

Approved Concept for Inspection of Modern and Historic Timber Structures: Theory and Practical Experiences

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Abstract

Based on the development of resistance drilling in 1986 and combined with other methods, such as visual inspection, wood moisture measurements, and stress-wave timing, a comprehensive concept for inspection of timber structures and documentation of the results was developed in conjunction with experts from several other professions. Since 1987, several thousand historic and modern timber structures have been inspected: for example, buildings (castles, churches, family houses, sport/swimming halls), bridges, poles, harbors, and playground equipment. The major goal of the specific type of color-coded inventory sketches was to comprehensively show all relevant results of the inspection and at the same time revealing these findings in a way that can be understood by architects, engineers, carpenters, and heritage administrations in a quick and easy way without having to read text reports. The biggest difference from ordinary concepts is the step from damage documentation to condition inventory. As a consequence, costs of restorations and maintenance typically dropped by about 50% because of significantly higher planning safety (achieved by significant, reliable, and clear results).

Keywords: Timber inspection, resistance drilling, color coded condition inventory

Introduction

More than 2.5 Mill historic half-timbered buildings and more than 5 Million buildings with wooden ceiling beams have to be preserved in Germany as good as possible due to regulations on historical monuments as the cultural heritage. More than 200 Billion Euro are spend for buildings in Germany every year. Approximately 60% of the building budget is spent for restoration and repair of existing buildings. However, the education of architects and engineers still mainly focusses on design of new buildings.

Between 1 and 3 Billion Euro are spent each year for preservation of historical monuments, mostly at least partially financed by taxes or lottery funds.

Approximately 5% of new houses are built with structural timber (+10% p.a.). The inspections of 'new' timber buildings (built > 1950) is growing, due to poor quality of design, wrong use and missing maintenance.

As a consequence, the need for non-destructive timber inspection increases. However, specific boundary conditions have to be regarded:

- Architects and engineers are still mostly paid a percentage of the total costs (thus are not primarily interested in saving costs, especially if public money is involved).
- If a building is 100, 200 or even more years old and does not show significant deformation, the timber structure is supposed to be strong enough and then only decayed parts of the structure have to be replaced. That's all! There is no need for structural analysis and calculation of load carrying capacity.
- If there are significant obvious deformations or the future use of the building will bring in more load (less than 5% of all cases) then stiffness and strength of beams have to be determined. Based on the market, the client's needs and the given boundary conditions, we developed a concept how to inspect timber structures in a fast, efficient and reliable way.

Major objection and tasks of our inspections

Non-destructively creating an easy to understand and clearly visible status report on timber structure condition without harming other (historic) fabric:

- ▶ create/modify sketch of construction covering all relevant timber beams
- ▶ determine dimensions of timber cross-sections and connections
- ▶ reliably identify decayed and intact parts of beams and connections
- ▶ (sometimes: determine MOE and estimate MOR)
- ▶ visualize results in color inventories (rather than writing long text reports)

The inspection concept was developed in cooperation with architects, engineers, carpenters and administrations. Meanwhile, several thousand buildings have been successfully inspected.

Major steps of the inspection are

1. Create new or modify existing sketches of the construction.
2. Visually inspect all accessible parts (condition, external defects, dimensions of beams, previous repairs) - often major part of total work to be done.
3. Technical measurements:
 - 3.1 moisture content measurement
 - 3.2 resistance drilling (with calibratable machines only, such as Resistograph®)
 - 3.3 stress wave timing (for example using impuls hammer or Arbotom®).
4. Documentation of all results and all relevant information about timber condition into a few graphical sketches by avoiding long text reports.

