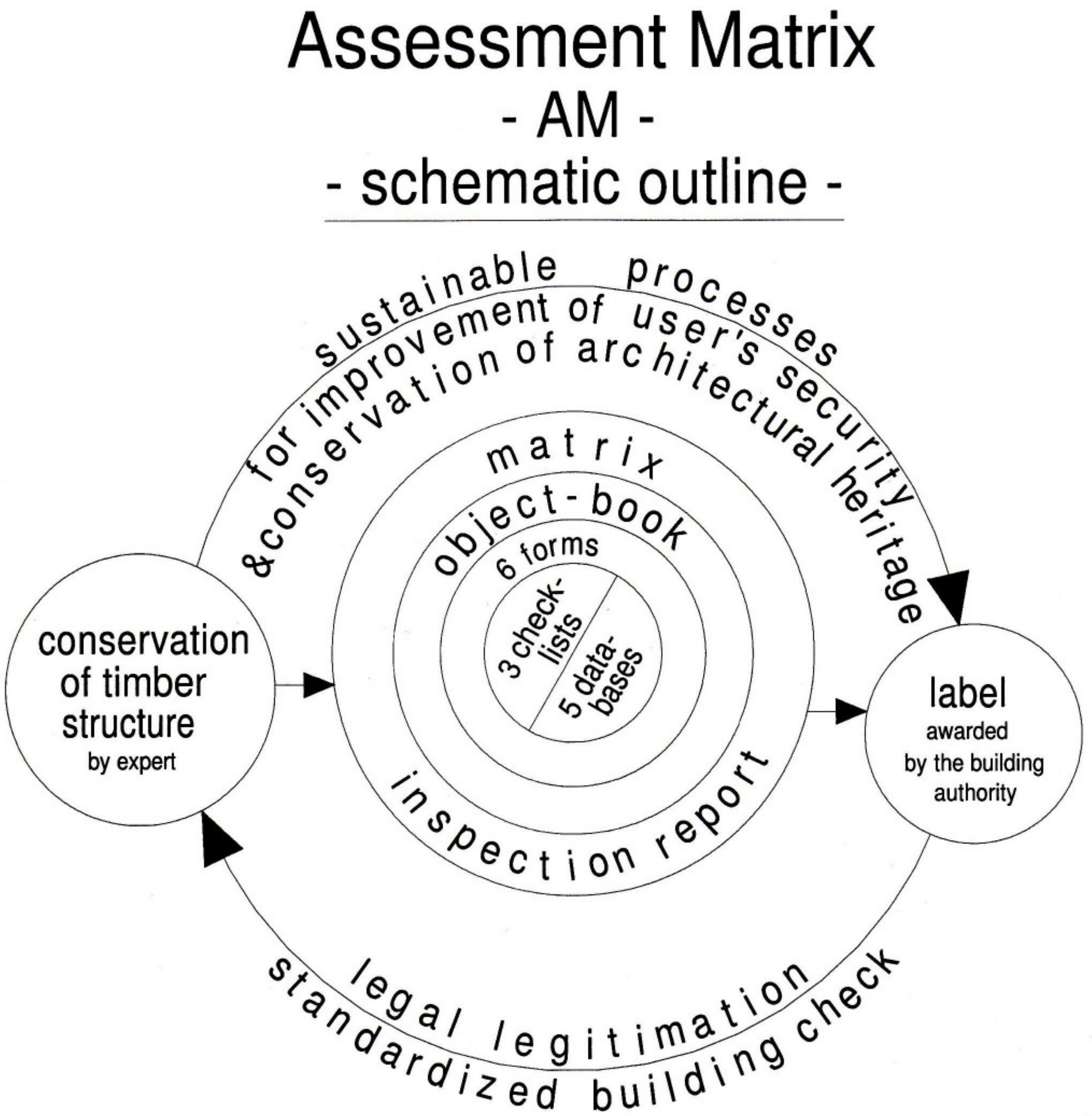
The last (= 6th) form allows for a regulated appraisal form according to which all previous inspection aspects are summarized into one assessment.

The present section is about the testing and presentation of the practical suitability of the assessment matrix; it demonstrates to the interested reader and potential future user the advantages that these new appraisal forms offer.

Because the aspiration of this thesis is a future comprehensive application of this assessment matrix - for example, in the form of an EU guideline that mandates defined inspection procedures for all buildings - a great deal of value is placed on the structure of this assessment form. Future benefits will be reaped from this sought after standardization of appraisals because the form (= structure), which can be offered as a computer program (see Chapter 4.1 of this thesis) can be constantly improved and optimized.

Important to note here is that the actual motive for the subsequently presented inspections was voluntary (for case studies 1 and 3) and conducted in connection with a planned change of use (= case study 2). The possibility of a legal obligation to such inspections being implemented will be described in greater detail in the course of Chapter 3. Likewise, the next section will address the impacts of appraisals, i.e. how to navigate impaired constructions with regard to building user safety and the preservation of structural cultural assets.
Its purpose is to grant the assessment matrix legal legitimacy so that this standardized building check represents a sustainable process in our society. This closed process is presented in detail at the end of the chapter.
The following graphic (see Figure 3.1) is a schematic outline of the process.

Figure 3.1: Schematic outline of the Assessment Matrix



3.2 Reason for the project selection

Because the previously described assessment matrix can and should be applied to all load bearing timber constructions, it is reasonable that the form presented in this thesis is merely an example and not a final version.

The author of this PhD-Thesis has not only been developing the matrix presented here for many years, but has also applied it on a permanent basis to a number of different timber constructions. Mostly engineering questions arise as the focus of research, for example, changes of use to existing constructions, e.g. in the case of structural modifications like additions and alterations or in the case of a variety of other structural circumstances, e.g., appraisals of wooden bridges, supporting frameworks, etc.

The purpose of this matrix, which is set to achieve the aforementioned legal legitimacy, makes it necessary to develop additional forms and other databanks and/or checklists so that they can be summarized in one logically organized form in the object book with understandable results.

The completion of this form shall be demonstrated using the following **3 case studies**.

Three intentionally different building types have been selected with extremely differing characteristics in terms of **size**, **age** and load bearing **type of timber construction**. Having said that, these intentionally selected buildings represent typical constructions in our society worth sustainably securing. The safety of users is the top priority followed by the preservation of structural cultural assets.

An **historic church building** was selected as the **1st case study**. This building has 3 timber constructions that were inspected. The first construction considered in detail is the historic spire, which had already been reinforced in the past at different positions. The remaining timber constructions are the historic belfry and the engineered timber frame construction over the nave, which was completely redone approximately 50 years ago.

Without a doubt, this case concerned a public building that urgently required inspections due to its purpose of use, large dimensions, and the partial old age of the timber constructions, especially since this had never been officially implemented. More information about the matrix application is provided in Chapter 3.3.

The appraisal of timber construction was conducted after consulting with the church proprietor, the Archbishopric of Cologne, who showed great interest in having additional church buildings inspected.

The **2nd case study** concerns a **medieval half-timbered building** also in Bedburg, which due to its prestigious location and old age is under monument protection. The building's carpenter-made roof construction was appraised with the help of the

assessment matrix. Additional load bearing timber constructions within the building are the wooden-beam ceilings and the half-timbered interior walls.
The actual reason for this inspection was the building owner's planned change of use, which required inspections of the state of the building. The building is momentarily exclusively used for private purposes and after the change of use will be a public cultural center for musical performances.
It was intentionally selected as a case study because the inspection represents a model building appraisal for which the interests of the responsible monument protection authority, the Rhenish Office for the Protection of Historic Monuments, are to be taken into account. Detailed information about the inspections is provided in Chapter 3.4.

The final **3rd case study** was selected in order to demonstrate an additional, commonly occurring type of timber construction. It concerns a **modern sports hall** constructed as a widespread engineered timber construction with glued laminated beams. This modern timber construction is used publically by the neighboring gymnasium and different sports clubs in the city of Mülheim an der Ruhr.

The author of this PhD-Thesis was commissioned for the appraisal of the object by the owner of the building, the city of Muelheim an der Ruhr, in order to comply with their legal obligation to undertake stability and usability inspections; this will be described in greater detail in the course of this chapter.
The application and analysis of the assessment matrix contains for the first time an official character and, in addition to the other case studies, represents a younger construction type.

These short descriptions of the 3 case studies show the diversity of application options for the assessment matrix. Larger buildings were intentionally selected, all of which are classified in building category 3 (see section 3.9.1 of this thesis), the highest category. The conducted inspections were especially comprehensive due to this classification. More information can be found in the following chapters. A number of documents (photos, planning documents, proofs of stability, etc.) have been organized in Chapter 5 for a better overview. Appraisals of buildings for the two lower building categories are not necessarily less complex, yet they are generally not as comprehensive as the 3 case studies presented in Chapter 3.

3.3 Case study 1

Historic church building St. Georg in Bedburg – Alt-Kaster

Figure 3.2: Photo – Church tower with aisle

Figure 3.3: Awarded “test badge” after verification (just a suggestion) (see Section 3.9.5)

Figure 3.4: Measurement drawings – Side and rear view of the church

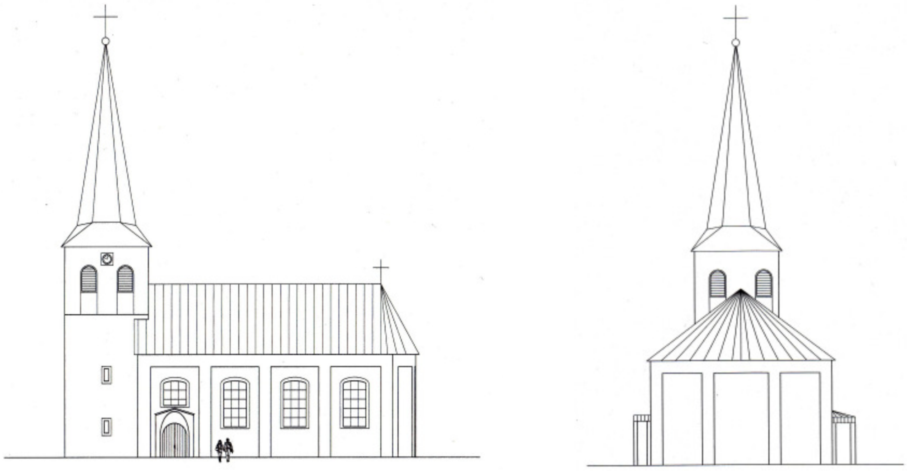


Figure 3.5: Drawing of the nave (registration by german timber expert)

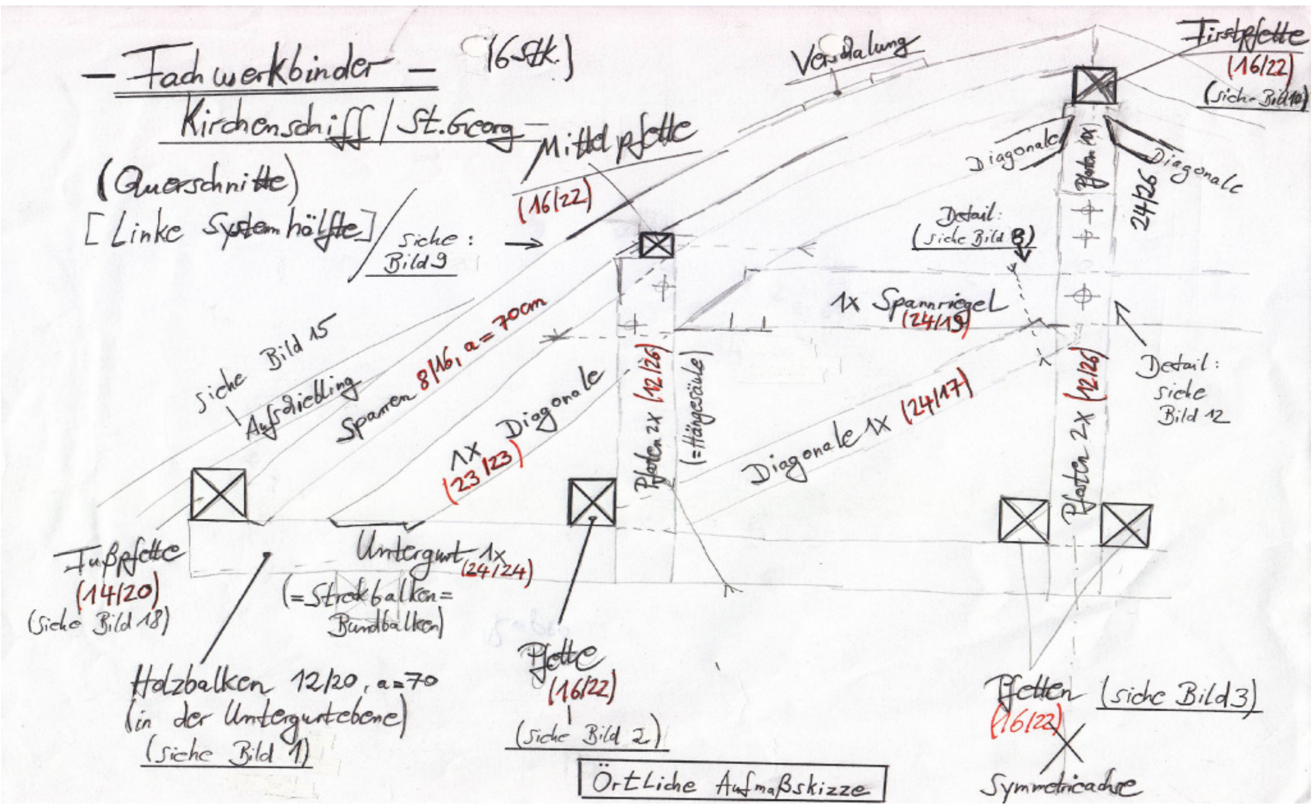


Figure 3.6: Spatial representation of the nave

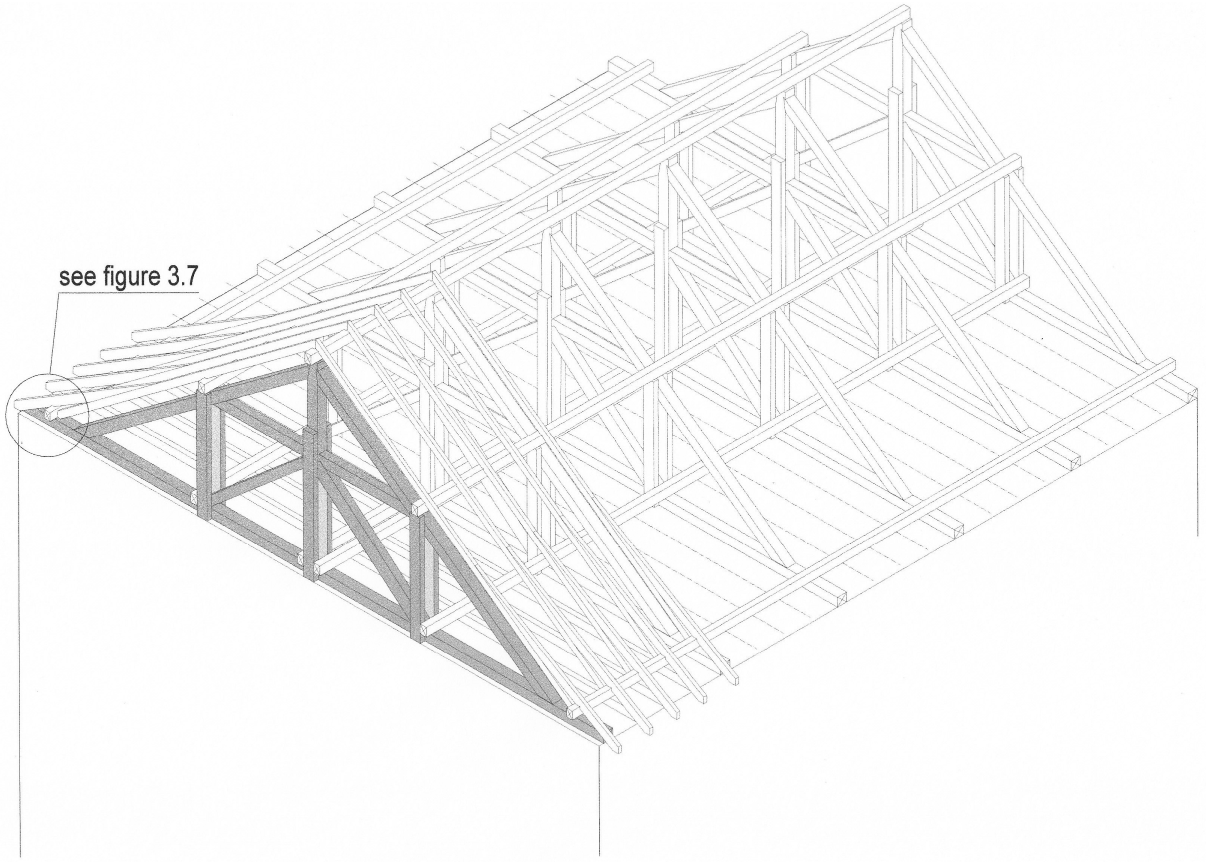
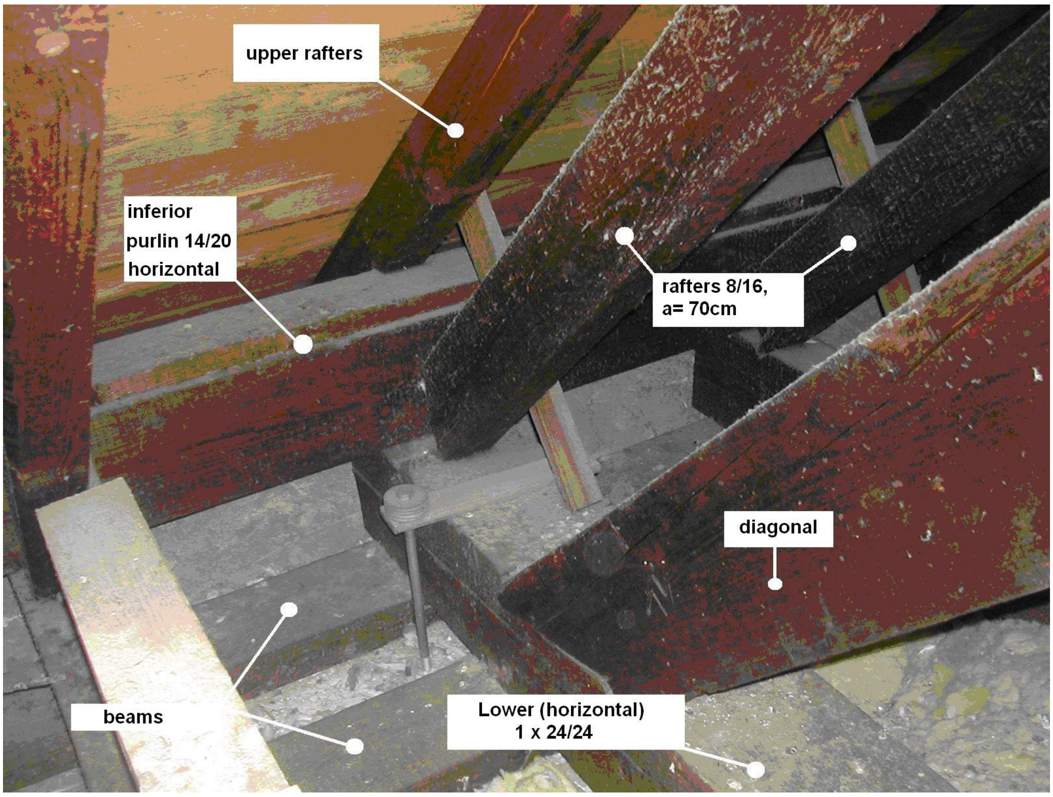


Figure 3.7: Half-timbered walls – Base point detail



- Object - Book –

object specified:

building(description): ***church building St. Georg***

photo of the building:

-components/ investigated structures: ***nave, church steeple, belltower***

-builder, owner: (name,address, phone, fax, e-mail): ***Erzbistum Köln, Marzellenstr. 32, 50668 Köln, phone: 0221-1642-1700, e-mail: 1***

- place: (street, postcode, place, district, landing, parcel, land registry number)

Hauptstraße, 50181 Bedburg – Alt-Kaster,

district: cadastral, area: 4, parcel: 48

- responsible building office:

Rhein-Erft-Kreis, Untere Bauaufsicht, Willy-Brandt-Platz 1, 50126 Bergheim

- file number (if any): **100-123-2009**

Building information by building check:

- timber expert: (name, address, phone, fax, e-mail)

Michael Abels, Dipl.-Ing., Am Mühlenkreuz 28, 50181 Bedburg,

phone.: 02272-905637, fax.: 02272-905635, info@michael-abels.de

-Building Category: (underline the right one)

BC 1 / BC 2 / **BC 3**

- Last monitoring: ***09.10.2009***

-partial acceptance / Professional Company Statement (PCS) no later than: ***09.10.2009***

Contained **Forms**:

Form:	**date:**	**index:** (= date of revision)
1	***09.10.2009***	**-**
2	***09.10.2009***	**-**
3	***09.10.2009***	**-**
4	***09.10.2009***	**-**
5	***09.10.2009***	**-**
Included experts	**-**	**-**
6 = final acceptance	***09.10.2009***	Signature of the timber expert: …………………………………………………

- Total “Building Stage Level”: **1 (nave) / 2 (belltower) / 2 (church steeple)**

- spezial features or spezial reports (date):**-**

- inspection sticker (red/green/**blue**) awared on (date):***09.10.2009*** / valid through: ***30.09.2019***

Form 1: ***date 09.10.2009***

*The completely filled out Form 1 is to be filed in the **object book**!*

The yes / no / unknown – fields are to be marked.

*Additional **appendices** are to be referenced!*

1. General project information:

General / preliminary remarks (reason for inspection):

After consulting the owner of the inspected building, the Archdiocese of Cologne, a building check was performed on a volunteer basis.

An initial inspection of the wooden constructions was conducted on the considered object for which no planning documents existed. The building has a total of 3 different (more or less independent) timber constructions: the church tower, the belfry and the nave.

The inspections service to identify whether mechanical and/or biological damages are present in timber constructions. Furthermore, it must be ensured that the supporting structure stability required by the building authorities is maintained. For this purpose, the entire building with its mentioned timber constructions was measured on-site and statically tested in the office.

The inspection results are summarized in the conclusion of the building inspection. A concept detailing restoration, inspection, and/or renovation measures for the sake of preserving the considered construction is outlined in the conclusion.

All inspections conducted meet the general state of the art and account for local circumstances. The evaluation of the timber construction was conducted according to the "assessment matrix for the conservation of valuable timber constructions" developed by the author.

Site inspections:

Different site inspections were conducted outside and inside of the considered object for the appraisal of the wooden roof construction.

The on-site inspections took place on:

- 07.30.2009
- 08.14.2009
- 08.20.2009

The timber expert involved in the present appraisal gained a complete picture of the considered object, in that he inspected it closely inside and out before he examined the wooden roof construction in greater detail.

Accessibility of the roof construction:

The load bearing timber constructions are uncovered and must be reached using different steps and ladders.

Form 1: ***date 09.10.2009***

*The completely filled out Form 1 is to be filed in the **object book**!*

The yes / no / unknown – fields are to be marked.

*Additional **appendices** are to be referenced!*

1. General project information:

General: General project information and the reasons for inspection can be specified in advance.

On-site meetings: All conducted on-site meetings are listed.

