COST Action FP 1402

Short-term Scientific Mission 2017, Trondheim

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STSM Report

1. Purpose / objective of the STSM

Existing constructions gain of importance in the building economy. One reason is an increasing need for living spaces in city centres and therefore revisions of existing structures due to change of use or damage are necessary. Energetic optimisations of existing structures can also lead to changes of structural elements. Furthermore, the preservation of cultural heritage is always of great societal interest. Thus, a qualified assessment and retrofitting of existing structures in situ is necessary. However, only some standards exist for the assessment of existing structures, most of them are national rules.

The prerequisite to a professional evaluation of existing constructions is a qualified survey in situ to gain valuable information for the reassessment. The level of detail of the survey has to be reasonable, this depends on the characteristics of the structure at hand. On one hand, an extensive assessment using technical devices to gain data that is processed by advanced probabilistic methods is not always necessary for smaller projects. On the other hand, probabilistic methods enable the engineer to model a structure quite appropriate and unnecessary intervention might be prevented which is especially relevant for construction heritage. Hence, different needs and requirements have to be taken into account, which is a challenge when standardising requirements for the assessment and retrofitting of existing structures.

Therefore, an adequate and standardised evaluation procedure is needed. It has to consider different levels of assessment and detail of modelling. Some approaches for the reassessment of historical buildings already exist. However, these approaches do not include all recent developments in the field of structural engineering and risk based decision making as they are applied in e.g. the reassessment of offshore structures. A clear need for the advanced basis for the reassessment and appropriate retrofitting of historic structures is identified. What is more, a great amount of historic structures are made from timber or contain wooden load-bearing elements.

This Short-Term Scientific Mission at NTNU, Trondheim aims to develop a procedure for the evaluation of existing timber structures. The level of detail of the survey on site and the intended design level are taken into account. Furthermore, options and decision criteria for the treatment of historic structures are defined.

2. Description of the work carried out during the STSM in Trondheim

2.1. Preparation for the stay in Trondheim

Preparing for the STSM, already existing procedures for the assessment and retrofitting of existing structures have been collected, analysed and open research fields have been defined. What is more, a first draft for an evaluation procedure containing different levels of design and investigation has been developed as a basis for further discussion in Trondheim.

2.2. Work carried out during and after the STSM

2.2.1. First approaches

During the STSM, methods to derive reasonable decisions have been discussed first. The decision tree developed by Benjamin & Cornell has been analysed regarding its applicability in an assessment and evaluation procedure for existing timber structures. Its application has been tested. It has been decided that due to a huge amount of unknown data a clear quantification of decisions, i.e. clear pre-posteriori decision making, is often not possible and not practicable for every-day engineering work. This is why a stepwise procedure including an increasing level of detail has been developed for practical application.

2.2.2. Chosen approach

Different possibilities of gathering information during a qualified survey in situ have been discussed and connected to the Knowledge Levels of JRC Science and Policy Report 2015 [1].

Kl 0 – basic:

- possible when no significant damages (biological, chemical, mechanical) are existent
- visual inspection of geometry and material properties in accordance with planning documents if available
- rather rough inspection without grading the material
- semi-probabilistic evaluation based on a distribution function representing the in historic structures relevant timber grades

KL 1 – limited:

- visual inspection of geometry and material properties in accordance with planning documents if available
- visual classification of material into grading classes
- semi-probabilistic design using characteristic values from EN 338
- partial safety factors consistent with the target reliability of EN 1990:2010-12

KL 2 – normal:

- visual inspection and non-destructive testing with technical devices in situ in accordance with planning documents
- visual grading supported by non/semi-destructive testing in situ
- semi-probabilistic design using characteristic values from EN 338
- partial safety factors for existing timber structures including information of correlated property from non-/semi-destructive investigation (using adapted target reliability as individual material properties are known to a certain extent)
- recommendation of measures using probabilistic optimisation possible

KL 3 – full:

- visual inspection and exhaustive testing (exhaustive non-destructive testing in situ or testing of specimens combined with limited non-destructive testing in situ) in accordance with planning documents
- no grading necessary as actual material properties are determined
- updated of material distribution functions to be used in probabilistic evaluation
- design using FORM/SORM, probabilistic exact methods (e.g. Monte Carlo)
- recommendation of measures using probabilistic optimisation possible

As mentioned within the description of the Knowledge Levels, three levels of evaluation have been taken into account: semi-probabilistic evaluation, probabilistic evaluation, probabilistic optimisation. Due to different available information in different Knowledge Levels, different Levels of Design are possible:

Table 1: Levels of Design for different Knowledge Levels

		Level of Design		
		Semi-probabilistic	**Reliability evaluation**	**Risk/ cost optimisation**
Knowledge Level	**KL 0**	✔ ($R_d > S_d$)	✖ (not enough information)	✖ (not enough information)
	KL 1	✔ ($R_d > S_d$)	✖ (not enough information)	✖ (not enough information)
	KL 2	✔ ($R_d > S_d$)	✔ ($\beta > \beta_t$)	✔ $Min[E(C_{measures})]$
	KL 3	✖ (great loss of information)	✔ ($\beta > \beta_t$)	✔ $Min[E(C_{measures})]$
✔ applicable ✖ not applicable				

2.3. Development of an evaluation procedure for existing timber structures

The aim of this STSM was to develop a standardised and flexible procedure for the assessment and evaluation of existing timber structures. The result is presented in the figure down below (Figure 1).

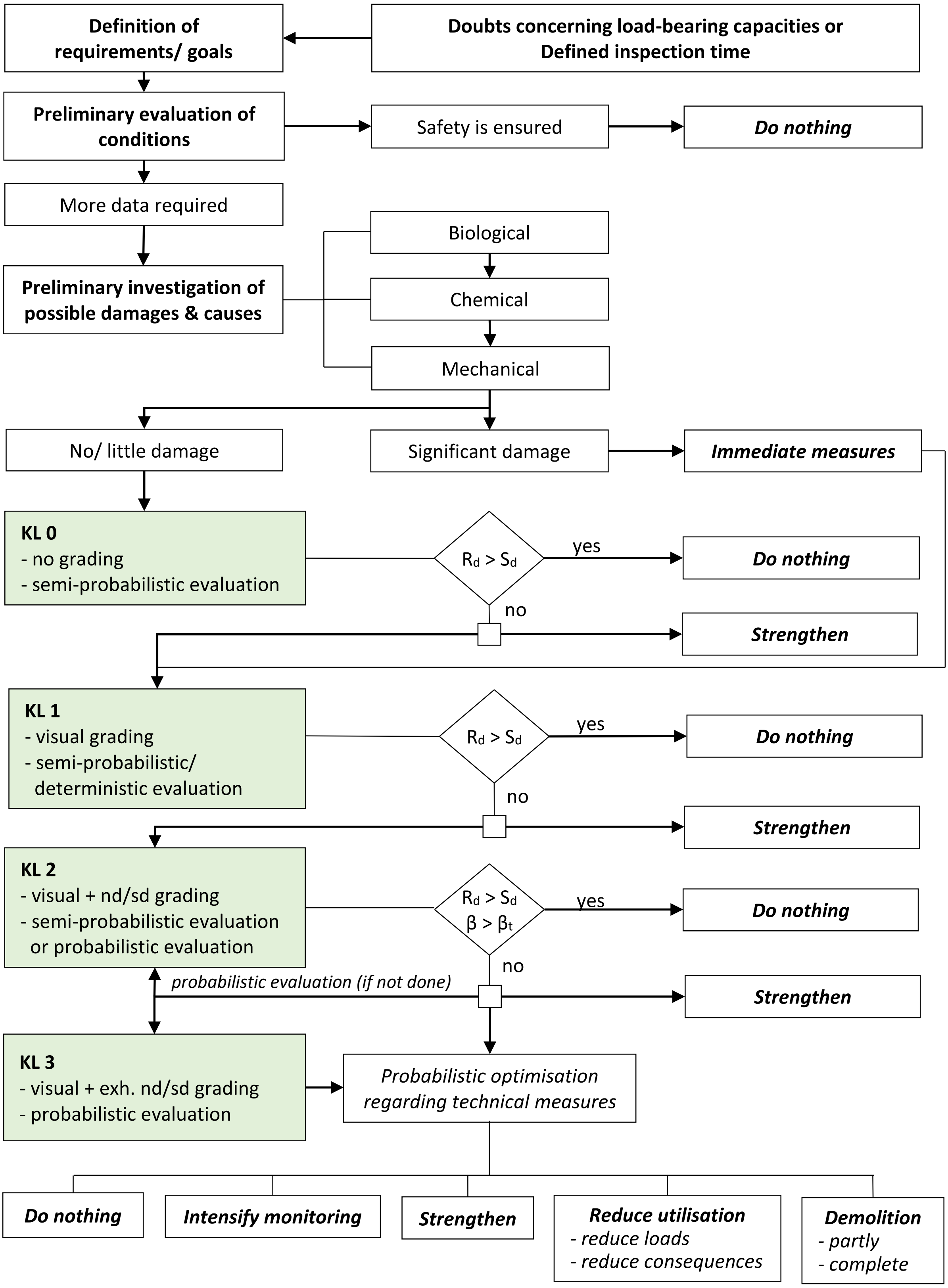

Figure 1: Optimisation-based and practice orientated procedure for the evaluation of existing timber structures