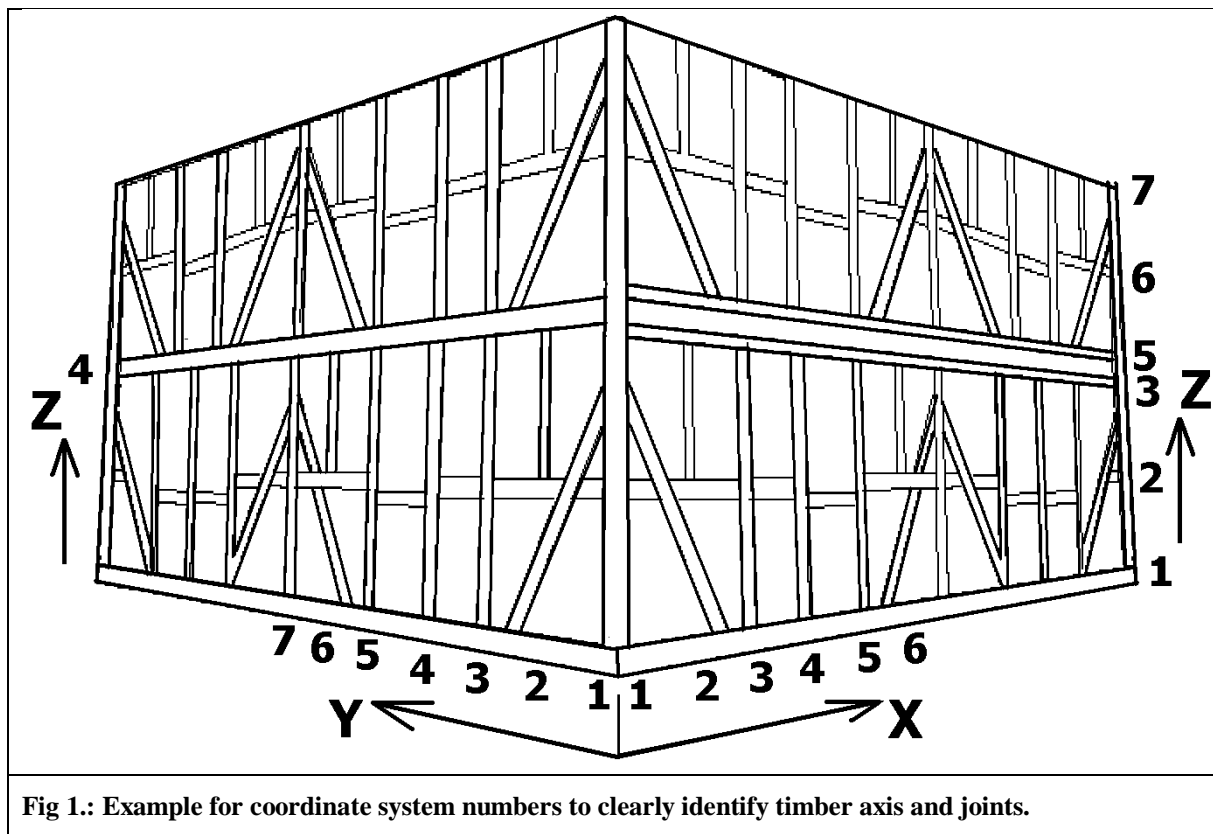


Fig 1.: Example for coordinate system numbers to clearly identify timber axis and joints.

Basic sketch for colored inventory

All relevant beams have to be shown in at least one of the sketches. A coordinate system reliably identifies each beam and connection.

The demands made for an inventory regarding the timber construction can be easily formulated:

- 1 All pieces of timber relevant for the statics of the construction must be drawn in at least one plan.
- 2 When possible, no piece of timber should be drawn on top of any other.
- 3 The relative position of the beams to each other must be correct.
- 4 Great deformations relevant to the static construction must be included.

Unfortunately, it can be determined that existing inventories often do not fulfill these conditions. The common ground plans at approx. 1 meter height over the ceiling beams are useless for this purpose. It has proven better to draw up a new schematic sketch of the construction according to the above-mentioned conditions instead of trying to correct existing plans.

In some cases it makes sense to examine the hidden timbers in the ceiling by means of thermography. Up to now, this technique can predominantly be used in winter, because great differences in temperature are required.

Visual (ordinary) inspection

This first part of the inspection is often the major part of the total working time and usually consists of the following steps:

1. Look for external decay (by fungi or insects).
2. Knock on all beams and connections with ordinary hammer
3. Use handcraft tools to check in all suspicious holes/connections
4. Take samples from insect or fungal decayed parts and determine decay species.