Accessibility of the timber construction: the accessibility of the regarded on-site timber constructions is described here in short.

no.:	term:	entry:	
1.1	building – description	*church building St. Georg*	
1.1.1	examined structure	*- nave – belltower - churchsteeple*	
1.2	builder / ownership:	name: *Erzbistum Köln* *Erzbischöfliches Generalvikariat* *Abteilung 730 - Bau* adress: *Marzellenstraße 32* *50668 Köln* phone: *0221-1642-1700* e-mail: *info@erzbistum-Koeln.de*	
1.3	responsible for building-check:	*Pfarrgemeinde St. Georg* *Der Kirchenvorstand* *phone: 02272-3374*	
1.4	leading office (complete adress): [= timber-expert]	*Michael Abels, Dipl.-Ing.* *Planung-Statik-Bauphysik* *Am Mühlenkreuz 28, 50181 Bedburg* *phone: 02272-905637*	
1.4.1	clerk:	*Michael Abels*	
1.5	date of check:	*09.10.2009*	
1.6	place (street, village):	*Hauptstraße* *50181 Bedburg – Alt-Kaster*	
1.7	geographical location, altitude (above see level):	*51°00`35,98``N ca. 62 ü.N.N.* *6°33`29,37``E*	unknown ☐
1.8	direction / cadastral extracts available:	*See abstract from geoinformation cadastrial*	
1.9	age of the building or of the structure:	*historical massive church building*	unknown ☐

Form 1: ***date 09.10.2009***

1.10	**date of setting-up:** ***See appendix 1, page 3/13***	***(see historical overview)***		unknown ☐
1.11	**design drafters / architect:**	**-**		unknown ☒
1.12	**exporting company:**	**-**		unknown ☒
1.13	**responsible building-office:**	***Rhein-Erft-Kreis*** ***Untere Bauaufsicht*** ***Willy-Brandt-Platz 1, 50126 Bergheim***		
1.14	**planned use in the planing:**	***churchbuildung (catholic)***		
1.15	**Is the building listed?**	yes ☒	no ☐	unknown ☐
1.15.1	**responsible conservation authority:**	***Landschaftsverband Rheinland*** ***Amt für Denkmalpflege im Rheinland*** ***Abtei Brauweiler, Ehrenfriedstr. 19,*** ***50259 Pulheim,*** ***Hr. Dr. Kretzschmar*** ***phone: 02234-9854-0***		
1.16	**Is the building used or unused? (unused since?)**	***used (church fair + concerts + exhibitions)***		
1.17	**classification in a building style:**	***gothic tower + nave in Late Baroque***		
1.17.1	**determined building style or construction era:**	***See abbove***		

Appendix 1: date 09.10.2009

History (short historical overview):

- *1365: A chapel in Kaster is mentioned for the first time in connection with a donation from Duke Wilhelm von Jülich.*
- *1542: The old chapel is destroyed.*
- *1551: The first parish church is built on the foundation of the old chapel. It is gothic in style with three naves.*
- *1624: After a fire in the city the church is only rebuilt provisionally.*
- *1750: The church receives the relics of the holy martyrs Ursula & Mauritius.*
- *1783: While preserving the old gothic tower, the church is renovated in the style of the late Baroque period, with single-nave brick hall and flat mirror ceiling. The ceiling slab measures: 27.50m x 13.25m.*
- *1788: The wooden main altar, four columns, and the altarpiece are built.*
- *19th century: The sacristy is added to the tower.*
- *20th century: The organ is revived; the organ prospect stems from the 18th century.*
- *1951: The church is restored to its original condition. The timber constructions over the nave and some of the restorations performed on the church tower were done in this year.*
- *1978: The foundation of the original 14th century church is discovered during renovations.*

Form 1: ***date 09.10.2009***

2.Occasion or reason of the building check:

2.1	**first check of the structure after completion**	yes ☒	no ☐
2.2	**commission per building check (= official normed building check)**	yes ☒	no ☐
2.3	**monitoring form 1**	yes ☐	no ☒
2.4	**monitoring form 2**	yes ☒	no ☐
2.5	**classification of the building in a building category: BC 1 / BC 2 / BC 3 (see Section: 3.9.1)**	***BC3***	
2.6	**Is a structure defect noted?**	yes ☐	no ☒
2.7	**Is a building-measure planned? (enlargement, extension, use change, expansion, etc.)**	yes ☐	no ☒
2.8	**Is a repair planned? (modernization, reconstruction, renovation, etc.)**	yes ☐	no ☒

continuation: see form 2

Form 2: ***date 09.10.2009***

Beginning of an "in-depth inspection" in the office:

Notes/ Comments:

*The completely filled out Form 2 is to be filed in the **object book**!*

Copies of the reviewed documents, such as building designs, static calculations, etc., are to be made and also filed in the object book.

*Additional **appendices** are to be referenced!*

1. Documents for classifying timber constructions:

Notes:

- The documents listed below are to be requested from the builder or authorized party and accepted by the building authority and land registry (= department of the appropriate district court) with a corresponding power of attorney (see page 13 on Form 2).

- The potentially available planning documents are to be compared at the following on-site meeting with the actual construction state. In doing so, the static span widths, the verified connections, and the indicated materials are inspected above all.

no.:	term:	present:	checked on site or performed:
1.1	Building and civil engineering drawings available	☐ yes / ☒ no	
	if 1.1 negative answered:		
1.1.1	allowance necessary (see e.g. figure 3.5)		☒ yes / ☐ no
1.1.2	building-application plans = approval plans scale = 1:100 (see e.g. figure 3.4)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.1	ground plans	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.2	sectional drawings	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.3	building-views	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.4	site map or cadastral extracts (not part of this thesis)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.3	execution plans or detailed plans scale = 1:50	☐ yes / ☒ no	☒ yes / ☐ no

Form 2: ***date 09.10.2009***

1.1.4	Detail drawings scale= 1:25 / 1:20 /1:10, etc. (see e.g. figures 3.6 and 3.7)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.5	Joinery drawings of the timber structures (see e.g. figures 3.6 and 3.7)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.6	Installation plan of the roofing, etc.	☐ yes / ☒ no	☐ yes / ☒ nein
1.2	Statics available?	☐ yes / ☒ no	
	If 1.2 is negative answered:		
1.2.1	Is the statical system important?/ The statical system is treated on the form 3.		☒ yes / ☐ no
1.2.2	Statical calculation	☐ yes / ☒ no	☒ yes / ☐ no
1.2.3	Check the constant load on the building		☒ yes / ☐ no
1.2.3.1	Maximum snow-load		☒ yes / ☐ no
1.2.3.2	Maximum wind-load		☒ yes / ☐ no
1.2.3.3	Structure of the components with the load-determination of the net weight		☒ yes / ☐ no
1.2.3.3.1	Cover plates		☒ yes / ☐ no
1.2.3.3.2	Walls		☒ yes / ☐ no
1.2.3.3.3	Roofing		☒ yes / ☐ no
	Specification of the used materials (=wood-types) Nave: softwood	☐ yes / ☒ no	☒ yes / ☐ no
1.2.3.1	determination of the wood-type	see *Checklist 1*	

Form 2: *date 09.10.2009*

1.2.4	Execution plans of the statical calculation, e.g. roof construction plan, etc.	☐ yes / ☒ no	
1.2.5	test report to the statical calculation from the auditor-structural engineer	☐ yes / ☒ no	
1.2.5.1	special structure	☐ yes / ☒ no	
1.2.5.2	license in individual cases	☐ yes/ ☒ no	
1.3	Physical evidence existing?	☐ yes / ☒ no	
1.3.1	energy-saving certification	☐ yes / ☒ no	not necessary
1.3.2	constructive fire-protection certification	☐ yes / ☒ no	not necessary
1.3.3	constructual fire-protection certificate = fire protection concept	☐ yes / ☒ no	not necessary
1.3.4	sound-protection certificate	☐ yes / ☒ no	not necessary
1.3.5	information to the moisture-protection	☐ yes / ☒ no	not necessary
1.4	montage-information	☐ yes / ☒ no	not necessary
1.5	glue-book of the timber structure company	☐ yes / ☒ no	glued timber not used

Form 2: ***date 09.10.2009***

2.1	Use of the building as:	present:	Checked on site or performed:
2.1.1	residential building	☐ yes / ☒ no	
2.1.2	public building	☒ yes / ☐ no	
2.1.3	commercial used building. Which crowds are possible?	☐ yes / ☐ no	
2.1.4	special loads on the structure of building. The load is be specified in kN.	☒ yes / ☐ no	
2.1.4.1	single load from machines, water bed, safe, watertank, bulk materials, bells, or other	☒ yes / ☐ no	☒ yes / ☐ no bell weight is still under investigation
2.1.4.2	roof construction: solar system/ photovoltaic system	☐ yes / ☒ no	Load in kN =
2.1.4.3	trafficability with vehicles of areas, or similar	☐ yes / ☒ no	Load in kN =
2.1.4.4	existing horizontal-loads by impacting of vehicles, handrailloads, etc.	☐ yes / ☒ no	Load in kN =
2.1.4.5	existing dynamical loads	☒ yes / ☐ no	bell weights
2.1.4.6	statement of other loads	☐ yes / ☒ no	Load in kN =
		Classification possible:	Checked on site:

Form 2: ***date 09.10.2009***

3.1	classification in use-classes:	Classification possible:	Checked on site:
3.1.1	use-class 0: Inside built wood, completely dry (wood moisture <20%); no wood preservatives required	☐ yes / ☒ no	
3.1.2	**use-class 1:** Internal components with an average room humidity ≤70%; requirements to the wood preservatives: insect-preventive	☒ yes / ☐ no	
3.1.3	use-class 2: Internal components with an average room humidity>70%, internal components in wet areas, external components without direct weather stress; requirements to the wood preservatives: insect-preventive, fungus-retardant	☐ yes / ☒ no	
3.1.4	use-class 3: External components with weather stress without permanent ground- an/or water contact internal components in wet rooms, wood exposed to the weather or condensation, but no ground contact; requirements to the wood preservatives: Iv, P, W= insect-preventive, fungus-retardant, weatherproof	☐ yes / ☒ no	
3.1.5	use-class 4: Timber with permanent ground- and/or fresh water contact, even with sheath, there are special conditions for wood on sea water; requirements to the wood preservative, insect preventive, fungus-retardant weatherproof, soft rot retardant (timber used in the ground)	☐ yes / ☒ no	

Form 3: ***date 09.10.2009***

1.) Construction the load bearing system:

(see e.g. figure 3.6)

- **1.1 Load bearing components for vertical loads**

  (dead weight, live/payloads, snow, etc.)

→ **1.1.1 Roof construction:**

Roof crossbars, rafters, purlins, binders, containers, frames, etc.

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figures 3.6 and 3.7)

- A: Engineered latticework structures over the nave

- B: Spatial timber framing (historic) as church tower

- C: Level timber framing (historic) as belfry

→ **1.1.2 Horizontal supporting elements:**

Beamed ceilings, beams/coatings, roof bracings (wind braces, plates, etc.)

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figures 3.6 and 3.7)

Form 3: ***date 09.10.2009***

- **1.2. Supporting structural elements for horizontal loads**
  (Wind, beam loads, reinforcement loads, LF: earthquakes, impact loads, dynamic loads (e.g. vibrations from church bells)
  - A: Cross bracing of the half-timbered walls through intact wind braces. Adequate reinforcement in both building directions (no distortions + cracks)
  - B: The 4 body diagonals arranged crosswise through intermediate levels (i.e. static plates) + each floor are evidently (no distortions + cracks) adequately reinforced.
  - C: Adequately reinforced evidently in both directions through sufficient forms of reinforcement (mainly braces + St. Andrew's crosses)

→ **1.2.1 In the entire building:**

Frames, latticework structures, bracings (roof and wall bracings), wind braces

Sketch(es) (possible use of additional sheets or refer to form 4):

see 1.2 above

2.) Identification / determination of all loads:

- **2.1 Outdoor loads:**
  - Wind
  - Snow/ rain ***see static calculation***
  - Earthquake zone (not part of this thesis)
  - Soil characteristics
- **2.2 Dead weight of the construction (construction and expansion loads):**
  - Roof cladding: ***see static calculation***
  - Collar beams framing: (not part of this thesis)
  - Collar beams over the …floor: (insert flat floor)
  - Collar beams over the …floor: (insert flat floor)
  - Wall construction (outside):
  - Wall construction (inside):
  - Balcony or projections (if present):
  - Other loads:

Form 3: ***date 09.10.2009***

3.) Connections:

Weak points are often the connections within a structure that can no longer sufficiently bear the existing weight as a result of various circumstances (cross-sectional weaknesses, gaping joints due to shrinkage and swelling, corrosion of metal connecting devices, overstraining due to changes of use, etc.).

For this reason they must also be documented in the form of sketches (photos, etc.) and the visible cross-sections, connecting devices, and materials documented. Here the difficulty is often present that internal connecting devices, such as e.g., studs of specific constructions types cannot be secured from outside. In this case, the inspecting timber expert must decide on a case-by-case basis which methods (see Sections 2.4.6 + 2.4.7) to implement for a more detailed and continued analysis.

Sketch(es) (possibly use further sheets or refer to Form 4):

(see e.g. figures 3.6 and 3.7)

4.) Cross-sectional dimensions of the supporting structural elements:

→ In the sketches of the static system(s) shown above (from top to bottom), the on-site measured cross-sectional dimensions are recorded. The wood type is also documented [potentially use checklist 1 (2.5.1)].

(The static calculation is not part of this thesis)

Continuation: see Form 4

2.4.5 Form 4: Condition mapping of the "actual state" *date 09.10.2009*

*The completely filled out Form 4 is to be filed in the **object book**!*
*Additional **appendices** are to be referenced!*

Conducting the construction state analysis is initially a matter of determining the current status and documenting it in a suitable form. In the ideal case, planning documents would have been reviewed in the previous process, which could be used for this purpose (see Form 2).
If original documents are not available, measurements are to be made and presented in a suitable (if possible, to scale) form. Digital photographs also present a good option these days for documentation. The drawings in Form 3 (see 2.4.4) can also be used.

Concerning the targeted standardization of form entry described in the previous sections, a legend is also provided here so that all future timber experts can use the same symbols, abbreviations, etc. for certain phenomena, such as pests (e.g. house longhorn beetles, dry rot, etc.) and types of damages (e.g. strong moisture penetrations, distortion, decay, etc.) to more precisely examine timber constructions or timber structural elements (e.g. ceiling beams, rafters, purlins, etc.) within the scope of a construction state analysis for the mapping of conditions described here.

As can be derived from the concept that was just explained, not only the condition of the timber construction's supporting elements should be mapped, but also visibly obvious damages should be identified and additional required areas of inspection specified. With this, a rough assessment of the construction is conducted within the scope of mapping, Form 5 (see Section 2.4.6) to follow contains, together with the expert database (see Section 2.4.7), the possible inspections to be undertaken later when mapping conditions.

(see e.g. figures 3.6 and 3.7)

2.4.6 Form 5: Examination methods for different material parameters

[Only approximate "on-site controls"] [7], [18] ***date 09.10.2009***

*The completely filled out Form 5 (including the expert database) is to be filed in the **object book**!*

*Additional **appendices** are to be referenced!*

Whether the timber expert personally performs a detailed inspection of the construction within the scope of a building inspection very much depends on his experience. A trained eye already sees a lot, yet a timber expert directly examines the critical areas.

For an approximate "on-site control" of different material parameters, tools are hardly necessary.

Subsequently, the first established inspections that the timber expert completes at the first on-site appointment are specified.

- Visual appraisals + photographic documentation:

Required tools: Digital camera, magnifier, hammer, nails, pocketknife, chisel, wood moisture meter, spiral and core drill, measuring tools (measuring tape, calliper + crack gauge, water level, wire for depth measurements of cracks)

Procedure:	**Parameter(s):**
- Visible damages that are recorded with hand drawings or digital photos.	- General building state: type, place, and extent of damage
- Hammer test (tapping) of suspicious areas.	- Positioning of: cavities and weak spots.
- Test with the pocketknife or chisel.	- Timber strength
- Drilling of suspicious areas with a core drill for core extraction (see also 2.4.7)	- A wide variety of inspections can be conducted in the test laboratory with the core drill (see also 2.4.7)
- Wood moisture meter	- Wood moisture
- Measuring or locating big deformations with a water level.	- Deformations

2.4.6 Form 5: Examination methods for different material parameters***date 09.10.2009***
[Only approximate “on-site controls”]

Procedure:	**Parameter(s):**
- Determination of wood type, e.g. with the help of pictures for comparison (= Checklist 1, see 2.5.1)	- Wood type
- Measuring or locating cracks with a crack gauge (= Checklist 2, see 2.5.2)	- Cracks
- Locating fungus and/or insect infestations, e.g. with the help of pictures for comparison (= Checklist 3, see 2.5.3)	- Fungus and/or insect infestation
- Drilling of suspicious areas with a spiral drill (mainly abutments)	- Rot + cavities (= physical condition of the timber)

Were experts from the expert database (see 2.4.7) consulted?

☐ yes / ☒ no

If yes, show the result:

………………………………………………………………………………………………

………………………………………………………………………………………………

2.6.7 Form 6: Final inspection protocol *date 09.10.2009*

It is important that the timber expert consider the structure permanently and not allow himself to be guided to a positive impression from the beginning. It makes no sense to examine individual components when the initial appearance of trivial damages can lead to bigger damages in a short amount of time. Static supporting and non-supporting structural elements belong to the whole construction. The following **structural elements** should be examined closely:

checked:

- **Walls:**
  - Exterior walls
  - Interior walls ☒
  - Facades
  - Moisture barriers
- **Floors/ceilings:**
  - Ceiling construction
  - Stairs ☒
  - Floor construction
- **Roof:**
  - Roof construction
  - Roofing ☒
  - Roof drain

With all components, the structural-physical aspects of noise, heat, fire, and moisture protection should be scrutinized and considered with the complete evaluation.
To this end, the details of Section 1.7 can be helpful.
All of the aforementioned aspects are included in the same assessment table presented.

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assessment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability	1	statical calculation according to EC1 + EC5 (buildings of BC2) (XX)	fully guaranteed	fully guaranteed (maximum is exceeded by 5%)	partially not guaranteed	mostly not guaranteed	1	4 (+1) measured strength on site (+1) for accurate detection
stability	2	state of the connections or lanyards	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	2 (+1) with an exact proof
stability	3	corrosion protection of the steel components	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	1 (+1) accurate check on site
usability	4	functioning (qualification for the planned use) (XX)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	2 (-1) if structure for more than 3 years unused
usability	5	deformation of the structure: (deflections, displacements, tilts) (deflections, shifts, oblique positions, etc.) (XX)	no f <= L / 300	no f > L / 200	no f > L / 150 (localized)	predominant deformation to breaks	1 are possible)	2 (+1) for accurate detection with control of e-module
building physics	6	heat protection by energy saving regulations (only relevant components of thermal building envelope)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) withe precise control of the insulating materials
building physics	7	sound-proof (only with statutory requirements, e.g. in apartment builings, but external noise, etc.)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
building physics	8	constructive fire proof (exact requirements as fire resistance according to structural fire protection) 2)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1 (+1) with precise control of the materials (=claddings, chemical wood protection) or structural analysis (for structural fire protection)
building physics	9	cracks (= desiccation cracks / shrinkage cracks) [assessment using the checklist 2]	no	low	partially	mainly	1	1 (+1) with accurate recording

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability / building physics	10	damages of the seatings (rot, twisting, wind uplift anchorage, ventilation)	no	low	partially	mainly	1	1 (+1) with precise control
timber protection	11	structually constructive moist protection (including weather protection)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1
timber protection	12	chemical timber protection (according to use class the corresponding chemical wood preservatives are prove)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	2	1 (+1) with precise laboratory verification
timber protection	13	attack by wood-damaging insects [assessment using the checklist 3]	no	low	partially	mainly	1	1 (+1) with an exact determination
timber protection	14	attack by wood-damaging mushrooms [assessment using the checklist 3]	no	low	partially	mainly	1 are possible)	1 (+1) with an exact determination
special aspects	15	special formations (water proofing, etc.) in wet areas and wet rooms	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with an exact determination
special aspects	16	roofing (with all transition points + execution of the roof drainage + wind resistance)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1
special aspects	17	Check the tightness with the "blower-door-Test" (e.g. for prefabricated houses of wood frame construction)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2
special aspects	18	check of lime-connections in case of chemical influences (e.g. chlorine, fertilizer, etc.)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	total "Building-Stage-Level": decimal: 1.06 / rounded 1 (X)	1 (+1) with precise laboratory verification

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: Final inspection protocol – assessment table

Averaged final scores:

Evaluation of all assessment criteria: With the help of the important factors, an average score of the construction status is calculated.

=> The whole construction is assigned the Building Stage Level (= average overall score / rounded):

(1x4 + 1x2 + 1x1 + 1x2 + 1x2 + 1x1 + 1x1 + 1x1 + 1x1 + 2x1 + 1x1 + 1x1)

= 19 / 18 = 1,06 => rounded = **1**

The reason for this decision follows in **Appendix 1**.

The definitions of construction status levels are taken from **Addition 1** of Form 6.

If more serious damage occurs, construction status level 2 cannot be reached!

Notes on the table:

(bracket value) = corresponding increase

1) Increase of the weighting factors with more exact proof or enabled experts.

2) The assessment of structural fire protection is not the purpose of this evaluation. When necessary, an external fire protection plan can be obtained from a fire protection expert.

3) To complete the full evaluation some recommendations could be pronounced by the timber expert. In addition to the requested time the color of the inspection badge is given

(X) To be able to approve an appraised construction for further use, at least construction status level 2 must be reached. In the case of a worse assignment corresponding repairs and/or strengthening (or others) are to be conducted according to the precise specifications of the timber expert. See: Form 6 _ Appendix 2

(XX) Basic requirements for the static examination:

- Well-defined static system of load transfer
- The supporting consists exclusively of materials approved by the building authorities

☒ = see **Addition 1** to Form 6 (= Definition of construction status levels)

2.6.7 Form 6: Final inspection protocol – assessment table

Addition 1: Definition of construction status levels

Building Stage Level (BSL) / Grading	Characteristics of building	Percentage of wear, that is, damaged parts (=damage in %) Brief description
1 very good – good	**- well maintained** - no loss of function whatsoever - negligible defects, which can be removed via maintenance and repairs	0 – 5 - SS fully ensured / secured - no damages
2 Satisfactory - fair	**- minor damages** - repairs are to be carried out in order to remove small disruptions in function and to avoid an expansion to larger damages	6 – 25 - SS ensured - marginal damages - almost secured
3 poor	**- serious damages** - sizeable defects, which compromise the continued existence or the functional efficiency; repairs of large areas are needed	26 – 50 - SS partly not ensured / secured - minor / partial / locally limited faulty
4 deficient	**- unusable** - paramount indemnifications are required for rehabilitation of the functional efficiency	> 50 - SS predominately not ensured / secured - significant damages
SS= structural safety		

Form 6: Final acceptance report *date 09.10.2009*

Appendix 1 = Reason for the assessment

After analyzing all conducted inspections that were adequately documented earlier in the work, the following results can be formulated for the wooden constructions of the St. George church building:

- The accessible appraisal of the wooden roof construction evaluated at random showed no peculiarities.
- There are no grave mechanical or biological damages to this roof construction.
- The supporting structure stability required by the building authorities is ensured.
- Constructional and chemical wood preservation appears evidently to be in order.
- At the moment no repair, restoration, or renovation measures are necessary.
- Due to the large span widths of the half-timbered walls over the nave, future structural modifications, e.g. for photovoltaic systems, new wall coverings, installation of insulation within the scope of energy efficiency, etc., static tests **must be conducted before commencing**.

The building is released for use by
the timber expert for the next 10 years

(see figure 3.3)

Appendix 2: Not required

Appendix 3 recommendation:

Regular maintenance in this period is required in any case.

As for the roof constructions under consideration, it is recommended that the roof cladding be regularly inspected by a roofing business inside and out. We recommend a maintenance/inspection contract with a local roofing business so that leaks in the roof cladding or damages to roof drainage, etc. can be recognized early and fixed immediately.

Due to the large dynamic strain of the belfry, we also recommend here regular inspections of the load-bearing timber construction for distortions, cracks, etc. in addition to mechanical maintenance of the belfry system. In doing so, the maintenance company commissioned with maintaining the mechanical systems can be asked to immediately report any damage of the timber construction to the named timber expert.