2.4. Particularities of design and verification in different Knowledge Levels

2.4.1. Knowledge Level KL 0

It has been discussed that a very general and rather rough level of detail is needed for some projects. This level enables a verification of load-bearing capacities including a general investigation. However, for this level no damages should be existent. In this Knowledge Level no grading of the material has to be done. A distribution function covering the whole softwood population is needed (Figure 2).

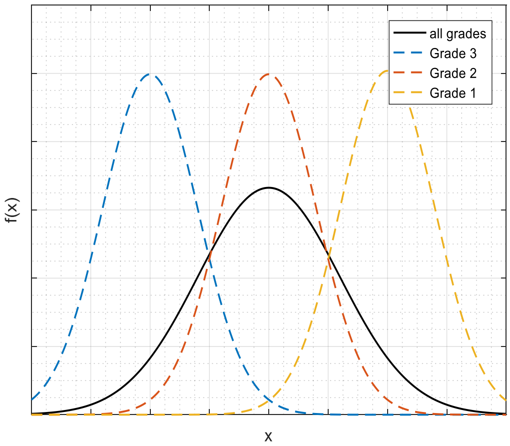

Figure 2: Distribution of material property including all grading classes compared to graded material - qualitative

Regarding current regulations in some countries, this level would not possible at present, as engineers are required to grade the material by authorities (e.g. Germany, Switzerland). However, this procedure is a suggestion for an adaption in the future.

For a semi-probabilistic design new partial safety factors have been derived for the material side. This has been done using the Design Value Method. As coefficients of variation of the material are different in every timber grade, three most important grades have been chosen and weighted. Partial safety factors are determined depending on the material property. As the underlying distribution function covers all the considered grades, it has a high variability. Hence, partial safety factors are high. Probabilistic evaluation and probabilistic optimisation are not possible in this level, as not enough information have been gathered in situ.

If the design value of the material in this Knowledge Level using a semi-probabilistic design is lower than the design value of the load ($R_d < S_d$) the designer has two options:

- Strengthen
- Increase to KL 1

Here it is stated that before a demolition of the structure is considered, the Knowledge Level should be increased first as the level of detail is very rough.

2.4.2. Knowledge Level KL 1

In this level the material is graded in situ by visual inspection. In some countries, historic structures can be evaluated by old standards. Recent drafts for code for existing structures do not support this point of view. As different conditions exist here, deterministic evaluation is taken into the procedure. In current praxis, partial safety factors for a semi-probabilistic design are taken from recent codes for timber engineering (EN 1990:2010-12 & EN 1995-1-1:2010-12). Studies show that the partial safety factors defined in these standards are not consistent with the target reliability fixed in EN 1990:2010-12 Annex C. Using the Design Value Method with fixed sensivity factors partial safety factors are derived which are significantly higher than in current codes when $\beta_t = 3.8$ is used as defined in EN 1990:2010-12. However, these calculations are simplified calculations using a fixed sensivity factor. Probabilistic parameter studies have to be carried out to study the influence of actions and limit state functions on the reached reliability. Research is currently carried out here. If the design value of the material in this Knowledge Level using a semi-probabilistic design is lower than the design value of the load ($R_d < S_d$) the designer has two options:

- Strengthen
- Increase to KL 2

2.4.3. Knowledge Level KL 2

General remarks

In this level, semi-/non-destructive technical devices are used to gather more individual information concerning the material of a special structure. Destructive techniques to gain direct information concerning strength parameters are often not possible for structures that are still in service. With this information a semi-probabilistic evaluation is applicable as well as probabilistic methods. As strength parameters can often not be measured directly, correlations between measured properties and strength properties have to be used to estimate the latter. An illustration can be found in Figure 3