5. Check quality of previous repairs and replacements.
6. Look for and measure major deformations.
7. Try to find reasons for decay and other defects.
8. Document all results in colored sketches.
9. Determine points where technical inspection is required.

At the end of the visual ('conventional') inspection, the colored sketch already contains a lot of information but has many white spaces where condition of the corresponding beams is still unknown.

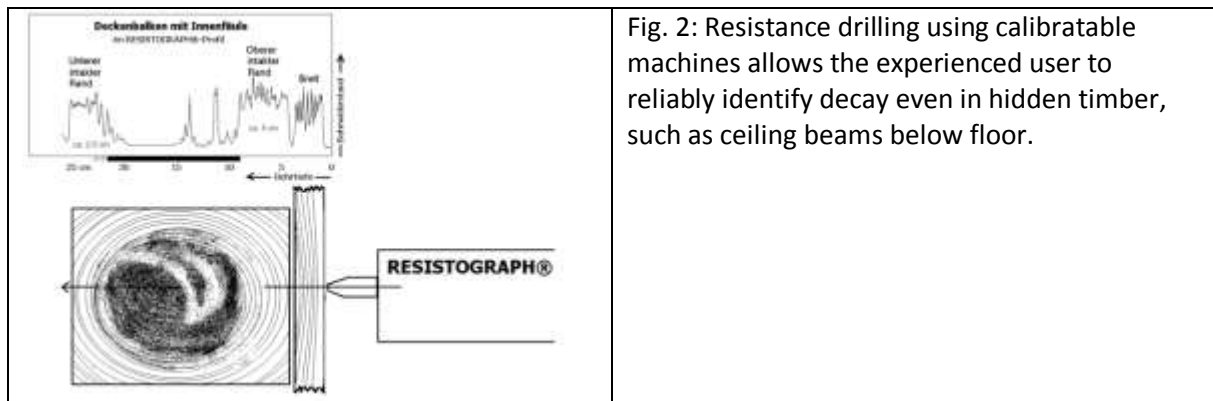


Fig. 2: Resistance drilling using calibratable machines allows the experienced user to reliably identify decay even in hidden timber, such as ceiling beams below floor.

Technical inspection

When visual inspection was not able to clear all questions or if hidden beams have to be evaluated, technical methods are used in order to answer the remaining open questions:






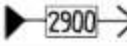

1. Relative moisture content.
2. Drill resistance measurements
 - a. find hidden beams behind stucco or below flooring
 - b. assess depth of obvious outside decay or cracks (e.g. in glue-lam)
 - c. check internal condition (of visible and hidden beams and connections)
 - d. determine gross density (after calibrating drilling machine)
3. Stress wave timing: speed of sound, detect hidden cracks or connections
4. Combine (not only numeric) results, e.g. $\text{density} * \text{speed}^2 = \text{MOE}$
5. Document all measurement points and all results in colored inventories.

Having inspected a timber structure visually and technically may lead to great results but does not help preserving historic fabric or making repair efficient if the experts planning and executing the repair work do not understand the results in an easy and clear manner.














Based on the success of the application of resistance drilling for inspecting timber starting 1986, we then developed a concept how to document inspection results that provides more precision and reliability but is, at the same time, more easy to understand for both engineers and carpenters.

LEGEND FOR DOCUMENTATION OF RESULTS OF VISUAL AND TECHNICAL TIMBER INSPECTION: INVENTORY WITH COLOURED CHARACTERIZATION OF CONDITION, OTHER PROPERTIES AND RESIDUAL CROSS SECTION

RESISTOGRAPH®, MOISTURE- UND STRESS-WAVE MEASUREMENTS

	NO OF RESISTOGRAPH®- MEASUREMENT (CALIBRATABLE MICRO-RESISTANCE-DRILLING)		DIAGONAL IN / OUT DRAWING PLANE
	MEASUREMENT IN/OUT DRAWING		RELATIVE MOISTURE CONTENT [%]
	MEASUREMENT		APPARENT STRESS WAVE SPEED [M/S]
	PHOTO-NO.		