3.4 Case study 2

Listed truss building
in Bedburg – Alt-Kaster

Figure 3.8: Photo – Front view of the building

Figure 3.9: Awarded "test badges" after verification (just a suggestion)
(see Section 3.9.5)

a.) red badge

b.) green badge

Figure 3.10: Photo – Side view of the building

Figure 3.11: Measurement drawing – Front view of the building

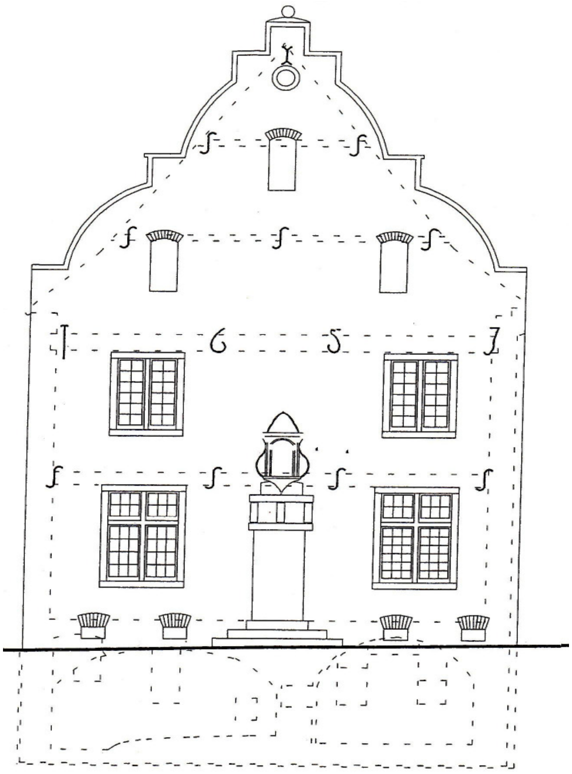


Figure 3.12: Measurement drawing – Side view of the building (left)

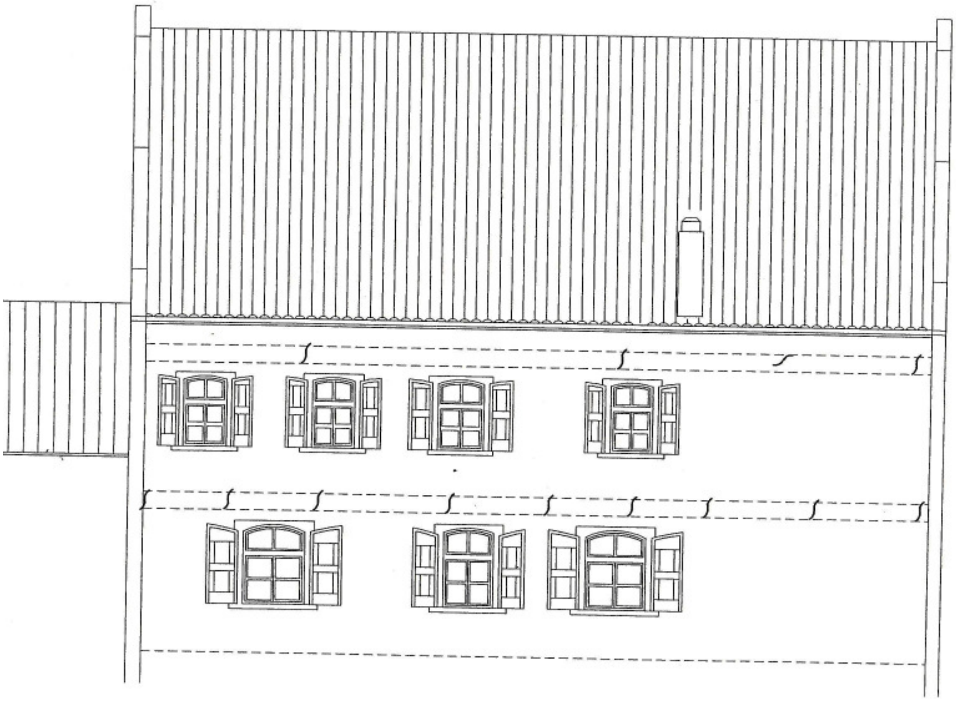


Figure 3.13: Measurement drawing – roof construction (registration by german timber expert)

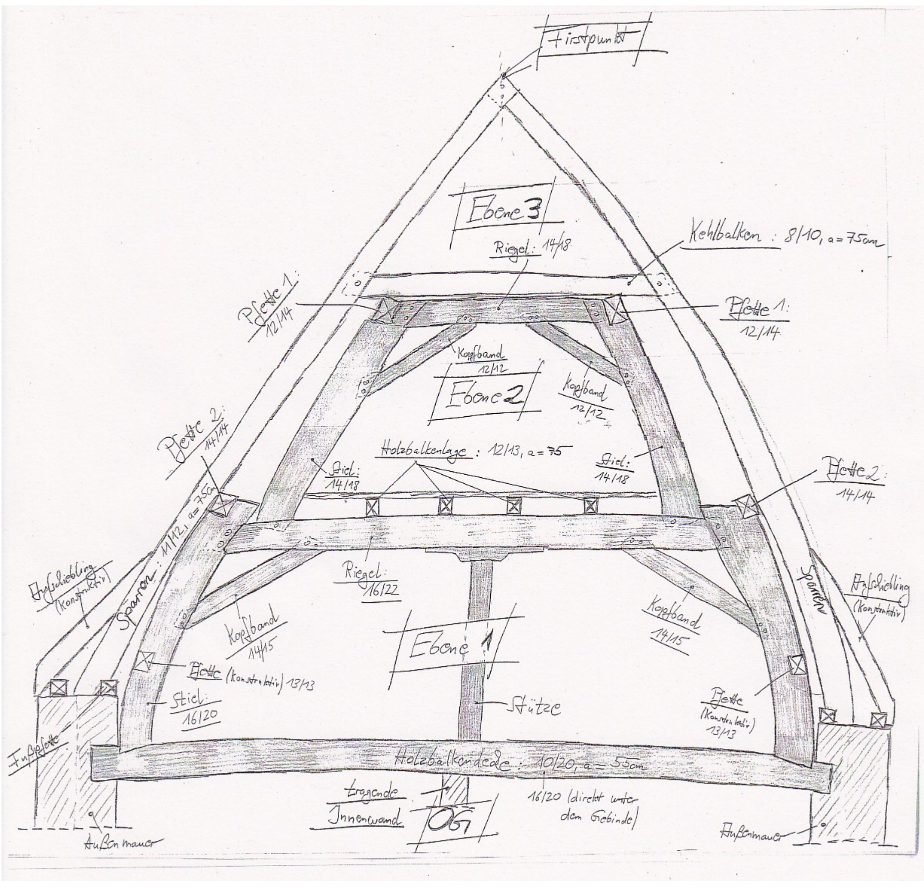


Figure 3.14: Photo – Level 1 of the roof construction (line of sight from front to back)

Figure 3.15: Photo – Level 2 of the roof construction

Figure 3.16: Photo – Transfer from level 2 onto level 3

Figure 3.17: Condition mapping – roof construction (floor plan)
(registration by german timber expert)

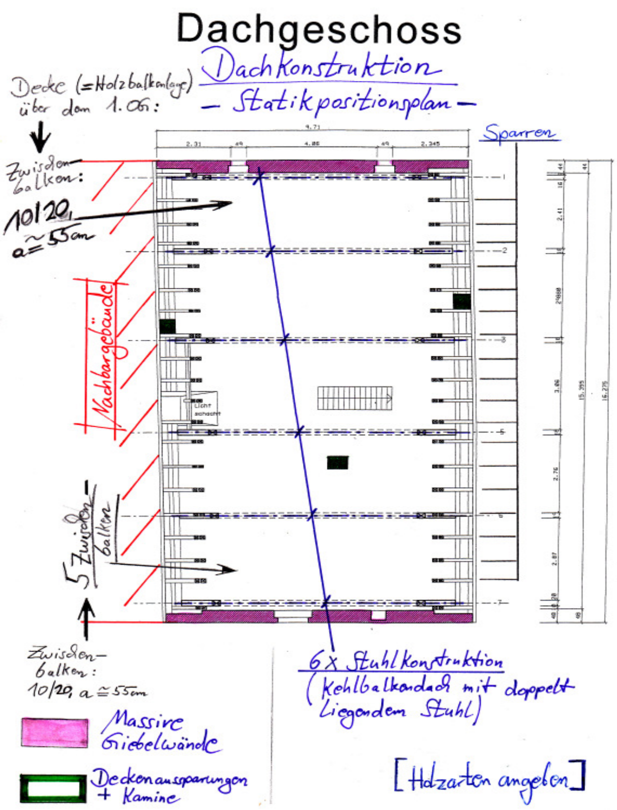


Figure 3.18: Condition mapping – 2nd level (floor plan)
(registration by german timber expert)

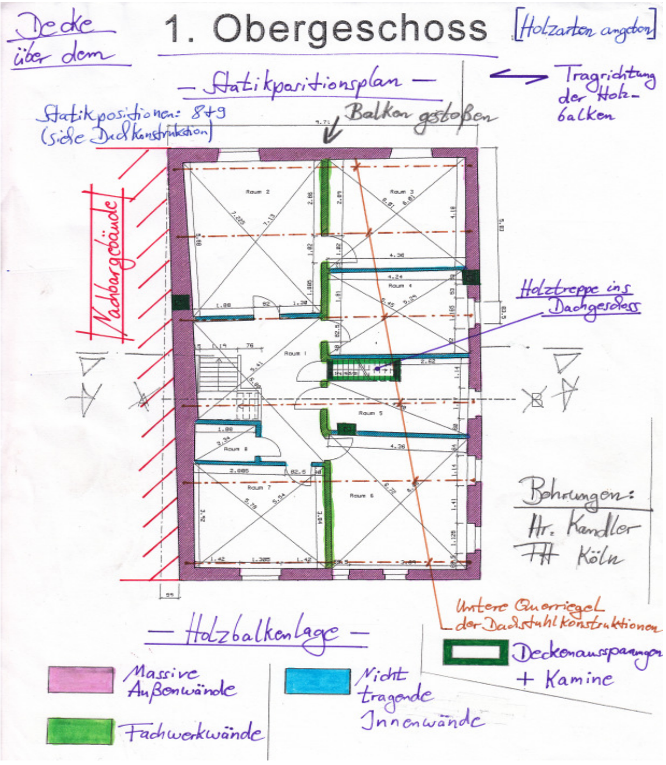


Figure 3.19: Condition mapping – Ground level (floor plan)
(registration by german timber expert)

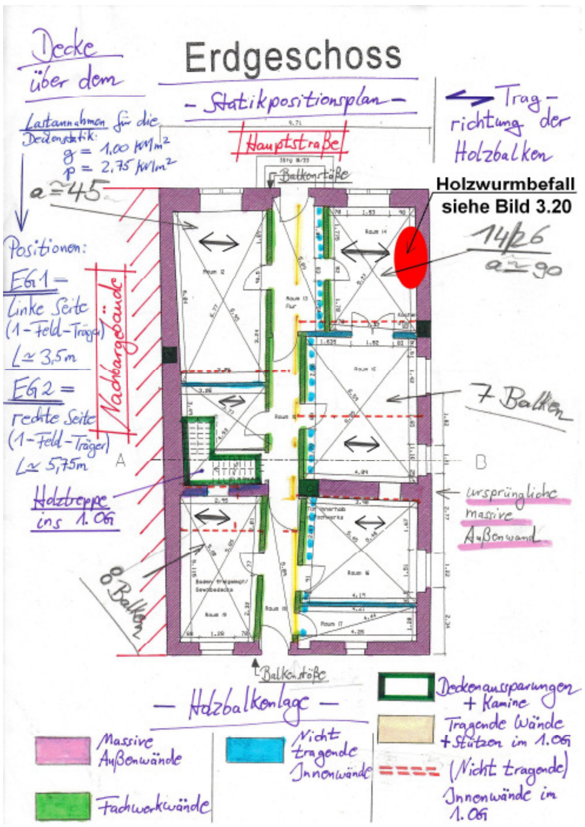


Figure 3.20: Destroyed beam ends in an area of the roof over the ground floor

destroyed beam ends of wooden beams

- Destroyed ends of wooden beams in outside wall by worms (= common furniture beetle) (Location see figure 3.19)
- Renovation with lateral timber lashing for example (see figure 2.19)

- Object - Book –

Object specified:

- building: ***listed truss resdidential building***

Photo of the building:

-components / investiated structures: ***roof construction, beamed ceilings and truss interior walls***

- builder, owner: (name, address, phone, fax, e-mail): ***Herr Klaus Weiler, Hauptstraße 10, 50181 Bedburg–Alt-Kaster, phone: 02272 - 1654***

- place: (street, postcode, place, district, landing, parcel, land registry number)

Hauptstraße 10, 50181 Bedburg – Alt-Kaster,
district: cadastral, area: 4, parcel: 85

-responsible building office:

Rhein - Erft - Kreis, Untere Bauaufsicht, Willy - Brandt - Platz 1,
50126 Bergheim

-file number: **-**

Building information by building check:

-timber expert: (name, address, phone, fax, e-mail)

Michael Abels Dipl.-Ing., Am Mühlenkreuz 28, 50181 Bedburg,
phone: 02272-905637, fax: 02272-905635, info@michael-abels.de

-building category: (underline the right one)

BC 1 / BC 2 / **BC 3**

- last monitoring: ***12.10.2009***

- partial acceptance / Professional Company Statement (PCS) no later than: **06.30.2010**

- next monitoring: ***06.30.2015***

Contained **forms**:

form:	**date:**	**index:** (= date of revision)
1	*12.10.2009*	-
2	*12.10.2009*	-
3	*12.10.2009*	-
4	*12.10.2009*	-
5	*12.10.2009*	-
Including experts	-	-
6 = final acceptance	*12.10.2009*	Signature of the timber expert: ....

- Total „Building Stage Level": **3 / after decrease + PCS (latest to 6/2010) 2**

- spezial features or spezial reports : **first „red" test badge with support and suspensive condition, later „green" test badage.**

- Inspection Badge (red) awarded on: ***12.10.2009*** / valid through: **(6/2010) _ *6/2015***

Form 1: ***date 12.10.2009***

*The completely filled out Form 1 is to be filed in the **object book**!*

The yes / no / unknown – fields must be checked off.

General project information:

General / preliminary remarks (reason for inspection):

The contractor and current resident of the considered real estate, Mr. Klaus Weiler, commissioned the author of this appraisal on 12.01.2009 with the inspection of the timber construction presented here. This should serve to evaluate the structural condition because a change of use from a residence to a public cultural center for musical performances is planned.

An initial inspection of all wooden-beam ceilings over the ground and 2nd level and all half-timbered inner walls was conducted for the considered object. In doing so, an accessible appraisal of the wooden supporting structure was conducted. These inspections service to identify whether mechanical or biological damages are present in timber constructions. Furthermore, it must be ensured that the supporting structure stability required by the building authorities is maintained.

The inspection results are summarized in the conclusion of this expert opinion. A concept detailing restoration, inspection and/or renovation measures for the sake of preserving the considered construction is outlined in the conclusion.

All inspections conducted meet the general state of the art and account for local circumstances. The evaluation of the timber construction was conducted according to the "assessment matrix for the conservation of valuable timber constructions" developed by the author.

Site inspections:

Different site inspections were conducted outside and inside of the considered object for the appraisal of the wooden roof construction.

The on-site inspections took place on:

- 12.01.2009
- 12.03.2009
- 12.07.2009

The timber expert involved in the present appraisal gained a complete picture of the considered object, in that he inspected it closely inside and out before he examined the wooden roof construction in greater detail.

Accessibility of the timber structures:

The load-bearing roof construction is not covered and therefore freely visible. The half-timbered walls are plaster for the most part and not visible in their construction. The wooden-beam ceilings are covered on the underside (plaster ceiling) as well as the topside (timber floor boards).

Form 1: ***date 12.10.2009***

The completely filled out Form 1 is to be filed in the ***object book****!*

The yes / no / unknown – fields are to be marked.

Additional ***appendices*** *are to be referenced!*

1. General project information:

no.:	term:	entry:	
1.1	building - description	*Historic listed residence/ two- storey rendered building/ house on the corner/ 3 axes*	
1.1.1	examined structure	*Roof construction + beamed ceilings + truss interior walls*	
1.2	builder / ownership:	name: *Herr Klaus Weiler* adress: *Hauptstraße 10* *50181 Bedburg* phone: *02272-1654,* e-mail: *-*	
1.3	responsible for building-check:	*See 1.2*	
1.4	leading office (complete adress): [= timber-expert]	*Michael Abels, Dipl.-Ing.* *Planung - Statik - Bauphysik* *Am Mühlenkreuz 28, 50181 Bedburg* *phone: 02272-905637, www.michael-abels.de*	
1.4.1	clerk:	*Michael Abels*	
1.5	date of check:	*12.10.2009*	
1.6	place (street, village):	*Hauptstraße 10* *50181 Bedburg – Alt-Kaster*	
1.7	geographical location, altitude (above see level):	*51°00`35,98``N ca. 62 ü.N.N.* *6°33`29,37``E*	unknown ☐
1.8	direction / cadastral extracts available:	*See abstract from geoinformation cadastral*	
1.9	age of the building or of the structure:	*Historical truss building with massive external walls + massive vault cellar*	unknown ☐
1.10	date of setting-up:	*Date 1653 in wall anchors on the roadside gable*	unknown ☐
1.11	design drafters / architect:	*-*	unknown ☒

Form 1: ***date 12.10.2009***

1.12	**exporting company:**	*-*		unknown ☒
1.13	**responsible building-office:**	*Rhein-Erft-Kreis* *Untere Bauaufsicht* *Willy-Brandt-Platz 1, 50126 Bergheim*		
1.14	**planned use in the planing:**	*Residentil building*		
1.15	**Is the building listed?**	yes ☒	no ☐	unknown ☐
1.15.1	**responsible conservation authority:**	*Landschaftsverband Rheinland* *Amt für Denkmalpflege im Rheinland* *Abtei Brauweiler, Ehrenfriedstr. 19,* *50259 Pulheim,* *Hr. Dr. Kretzschmar* *phone: 02234 - 9854 - 0*		
1.16	**Is the building used or unused? (unused since?)**	*used as a residential building*		
1.17	**classification in a building style:**	*transition between* *- early baroque 1600- 1650 and* *- high baroque 1650- 1720*		
1.17.1	**determined building style or construction era:**	*See above*		

Form 1: ***date 12.10.2009***

2. Occasion or reason of the building check:

2.1	**First check of the structure after completion?**	yes ☒	no ☐
2.2	**commission per building check (= official normed building check)**	yes ☒	no ☐
2.3	**monitoring form 1**	yes ☐	no ☒
2.4	**monitoring form 2**	yes ☒	no ☐
2.5	**classification of the building in a building category: BC 1 / BC 2 / BC 3 (see Section 3.9.1)**	***BC3***	
2.6	**Is a structure defect noted?**	yes ☐	no ☒
2.7	**Is a building-measure planned? (enlargement, extension, use change, expansion, etc.)**	yes ☒	no ☐
2.8	**Is a repair planned? (modernization, reconstruction, renovation, etc.)**	yes ☐	no ☒

continuation: see form 2

Form 2: ***date 12.10.2009***

Beginning of an "in-depth inspection" in the office:

Notes/ Comments:

- The completely filled out Form 1 is to be filed in the object book!

Copies of the reviewed documents, such as building designs, static calculations, etc., are to be made and also filed in the object book.

1. Closely inspect documents on timber construction:

Notes:

- The documents listed below are to be requested from the builder or authorized party and accepted by the building authority and land registry with a corresponding power of attorney.

- The potentially available planning documents are to be compared at the following site inspection with the actual construction state. In doing so, the static span widths, the verified connections, and the indicated materials are inspected above all.

no.:	term:	present:	checked on site or performed:
1.1	Building an civil engineering available	☐ yes / ☒ no	
	If 1.1 negative answered:		
1.1.1	allowance necessary (see e.g. figures 3.8, 3.10 and 3.13)		☒ yes / ☐ no
	If 1.1 positive answered:		
1.1.2	building-application plans = approval plans scale = 1:100	☐ yes / ☒ no	
1.1.2.1	ground plans (see e.g. figures 3.11 and 3.12)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.2	sectional drawings	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.3	building-views (see e.g. figures 3.11 and 3.12)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.2.4	site map or cadastral extracts (not part of this thesis)	☒ yes / ☐ no	☒ yes / ☐ no
1.1.3	execution plans or detailed plans scale = 1:50	☐ yes / ☒ no	☐ ja / ☒ no

Form 2: ***date 09.10.2009***

1.1.4	Detail drawings (connections) scale = 1:25 / 1:20 / 1:10, etc. (see e.g. figures 3.13, 3.14, 3.15 and 3.16)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.5	Joinery drawings of the timber structures (see e.g. figure 3.13)	☐ yes / ☒ no	☒ yes / ☐ no
1.1.6	Installation plan of the roofing, etc.	☐ yes / ☒ no	☐ yes / ☒ no
1.2	Statics available ?	☐ yes / ☒ no	
	If 1.2 is <u>negative</u> answered:		
1.2.1	Is the statical system important?/ The statical system is treated on the form 3.		☒ yes / ☐ no
1.2.2	Statical calculation	☐ yes / ☒ no	☒ yes / ☐ no
1.2.3	Check the constant load on the building		☒ yes / ☐ no
1.2.3.1	Maximum snow-load ! Attention: There are accumulatons of snow possible to the right neighbor building!		☒ yes / ☐ no
1.2.3.2	Maximum wind-load		☒ yes / ☐ no
1.2.3.3	Structure of the components with the load-determination of the net weight		☒ yes / ☐ no
1.2.3.3.1	Cover plates		☒ yes / ☐ no
1.2.3.3.2	Walls		☒ yes / ☐ no
1.2.3.3.3	Roofing		☒ yes / ☐ no
1.2.3	Specification of the used materials (=wood-types) both softwood and hardwood (oak)	☐ yes / ☒ no	☒ yes / ☐ no
1.2.3.1	determination of the wood-species	see ***Checklist 1*** (2.5.1)	

Form 2: ***date 12.10.2009***

1.2.4	Execution plans of the statical calculation, e.g roof construction plan, etc.	☐ yes / ☒ no	
1.2.5	test report of the statical calculation of the auditor-structural engineer	☐ yes / ☒ no	
1.2.5.1	special structure	☐ yes / ☒ no	
1.2.5.2	license in individual cases	☐ yes / ☒ no	
1.3	physical evidence existing?	☐ yes / ☒ no	Requirements and properties of building physics are investigsted
1.3.1	heat protection certification	☐ yes / ☒ no	
1.3.2	constructive fire-protection certification	☐ yes / ☒ no	
1.3.3	constructual fire-protection certificate = fire protection concept	☐ yes / ☒ no	
1.3.4	sound-protection certificate	☐ yes / ☒ no	
1.3.5	information to the moisture-protection	☐ yes / ☒ no	
1.4	montage-information	☐ yes / ☒ no	
1.5	glue-book of the timber structure company	☐ yes / ☒ no	no use of glued timber

Form 2: ***date 12.10.2009***

2.1	Use of the building as:	present:	Checked on site or performed:
2.1.1	residential building	☒ yes / ☐ no	
2.1.2	public building After the planned change of use, a public use is planned	☒ yes / ☐ no	
2.1.3	commercial used building. Which crowds are possible?	☐ yes / ☒ no	
2.1.4	special loads on the structure of building. The load is be specified in kN.	☒ yes / ☐ no	
2.1.4.1	point loads from machines, water bed, safe, watertank, bulk materials, bells, or other	☐ yes / ☒ no	☐ yes / ☐ no
2.1.4.2	roof construction: solar system/ photovoltaic system	☐ yes / ☒ no	Load in kN =
2.1.4.3	trafficability of areas by vehicles, or similar	☐ yes / ☒ no	Load in kN =
2.1.4.4	existing horizontal-loads by impacting of vehicles, handrailloads, etc.	☐ yes / ☒ no	Load in kN =
2.1.4.5	existing dynamical loads	☐ yes / ☒ no	
2.1.4.6	statement of other loads	☐ yes / ☒ no	Load in kN

Form 2: ***date 12.10.2009***

3.1	Classification in use-classes:	**Classification possible:**	**Checked on site:**
3.1.1	**use-class 0:** ground und first floor Inside built wood, completely dry (wood moisture <20%); no wood preservatives required	☒ yes / ☐ no	
3.1.2	**use-class 1:** atticfloor Internal components with an average room humidity $\leq$70%; requirements to the wood preservatives: insect-preventive	☒ yes / ☐ no	
3.1.3	use-class 2: Internal components with an average room humidity>70%, internal components in wet areas, external components without direct weather stress; requirements to the wood preservatives: insect-preventive, fungus-retardant	☐ yes / ☒ no	
3.1.4	use-class 3: External components with weather stress without permanent ground- an/or water contact internal components in wet rooms, wood exposed to the weather or condensation, but no ground contact; requirements to the wood preservatives: Iv, P, W= insect-preventive, fungus-retardant, weatherproof	☐ yes / ☒ no	
3.1.5	use-class 4: Timber with permanent ground- and/or fresh water contact, even with sheath, there are special conditions for wood on sea water; requirements to the wood preservative, insect preventive, fungus-retardant weatherproof, soft rot retardant (timber used in the ground)	☐ yes / ☒ no	

Form 3: ***date 12.10.2009***

General information about static calculations:

The aim of the appraisal conducted on the wooden constructions of the historical half-timbered home considered here was above all to assess the adequate stability required by the building authorities as described above. The actual static system had to be inspected to accomplish this. Because static calculations were not conducted at the point in time of the building's construction, the present static systems were identified and assessed in this section of the inspection. In doing so, the dimensions, timber cross sections, wood qualities, and the constructed connections were inspected on-site and partially documented (see the attached photographs + system sketches).