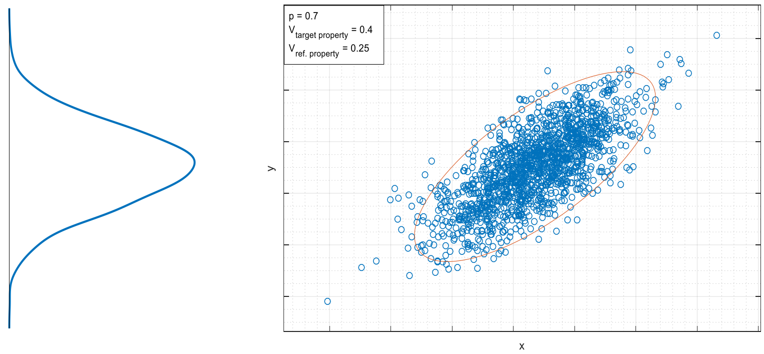

Figure 3: Correlation of reference property (x; e.g. ultrasonic measurement) and target property (y; e.g. bending strength), failure ellipsis with 95% confidence level – exemplary illustration

Semi-probabilistic evaluation

In this semi-probabilistic evaluation, the characteristic vale is not updated. Grading has to be done on side and characteristic values defined in EN 338 shall be used for the design. This has been defined due to simplification for everyday engineering practice. The aim was to adapt the partial safety factor and include the information gained in situ this way. By measurements in situ the distribution function of the property could be updated and another characteristic value could be used. As the characteristic value is kept, adapted partial safety factors are suggested to use the same design point which would be used when applying the adapted characteristic value (see Figure 4).

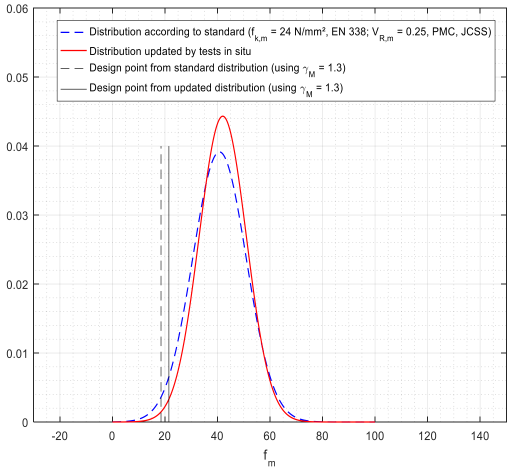

Figure 4: Exemplary update of material distribution of soft wood and comparison of design points

To use the information gained on side, a formula is developed that includes the measurements to derive adapted partial safety factors. Coefficients of variation for material properties and correlation coefficients can be used from Part 3.5 Probabilistic Model Code [2] worked out by the Joint Committee on Structural Safety. If the design value of the material in this Knowledge Level using a semi-probabilistic design is lower than the design value of the load ($R_d < S_d$) the designer has three options:

- Strengthen
- Probabilistic evaluation in KL 2
- Increase to KL 3

Probabilistic evaluation

Using the information of the reference parameters and correlation coefficients, material distributions can be updated for probabilistic studies. An adapted target reliability index can be used as individual information on the structure is available. If the reliability index in this Knowledge Level using a probabilistic evaluation is lower than the target value ($\beta < \beta_t$) the designer has three options:

- Strengthen
- Probabilistic optimisation between possible measures
- Increase to KL 3

Using these updated material distribution functions, a probabilistic optimisation of measures and costs can be done without increasing the Knowledge Level to KL 3.

2.4.4. Knowledge Level KL 3

This Knowledge Level contains an exhaustive investigation in situ and testing in a laboratory. Hence, material distribution functions can be updated directly. As a lot of effort arises, a semi-probabilistic evaluation is not recommended. Probabilistic models can be updated using Bayes Theorem. A probabilistic optimisation regarding possible technical measures is recommended.

This update of information includes material and demand side. For example, information concerning permanent actions can be gained by geometrical measurements in situ, as e.g. determined in SIA 269 [3]. For wind and snow loads it recommended to check for updated information from measurements for the special area. Live loads can be determined by considering past and planned utilisation.