CONDITION CODING

	NOT INSPECTED		REMOTE EVALUATION: NO SIGN OF DAMAGE
	3 DELAMINATIONS IN PROFILE		NO DAMAGE/DECAY DETECTED
	INPROPER REPAIR		SURFACE DECAY (<~ 1 CM)
	VISIBLE DEFORMATION		CROSS SECTION LOST <~ 30%
	INTERNAL / EXTERNAL DECAY		CROSS SECTION LOST > ~ 30%
	CRACK / SPLIT		MANY KNOTS
	GRAIN DEVIATION, CIRCULAR GROWTH		

CONSTRUCTIVE SYMBOLS

	EXPECTED TIMBER		FUNGAL / INSECT DECAY
	NO FORCE LOCKING		MISSING WOOD WANE [%]
	DESTROYED WOOD NAIL		NO FORM LOCKING
			METAL CONNECTORS






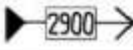

Q C GL WOOD SPECIES: OAK (Q), CONIFER (C), GLUE-LAMINATED BEAM (GL), ...

AREAS WITHOUT COLOUR HAVE NOT BEEN INSPECTED (DUE TO ORDER OR ACCESSIBILITY). IN AREAS WHERE NO DRILLINGS WERE CARRIED OUT, THE CONDITION EVALUATION IS ONLY BASED ON VISUAL INSPECTION, THUS WITHOUT RELIABLE DETERMINATION OF THE INTERNAL SITUATION.






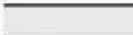


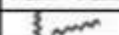

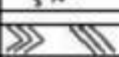

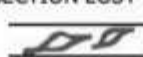
Fig. 3: Legend of colored inventory sketches showing the condition of timber in three major colors and describing additional signs for specific symptoms identified at a beam or structure.

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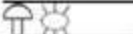


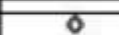


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Fig. 4: Black and white copy of the condition legend still providing three major condition markers reliably differentiated by different grey scales.

Documentation concept

The first step forward coming from black and white sketches of timber structures with shadings for marking decay was to use colors. But, in order to make the drawings as easy as possible to read, the number of main colors had to be as small as possible, at most three or four.

At the time we developed our concept (late 1980ies / early 1990ies), color copies were still quite expensive, especially if printing in larger than standard letter sizes. The colors thus had to be selected in a way that allows black and white copies still providing the major information about decay and condition (Fig. 3). Consequently, we selected red (extensively decayed), orange (mean decay), and yellow (intact) as the major colors – because they can be differentiated easily on the first view and because black and white copies still show the three colors reliably in differentiated types of grey (Fig. 4).

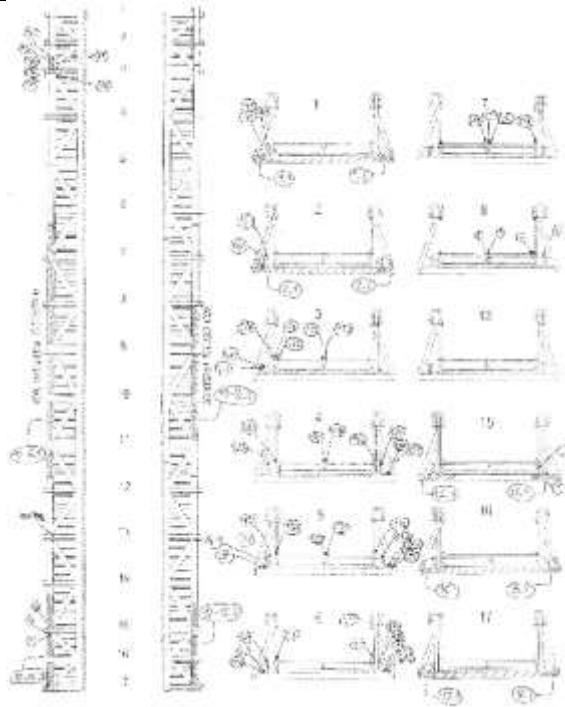
The traffic-light color scheme, green for intact), yellow for partially decayed, and red for strongly decayed parts, was no option because of several reasons: in a black and white copy, green was commonly darker than red, leading to a wrong impression about the condition of the corresponding parts. In addition, structural engineers in Germany commonly used green for marking structurally relevant, local aspects and symptoms, such as cracks.