The present static systems were inspected using comparative calculations on the basis of all dimensions and determined loads on-site (dead weight and live loads) **[see appendix 5]**.

1.) Design of the load-bearing system:

(see e.g. figures 3.17, 3.18 and 3.19)

- **1.1 Supporting structural elements for vertical loads:**

  (Dead weight, live/payloads, snow, etc.)

  Wooden-beam ceilings and load-bearing half-timbered walls

→ **1.1.1 Roof construction:**

Roof crossbars, rafters, purlins, binders, containers, frames, etc.

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figure 3.13)

Collar beam roof with double lying and freestanding roof construction and a tier of collar beams

→ **1.1.2 Horizontal supporting elements:**

Beamed ceilings, beams/coatings, roof bracings (wind braces, plates, etc.)

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figures 3.13 ÷ 3.19)

Wooden-beam ceilings over the ground and 2nd floors.

Two additional wooden-beam tiers are located within the roof construction.

A massive vaulted brick ceiling spans over the basement level.

Form 3: ***date 12.10.2009***

- **1.2. Load-bearing components for the horizontal loads**

  (Wind, beam loads, reinforcement loads, LF: earthquakes, impact loads, dynamic loads (e.g. vibrations from church bells)

  Living area floors: The wooden-beam ceilings act as static plates over the ground and 2nd level (the basement ceiling is a massive vaulted ceiling).

  The half-timbered walls and massive outer walls can absorb all occurring horizontal loads from wind earthquakes due to their adequate length and configuration in both building directions (longitudinal + diagonal).

  Top floor: The roof construction has wind braces in the longitudinal direction of the building in both directions on the underside of the sloping roofs. In the transverse direction, the struts form the supporting frame corner for the horizontal load bearing.

→ **1.2.1 In the entire building:**

Frames, latticework structures, bracings (roof and wall bracings), wind braces

Sketch(es) (possible use of additional sheets or refer to form 4):

see 1.2

2.) Identification and determination of all loads:

- **2.1 External loads according to DIN 1055:**

  - Wind
  - Snow ***see static calculation***
  - Earthquake zone (not part of this thesis)

- **2.2 Dead weight of the construction (construction and expansion loads):**

  - Roof cladding: ***see static calculation***
  - Tiers of collar beams: (not part of this thesis)
  - Tier of beams over the 2nd floor:
  - Tier of beams over the ground floor:
  - ~~Wall construction (outside):~~
  - Wall construction (inside):
  - ~~Balcony or projections (if present):~~
  - ~~Other loads:~~

Form 3: ***date 12.10.2009***

3.) Connections:

Weak points are often the connections within a structure that can no longer sufficiently bear the existing weight as a result of various circumstances (cross-sectional weaknesses, gaping joints due to shrinkage and swelling, corrosion of metal connecting devices, overstraining due to changes of use, etc.).

For this reason they must also be documented in the form of sketches (photos, etc.) and the visible cross-sections, connecting devices, and materials documented. Here the difficulty is often present that internal connecting devices - such as studs of specific constructions types - cannot be secured from outside. In this case, the inspecting timber expert must decide on a case-by-case basis which methods (see sections 2.4.6 + 2.4.7) to implement for a more detailed and continued analysis.

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figures 3.13, 3.14, 3.15, 3.16)

The main focus of the conducted inspection documented here was the support points of the wooden-beam ceilings over the ground and 2nd floors.

Of further importance are all of the connections of the roof construction described above. Special precaution must be taken for their inspection because most of the connecting points are mortised.

4.) Cross-sectional dimensions of the load-bearing components:

→ The load-bearing timber cross sections measured on-site were entered into the attached condition mapping (= Form 4). Furthermore, all static systems were identified and documented. The wood types are also entered.

(see e.g. figures 3.13, 3.17, 3.18, 3.19)

Continuation: see form 4

2.4.5 **Form 4**: Condition mapping the "actual condition" ***date 12.10.2009***

The condition mapping conducted using Form 4 is to be filed in the ***object book****!*

The complete construction was measured during the aforementioned site inspections because planning documents for the building were not available.
(see e.g. figures 3.17, 3.18, 3.19)
With the help of the plans, the static proofs could be conducted on one hand and the correct positions and dimensions of identified defects and damages could be mapped on the other hand.
With the help of this condition mapping, additional required steps - e.g. in case of required restoration measures - can be passed on in a simple and clear form.

The following form 5 along with the expert databank provides the possible inspections that can be integrated into the condition mapping at a later point.

2.4.6 **Form 5**: Inspection methods for different_ *date 12.10.2009*

material parameters [only approximate "on-site inspections"]

Process:	Parameter(s):	Implemented:
- Detecting and measuring distortions with a long spirit level.	- Distortions	☒
- Determining the wood type with pictures for comparison (= check list 1, see 2.5.1)	- Wood type	☒
- Detecting and measuring cracks using a crack gauge (= check list 2, see 2.5.2)	- Cracks	☒
- Detecting and inspecting a fungus and/or insect infestation using pictures for comparison (= check list 3, see 2.5.3)	- Fungus and/or insect infestation	☒
- Drilling of suspicious areas with a spiral drill (mainly abutments). Otherwise, some areas were not visible; Abutment support points inspected with an endoscope.	- Rots + cavities (= physical state of the wood)	☒

Were experts from the **expert database** (see 2.4.7) consulted?

☒ yes / ☐ no

If yes, show the result:

....

....

....

....

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1	BSL2	BSL3	BSL4	classification made (including half notes are possible)	weighting factor 1)
stability	1	statical calculation according to EC1 + EC5 (buildings of BC2) (XX)	fully guaranteed	fully guaranteed (maximum is exceeded by 5%)	partially not guaranteed	mostly not guaranteed	3	4 (+1) measured strength on site (+1) for accurate detection
stability	2	state of the connections or lanyards	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	2	2 (+1) with an exact proof
stability	3	corrosion protection of the steel components	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	2	1 (+1) accurate check on site
usability	4	functioning (qualification for the planned use) (XX)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	3	2 (-1) if structure for more than 3 years unused
usability	5	deformation of the structure: (deflections, displacements, tilts) (deflections, shifts, oblique positions, etc.) (XX)	no f <= L / 300	no f > L / 200	no f > L / 150 (localized)	predominant deformation to breaks	2 are possible)	2 (+1) for accurate detection with control of e-module
building physics	6	heat protection by energy saving regulations (only relevant components of thermal building envelope)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) withe precise control of the insulating materials
building physics	7	sound-proof (only with statutory requirements, e.g. in apartment builings, but external noise, etc.)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
building physics	8	constructive fire proof (exact requirements as fire resistance according to structural fire protection) 2)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	3	1 (+1) with precise control of the materials (=claddings, chemical wood protection) or structural analysis (for structural fire protection)
building physics	9	cracks (= desiccation cracks / shrinkage cracks) [assessment using the checklist 2]	no	low	partially	mainly	2	1 (+1) with accurate recording

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assessment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability / building physics	10	damages of the seatings (rot, twisting, wind uplift anchorage, ventilation)	no	low	partially	mainly	2	1 (+1) with precise control
timber protection	11	structually constructive moist protection (including weather protection)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	2	1
timber protection	12	chemical timber protection (according to use class the corresponding chemical wood preservatives are prove)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with precise laboratory verification
timber protection	13	attack by wood-damaging insects [assessment using the checklist 3]	no	low	partially	mainly	3	1 (+1) with an exact determination
timber protection	14	attack by wood-damaging mushrooms [assessment using the checklist 3]	no	low	partially	mainly	2 are possible)	1 (+1) with an exact determination
special aspects	15	special formations (water proofing, etc.) in wet areas and wet rooms	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with an exact determination
special aspects	16	roofing (with all transition points + execution of the roof drainage + wind resistance)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	2	1
special aspects	17	Check the tightness with the "blower-door-Test" (e.g. for prefabricated houses of wood frame construction)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2
special aspects	18	check of lime-connections in case of chemical influences (e.g. chlorine, fertilizer, etc.)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		1 (+1) with precise laboratory verification
							total "Building-Stage-Level": decimal: 2.47 / rounded 3 (X)	

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: Final inspection protocol – assessment table

Averaged final scores:

Evaluation of all assessment criteria: With the help of the important factors, an average score of the construction status is calculated.

⇨ The whole construction is assigned the Building Stage Level (= average - overall score / rounded): **3**

(Genaue Berechnung = 3x5 + 2x2 + 2x1 + 3x2 + 2x2 + 3x1 + 2x1 + 2x1 + 2x1 + 3x1 + 2x1 + 2x1 = 47 / 19 = 2,47 → **rounded = 3**)

The reason for this decision follows in **Appendix 1.**

The definitions of construction status levels are taken from **Addition 1** of Form 6.

If more serious damage occurs, construction status level 2 cannot be reached!

Notes on the table:

(bracket value) = corresponding increase

1) Increase of the weighting factors with more exact proof or enabled experts.

2) The assessment of structural fire protection is not the purpose of this evaluation. When necessary, an external fire protection plan can be obtained from a fire protection expert.

3) To complete the full evaluation some recommendations could be pronounced by the timber expert. In addition to the requested time the color of the inspection badge is given

(X) To be able to approve an appraised construction for further use, at least construction status level 2 must be reached. In the case of a worse assignment corresponding repairs and/or strengthening (or others) are to be conducted according to the precise specifications of the timber expert. See: Form 6 _ Appendix 2

(XX) Basic requirements for the static examination:

- Well-defined static system of load transfer
- The supporting system consists exclusively of materials approved by the building authorities

☒ = see **Addition 1** to Form 6 (= Definition of construction status levels)

2.6.7 Form 6: Final inspection protocol – assessment table

Addition 1: Definition of construction status levels (based on [6] + [16])

Building Stage Level (BSL) / Grading	Characteristics of building	Percentage of wear, that is, damaged parts (=damage in %) Brief description
1 very good – good	**- well maintained** - no loss of function whatsoever - negligible defects, which can be removed via maintenance and repairs	0 – 5 - SS fully ensured / secured - no damages
2 Satisfactory - fair	**- minor damages** - repairs are to be carried out in order to remove small disruptions in function and to avoid an expansion to larger damages	6 – 25 - SS ensured - marginal damages - almost secured
3 poor	**- serious damages** - sizeable defects, which compromise the continued existence or the functional efficiency; repairs of large areas are needed	26 – 50 - SS partly not ensured / secured - minor / partial / locally limited faulty
4 deficient	**- unusable** - paramount indemnifications are required for rehabilitation of the functional efficiency	> 50 - SS predominately not ensured / secured - significant damages
SS = structural safety		

2.6.7 Form 6: Final acceptance report *date 12.10.2009*

Appendix 1: Reason for the assessment = conclusion

After analyzing all conducted inspections that were adequately documented earlier in the work, the following results can be formulated for the wooden roof bearing structure of Mr. Klaus Weiler's half-timbered home protected as a landmark:

- The accessible appraisal of the wooden roof bearing structure (= roof construction, wooden-beam ceilings, and half-timbered inner walls) evaluated at random showed different peculiarities.

- **Wooden-beam ceilings:**
- Serious biological damages are present in the support points of the outer walls that require immediate (See Appendix 2) renovation!
- The adequate stability required by the building authorities is not ensured for the wooden-beam ceilings over the ground level!

- **Roof construction:**
- The supporting structure stability required by the building authorities is ensured for the roof bearing structure.
  The entire roof construction, however, is in a very poor state. It is susceptible during storms and under snow that might accumulate next to the neighboring house on the right side. All use of the top floor is strictly prohibited!
- Constructional and chemical wood preservation appears evidently to be in order.

- **Half-timbered inner walls:**
- The half-timbered inner walls were also sampled at random. No peculiarities were detected. At the moment <u>no</u> repair, restoration or renovation measures are necessary.

For all considered timber constructions it can be said:

- The change of use of the construction conceived by the contractor should be seen as extremely critical, because the wooden constructions (roof construction, wooden-beam ceilings and half-timbered inner walls) have no load reserves whatsoever. If the property is converted, however, special proofs of stability will need to be conducted that taken into account the poor state of the current construction and determine necessary restoration measures.

Appendix 2: Necessary repairs of the identified deficiencies

During the building inspection ends of wooden beams (above the ground floor) destroyed by beetles were found. This is documented in the corresponding state mapping (see figure 3.19). Usind the database 1 (see section 2.62) a repair method has been proposed (see figure 3.20).

2.6.7 Form 6: Final acceptance report – evaluation table *date 12.10.2009*

Appendix 3:

Recommendation:

Regular maintenance in this period is required in any case.

As for the roof constructions under consideration, it is recommended that the roof cladding be regularly inspected by a roofing business inside and out. We recommend a **maintenance/inspection contract** with a local roofing business so that leaks in the roof cladding or damages to roof drainage, etc. can be recognized early and fixed immediately. These measures are strongly recommended due to unique shape of the roof (with potential accumulations of snow directly next door at the neighboring house) and because it shares roof drainage with the neighbor. Additional significant loads may come to bear on the considered roof cladding for which it is not designed!

Also due to the unique shape of the roof, snow accumulations may occur that are not taken into account by the static calculation. Only a standard load of 75 kg/m² roof cladding was taken into account. It is highly recommended that the owner of the house has the roof cladding inspected under winter weather conditions (heavy snowfall) in order to arrange snow and/or ice removal early on. The author of this expert opinion is available to answer any queries on the matter as well as develop an inspection concept for heavy and ongoing snowfall.

General information about the appendices:

All of the measurement drawings, different photographs, system sketches, conducted proofs of stability, etc. are attached in the appendices.

Approval:

Use of the building (as a residence) can only be released by the appraiser for the next 5 years (see figure 3.9b).

Due in part to serious damages present in the building, the approval is contingent upon the restoration of the dilapidated wooden-beam ends within the wooden-beam ceiling over the ground level within the next 6 months. They must then be removed again. Until then the "red" test badges (see figure 3.9a) are valid. Only then can the final "green" badges be installed.

The condition precedent for the approval for use of the building is the restoration of the entire roof construction according to the information in Appendix 7 (supporting structure + impermeability of the roof cladding + securing the roof drainage) construction and roofing businesses! Special contractor's statements (= SCS) must be presented afterward!

The renewed approval procedure and SCS template must occur by:

The end of June 2010 at the latest.

3.5 Case Study 3

Sports Hall Kleiststraße in Mülheim an der Ruhr

Figure 3.21: Photo – outside view

Figure 3.22: Photo – view of roof from below with roof bracing

Figure 3.23: Awarded "test badge" after verification (just a suggestion) (see Section 3.9.5)

Figure 3.24: Original drawing – general plan / site plan (expert of the original plan)

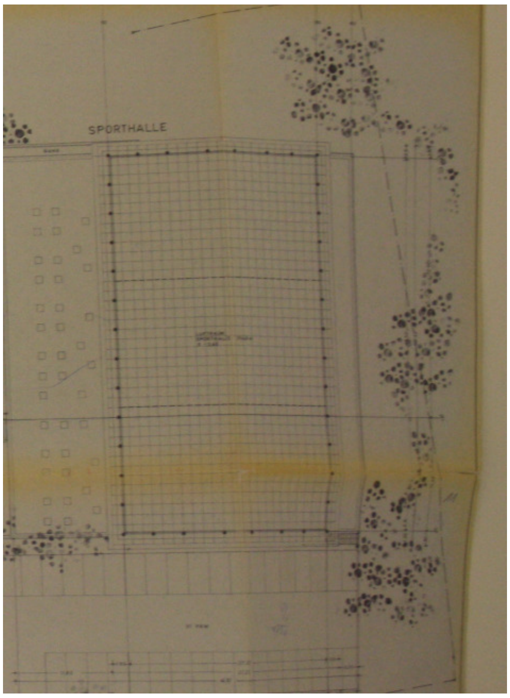


Figure 3.25: State mapping – floor plan drawing

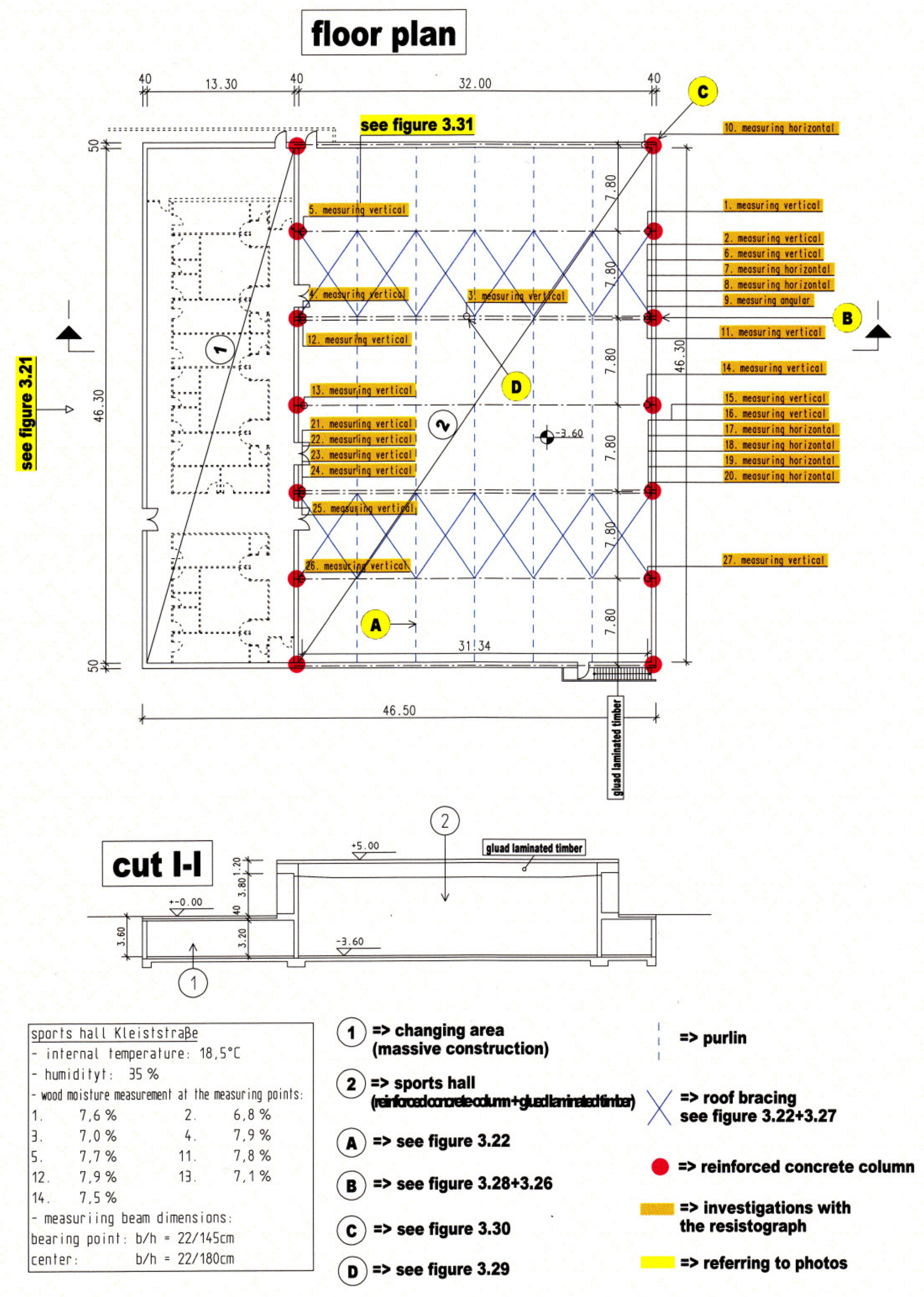


Figure 3.26: Original structural analysis – steel shoe binder connections (excerpt of the original plan)

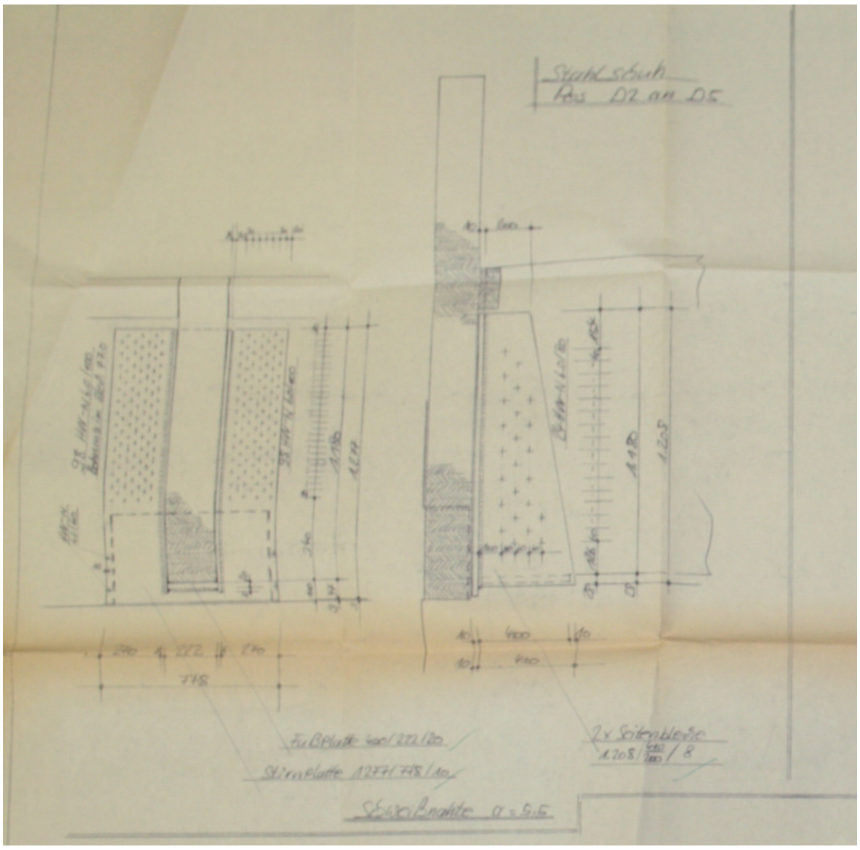


Figure 3.27: Original structural analysis – roof bracing (excerpt of the original plan)

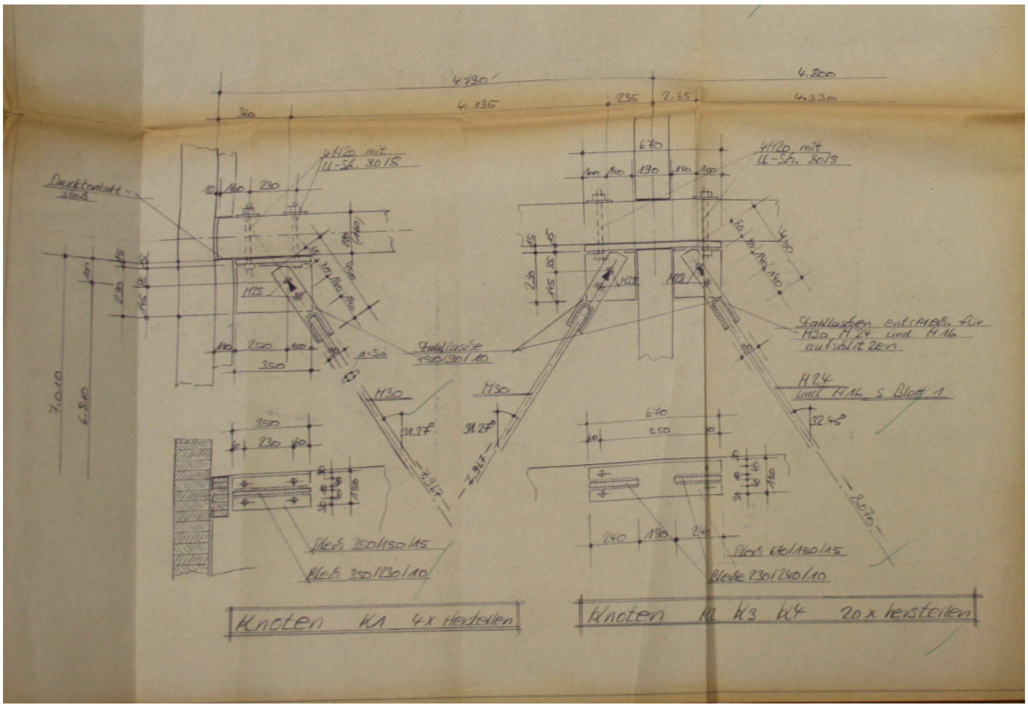
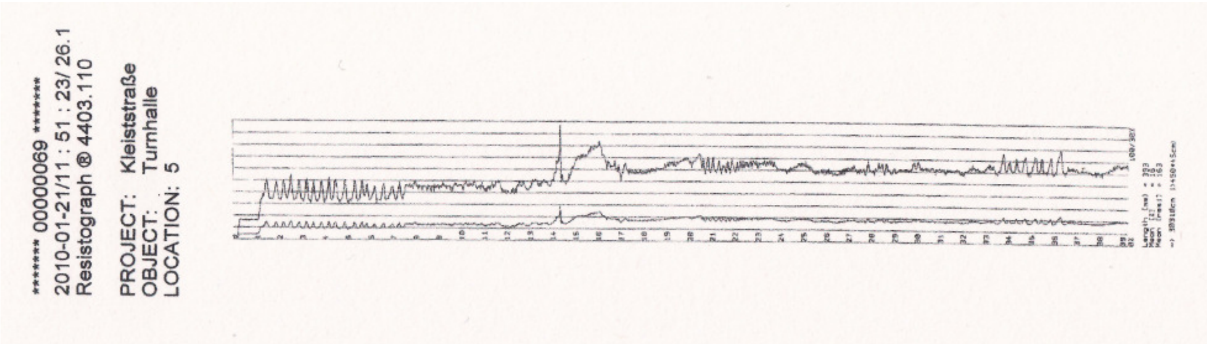


Figure 3.28: Inspection of the binder support points using the resistograph

Figure 3.29: Inspection of a crack using a crack gauge

Figure 3.30: Electrical wood moisture test

Figures 3.31: Output log of a drill resistance measurement using the resistograph



(The protocol shows no abnormalities.)

