Modeling the properties of strength graded timber material

Jochen Köhler, Markus K. Sandomeer

ETHZ, Swiss Federal Institute of Technology Zurich, CH-8093 Zurich, Switzerland

jochen.koehler@ibk.baug.ethz.ch sandomeer@ibk.baug.ethz.ch

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ABSTRACT

The subordinate goal of the COST Action E53 is to increase the market share of wood based products in the construction-, furniture- and other related sectors by means of advanced methods for quality control. A prerequisite for the development of strategies for quality control is that the requirements of the end users are considered carefully. In the present presentation user requirements for wood and wood products are first discussed in general and then the specific requirements for timber as a structural material are discussed.

BACKGROUND

According to the presentation of Gerald Reiner at the COST E53 meeting in Sopron (2006) [3] there are two different strategies of quality control enhancement – progressive and reactive (*Table 1*).

Table 1: *Strategies of quality control enhancement – progressive and reactive [3].*

STRATEGIES FOR ENHANCING QUALITY CONTROL	
PROGRESSIVE	**REACTIVE**
More possibilities by better control/knowledge of properties.	**Better quality of existing products.**
Increasing market share by means of exploring new products and markets.	**Increasing market share by means of increased customer contentedness.**

It is important that the focus of this COST Action is not only directed on reactive aspects of quality control enhancement. The quality control of the whole timber production chain has to be considered closely starting from harvesting logs and ending at e.g. the development of new solid or engineered timber products.

After sawmilling the timber is graded to the product 'graded material' which is utilized to produce timber structures. For the end-product 'timber structures' there are different user requirements as indicated in *Figure 1*. Structures which fulfil these requirements are competitive and will stimulate the demand for forest products in the construction sector. The efficient quality control with relation to the requirements as well as to the end product (timber structure) is also illustrated in the graphic and performs a close and interacting relationship with triangular shape.

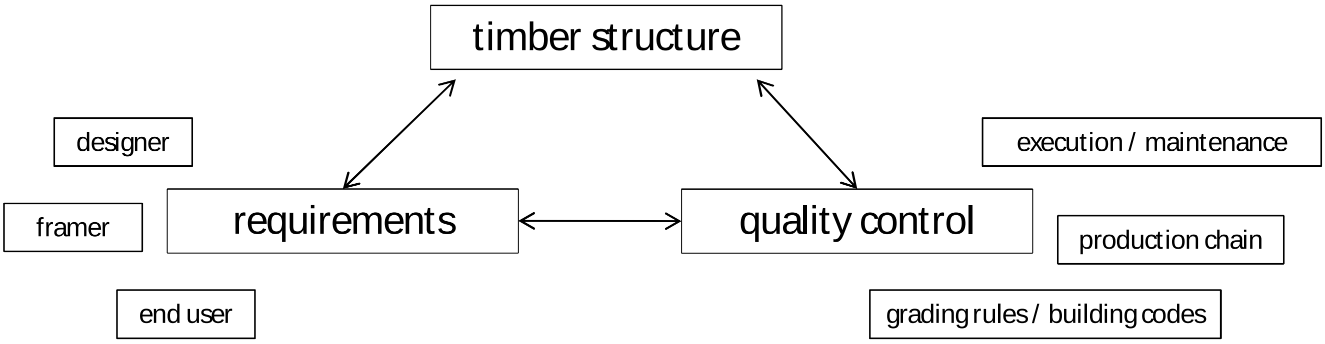

Figure 1: *Interrelationship between the end product (timber structure), the product requirements and quality control.*

The end users of the structure will state their preferences in regard to the building material to be used in the contracting phase, more or less detailed. Of course they will support their decision on the expectation that their preferences (requirements) will be fulfilled by the chosen material. The architect or engineer who performs the design and detailing will have some freedom to choose his preferred material or will influence the stated preferences of the end user with adequate consulting. The timber framer will not decide which building material will be used, but he will look for proper timber material at the market.

Table 2: *Requirements for structural timber according to different pressure groups.*

designer	framer	end user
<u>explicitly:</u> sufficient strength, stiffness and density	- correct target moisture content	- reliability
	- appropriate form	- serviceability
	- sawing accuracy	- durability
<u>implicitly:</u> cp. framer next column	- sufficient durability	- good appearance
	- good appearance	- value for money
	- price value	- …

Table 2 shows the particular requirements of the affected pressure groups. For designers mechanical properties like strength, stiffness and density of the material are of special importance for the design of the load bearing constructions. Rather physical properties related to moisture content, form and appearance are assessed with regard to the general market situation. However, the latter properties are also the crucial quality requirements for practitioners / timber framers.