The biggest step forward was introducing a color for marking parts of timber that were inspected (either visually, by tapping and/or resistance drilling) and where found to be intact and sound. This means, if a beam was tested in whatever kind and no sign of decay was found, this beam is marked with a certain color.

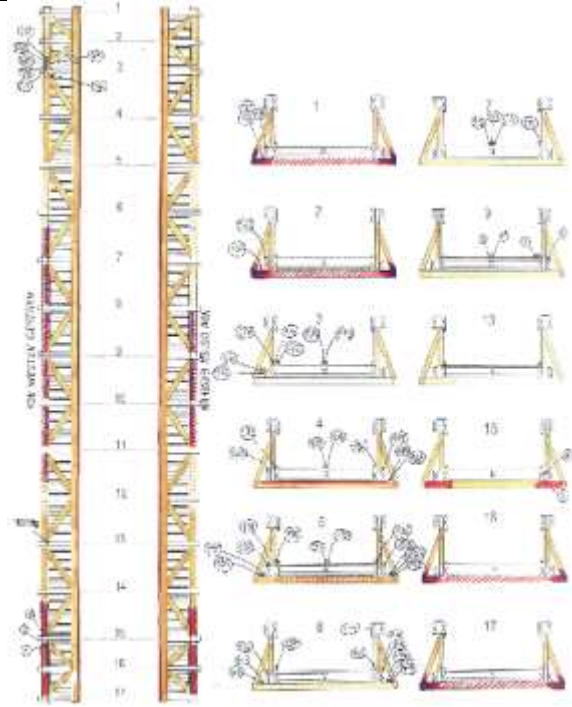
For the first time, this way it was possible to distinguish between the sections of a timber structure that were not inspected (no color) and the parts that were inspected without finding damages (yellow). This may sound as a tiny little aspect but changed a lot because from then on later planning and working steps did know what parts of the structure they can rely on without doubting whether these parts had been checked or not (because there was no decay marked).

Another big step forward was combining as many parts of the usually many individual sketches of a structure as possible into one single overview drawing: this reduced the total number of sketches representing the condition of a structure often from 10 to 1 or 2 – making it much easier for engineers and architects as well as for carpenters getting an overall impression about the condition of the bridge or structure as a whole. In addition, the overview given by a single sketch with a color coded condition inventory allows the identification of connections between sources and reasons of different spots or areas of decay. That means, these overview inventories provide a base for a much deeper understanding of the structure as a whole instead of only working locally on repair of individual parts.

Fig. 5:
 Typical timber bridge to be inspected because of decay (although made by tropical hardwoods).



Conventional black and white damage map of a timber bridge. Originally it was common to mark decayed parts with a certain kind of shading and a label that refers to the text list position of the corresponding description of the found damage. Such a drawing consisted usually of 18 individual sketches of each axis and was accompanied by many pages of text within the report.



Colored version of an inventory map showing wood condition in different colors. The colors do not only reveal where decay was found but furthermore show what parts of the structure were found and proven to be intact. Because colors allow the reader to much easier identify damaged areas, such a combined sketch replaces many conventional drawings.

Practical working steps

Commonly we prepare the basic drawings of structures before the technical inspection starts. Such structural sketches have to show all relevant timber parts that belong to at least one plane of the structure or are connected with this plane. While doing that, we try to avoid showing different beams in one sketch that in reality overlay each other and represent different planes – because it is impossible to show correct colors if these beams have different conditions and thus would have to be characterized by different colors overlaying each other.

Usually, the sketches are prepared in a larger size and scale for enabling the inspector on site to put in all relevant information while inspecting - as one of our major goals was to avoid text notes but reveal all relevant aspects in the sketch. And, all evaluations should be done on the spot without having to go back to office and again work on profile analysis and come to a conclusion that, for example, additional assessments are required. This is time consuming and inefficient. Our goal was to always come to a final conclusion about the condition of timber on site while inspecting because only on site at the structure you can just tap or drill another time at another spot in order to confirm unclear results or suspicious symptoms. The highest (cost and time) efficiency we always achieved when the inspection came to a final conclusion on the site and when all relevant results were documented in the color coded inventory map on site. This drawing has then only to be reproduced in the office and surrounded by a short text note.