- Object - Book –

object specified:

- building: ***Sports hall Kleiststraße (=triple gym)***

Photo of the building:

-components/ investigated structures: ***Engeneering- style wooden roof construction***

-builder, owner: (name,address, phone, fax, e-mail): ***Stadt Mülheim an der Ruhr, Hans-Böckler-Platz 5, 45468 Mülheim***
Immobilienservice der Stadt Mülheim an der Ruhr
phone: 0208-455-2336, e-mail: info@stadt-mh.de

- place: (street, postcode, place, district, landing, parcel, land registry number)

Kleiststraße 50, 45472 Mülheim

- responsible building office:

Stadt Mülheim an der Ruhr (adress, see above)

- file number (if any): ***200/10/1975***

Building information by building check:

- timber expert: (name, address, phone, fax, e-mail)

Michael Abels, Dipl.-Ing., Am Mühlenkreuz 28, 50181 Bedburg,
phone: 02272-905637, fax: 02272-905635, info@michael-abels.de

-building category: (underline the right one)

BC 1 / BC 2 / **BC 3**

- Last monitoring: **the monitoring documented here *is 1.***
-partial acceptance / Professional Company Statement (PCS) no later than :

Contained **Forms**: ***12.01.2019***

Form:	date:	index: (= date of revision)
1	*12.29.2009*	-
2	*12.29.2009*	-
3	*12.29.2009*	-
4	*12.29.2009*	-
5	*12.29.2009*	-
Included experts	-	-
6 = final acceptance	*12.29.2009*	Signature of the timber expert ....

- Total "Building Stage Level": ***1***

- spezial features or spezial reports (date): **-**

- Inspection Badge (blue) awarded on (date): ***12.01.2009*** / valid through: ***12.01.2019***

Form 1: ***date 11.29.2009***

*The completely filled out Form 1 is to be filed in the **object book**!*

The yes / no / unknown – fields must be checked off.

1. General project information:

General / preliminary remarks (reason for inspection):

The city Mülheim an der Ruhr, represented by ImmobilienService, commissioned the author of this expert opinion on 11.18.2009 as the result of an offer on 10.26.2009 and a public request for bids on 10.02.2009 for the inspection of the timber construction presented here.

An initial inspection of the wooden roof construction was conducted on the considered object. In doing so, an accessible appraisal of the wooden supporting structure was conducted. The inspections service to identify whether mechanical and/or biological damages are present in timber constructions. Furthermore, it must be ensured that the supporting structure stability required by the building authorities is maintained.

The inspection results are summarized in the conclusion of this expert opinion. A concept detailing restoration, inspection, and/or renovation measures for the sake of preserving the considered construction is outlined in the conclusion.

All inspections conducted, meet the general state of the art and account for local circumstances. The evaluation of the timber construction was conducted according to the "assessment matrix for the conservation of valuable timber constructions" developed by the author.

Site inspections:

Different site inspections were conducted outside and inside of the considered object for the appraisal of the wooden roof construction.

The on-site inspections took place on:

- 10.30.2009
- 11.14.2009
- 11.20.2009

The timber expert involved in the present appraisal gained a complete picture of the considered object, in that he inspected it closely inside and out before he examined the wooden roof construction in greater detail.

Accessibility of the roof construction:

The load-bearing roof wood glue binders are uncovered. All positions were able to be appraised first-hand using a lifting platform.

Form 1: ***date 11.29.2009*** **(1/3)**

no.:	**term:**	**entry:**	
1.1	**building – description**	*Sports hall (triple gym)*	
1.1.1	**examined structure**	*Engineering- style wooden roof construction (glued timber beams)*	
1.2	**builder / ownership:**	**name:** *Stadt Mülheim* *Immobilienservice der Stadt* *Jörn Sprenger* *Mülheim an der Ruhr* **adresse:** *Hans - Böckler - Platz 5* *45468 Mülheim* **phone:** *0208-455-6030* **e-mail:** *info@stadt-mh.de*	
1.3	**responsible for building-check:**	*Stadt Mülheim* *Immobilienservice der Stadt* *Mülheim an der Ruhr* *(Adresse: siehe oben)*	
1.4	**leading office** **(complete adress):** **[= timber-expert]**	*Michael Abels, Dipl.-Ing.* *Planung - Statik - Bauphysik* *Am Mühlenkreuz 28, 50181 Bedburg* *Tel.: 02272-905637, www.michael-abels.de*	
1.4.1	**clerk:**	*Michael Abels*	
1.5	**date of check:**	*29.01.2010*	
1.6	**place (street, village):**	*Kleiststraße 50* *45472 Mülheim an der Ruhr*	
1.7	**geographical location, altitude (above see level):**	*51°25`39,82`` N* *6°56`18,86`` E*	unknown ☐
1.8	**direction / cadastral extracts available:**	*entrance = NO – site* yes ☐	no ☐
1.9	**age of the building or of the structure:**	*vintage 1975* *35 years*	unknown ☐
1.10	**date of setting-up:**	*vintage 1975*	unknown ☐
1.11	**design drafters / architect:**	*Architekturbüro A. Riege* *Mülheim an der Ruhr*	unknown ☐

Form 1: *date 11.29.2009* **(2/3)**

1.12	**exporting company:**	*Hallenbau J. Brüninghoff* *Knufdrees 5, 4284 Helden*		unknown ☐
1.13	**responsible building-office:**	*Stadt Mülheim* *Bauaufsichtsamt* *45468 Mülheim*		
1.14	**planned use in the planing:**	*gym (mainly for school sports)*		
1.15	**Is the building listed?**	yes ☐	no ☒	unknown ☐
1.15.1	**responsible conservation authority:**	*-*		
1.16	**Is the building used or unused?** **(unused since?)**	*used*		
1.17	**classification in a building style:**	*-*		
1.17.1	**determined building style or** **construction era:**	*-*		

Form 1: ***date 11.29.2009*** **(3/3)**

2. Occasion or reason of the building check:

2.1	**first check of the structure after completion**	yes ☒	no ☐
2.2	**commission per building check (= official normed building check)**	yes ☒	no ☐
2.3	**monitoring form 1**	yes ☐	no ☒
2.4	**monitoring form 2**	yes ☒	no ☐
2.5	**classification of the building in a building category: BC 1 / BC 2 / BC 3 (see Section 3.9.1)**	***BC3***	
2.6	**Is a structure defect noted?**	yes ☐	no ☒
2.7	**Is a building-measure planned? (enlargement, extension, use change, expansion, etc.)**	yes ☐	no ☒
2.8	**Is a repair planned? (modernization, reconstruction, renovation, etc.)**	yes ☐	no ☒

continuation: see form 2

Form 2: ***date 11.29.2009***

Beginning of an "in-depth inspection" in the office:

Notes:

- The completely filled out Form 1 is to be filed in the object book!

Copies of the reviewed documents such as building designs, static calculations, etc., are to be made and also filed in the object book.

1. Closely inspect documents on timber construction:

Notes:

- The documents listed below are to be requested from the builder or authorized party and accepted by the building authority and land registry with a corresponding power of attorney.

- The potentially available planning documents are to be compared at the following site inspection with the 75 actual construction state. In doing so, the static span widths, the verified connections, and the indicated materials are inspected above all.

no.:	term:	present:	checked on site or performed:
1.1	Building an civil engineering drawings available **(see e.g. figures 3.24, 3.26, 3.27)**	☒ yes / ☐ no	
	if 1.1 negative answered:		
1.1.1	allowance necessary		☐ yes / ☒ no
	if 1.1 positive answered:		
1.1.2	building-application plans = approval plans scale = 1:100	☒ yes / ☐ no	-
1.1.2.1	ground plans	☒ yes / ☐ no	☒ yes / ☐ no
1.1.2.2	sectional drawings	☒ yes / ☐ no	☒ yes / ☐ no
1.1.2.3	building-views	☒ yes / ☐ no	☒ yes / ☐ no
1.1.2.4	site map or cadastral extracts	☒ yes / ☐ no	☒ yes / ☐ no
1.1.3	execution plans or detailed plans scale = 1:50	☒ yes / ☐ no	☒ yes / ☐ no

Form 2: ***date 11.29.2009***

1.1.4	Detail drawings (connections) scale = 1:25 / 1:20 / 1:10, etc. **(see e.g. figures 3.26, 3.27)**	☒ yes / ☐ no	☒ yes / ☐ no
1.1.5	Joinery drawings of the timber structures	☒ yes / ☐ no	☒ yes / ☐ no
1.1.6	Installation plan of the roofing, etc.	☐ yes / ☒ no	☐ yes / ☒ no
1.2	Statics available? *The test report of the chief structural engineer also exists* Not part of this thesis	☒ yes / ☐ no	
1.2.1	Is the statical system important?/ The statical system is treated on the form 3.	☒ yes / ☐ no	☒ yes / ☐ no
1.2.2	Statical calculation	☒ yes / ☐ no	☒ yes / ☐ no
1.2.3	Check the constant load on the building		☒ yes / ☐ no
1.2.3.1	Maximum snow-load		☒ yes / ☐ no
1.2.3.2	Maximum wind-load		☒ yes / ☐ no
1.2.3.3	Structure of the components with the load-determination of the net weight		☒ yes / ☐ no
1.2.3.3.1	Cover plates *(not necessary)*		☐ yes / ☒ no
1.2.3.3.2	Walls *(not necessary)*		☐ yes / ☒ no
1.2.3.3.3	Roofing		☒ yes / ☐ no
1.2.3	Specification of the used materials (=wood-types) *roof beams as glued timber*	☒ yes / ☐ no	☒ yes / ☐ no
1.2.3.1	determination of the wood-type	*Not necessary*	

Form 2: date 11.29.2009

1.2.4	Execution plans of the statical calculation, e.g roof construction plan, etc.	☒ yes / ☐ no	☒ yes / ☐ no
1.2.5	test report of the statical calculation of the auditor-structural engineer (not part of this thesis)	☒ yes / ☐ no	
1.2.5.1	special structure	☐ yes / ☒ no	
1.2.5.2	license in individual cases	☐ yes / ☒ no	
1.3	physical evidence existing? *non- existent*	☐ yes / ☒ no	
1.3.1	heat protection certification	☐ yes / ☒ no	
1.3.2	constructive fire-protection certification	☐ yes / ☒ no	
1.3.3	constructual fire-protection certificate = fire protection concept	☐ yes / ☒ no	
1.3.4	sound-protection certificate	☐ yes / ☒ no	
1.3.5	information to the moisture-protection	☐ yes / ☒ no	
1.4	montage-information	☐ yes / ☒ no	
1.5	glue-book of the timber structure company	☐ yes / ☒ no	

Form 2: ***date 11.29.2009***

2.1	**Use** of the building as:	present:	Checked on site or performed:
2.1.1	residential building	☐ yes / ☒ no	
2.1.2	public building	☒ yes / ☐ no	
2.1.3	commercial used building. Which crowds are possible?	☐ yes / ☒ no	
2.1.4	special loads on the structure of building. The load is be specified in kN.	☐ yes / ☒ no	
2.1.4.1	point loads from machines, water bed, safe, watertank, bulk materials, bells, or other	☐ yes / ☒ no	☒ yes / ☐ no
2.1.4.2	roof construction: solar system/ photovoltaic system	☐ yes / ☒ no	Load in kN =
2.1.4.3	trafficability of areas by vehicles, or similar	☐ yes / ☒ no	Load in kN =
2.1.4.4	existing horizontal-loads by impacting of vehicles, handrailloads, etc.	☐ yes / ☒ no	Load in kN =
2.1.4.5	existing dynamical loads	☐ yes / ☒ no	
2.1.4.6	statement of other loads	☐ yes / ☒ no	Load in kN

Form 2: ***date 11.29.2009***

3.1	Classification in use-classes:	**Classification possible:**	**Checked on site:**
3.1.1	**use-class 0:** Inside built wood, completely dry (wood moisture <20%); no wood preservatives required	☒ yes / ☐ no	☒ yes / ☐ no
3.1.2	use-class 1: Internal components with an average room humidity ≤70%; requirements to the wood preservatives: insect-preventive	☐ yes / ☐ no	☐ yes / ☐ no
3.1.3	use-class 2: Internal components with an average room humidity >70%, internal components in wet areas, external components without direct weather stress; requirements to the wood preservatives: insect-preventive, fungus-retardant	☐ yes / ☐ no	☐ yes / ☐ no
3.1.4	use-class 3: External components with weather stress without permanent ground- an/or water contact internal components in wet rooms, wood exposed to the weather or condensation, but no ground contact; requirements to the wood preservatives: Iv, P, W= insect-preventive, fungus-retardant, weatherproof	☐ yes / ☐ no	☐ yes / ☐ no
3.1.5	use-class 4: Timber with permanent ground- and/or fresh water contact, even with sheath, there are special conditions for wood on sea water; requirements to the wood preservative, insect preventive, fungus-retardant weatherproof, soft rot retardant (timber used in the ground)	☐ yes / ☐ no	☐ yes / ☐ no

Form 3: ***date 11.29.2009*** **(1/3)**

General information about static calculations:

The aim of the appraisal conducted on the wooden constructions of the **Kleiststraße sports hall** considered here was, most importantly, to assess the adequate stability required by the building authorities as described above. The actual static system had to be inspected to accomplish this. The existing static calculation that was tested before the construction of the building, constituted the basic requirement. This system warranted on-site inspections. In doing so, the dimensions, timber cross sections, wood qualities, and the constructed connections were inspected and partially documented (see the attached photographs).

All points of the original static calculation, including all construction plans **[see appendix 2]**, were comprehensible and sometimes supported with comparative calculations **[see appendix 5]**. The plans and calculation information agreed with the local circumstances.

1.) Design of the load-bearing system:

(see e.g. figure 3.25)

- **1.1 Load-bearing components for vertical loads**

  (dead weight, live/payloads, snow, etc.)

  Wood glue binders (1 - field - support)

→ 1.1.1 Roof construction:

Roof crossbars, rafters, purlins, binders, containers, frames, etc.

Sketch(es) (possible use of additional sheets or refer to form 4):

Trapezoidal steel sheets (freely supported from binder to binder)

(see e.g. figures 3.22)

→ 1.1.2 Horizontal supporting elements:

Beamed ceilings, beams/coatings, roof bracings (wind braces, plates, etc.)

Sketch(es) (possible use of additional sheets or refer to form 4):

Crossed round bars as roof bracings

(see e.g. figures 3.22, 3.27)

Form 3: ***date 11.29.2009*** **(2/3)**

- **1.2. Load-bearing components for the horizontal loads**
  (Wind, beam loads, reinforcement loads, LF: earthquakes, impact loads, dynamic loads)
  Reinforced concrete columns

→ **1.2.1 In the entire building:**

Frames, latticework structures, bracings (roof and wall bracings), wind braces

Sketch(es) (possible use of additional sheets or refer to form 4):

(see e.g. figure 3.25)

2.) Identification and determination of all loads:

- **2.1 External loads according to Eurocode 1:**
  - Wind
  - Snow ***see static calculation***
  - Earthquake zone (not part of this thesis)
- **2.2 Dead weight of the construction (construction and expansion loads):**
  - Roof cladding: ***see static calculation***
  ~~- Tier of collar beams:~~ (not part of this thesis)
  ~~- Tier of beams over the …floor:~~
  ~~- Tier of beams over the …floor:~~
  - Wall construction (outside):
  ~~- Wall construction (inside):~~
  ~~- Balcony or projections (if present):~~
  ~~- Other loads:~~

Form 3: ***date 11.29.2009***

3.) Connections:

Weak points are often the connections within a structure that can no longer sufficiently bear the existing weight as a result of various circumstances (cross-sectional weaknesses, gaping joints due to shrinkage and swelling, corrosion of metal connecting devices, overstraining due to changes of use, etc.).

For this reason they must also be documented in the form of sketches (photos, etc.) and the visible cross-sections, connecting devices, and materials documented. Here the difficulty is often present that internal connecting devices - such as studs of specific constructions types - cannot be secured from outside. In this case, the inspecting timber expert must decide on a case-by-case basis which methods (see sections 2.4.6 + 2.4.7) to implement for a more detailed and continued analysis.

Sketch(es) (possible use of additional sheets or refer to form 4):

The main focus of the inspection was on the support points of the binders. They rest in steel beam shoes, which in turn are connected to wooden cross members.

(see e.g. figure 3.26)

4.) Cross-sectional dimensions of the load-bearing components:

→ The load-bearing timber cross sections measured on-site that agreed with the information in the available planning documents were entered into the attached condition mapping.

All load-bearing wood parts are laminated timber (= laminated wood).

Continuation: see form 4

Form 4: Condition mapping the "actual condition" ***date 11.29.2009***

*The condition mapping conducted using Form 4 is to be filed in the **object book**!*

(see e.g. figure 3.25)

Using the documents available in the archive that are listed above, it was possible to prepare drawings (floor plan + section) prior to the site inspection that include the wooden roof construction. The dimensions and cross sections were compared with the conditions on-site.

The floor plan sketch is attached with Appendix 6.

This plan serves to correctly map the positions and dimensions of detected defects and/or damages.

With the help of this condition mapping, additional required steps - e.g. in case of required restoration measures - can be passed on in a simple and clear form.

Furthermore, this plan contains the requirements for the following static inspection of the timber construction.

The following form 5 along with the expert databank provides the possible inspections that can be integrated into the condition mapping at a later point.

Form 5: Inspection methods for different material parameters [only approximate "on-site inspections"] ***date 11.29.2009***

Process:	**Parameter(s):**	**Implemented:**
- Detecting and measuring distortions (e.g. with a long spirit level).	- Distortions	☒
- Determining the wood type using pictures for comparison ***Not necessary for laminated binders***	- Wood type	☐
- Detecting and measuring cracks using a crack gauge (⇒inspection according to check list 2) ***No noteworthy cracks were detected***	- Cracks (see e.g. figure 3.29)	☒
- Detecting and inspecting a fungus and/or insect infestation using pictures for comparison (⇒ Inspection according to check list 3) ***No patterns of damage were detected***	- Fungus and/or insect infestation	☒
- Drilling of suspicious areas with a spiral drill (mainly abutments). ***Inspection of the beamed ceilings was conducted using a resistograph (see below)***	- Rots + cavities (= physical state of the wood) **Rinntech drill resistance measuring apparatus, type: Resistograph series 4, 4453-P** (see e.g. figures 3.28, 3.31)	☐

Were experts from the **expert database** consulted?

☒ **yes** / no☐ }

<u>If yes, with what outcome:</u>

....

All of the beamed ceilings were drilled with the resistograph for the inspection. The inspection results (which are all positive) are attached.

(see e.g. figure 3.31)

....

....

....

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability	1	statical calculation according to EC1 + EC5 (buildings of BC2) (XX)	fully guaranteed	fully guaranteed (maximum is exceeded by 5%)	partially not guaranteed	mostly not guaranteed	1	4 (+1) measured strength on site (+1) for accurate detection
	2	state of the connections or lanyards	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	2 (+1) with an exact proof
	3	corrosion protection of the steel components	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	1 (+1) accurate check on site
usability	4	functioning (qualification for the planned use) (XX)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	1	2 (-1) if structure for more than 3 years unused
	5	deformation of the structure: (deflections, displacements, tilts) (deflections, shifts, oblique positions, etc.) (XX)	no f <= L / 300	no f > L / 200	no f > L / 150 (localized)	predominant deformation to breaks	1 are possible)	2 (+1) for accurate detection with control of e-module
building physics	6	heat protection by energy saving regulations (only relevant components of thermal building envelope)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	2	1 (+1) withe precise control of the insulating materials
	7	sound-proof (only with statutory requirements, e.g. in apartment builings, but external noise, etc.)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1
	8	constructive fire proof (exact requirements as fire resistance according to structural fire protection) 2)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1 (+1) with precise control of the materials (=claddings, chemical wood protection) or structural analysis (for structural fire protection)
	9	cracks (= desiccation cracks / shrinkage cracks) [assessment using the checklist 2]	no	low	partially	mainly	1	1 (+1) with accurate recording

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: final acceptance-rating table

Evaluation criteria of the databases 1-4 (the database 5 is included in the table) for a determination of a building state level for a timber structure

Assess-ment area	nr.	evaluation criterion	BSL1 ☒	BSL2 ☒	BSL3 ☒	BSL4 ☒	classification made (including half notes are possible)	weighting factor 1)
stability / building physics	10	damages of the seatings (rot, twisting, wind uplift anchorage, ventilation)	no	low	partially	mainly	1	1 (+1) with precise control
timber protection	11	structually constructive moist protection (including weather protection)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1
timber protection	12	chemical timber protection (according to use class the corresponding chemical wood preservatives are prove)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1 (+1) with precise laboratory verification
timber protection	13	attack by wood-damaging insects [assessment using the checklist 3]	no	low	partially	mainly	1	1 (+1) with an exact determination
timber protection	14	attack by wood-damaging mushrooms [assessment using the checklist 3]	no	low	partially	mainly	1 are possible)	1 (+1) with an exact determination
special aspects	15	special formations (water proofing, etc.) in wet areas and wet rooms	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed		1 (+1) with an exact determination
special aspects	16	roofing (with all transition points + execution of the roof drainage + wind resistance)	fully guaranteed	almost secured	partially not guaranteed	mostly not guaranteed	1	1
special aspects	17	Check the tightness with the "blower-door-Test" (e.g. for prefabricated houses of wood frame construction)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed		2
special aspects	18	check of lime-connections in case of chemical influences (e.g. chlorine, fertilizer, etc.)	fully guaranteed	fully guaranteed	partially not guaranteed	mostly not guaranteed	 total "Building-Stage-Level": decimal: 1.05 / rounded 1 (X)	1 (+1) with precise laboratory verification

• All remarks and comments of form 6 (page 8/14) are applying !