2.4.5. Probabilistic Optimisation regarding technical measures

As for a probabilistic optimisation of technical measures some more information is needed and some more calculations are needed, this option is recommended for KL 2 and KL 3. This optimisation tasks consist of several parts, as for every measure the optimal costs have to be determined. Overall it is a minimisation task:

$$E[C_{Interv.}] = Min\begin{bmatrix} C_{Do\ nothing}; \\ C_{Strengthen}; \\ C_{Reduce\ utilisation}; \\ C_{Demolition} \end{bmatrix} \qquad \textit{Eq. 1}$$

Here the costs of every measure refer to the optimal costs for the individual case. To find the optimal costs for every measure an optimisation task for every possible measure has to be solved. This overall minimisation tasks consists of discrete and continuous optimisation tasks. The discrete part is a decision between the possible measures shown above whereas a continuous decision is part of some analyses to find the optimum of a certain measure (e.g. design parameter in option "strengthen").

2.4.6. References

[1] P. Luechinger, J. Fischer, C. Chrysostomou, G. Dieteren, F. Landon, S. Leivestad, N. Malakatas, G. Mancini, J. Markova, S. Matthews, T. Nolan, C. Nutti, E. Osmani, G. Rønnow, J. Schnell, P. Tanner, S. Dimova, A. Pinto und S. Denton, *New European technical rules for the assessment and retrofitting of existing structures*. Luxembourg, 2015.

[2] Joint Committee on Structural Safety, "Probabilistic Model Code. Part 3: Resistance Models: 3.5 Properties of Timber", Joint Committee on Structural Safety, 2006.

[3] SIA 269:2011, *Grundlagen der Erhaltung von Tragwerken*, 2011.

3. Summary of the main results obtained

The main result of this STSM is the development of an evaluation procedure for existing timber structures including different levels of investigation and different levels of design. This procedure is practice orientated and applicable on different kinds of projects. Detailed information on every Knowledge Level is given, some parts require an extended research. Possibilities to define assumptions are given, adaption to extended knowledge at a later state is possible. The stepwise information including process can be illustrated and summarised as shown in Figure 5.

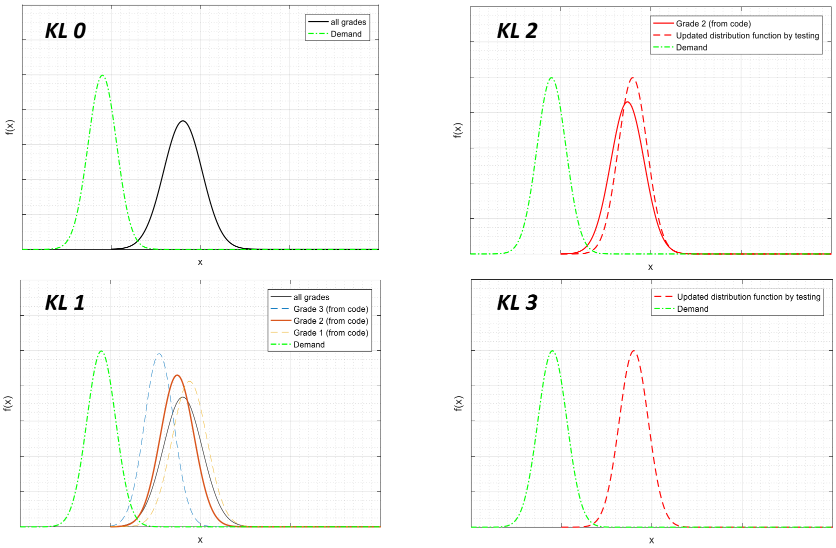

Figure 5: Stepwise procedure to take into account information gained in situ

A hypothetic example has been analysed to evaluate and improve the procedure assuming enough information to use quantified methods of decision making. Application on a real practical example is planned. The procedure can be used for the development of a code for existing timber structures.

4. Future collaboration with the host institution

The work done during the STSM will lead to at least one journal publication. Further collaboration will be decided once this publication is issued successfully.

5. Foreseen publications / articles resulting from the STSM

An article is currently worked out. It provides the procedure for the assessment and evaluation of existing timber structures presented in this document and contains more detailed explanations for every assessment and evaluation step. An application example will be included. The article will be submitted to an international scientific journal. The submission is planned until the beginning of July 2017, as last details are currently worked out and planning documents of the application example have to be analysed and included.

6. Appendix:

Confirmation by the host institution of the successful execution of the STSM

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COST FP1402

COST FP1402 – Confirmation of successful execution of STSM

Trondheim, 19.06.2017

To whom it may concern.

Within the COST action FP1402, Maria Loebjinski carried out a STSM at NTNU in Trondheim, Norway from 9.–19.05.2017.

As host institution, the Institute of Structural Engineering herewith confirms the successful execution of the STSM.

Best regards,

Jochen Köhler

Prof. Dr. Jochen Köhler