The reproduction of the colored on-site drawing is usually done by a reduction factor of 4. These squeezed sketches then represent the most significant part of the report. In addition, the report usually contains some illustrating pictures and a short text summary with recommendations. Even the recommendations for repair work can be partially included in the color coded sketch because lines may be implemented indicating where and how damaged beams should be cut and/or replaced.

All this fits to the traditional German saying: “A good drawing is the language of a good engineer”.



Fig. 6: Example for a simple, combined plan presentation of a half-timbered building. On top of the facade the complete rafter plane of this side is drawn. Such a combination allows for one, the recognition of possible reasons for damage, if, for example, the leaky roof has caused damages to the rafter foot points as well as to the purlin and the post head underneath it in the facade. In individual inventory plans with individual rafter axis and facade drawings, such correlations are often overlooked.

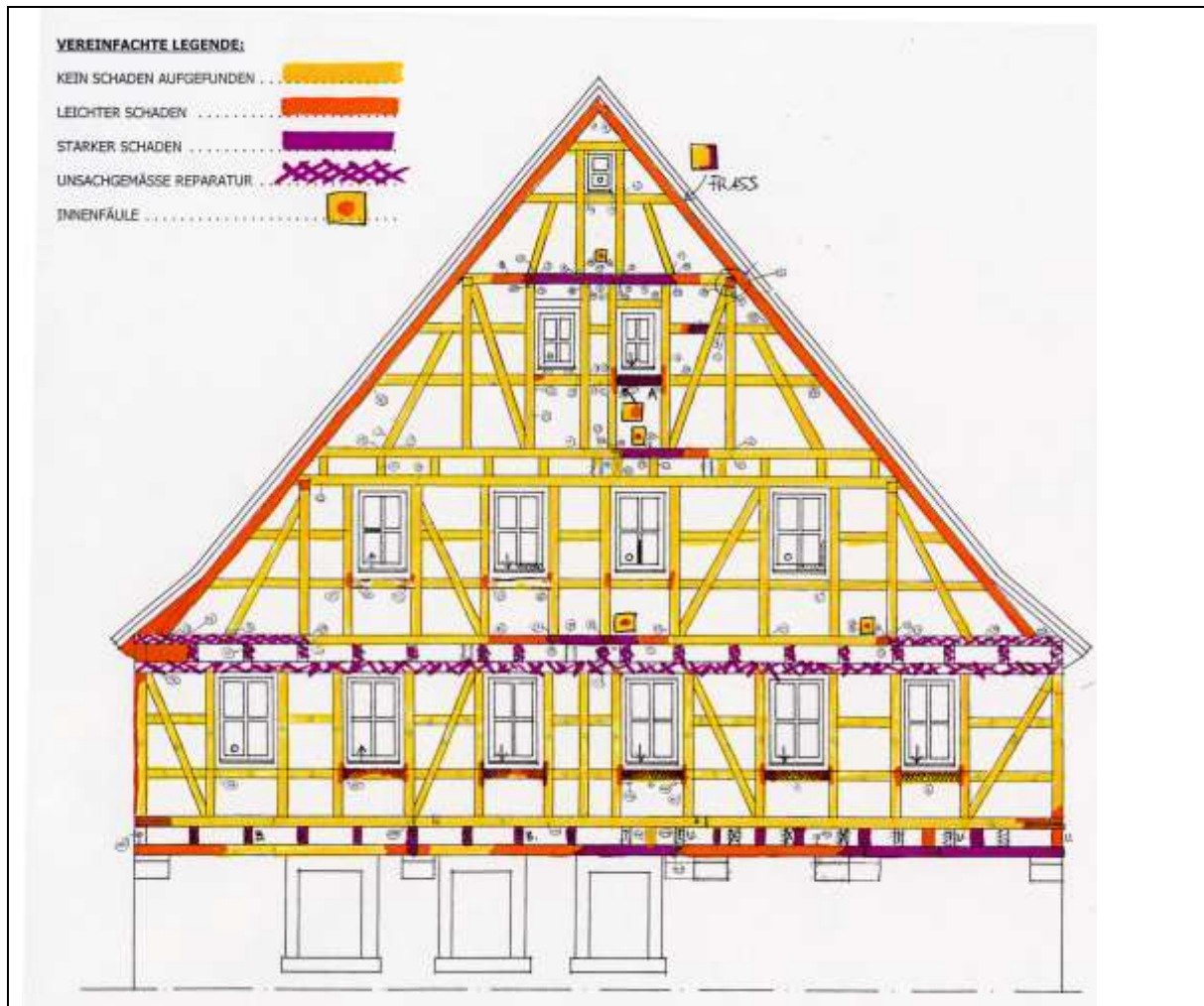


Fig. 7: Overview sketch with a simplified color coded condition inventory. This inspection was carried out by one person on one day including the drawing of the inventory what is usually done on site.

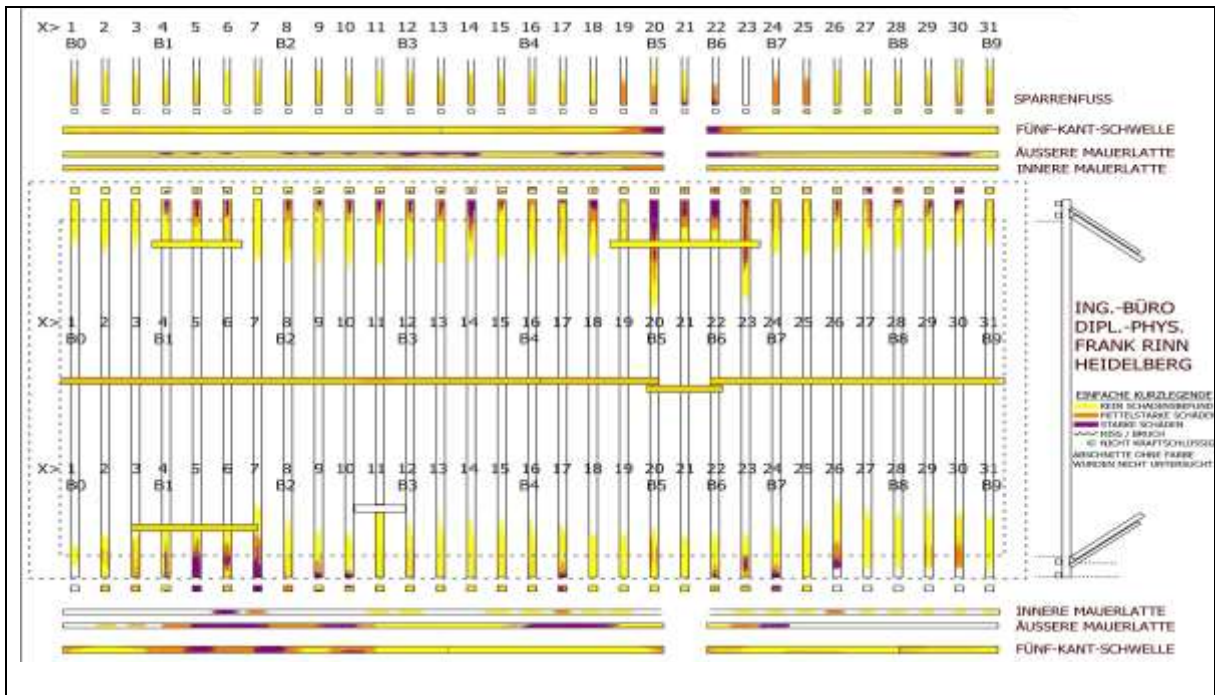


Fig. 8: Ceiling beams of a historic church plus underneath wall beams and the foot parts of looming rafters. This one sketch replaced several dozen sketches of all axes of conventional documentations.

Consequences

Practical application of this concept in several hundred real market projects of very different size scales proved its suitability and led to a significant increase of planning safety and furthermore to dramatically reduced total costs.

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