2.6.7 Form 6: Final inspection protocol – assessment table

Averaged final scores:

Evaluation of all assessment criteria: With the help of the important factors, an average score of the construction status is calculated.

=> The whole construction is assigned the Building Stage Level (= average -overall score / rounded):

(1x4 + 1x2 + 1x1 + 1x2 + 1x2 + 2x1 + 1x1 + 1x1 + 1x1 + 1x1 + 1x1 + 1x1 + 1x1 + 1x1) = 21 / 20 = 1,05 => rounded 1

The reason for this decision follows in **Appendix 1**.

The definitions of construction status levels are taken from **Addition 1** of Form 6.

If more serious damage occurs, construction status level 2 cannot be reached!

Notes on the table:

(bracket value) = corresponding increase

1) Increase of the weighting factors with more exact proof or enabled experts.

2) The assessment of structural fire protection is not the purpose of this evaluation. When necessary, an external fire protection plan can be obtained from a fire protection expert.

3) To complete the full evaluation some recommendations could be pronounced by the timber expert. In addition to the requested time the color of the inspection badge is given

(X) To be able to approve an appraised construction for further use, at least construction status level 2 must be reached. In the case of a worse assignment corresponding repairs and/or strengthening (or others) are to be conducted according to the precise specifications of the timber expert. See: Form 6 _ Appendix 2

(XX) Basic requirements for the static examination:

- Well-defined static system of load transfer
- The supporting system consists exclusively of materials approved by the building authorities

☒ = see **Addition 1** to Form 6 (= Definition of construction status levels)

2.6.7 Form 6: Final inspection protocol – assessment table 4/7

Addition 1: Definition of construction status levels (based on [6] + [16])

Building Stage Level (BSL) / Grading	Characteristics of building	Percentage of wear, that is, damaged parts (=damage in %) Brief description
1 very good – good	**- well maintained** - no loss of function whatsoever - negligible defects, which can be removed via maintenance and repairs	0 – 5 - SS fully ensured / secured - no damages
2 Satisfactory - fair	**- minor damages** - repairs are to be carried out in order to remove small disruptions in function and to avoid an expansion to larger damages	6 – 25 - SS ensured - marginal damages - almost secured
3 poor	**- serious damages** - sizeable defects, which compromise the continued existence or the functional efficiency; repairs of large areas are needed	26 – 50 - SS partly not ensured / secured - minor / partial / locally limited faulty
4 deficient	**- unusable** - paramount indemnifications are required for rehabilitation of the functional efficiency	> 50 - SS predominately not ensured / secured - significant damages
SS = structural safety		

Form 6: Final acceptance report *date 11.29.2009*

Appendix 1: Conclusion = reason for the assessment

After analyzing all conducted inspections that were adequately documented earlier in the work, the following results can be formulated for the wooden roof bearing structure of the **Kleiststraße sports hall**:

- The accessible appraisal of the wooden roof construction evaluated at random showed no peculiarities.
- There are no grave mechanical or biological damages to this roof construction.
- The supporting structure stability required by the building authorities is ensured [JAZ: there may be formatting to replicate here].
- Constructional and chemical wood preservation appears evidently to be in order.
- At the moment no repair, restoration, or renovation measures are necessary.
- Due to the extremely large span widths of the binders and the pure wood-to-wood connections over steel beam shoes, future structural modifications, e.g. for installing photovoltaic systems, new ceiling coverings, new sport and/or acoustics equipment, insulation within the scope of energy efficiency, etc., static tests **must be conducted before commencing**.

The building is released for use
by the timber expert for the next 10 years
(see figure 3.23)

Appendix 2: Not required

Appendix 3: Recommendation:

Regular maintenance in this period is required in any case.
As for the roof constructions under consideration, it is recommended that the roof cladding be regularly inspected by a roofing business inside and out. We recommend a maintenance/inspection contract with a local roofing business so that leaks in the roof cladding or damages to roof drainage, etc. can be recognized early and fixed immediately. This measure is highly recommended due to the unique shape of the roof (with continuous parapet) and the inner drainage pipes. Due to backed up roof gullies and the resulting masses of water and/or snow, additional significant loads may affect the considered roof cladding for which it is not designed!
Also due to the unique shape of the roof, snow accumulations may occur that are not taken into account by the static calculation. Only a standard load of 75 kg/m² roof cladding was taken into account. It is highly recommended that city workers inspect the roof cladding under winter weather conditions (heavy snow fall) in order to arrange snow and/or ice removal from inside the auditorium early on. The author of this expert opinion is available to answer any queries on the matter as well as develop an inspection concept for heavy and ongoing snowfall.

Form 6: Final acceptance report *date 11.29.2009*

General information about the appendices:

All construction documents available in the Mülheim an der Ruhr city archive were reviewed at the beginning of the construction state analysis.

The following important documents were found:

- File no.: 42719 / IIa, school complex (sport halla) 1st addendum
- File no.: 42719 / II, expansion of the school - structural analysis
- File no.: 42719 / II, school complex

Contained therein are original architectural plans (floor plans, building views + building section) from 11.30.1975.

Furthermore, they contain the original structural analysis of the hall construction. They were produced on 08.31.1977 by the engineering firm Karl Kolb and reviewed by structural engineer Dr.-Ing Werner Schneider on 11.21.1978.

Different copies and photographs (of the plans) of the planning documents are attached in the appendix.

3.6 Peculiarities of previous applications + evaluation of previous matrix applications

Because of the complexity of this task, it should be re-emphasized here that the maxtrix application can and should be continually optimized with regular evaluations by users of the matrix. A programmed form of the assessment matrix is indispensable for this purpose (see section 4.1).
Over the course of last year and in connection with numerous applications of the considered matrix, the author of this thesis undertook sylistic, formal, and logical corrections and amendments along with optimizations for specialist areas.

The user of the assessment matrix, the timber expert, plays a lead roll in every appraisal. It is of fundamental importance that the quality of the expert be controlled by an official office and that he/she is only granted this title upon proof of adequate qualifications (proof of professional experience + passing a test). Additional points on this topic are listed in section 3.9.4. It must be ensured in every case that the standardized appraisals described in this thesis are not abused, like what has happened in the past when issuing of energy certifications from internet offices without any on-site controls whatsoever.

Peculiarities that have stood out during past matrix applications, including these 3 case studies, will be subsequently named in order to formulate general **regulations**.

Case study 1 showed that a building may consist of multiple and extremely different timber constructions that are interconnected, such as for example, the church tower next to the nave, which exercise no static influence on each other.

Rule 1: *All constructions (not only the load-bearing constructions) must be identified and inspected during the appraisal of a building. No weightings are to be applied with regard to the age, size, or any other aspects of the construction. All load-bearing constructions must be inspected in regard to building user safety. They can only be approved for use once all directly adjoining constructions have been sufficiently inspected.*

All 3 case studies have shown that it is necessary to complete the entire assessment matrix because only then are all aspects considered.

Rule 2: *In order to be able to conduct a final appraisal of a timber construction, it is necessary to use the entire assessment matrix and fill out all forms.*

The peculiarity of the 2nd case study is that, independent of regular appraisals of timber constructions, the building was supposed to have been adequately inspected before a planned building project because necessary restoration measures must be conducted in conjunction with or before the other construction work if possible.

Rule 3**:** *In addition to regular building maintenance, sufficient building appraisals must be conducted before all planned building measures on the object, such as for example, remodels and/or additions, changes of use, etc. in order to inspect the effects and tolerances of the existing load-bearing constructions early on.*

A peculiarity of the 3rd case study is that the experienced and trained eye of the timber expert as well as "on-site inspections" are sometimes not enough for identifying hidden damages within a construction. It is often indispensable to inspect the widespread support points of wood glue binders with a resistograph because internal rots can have fatal consequences in these areas.

Rule 4: *In addition to the experience of the wood expert, the use of modern inspection methods must not be foregone when inspecting complex wood constructions in order to be able to inspect invisible areas from the outside.*

Likewise, all 3 case studies showed that it is indispensable to personally inspect the object because planning documents (if at all available) often do not show everything. The unique shape of the sport hall roof (= case study 3) can be named as an example here, which has roof drainage not shown in the plans. A continuous parapet presents the high risk that the complete roof surface can flood if the roof gullies become backed up (the only roof drainage), which would lead to a significant increase in strain that was not taken into account in the static calculation.

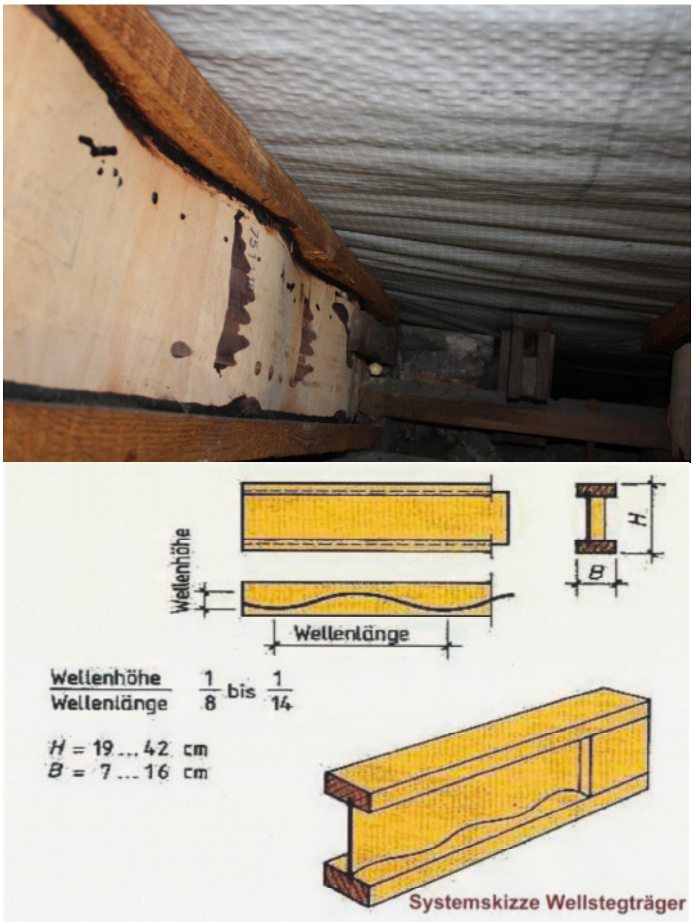
Rule 5: *The timber expert's site inspection is indispensable within the scope of any timber construction appraisal, independent of how many documents are available for the object. With his signature, the timber expert confirms that he has personally inspected the construction.*

As previously described, all 3 case studies concern larger buildings classified as (the later described) building category 3. For logical reasons, points should be adopted from similar processes that have proven to be effective in practice. Named here, for example, is the obligatory testing of proofs of stability prescribed by German building law. In the case of larger buildings (for example residential buildings with more than 3 units or all public buildings), the static calculations must be conducted by officially certified structural engineers (= state approved expert for testing stability). This process is governed in Germany by regional building regulations, e.g. Building Regulations of the Land NRW. The 4 eyes principle should also apply to the appraisal of timber constructions for building categories 2 and 3.

Rule 6: *The finished forms with the final test report and all associated building documents must be countersigned by an additional timber expert in the case of building inspections for structures in building classes 2 and 3 (= using the 4 eyes principle).*

An additional peculiarity was noticed during the inspection of the tournament hall (none of the 3 case studies just reviewed) to which a so-called **corrugated web beam** was applied. The author of this thesis conducted extensive research on this special construction, which was used in the 1950s and 60s and was/is particularly vulnerable to damage.

Figure 3.32: Corrugated web beam as rafters of a tournament hall roof + system sketch



This showed, however, that due to the versatility of wood, this assessment matrix will never be finished. The qualified timber expert possesses enough know-how, however, to fill any gaps in knowledge on his own.

Rule 7: *If special constructions are being appraised that are unknown to the timber expert, they are to conduct literature research and consult external experts where necessary in order to then be able to develop solid conclusions about the considered timber construction. The construction is then added to the corresponding databank so that henceforth matrix users can exchange information.*

A peculiarity was exposed in the evaluation of the 2nd case study. Whether a building is used publicly is of vital importance. In this case study, the planned change of use from a residence to a public cultural center was the focus of this inspection. The conceived test badges developed over the course of this chapter must reveal a public building.

Otherwise, the significant damages identified within the scope of the inspection must be indentified and remedied for the user before the building can be approved for unobjectionable use.

Rule 8: *The test badges installed on the inspected building must reveal to the user whether the building is public and whether significant damages are present in the building (see section 3.9.5).*

The 8 rules above were formulated using the individual evaluations of the matrix applications used in the case studies. They should be made valid for all participants in future test procedures (see section 3.7ff).

3.7 Social applications of the Assessment Matrix

The concrete application (previous sections of Chapter 3) of the assessment matrix described in Chapter 2 has already shown how it can be used for all timber constructions. There are no minimum requirements whatsoever, e.g. with regard to the size or age of the considered timber constructions. In the following sections 3.8 and 3.9, however, specifications will be proposed regarding the extent of evaluations depending on building use. With this a social application of the assessment matrix will be presented.

The requirements for the group of people who are at all allowed to conduct evaluations are also described in greater detail in the sections to follow. It is clear from the previous passages that the timber expert must have many years of concrete experience (= professional practice) with timber constructions of all types in addition to more than sufficient scientific and theoretical knowledge gained in Germany within the scope of academic studies in architecture, wood technology, and/or civil engineering.

It is also important to note that the evaluation is not restricted to German and Dutch wood constructions. This thesis concerns primarily German processes only because of the nationality of the author. As mentioned in section 3.10, it is the goal of this thesis to expand to all of Europe with this type evaluation. This is pursued without a second thought because the building techniques are very similar and the materials

are practically identical. A positive side effect will be the Europe-wide exchange over newer constructions, connection means, materials, and a much larger group of people and users will become informed of older defects and damages and will therefore also be forewarned.
The QM system (= quality management system) described in Chapter 2 within the scope of developing an assessment matrix (= main matrix) would be much more useful if it could be expanded to a European group of users.

In addition to the many positive features of the assessment matrix that contribute to an extensive, prompted, and above all, universal construction state analysis of timber constructions, the lack of sustainability, which was described in greater detail in section 2.2, must not go unmentioned here.
Applying the assessment matrix is only momentarily useful to the owner of the considered construction since legal obligations for regular monitoring are not in place. The potential resulting hazards are not regulated by the current building law situation. The owner of a timber construction is in no way obligated to inspections. A model building check is presented in the following section 3.8, which should result in sustainability in the entire construction sector for preventing future catastrophes caused by collapsing timber constructions.

3.8 Approval of the final acceptance report for creating a model for introducing and implementing a standardized building check.

An assessment matrix was presented in detail earlier in the thesis at the end of which a final acceptance report (see section 2.6.7) (= form 6) is attached with the described evaluation groups and construction state classifications. In addition, an object book (see section: 2.7.2) was presented.

As already described, it is emphasized that different timber experts can come to the same results using a sophisticated and universal assessment matrix.

When everything is aimed at this final assessment result, the question of how to deal with the evaluations and what their consequences are must be addressed. If we attempt to draw a comparison with vehicle inspections in Germany, the name "TÜV" (Technical Inspection Association) comes immediately to mind. In this case, it is understood that only authorized persons or workshops with certain minimum qualifications are entitled to inspect the vehicles according to prescribed guideliness. The vehicle is then approved for public roads for a certain period of time if it complies with defined criteria. Defects are often detected in TÜV inspections, which must then be completely remedied. Once all defects have been fixed, the TÜV grants the vehicle a test badge for the license plate for all to see (see Figure 3.33).

Figure 3.33: German TÜV badges (individually and on a license plate)

This process is well known by every vehicle owner in Germany. The same testing principal is applied in Austria, to give an example of another European land (see Figure 3.34). The police write tickets for missing or invalid TÜV badges until the TÜV inspection is conducted. If a vehicle owner who is involved in an accident does not have valid TÜV badges, his/her liability insurance agency is capable of denying compensation.

When purchasing a vehicle, the buyer is usually extremely interested in knowing how long the vehicle has had approval from the TÜV.

In the case of technical consumer goods, these neutral TÜV inspections are associated with costs (TÜV fee + usually an inspection beforehand) and are not met with criticism, however, because they ensure the safety and overall well-being of societies where residents are in direct contact with public roads. It is clear to every user that the different TÜV workshops arrive at the same result.

Figure 3.34: TÜV badge in Austria

In connection with the theme of this thesis, the question presses as to why there are no comparable testing standards for buildings, which after all are technical consumer goods. No one would take a long journey on a bus with a TÜV badge that has been expired for a year. On the other hand, people enter buildings of all kinds (size, condition, age, etc.) and without thinking about the stability and fitness for use. These unapparent conditions can result in anything from buildings being closed down to collapse. Subsequent inspections, e.g. of the Bad-Reichenhall ice rink showed that the catastrophe was caused by construction defects that could have been detected beforehand within the scope of inspections.

Because the principal necessity of a "Building TÜV is comprehensible as a result of each of the previous arguments, the concern is now a solution that creates a conclusive and therefore sustainable process for the construction industry.

The following questions are pressing: **"Who"** (which inspection personnel, with which superior inspection institution) monitored or inspected **"What"** (which building) and **"When"** (in which monitoring cycles)?

The **"How"** (how the inspection is conducted) of a building inspection can be sufficiently answered for at least wood constructions using the presented assessment matrix. How comprehensive an appraisal should be is explained in greater detail over the course of this section.

This question, which also covers some legal aspects, will be addressed in detail in the next section (3.9). The conclusive answers to these questions allow the targeted sustainability of the evaluation process for timber structures described earlier in the thesis to be achieved.

3.9 Preliminary conditions regarding the obligations governed by building law for cyclical monitoring depending on the building categories and different criteria

In this section the question: **"What"** (= which building) needs to be inspected, will be answered.
For this purpose, all buildings will be classified into building categories, which is subsequently described.

3.9.1 Buildings Categories (= BC) (based on [9] and [10])

Inspections are divided among the following building categories:

BC1: Inferior buildings

- Smaller residential houses (with up to 2 housing units = HU)
- Pedestrian bridges with a span of ≤ 10m
- Agricultural buildings (barns, stables, etc.)
- Functional buildings (small garages, sheds, etc.)

BC2: Building with larger crowds of people
(= public building)
+ more complex timber constructions in non-prominent locations
+ objects protected as landmarks (that would fall under BC1)

- Multiple family houses (with ≥ 3 HU)
- Commercial buildings
- Government buildings (with low public traffic)
- Lodging buildings (guest houses, hotels mit a max. 20 rooms)

- Windmills
- Lake dwellings (= stilt houses)
- Public buildings with low public traffic (e.g. fire houses, etc.)

BC3: **Special timber constructions [all buildings with special approvals (authorizations in each individual case)]**
+ all timber constructions in prominent locations (e.g. small inner-city timber house), buildings with high risk potential (e.g. laboratories, etc.)

- Pedestrian bridges with a span > 10m (+ all other bridges)
- Sports facilities (stages + roof constructions), halls + stadiums of all types
- Public buildings: Educational establishments, museums, churches, goverment buildings with high public use, halls, etc.
- Towers
- Widespread, engineered timber construction

The completed inspections, which were documented in the abovementioned forms of the assessment matrix, must be countersigned by another timber expert. Through this additional examination, which should only be conducted using the written documents and contain arrangements for an additional site inspection if requested by a second inspector, the already approved 4 eyes principle (see section 3.6) will be utilized in the construction processes.

3.9.2 Monitoring forms (based on [9] and [10])

After the building categories were determined, the question: **"When"** [in which monitoring cycles should inspections occur?] should be answered.

In doing so, there are **2 monitoring forms**

M1= Site inspections of the considered timber construction with a simple visual inspection by the timber expert.

M2= In-depth (= extensive) examination by the timber expert using the assessment matrix.

All monitorings are documented in the object book (see 2.7.2).
The "local building control authority" is responsible for examining the registration of all required inspections.

3.9.3 Monitoring cycles (in years) = release periods = RP (based on [9] and [10])

In addition to the previously mentioned monitoring forms, the following monitoring cycles [in years] are also significant:

← building category →	RP	← monitoring form → MF1	MF2
	BC 1	15	-
	BC 2	10	20 (MF2 replaces MF1)
	BC 3	-	10

The RP changes, if:

- the timber construction is completed:
  UC 0 → RP +3

- the construction is ≥ 50%
  UC 3 oder 4 → RP –3

- the timber expert has reasonable concerns :
  → RP -1/ -5

BC= building category,
definition: see 3.9.1
MF= monitoring form,
definition: see 3.9.2

It is important to say again, that buildings only be made available for use, if the check (using the Assessment Matrix) results at least Building Stage Level 2 (see section 2.6.7).

⇒ cange/ correction of release periods (= RP)

- If there are reasonable (significant) concerns, the RP can be reduced up tp 5 years

- Influence of **use classes**(= UC) (see form 2, section 2.4.3)
  - o If the timber construction completly concerns to UC 0
    ⇒ extention of the RP **+3**
  - o If the construction concerns to UC 3 + 4 for over 50%
    ⇒ reducing of the RP **-3**

If the timber expert is in doubt, the monitoring cycles can be reduced by up to 5 years and individual (up to 3; with more than 3 repairs an additional M1 must be implemented after the work.) repairs may be called for in special reports.

- The year of completion (= final inspection) is standard for the first inspection of new buildings.
- If construction measures that are subject to approval are conducted on timber constructions in building categories 2 or 3 (e.g. renovations/additions, changes of use, etc.), a simultaneous M2 examination is implemented.

3.9.4 Requirements of the timber expert and testing process

We still need the answer to the question: **"Who"** [Which test personnel with which qualifications and which superior testing institution] conducts the appraisals of the timber construction?

The following is required of this person:

- Minimum requirements for timber experts:
  Course of study: Architecture, timber/civil engineering,
  Professional practice: At least 7 years with credentials in the timber sector.

- Who appoints the timber experts, ensures their suitability, and requires them to undergo routine advanced training?
  The federal chambers of architects and engineers, e.g. in North Rhine-Westphalia, conduct inspection procedures similar to those of structural engineers and appoint "state-certified timber experts" who they manage in corresponding lists.

- Who calls for M1 and M2 according to the determined monitoring cycles depending on the building categories 1 through 3?

  The local building control authorities ask the owner to have the monitoring conducted according to legal guidelines and at their expense.

3.9.5 Test badges

Upon completing an inspection with positive results, the local building control authority grants the owner a test badge, which is to be mounted on the building in a highly visible place. The author of this thesis has designed a badge.
Modeled after the EU flag, the 12 stars were positioned in a circular formation. The internationally oriented test badge label, which is also circular and reads: "Official - Normed - Building – Check" was attached.

Additionally, the seals include the following general information:

- The country code indicates in which state, province, or territory, etc. the badge was issued. This can only be carried out by the appropriate local building control authority according to regional circumstances.
- The building category is also shown so that the classification is recognizable from outside.
- Furthermore, the expiration date (month and year) of the approval is shown. The official approval expires 3 months at the latest after the stated date. Expired test badges must be replaced with a badge indicating the badge has expired. In the best case, a new badge of approval is pasted over the existing one that has expired.

Furthermore, the test badges differ in color so that these important criteria can be recognized immediately:

- Public buildings receive a "blue" test badge after approval
  (see Figure 3.35). The design and the color were chosen based on the EU flag.

Figure 3.35: Porposal of a "Blue" test badge

legend:

BC3 = building code 3

D = Germany

released until december 2019,

referred to 3.9.3

- Only privately used residential buildings or smaller buildings in categories 1 and 2 receive a "green" test badge (see Figure 3.36).

  The green color was modelled after the german construction sign with a "green point," according to Appendix B, no. 14.3 of the administrative regulations in the North Rhine-Westphalian building regulations (see Figure 3.37), which is awarded with the approval. To this end "only" smaller residential buildings that fulfill all requirements of a development plan generally count.

Figure 3.36: Proposal of a "Green" test badge

legend:

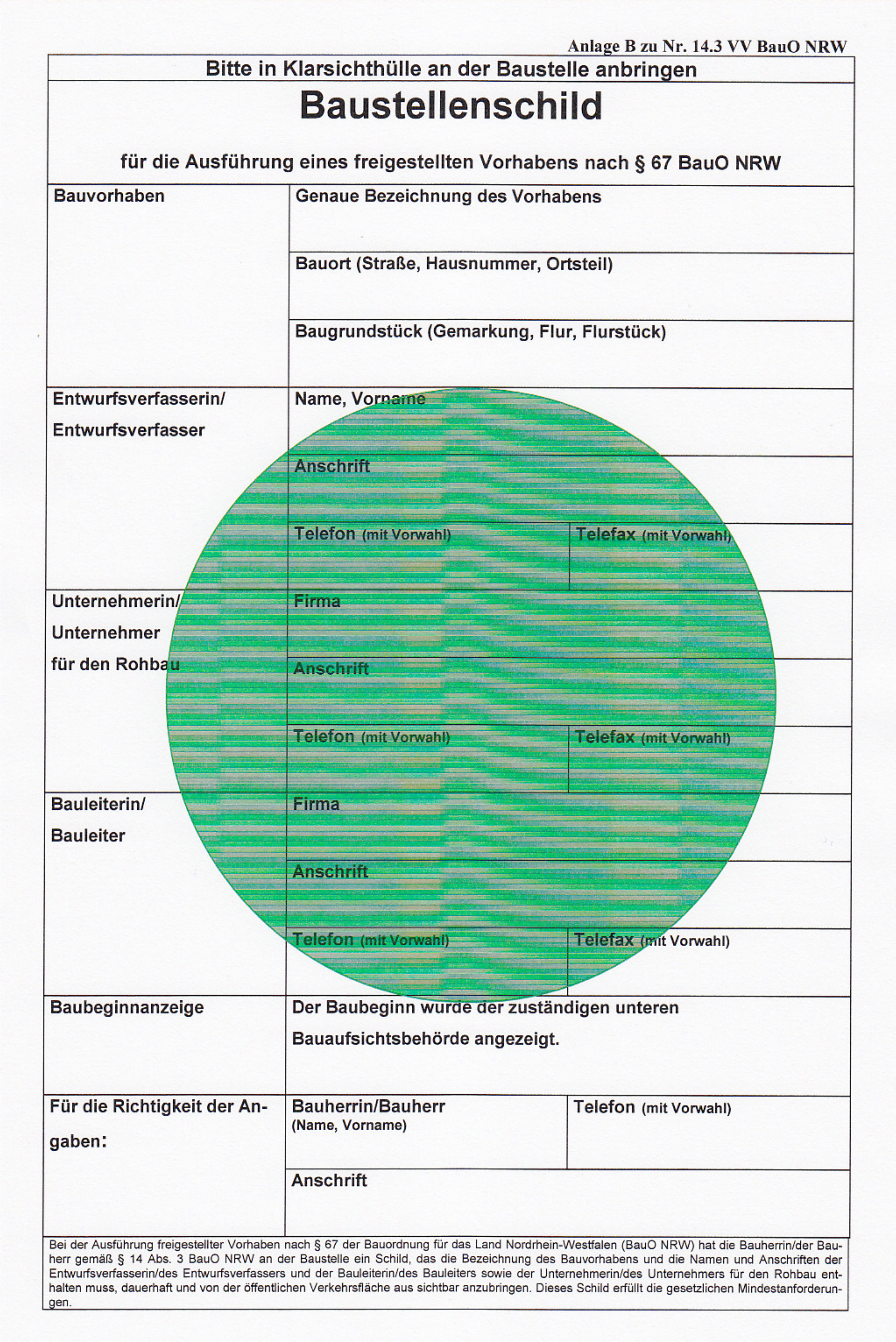
BC = building code

D = Germany

released until september 2019,

referred to 3.9.3

Figure 3.37: Existing "Green" construction sign in the german region NRW



Anlage B zu Nr. 14.3 VV BauO NRW

Bitte in Klarsichthülle an der Baustelle anbringen

Baustellenschild

für die Ausführung eines freigestellten Vorhabens nach § 67 BauO NRW

Bauvorhaben	Genaue Bezeichnung des Vorhabens	
	Bauort (Straße, Hausnummer, Ortsteil)	
	Baugrundstück (Gemarkung, Flur, Flurstück)	
Entwurfsverfasserin/ Entwurfsverfasser	Name, Vorname	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Unternehmerin/ Unternehmer für den Rohbau	Firma	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Bauleiterin/ Bauleiter	Firma	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Baubeginnanzeige	Der Baubeginn wurde der zuständigen unteren Bauaufsichtsbehörde angezeigt.	
Für die Richtigkeit der Angaben:	Bauherrin/Bauherr (Name, Vorname)	Telefon (mit Vorwahl)
	Anschrift	

Bei der Ausführung freigestellter Vorhaben nach § 67 der Bauordnung für das Land Nordrhein-Westfalen (BauO NRW) hat die Bauherrin/der Bauherr gemäß § 14 Abs. 3 BauO NRW an der Baustelle ein Schild, das die Bezeichnung des Bauvorhabens und die Namen und Anschriften der Entwurfsverfasserin/des Entwurfsverfassers und der Bauleiterin/des Bauleiters sowie der Unternehmerin/des Unternehmers für den Rohbau enthalten muss, dauerhaft und von der öffentlichen Verkehrsfläche aus sichtbar anzubringen. Dieses Schild erfüllt die gesetzlichen Mindestanforderungen.

- The approval initially occurs with one or more conditions or with a condition precedent (e.g. submission of a proof by a certain date, or the like). A "red" test badge is then granted according to Appendix A, no. 14.3 of the administrative regulations in the North-Rhine Westphalian building regulations (see Figure 3.38). This is replaced by the "blue" or "green" badge after a new (successful) final inspection. The "red" test badge represents a maximum 6-month-long transitional period and shows the building users that there are serious defects on or in the building that must be repaired. This "alarm signal" should have been enough motivation for the building owner to have the damages quickly repaired.

  The red color was modeled after the "red construction sign" (see Figure 3.39), which shows that the considered building was inspected and an additional inspection (after completion of a new building) was required.

Figure 3.38*:* Proposal of a "Red" test badge

legend:

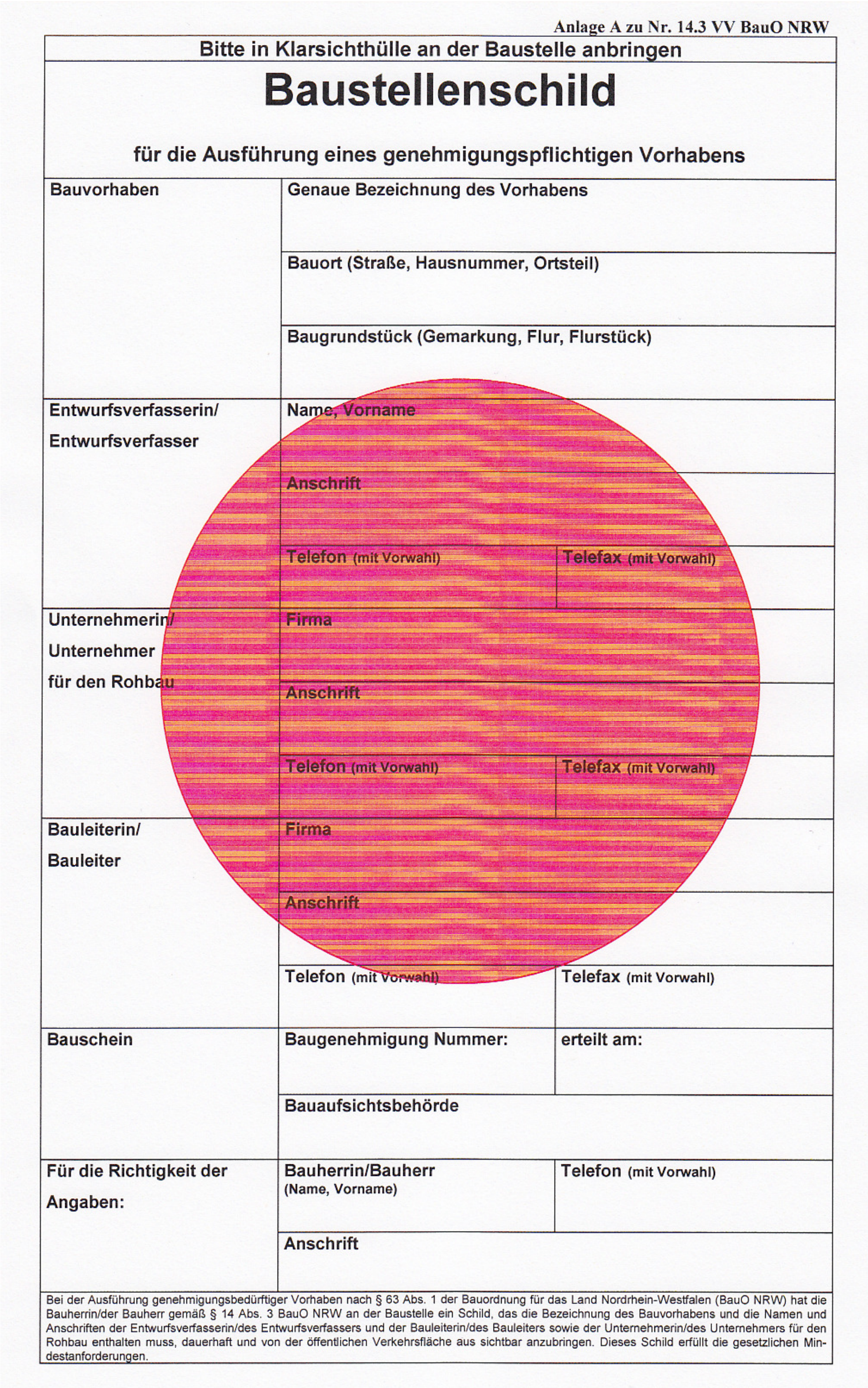
BC = building code

D = Germany

released only for 6 month under reserve,

in this example until june 2010

Figure 3.39*:* Existing "Red" construction sign in the german region NRW



Anlage A zu Nr. 14.3 VV BauO NRW

Bitte in Klarsichthülle an der Baustelle anbringen

Baustellenschild

für die Ausführung eines genehmigungspflichtigen Vorhabens

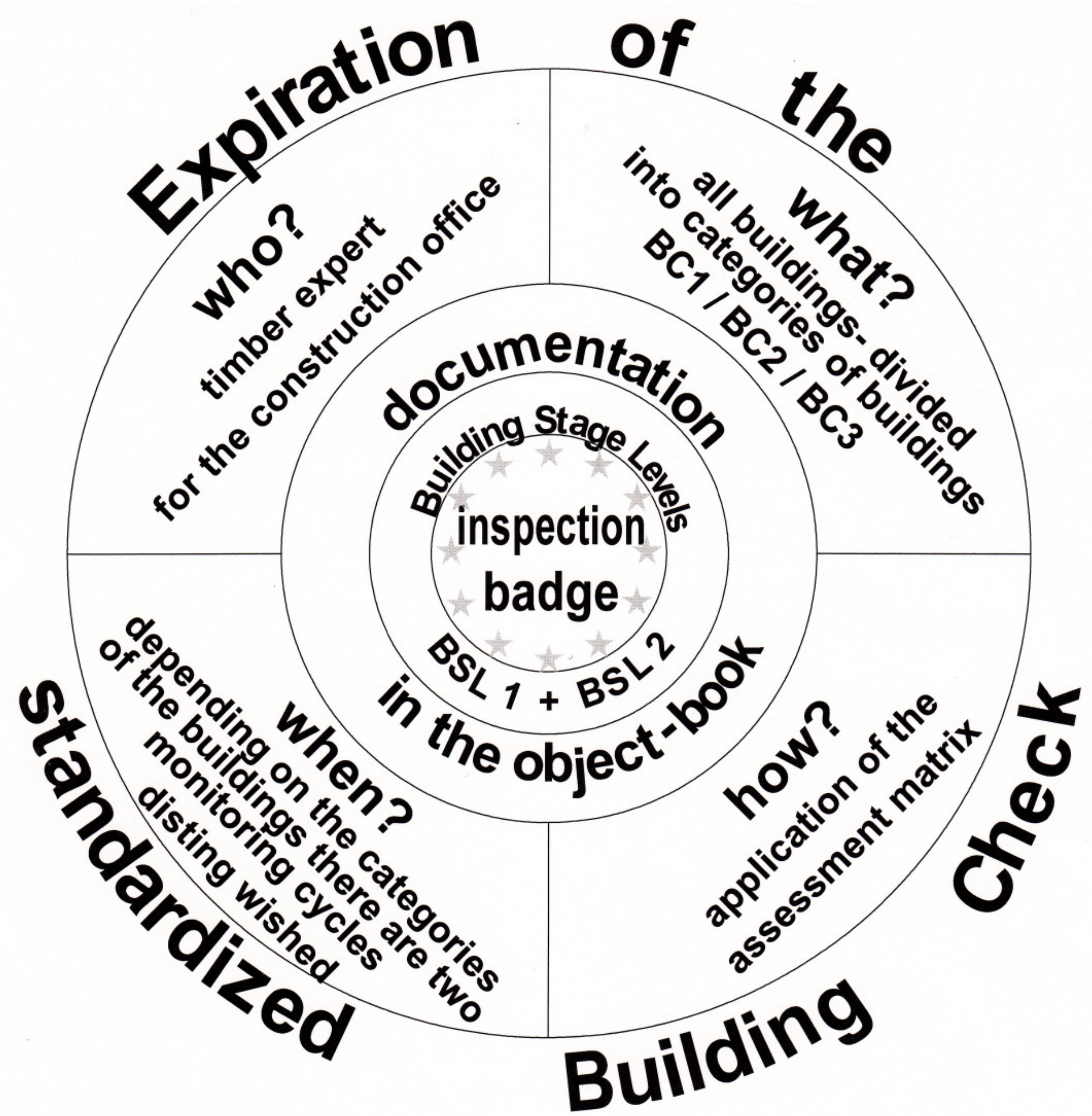
Bauvorhaben	Genaue Bezeichnung des Vorhabens	
	Bauort (Straße, Hausnummer, Ortsteil)	
	Baugrundstück (Gemarkung, Flur, Flurstück)	
Entwurfsverfasserin/ Entwurfsverfasser	Name, Vorname	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Unternehmerin/ Unternehmer für den Rohbau	Firma	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Bauleiterin/ Bauleiter	Firma	
	Anschrift	
	Telefon (mit Vorwahl)	Telefax (mit Vorwahl)
Bauschein	Baugenehmigung Nummer:	erteilt am:
	Bauaufsichtsbehörde	
Für die Richtigkeit der Angaben:	Bauherrin/Bauherr (Name, Vorname)	Telefon (mit Vorwahl)
	Anschrift	

Bei der Ausführung genehmigungsbedürftiger Vorhaben nach § 63 Abs. 1 der Bauordnung für das Land Nordrhein-Westfalen (BauO NRW) hat die Bauherrin/der Bauherr gemäß § 14 Abs. 3 BauO NRW an der Baustelle ein Schild, das die Bezeichnung des Bauvorhabens und die Namen und Anschriften der Entwurfsverfasserin/des Entwurfsverfassers und der Bauleiterin/des Bauleiters sowie der Unternehmerin/des Unternehmers für den Rohbau enthalten muss, dauerhaft und von der öffentlichen Verkehrsfläche aus sichtbar anzubringen. Dieses Schild erfüllt die gesetzlichen Mindestanforderungen.

- If the damages assessed in an inspection are so serious that use can no longer be authorized, the timber expert calls for an immediate closure. This can occur, for example in Germany, in cooperation with the administrative offices that bar access to buildings until the indicated damages are repaired. The administrative offices are a section of the local government under the German administrative structure. They oversee all legal, security, and organizational matters.

The following graphic (see Figure 3.40) summarizes the now completely described standardized building check.

Figure 3.40*:* Summary of the standardized building check as a graphic



3.9.6 Implementation of the standardized building check in society

For all new legal obligations there are often opposing voices to be heard that denounce an ever growing bureaucracy in today's society.

Because the in-depth explanations explored above show that the control over the implementation of structural inspections is subject to the already existing local building control authorities, the personnel must be supplemented where possible. The personnel costs would be covered by the fees for the building owner.
Additional counter arguments are insignificant because the described structural legal obligations mainly serve the safety of all users. One possibility for keeping additional adminstrative tasks to a minimum might be, for example, that timber experts are all dedicated to monitoring entire, related regions, similar to the chimney sweeper system in Germany. Subsequently, the experts would independently take charge of the examinations of all assigned buildings.
In the recent past it was shown that new legal requirements in construction could be implemented as quickly as possible, such as the introduction of the energy-saving certificate according to the current Energy Conservation Regulations [S18], shown for residential buildings. The energy certificate is an EU guideline (2002/91/EC) [S19] of the European Parliament and Council for the overall efficiency of buildings.

In today's society laws related to energy conservation or public safety can be instituted much easier than before.

In the following section (3.10) of this thesis, preliminary considerations for a bill are described that must be passed in order to create an official obligation to introduce routine structural monitorings.

3.10 Preliminary consideration of a bill

Even after developing the conclusive assessment matrix described in previous sections, who can and may conduct these examinations and at what times is still lacking the lawful legitimacy that would create a legal obligation to fulfill this sustainable assessment plan.

With the development of the assessment matrix (= main matrix) in the 2nd chapter of this PhD-Thesis it was always noted that only the appraisal of timber constructions is concerned here. Otherwise it would go beyond the scope of this dissertation.

The preliminary considerations mentioned in the last section for the introduction of a standardized building check and the following suggestions for the introduction of national laws, or better yet, EU guidelines, apply to buildings. Only a classification into one of the three various building categories must be specified for universal validity on all buildings. With the current selection (see section: 3.9ff) timber constructions stand at the forefront.

A better understanding of the hierarchy of building control authorities in the German states (e.g. North Rhine-Westphalia = NRW) is subsequently presented. The local building control authority, which performs various functions, has been mentioned often.

A hierarchy of building control authorities exists in the German states.

An example is North Rhine-Westphalia (= *NRW)*. The following building control authorities are concerned:

- ***Local building control authority:*** *Building authorities for cities, municipalities, districts, etc.*
- ***Superior building control:*** *District government for the monitoring of* the local building control authority.
- ***Superior building control:*** *Ministry of the state government*

The superior building control is responsible for the enactment of building law and administration regulations and for the introduction of technical building regulations, etc.

In NRW this is the Ministry for Building and Transport, Construction and Urban Development.

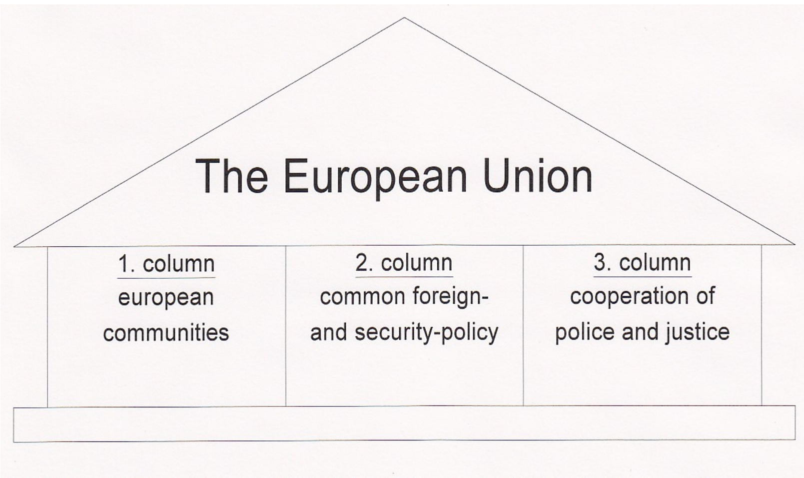
The State Ministry for Transport, Building and Urban Development is responsible if nationwide building laws are enacted.

The German law "For the protection and care of monuments in the state of NRW" [S22] *can serve comparitively or as a template.*

There are EU guidelines in addition to national requirements. These were implemented in national law.

The Committee on Culture and Education in the European Parliament is responsible for the preservation and protection of cultural legacies, cultural exchange and artistic creations, among other things. The theme of this PhD-Thesis falls within the area of responsibility of this committee.

Figure 3.41*:* Three-pillar model of the European Union



3.11 Intermediate conclusion + outlook of the following section

The previous chapters of this thesis, initially in Chapter 1, provided a variety of knowledge about timber structures so that the work can serve a larger group of people than the just addressed timber experts. The development of the assessment matrix detailed in Chapter 2, which was shown in chronological order, was able to be applied in this 3rd chapter to practical, complex case studies of different buildings. In doing so its concrete practical application was adequately displayed.

The application of the matrix in our society already suggested was precisely described at the end of Chapter 3.
A potential legal legitimation was suggested, which would include the assessment matrix as part of a standardized building check and, therefore, create a sustainable and closed process for our building laws.
These loopholes can be closed in order to attain a considerable improvement in the safety of building users and the sustainable protection of structural cultural possessions.
Big catastrophes such as the ice pavilion collapse in Bad-Reichenhall in 2006 create strong public support for an official building check. The unfortunate increasing

frequency of natural disaster such as earthquakes or seaquakes (e.g.: Tsunami in 2004), extreme storms [e.g.: Hurricane Kyrill in 2007 or Hurricane Xynthia in 2010] or the extreme winter (as a result of global climate changes) of the past years, including more snow than in previous decades, bring about an increased awareness for the protection of existing buildings in our society.

This aspect was taken up in the current chapter and extensively discussed.

4. Summary and Outlook

The focus in this concluding section of the PhD-Thesis is on outlooks and future perspectives regarding the application of the developed assessment matrix. Scientific and societal benefits of the new assessment matrix should be highlighted.

4.1 Possible matrix programming implementations for a simple data processing application

It would not be consistent with today's modern age of electronic data processing, if the presented forms, checklists and databases were to be manually processed. The programming implementation of the complete assessment matrix as a computer-based program would make sense. This form of input would have many advantages. Besides faster data input, to some extent even on-site using a notebook, data could be provided to the involved experts (see section 2.4.7) in a simple form, e.g. via programming interfaces, for further processing.
Furthermore, it would make sense to use already available Internet links in modern data processing programs for an online platform for timber construction experts. On such a platform appraisals could for example be stored (on a voluntary basis), if questions, problems or specifics must be resolved within the expert community. This platform could also be used to announce regular meetings and symposiums for users of the assessment matrix.

In comparison, this form of program utilization is already used today by different program providers.
The described exchange with other users can take place here as well. However, each program license holder can design his own user interface according to his requirements. This way he can generate a time advantage by e.g. using individual sequences from already existing project entries and embedding them in new sequences.

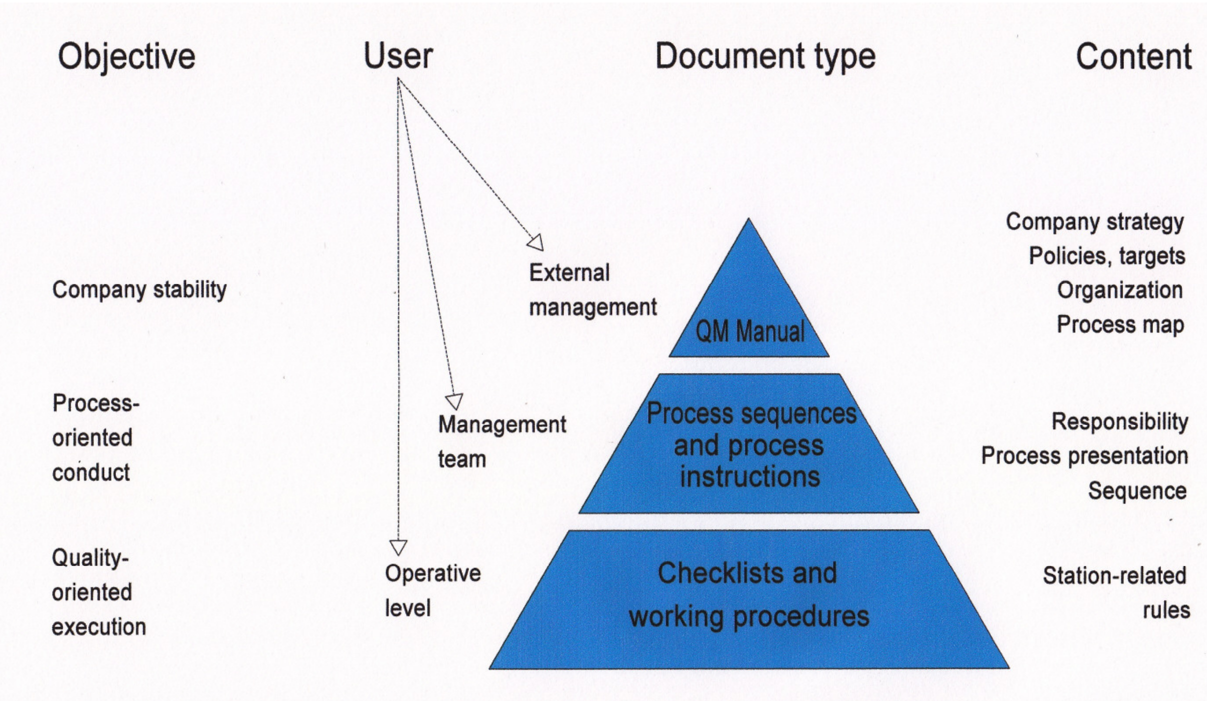
The goal of different device manufacturers of expert databases (2.4.7) could be to save their research results in a data format, which could be imported by the still to be implemented program. An example would be today's exchange between statics and

CAD (Computer Aided Design) programs. It is of rather large help to the CAD designer, if he e.g. can import the computation results of a FEM (Finite Element Method) analysis of a statics program for further processing in his program.

4.2. Continuous research and extension suggestion into non-timber constructions and transnational studies

A permanent exchange between several wood experts conducting the described future monitoring activities (see 3.9.2) using the assessment matrix developed and described in this paper, would be of interest. This exchange, which could be conducted in the form of a professional quality management system (QM system), can be the focus of a follow-on research paper based on this dissertation.

Figure 4.1: QM system structure, taken from [17]



The permanent extension or supplementation of checklists and databases could be of interest and could be the topic of a scientific diploma, bachelor's or master's thesis. Country-specific constructions could be included as well. For example, a database regarding "timber piers" would be of great interest in the Netherlands.

In this thesis the assessment matrix is exclusively focused on the German construction monitoring system (with respect to approval procedures, building/construction laws and processes etc.). Another suggestion for future research based on this dissertation would be the preparation of the assessment matrix for a transnational application.

Qualified work, service and process monitoring is continuously gaining in importance. These processes could be applied to permanently improve the assessment matrix developed in this thesis.

In Germany the certification of service providers in different areas, such as architects and engineering offices, doctors, hospitals etc., by accredited inspection authorities is increasingly becoming a standard. Purpose of these certifications is to confirm the existence of a good quality management system. As they are currently still voluntary qualifications, future user behavior will most likely promote an obligation, as uncertified institutions will be less frequented.

In the following an inspection certificate is presented confirming the QM qualification.

Figure 4.2: TÜV inspection sticker after passed quality inspection
(TÜV-certified: German Association for Technical Inspection]

From engineering scientific point of view additional research based on this PhD-Thesis makes sense as well. One obvious option is the extension of the assessment matrix to non timber constructions. In older buildings almost only brickwork elements are used in addition to load-bearing timber elements. Similar to the steel and ferroconcrete constructions in newer buildings, these brickwork elements must be investigated in more detail within the framework of building monitoring. The contents in chapter 3 are, as already described, almost generally applicable to all buildings regardless of the selected material (wood, steel, ferroconcrete and brickwork).

Thus, as already mentioned several times within this paper, it would be desirable to extend the assessment matrix in future to the entire building/construction area regardless of the material used.
Furthermore, it could be investigated if other areas, such as mechanical engineering or shipbuilding, would benefit from assessment forms already tested in similar areas.

Besides engineering-scientific areas, this thesis also addresses legal topics. One example would be the discussion of new laws, which should establish building inspections and require building owners to have their buildings inspected on a regular basis.

Scientific research with respect to this range of topics could be conducted in the near future by legal faculties.

In addition, the following question could be discussed in more detail from a philosophical point of view: *"Why do we need a building assessment matrix in our modern, high-tech societies?"* There are already several different philosophical texts available regarding technology philosophy. For example, the well-known authors Martin Heidegger and Hans Jonas address in their work basic questions with respect to technical developments of modern societies. In future philosophical papers, these viewpoints could critically question the whole purpose of a building inspection using the here developed matrix.
With that several possible future research topics are listed. They pick up on the topics of this dissertation and in parts sharpen or promote them.

4.3 Conclusions

As a conclusion of this thesis it can be said that within the scope of this work (in chapter 2) a matrix was developed, which can be used to assess different load-bearing timber constructions. Due to the described complexity of the topic, the currently available assessment matrix cannot cover all possible timber construction details. The presented case studies show the variety of wood materials used in the last centuries and that wood will be irreplaceable in the future as well.

Using the exchange of experiences promoted in chapter 2, the matrix should be continuously extended. As the common book form is unsuitable, the matrix can only be implemented as a computer-based program suggested here as well. Based on continuously ongoing evaluation by the matrix users, the matrix will not only be optimized, but also continuously adapted to new technical developments.
This thesis is mainly focused on the coherent structure of the assessment matrix, which brings different terms, such as forms, checklists and databases to life.
In addition to concrete practical applications, the societal benefits of this matrix are addressed in chapter 3. The author's highest priorities are praxis orientation and societal benefits. The process sequence described in detail, lends itself to be the legal basis for an official standardized building inspection. A desirable result could be a respective EU Directive.
Thus, beside the social relevance of this PhD-Thesis of improving the safety of building users, the societal relevancy of sustainable preservation of structural cultural assets is provided as well.

The assessment matrix presented in this dissertation provides an original and fundamental contribution to the "body of knowledge" of architectural, construction and engineering science. This thesis closes a sensitive gap of technical-scientific as well as societal relevancy.

In addition to the positive thoughts and requests in these conclusions, some critical challenges should be mentioned as well.
Unfortunately, it must be expected that a legal implementation of the developed building inspection will meet partial resistance. Standard complains about increasing bureaucracy will most likely be expressed. In the past, after the accident in Bad-Reichenhall in January 2006, the public was horrified at first. As the first concerns that technical deficiencies caused the accident, were confirmed in the court proceedings in November 2008, no renewed requests for building inspections were expressed. These technical deficiencies could have been detected in advance by building monitoring.

The author of this dissertation would like to create new awareness by publications in different print media and the Internet. Furthermore, he hopes that a fast computer implementation of the assessment matrix will allow the release of a program

specifically for timber experts as soon as possible. This will further increase the awareness level.
Beside his commitment to publish the objectives of this thesis within the society and higher political levels, lobbying is required, pursuing the interest in the legal implementation of an official building inspection.
For this purpose the definition by Hans Merkle [31] is provided: *"The target-oriented persuasion of decision makers in politics and administration is called lobbying".*
Thus, the author of this PhD-Thesis hopes for the support by lobbyists in important organizations, professional associations, publishers or chambers, in order to promote a political implementation.

The application of the targeted building inspection to all buildings may be equally challenging, whereas the assessment matrix in this dissertation only addresses wood materials - anything else would go beyond the scope of this thesis. Thus, it may be beneficial to develop in the future, in parallel to possible legal preparations, assessment matrices for massive building materials: brickwork, concrete and ferroconcrete constructions, as well as lightweight construction materials: steel etc.

As a legally obligatory building inspection is a global topic of civilized societies, a worldwide research could have been conducted within the scope of this thesis. Focus of this research could be the existence of similar procedures on different continents, which could be used as template for EU member states. For time reasons this was omitted. Solely the reviewed directive SIA 462 of the Swiss Engineers and Architects Association picks up on the basics of the topic of this work. However, in order for Switzerland to benefit from the presented work, a sustainable process and the necessary assessment matrix must still be developed.

For the practical applicability of this new tool (=assessment matrix) it is necessary to focus necessary attention on the mostly German standards (and/or if possible European standards). These standards may have to be modified when applied to other countries. For this purpose, respective (suggested) follow-on investigations within the European framework would be useful, necessary and beneficial.

In conclusion, it must be stated that catastrophes like the collapse of the ice pavilion in Bad-Reichenhall (Germany) can be avoided by the means of the matrix, whose application will hopefully be legally required in the near future. Initial spontaneous thoughts and requests for an official building inspection disappeared from the media and thus, from public attention.

The public should naturally expect that each building has an inspection sticker (as proposed in this PhD-Thesis) as the result of a building inspection.
Unfortunately, the society only requests statutory obligatory monitoring forms after tragedies such as the catastrophe at the Love Parade music event in Duisburg (Germany, summer 2010). Here, 21 people died after a mass panic. In this case, an event safety TÜV was requested in the media on the same day.
An official standardized building inspection as suggested in the present thesis, which is essential for the assessment matrix, would close a large gap in the building/construction laws.
This PhD-Thesis can provide a significant contribution to our building/construction culture and thus impact in various social-cultural ways.

5.1 Summary of the PhD-Thesis in different languages:

5.1.1 German summary

Beurteilungsraster für Holzkonstruktionen

Wie kann zukünftig sichergestellt werden, dass Menschen permanent und überall standsichere und gebrauchstaugliche Gebäude betreten, um sich in diesen sicher aufhalten, leben und arbeiten zu können?

Damit Katastrophen, wie der Einsturz der Eissporthalle in Bad-Reichenhall (Deutschland) aus dem Jahr 2006 nie wieder vorkommen, wurde ein Beurteilungsraster (auch als Matrix bezeichnet) entwickelt, das zukünftig zur Bewertung von Bauwerken herangezogen werden soll.

In dem Beurteilungsraster, der in dieser Arbeit schwerpunktmäßig für tragende Holzkonstruktionen, unabhängig der Größe und des Alters, entwickelt wurde, wurde unter anderem der aktuelle wissenschaftliche Stand aller üblichen Konstruktionsarten, die gängigen Untersuchungsmethoden, der Umgang mit eventuellen Schäden und Kenntnisse über Materialeigenschaften eingearbeitet.

Neben der sozialen Relevanz dient die Beurteilungsmatrix ebenfalls der Erhaltung von baulichem Kulturgut, auch im Hinblick auf eine nachhaltige Entwicklung, da die Matrix die Grundlage einer zukünftigen, gesetzlich verpflichtenden Überwachung jeglicher Gebäude darstellen soll.

Die Matrix wurde bereits über einen längeren Zeitraum an verschiedenen Bauwerken mit Holzkonstruktionen erprobt. An drei konkreten Gebäuden, die als Fallstudien dieser Arbeit dienten, konnte das Beurteilungsraster erprobt und abschließend validiert werden.

Ziel ist es, auf der Basis dieser Arbeit eine neue EU-Richtlinie vorzugeben, die die regelmäßige Überwachung von Gebäuden in Abhängigkeit von definierten Gebäudekategorien im Hinblick auf deren Gebrauchstauglichkeit und Standsicherheit hin regelt.

Eine abschließend verliehene und am Gebäude für alle sichtbar angebrachte Prüfplakette, ähnlich den bekannten deutschen TÜV-Siegeln, zeigt dem Nutzer die Freigabe für einen bestimmten Zeitraum und könnte bald zur festen Ausstattung aller Bauwerke gehören, um ein entsprechendes Bewusstsein innerhalb der Bevölkerung zu wecken.

5.1.2 Dutch summary

Ontwikkeling van een beoordelingsraster voor houtconstructies

Hoe kan in de toekomst worden gegarandeerd dat mensen permanent en overal stabiele en onverslijtbare gebouwen betreden om er veilig te kunnen vertoeven, leven en werken?

Opdat catastrofes zoals de instorting van de ijsbaan in Bad-Reichenhall (Duitsland) in 2006 zich nooit meer zouden kunnen voordoen, werd een beoordelingsraster (ook wel matrix genoemd) ontwikkeld voor de toekomstige technische beoordeling van bouwwerken.

Het beoordelingsraster dat in dit werkstuk speciaal werd ontwikkeld voor dragende houtconstructies, bevat, onafhankelijk van de grootte en leeftijd, onder andere de huidige wetenschappelijke stand van alle gebruikelijke constructiewijzen, de gangbare onderzoeksmethodes, de omgang met eventuele schade en kennis over materiaaleigenschappen.

Naast de maatschappelijke relevantie dient de beoordelingsmatrix ook voor het behoud van bouwkundig cultuurgoed, ook met het oog op een duurzame ontwikkeling aangezien de matrix de basis moet vormen voor een toekomstige, wettelijk verplichte controle van alle gebouwen.

De matrix werd reeds gedurende een langere periode getest op verschillende bouwwerken met houtconstructies. Voor drie concrete gebouwen, die als casestudy’s van dit werk dienden, kon het beoordelingsraster worden getest en tot bestluit worden gevalideerd.

Het doel is om op basis van dit werk een nieuwe EU-richtlijn op te stellen, die de regelmatige controle van gebouwen op basis van gedefinieerde gebouwcategorieën met het oog op hun bruikbaarheid en stabiliteit regelt.

Na de test wordt op het gebouw voor iedereen zichtbaar een testplaat aangebracht, vergelijkbaar met de bekende Duitse TÜV-zegels, waardoor de gebruiker weet dat het gebouw voor een bepaalde periode is vrijgegeven. Deze plaat zou weldra tot de vaste uitrusting van alle bouwwerken moeten behoren, om de bevolking hiervan bewust te maken.

5.1.3 English summary

Assessment Matrix for Timber Structures

How can futurily be secured enabling people to enter stable and utilisable buildings permanently and everywhere for them to stay, live and work safely?

In order to avoid catastrophies like the collapse of the Bad Reichenhall ice pavillion (Germany) in 2006, a method of evaluation (= assessment matrix) had been designed which will be used to assess constructions prospectively.

The matrix developed in this dissertation has its main focus on bearing timber constructions, independent of size and age.

The actual scientific level of information referring to main methods of contruction, current examination methods, handling of potential damage and knowledge of material properties is included in this matrix.

Besides a social relevance the matrix as well serves conservation of structural cultural assets – in view of a lasting development, too.

It is supposed to be constituted as a foundation of legally obligated monitoring for all buildings in future.

The matrix has been tested on several buildings with timber construction for a longer period of time already. Three buildings are case studies of this dissertation and helped to prove and finally validate the matrix.

Based on the dissertation, it is the aim to create a new EU directive to regulate a continuous supervision of buildings in dependence on serviceability and stability.

Finally a test badge similar to the german TÜV seals should be attached visibly to everybody at the building. It displays approval for a certain period of time and could soon be definite equipment of all buildings to raise awareness within the population.

5.1.4 Spanish summary

Desarrollo de un sistema de evaluación para el mantenimiento de estructuras de madera valiosas

¿Cómo puede garantizarse a futuro que las personas entren siempre y en todo lugar en edificios estables y aptos para usar a fin de poder permanecer, vivir y trabajar en ellos sintiéndose seguras?

Para que no vuelvan a ocurrir catástrofes como el derrumbe del pabellón de deportes sobre hielo de Bad-Reichenhall (Alemania) en 2006 se desarrolló un sistema de evaluación (también denominado matriz) al que podrá recurrirse para calificar construcciones.

En el sistema de evaluación que se desarrolló como tema central de este trabajo para construcciones portantes de madera independientemente del tamaño y de la antigüedad, se integraron, por ejemplo, el actual estado científico de todos los tipos de estructura habituales, los métodos usuales de examen, el manejo de daños eventuales y conocimientos de las propiedades de los materiales.

Junto con la relevancia social, la matriz de evaluación también sirve para la conservación del acervo arquitectónico, también en lo que respecta a un desarrollo sustentable, ya que la matriz representa el fundamento de una vigilancia futura de todos los edificios y obligatoria por ley.

La matriz ya ha sido probada por un largo período en diversas construcciones con estructuras de madera. El sistema de evaluación pudo probarse y finalmente validarse en tres edificios concretos que sirvieron como estudios de casos para este trabajo.

El objetivo es establecer, sobre la base de este trabajo, una nueva directiva de la UE que reglamente la vigilancia regular de edificios en función de categorías de edificios definidas en relación con su aptitud para ser usados y su estabilidad.

Una plaqueta de evaluación que se otorga tras la finalización e instalada de forma visible para todos, similar a los conocidos sellos alemanes TÜV, que muestra al usuario la autorización por un período de tiempo determinado y que podría ser parte prontamente del equipamiento fijo de todas las construcciones para despertar una conciencia análoga en la población.

5.1.5 French summary

Développement d'une grille d'évaluation pour la préservation de constructions en bois précieuses

De quelle manière peut-on assurer la stabilité statique et la capacité d'emploi de bâtiments afin que tout le monde puisse y accéder, rester, vivre et travailler en toute sécurité ?

Afin de garantir que des catastrophes telles l'effondrement de la patinoire couverte de Bad-Reichenhall (Allemagne) en 2006 ne se reproduisent plus jamais, une grille d'évaluation (appelée matrice aussi) a été développée qui pourra être appliquée à l'évaluation de bâtiments.

Développée pour des constructions en bois portantes avant tout et en dépit de leurs dimensions et leur âge, la grille d'´évaluation du présent travail comporte entre autres le savoir scientifique actuel de tous les types de constructions, les méthodes d'investigation habituelles, la prise en charge de dégâts éventuels et les connaissances sur les caractéristiques de matériaux.

Outre son importance pour domaine social, la matrice d'évaluation servira également à la préservation de bâtiments classés patrimoine culturel, compte tenu d'un développement durable aussi, car la matrice devra constituer la base pour des contrôles ultérieurs obligatoires et applicables à tous les bâtiments.

La matrice a déjà été testée pour une période prolongée sur de différents bâtiments avec des constructions de bois. La grille d'évaluation a été testée et validé définitivement sur trois bâtiments concrets qui servent d'études de cas dans le présent travail.

Nous visons l'établissement d'une nouvelle directive CE sur la base du présent travail. Celle-ci devra stipuler le contrôle régulier de bâtiments en fonction de catégories de bâtiments définies toujours dans l’optique de leur capacité d'emploi et de leur stabilité statique.

Un label de sécurité contrôlée similaire aux labels du TÜV allemand informera les usagers sur l'autorisation d'exploitation délivrée pour une période définie. De tels labels pourront bientôt faire partie intégrante de tous les bâtiments afin de sensibiliser la population.

5.1.6 Italian summary

Sviluppo di una griglia di valutazione per la conservazione di costruzioni in legno pregiate

Come si può assicurare in futuro che le persone entrino sempre e dappertutto in edifici stabili e idonei all'uso per potervi soggiornare, vivere e lavorare?

Affinché non si ripetano catastrofi come quella avvenuta a Bad-Reichenhall (Germania) nel 2006 dove crollò il tetto del palaghiaccio, è stata sviluppata una griglia di valutazione (chiamata anche "matrice") che dovrà essere utilizzata in futuro per valutare gli edifici.

Nella griglia di valutazione, che in questo lavoro è stata sviluppata ponendo l'attenzione sulle costruzioni portanti in legno, indipendentemente dalle dimensioni e dall'età, sono stati inseriti, fra le varie cose, lo stato attuale delle conoscenze scientifiche su tutti i tipi tradizionali di costruzione, i metodi di analisi in uso, la gestione di eventuali danni e le conoscenze sulle caratteristiche dei materiali.

Oltre ad avere un'importanza a livello sociale, la griglia di valutazione serve alla conservazione del patrimonio edile anche in vista di uno sviluppo sostenibile, in quanto la griglia deve rappresentare la base per il controllo futuro, imposto dalla legge, di tutti gli edifici.

La griglia è già stata collaudata per un periodo di tempo piuttosto lungo per la valutazione di diversi edifici con costruzioni in legno. La griglia di valutazione è stata collaudata su tre edifici concreti, che sono stati utilizzati come studi di caso per questo lavoro, ed infine validata.

L'obiettivo è quello di creare, sulla base di questo lavoro, una nuova Direttiva UE che regoli il controllo degli edifici sulla base di categorie predefinite di edifici valutandone l'idoneità all'uso e la stabilità.

Un contrassegno conferito al termine dei controlli eseguiti e fissato sull'edificio in modo da risultare visibile a tutti (simile al famoso sigillo TÜV tedesco) mostra agli utenti l'abilitazione per un certo periodo di tempo e potrebbe presto diventare un elemento fisso di tutti gli edifici al fine di sensibilizzare la popolazione.

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Entwurfsüberlegungen bei Holzbauten	1,1,1	
Überdachungen mit großen Spannweiten	1,1,2	1.5.7
Bauen mit Holzwerkstoffen	1,1,3	1.2.1.3
Holzbausysteme	1,1,4	
Mehrzweckhallen (08/96)	1,2,1	1.5.7
Mehrzweckhallen (07/01)	1,2,1/1	1.5.7
Sport- und Freizeitbauten	1,2,2	1.5.7
Zukunftsmodell Turn- und Mehrzweckhalle	1,2,3	
Mehrgeschossiger Wohnungsbau in Holz	1,3,1	1.5.5
Niedrigenergiehäuser – Bauphysikalische Entwurfsgrundlage	1,3,2	1.7.4
Niedrigenergiehäuser – Planungs- und Ausführungsempfehlungen	1,3,3	1.7.4
Holzrahmenbau	1,3,4	1.5.5
Das Wohnblockhaus	1,3,5	1.5.4
Holzskelettbau	1,3,6	1.5.4
Skelettbaudetails, Teil 1: Gestalten-Bauen	1,3,7	
Skelettbaudetails, Teil 2: Bauphysik-Haustechnik-Lebensdauer	1,3,8	
Familienhäuser	1,3,9	1.5.5
Das Passivhaus – Energieeffizientes Bauen	1,3,10	1.7.4
Lärmschutzwände	1,6,1	1.7.1
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Industrie- und Gewerbebauten	1,8,3	1.5.7

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Details für Holzbrücken	1,9,2	1.5.7
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Holz-Glas-Fassaden	1,10,3	
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5.8 Composition of all tables, images, pictures, etc., of all chapters

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5.9 Curriculum Vitae

Michael Abels was born on September 10, 1971 in Grevenbroich, Germany. He grew up in Bedburg, Germany and completed his Abitur (high school diploma) at the Städtischen Gymnasium in 1991.

He completed a graduate degree in civil engineering in Aachen in 1996.
In the first couple years he worked in an engineering office as a structural engineer and building physicist in the areas of fire, sound and moisture proofing, as well as heat insulation.

Since 1999 Michael Abels has been a state-approved specialist for soundproofing and heat insulation and is also authorized to present building documents.
In the same year he began his own architecture and engineering firm in his hometown of Bedburg. His sphere of activity is wide-ranging. Aside from various building plans, he also conducts stability checks of any kind in solid, timber, steel and lightweight constructions.
Michael Abels' architecture and engineering firm perfects structural-physical proofs, especially as experts in the field of heat insulation and soundproofing, and develops expert opinions on various problems in civil engineering.
Within the scope of their work they have appraised a number of different timber constructions, experiences that were necessary to complete this work.

His second course of studies as a technical instructor in the professions of structural and timber engineering at the Rheinland-Westphalian Technical University (= Rheinisch-Westfälisch-Technischen-Hochschule/RWTH) in Aachen, which Michael Abels completed while carrying out his work as an engineer from 2000 to 2004 with successful first and second state examination. He also expanded his engineering approach by improving his own craftsmanship with various teachings from construction workers and master craftsmen.

Through his professional contact and the resulting friendship with Dr. Hans Löfflad, who received his Ph.D. from the TU Einhoven in 2002, Michael met Prof. Peter Schmid in 2004, which, in turn, led to contact with Prof. Dr. André Jorissen.

With both of these people, Michael Abels has been able to carry out his dream of writing a dissertation that unifies his professional knowledge in engineering with his interest in scientific works and research and the concept of the present work's subject, which delivers a great and sustainable advancement in smart building inspections.

Michael Abels has been married to Helga Abels since 1997. They have two children, Magnus and Amélie, and they currently reside in Bedburg.

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