To ensure the mentioned requirements to be fulfilled, the timber research and code authorities provide the timber building sector rules and guidelines to produce the end product “timber structures”. This includes also codified grading rules to insure properties as sufficient strength, stiffness and density. Therefore grading of structural timber becomes an important core element in the field of quality control.

Traditionally, codes are very much based on experience. However, recently codes are to a large extend also drawn upon a rational support, where reliability and serviceability are considered explicitly. Modern building materials are defined on basis of required properties which are assessed probabilistically. The probabilistic modeling of timber material properties can be performed by directly analyzing graded timber material. This includes the consideration of all possible combinations of different grading schemes and raw material, since these two conditions are crucial for the statistical characteristics of graded sub-populations. It is therefore of utmost importance that existing grading provisions allow for the formulation of consistent probabilistic models of the grading procedure itself – not only for properties of the material which is already graded.

GRADING STRUCTURAL TIMBER

Reliability analysis of structures for the purpose of code calibration in general or for the reliability verification of specific structures requires that the relevant failure modes are represented in terms of limit state functions. The limit state functions define the realizations of resistance parameters, i.e. the material properties and the load variables resulting in structural failure. In reliability analysis of timber structures the probabilistic modeling of the material properties is an issue of special interest due to the particular way this material is "produced".

Considering timber as a natural very inhomogeneous building material the material properties are a product of e.g. the specific wood species and the geographical location where the wood has been grown. Given species and geographical location the material properties depend on factors such as the age, the diameter of the timber logs and the number of knots together with the moisture contents and the duration of loading. In comparison to other building materials such as steel and concrete, the properties of timber materials are not designed or produced by means of some recipe but may be ensured to fulfil given requirements only by quality control procedures – hereafter referred to as grading. Quality control and selection schemes are implemented in the production line, typically already at sawmills where the construction timber is produced from the timber logs. Various schemes for grading have been developed using different principles, however, the basic idea behind them all is that the material properties of interest such as, e.g. the ultimate compression stress, are assessed indirectly by means of other properties such as e.g. the density or the modulus of elasticity (see for example Madsen [4], Walker et al. [5] and Green and Kretschmann [6]).

The Strength Class System

As a result of grading, timber is provided to the market as a graded material. The grades imply that the material properties lie within desirable and predictable limits. However, the material properties of timber grades have to be considered as random variables and the properties of timber grades are characterised (and communicated) through specific fractile values of the assumed probability distribution functions of the material properties of interest.

In general, structural timber is assigned to a specific strength class. Several strength class systems exist on an international scale, e.g. in Europe it is the EN 338 which constitutes the classification of timber based on the prescription of characteristic values for the material properties; i.e. for every timber strength class a characteristic value for every relevant material property is given. Timber that is assigned to a certain strength class is also referred to as a timber grade. In EN 338 the characteristic values for the strength properties and the density are defined as the 5^{th}-percentile values of the underlying distribution functions. The modulus of elasticity (MOE) and the shear modulus are specified by mean values.

Grading Strategies

In general two different strategies of timber grading exist: visual grading and machine grading. Visual grading is based on visual inspection of timber structural elements. Visible defects, such as knots, fissures and cross grain are assessed and according to the appearance of timber structural elements in regard to these defects they are sorted to a certain grade. Visual grading in general is standardized; the first formal visual grading rules, the USA ASTM Standard D245 were published in 1927 (Madsen [4]). Since the 1930s formalized rules for visual grading were introduced in the European countries (Glos in [7]). Visual grading has proven as an efficient tool to reduce the variability of timber material properties, however, the grading effect strongly depends on the person who is performing the visual grading. The statistical characteristics of the material properties of visual graded timber are therefore difficult to assess explicitly based on information about the applied visual grading rules.

The above mentioned disadvantages of visual strength grading may be overcome by machine grading, where a more formal assessment of the grading process can be performed. In contrast to visual grading, machine grading is in general based on indicative characteristics of a timber structural element which can be measured non-destructively by some device. The indicative characteristics have to be related to the basic material properties of interest. Typical indicative characteristics are:

- Directly related to the MOE: flat wise bending stiffness, ultrasonic pulse measurement, frequency response measurement.
- Directly related to the density: measurements of weight and dimensions, X-ray detection.
- Directly related to visible defects: microwave response, optical detection and subsequent image processing.

A good overview about the different measuring schemes can be found in Thelandersson and Larsen [8].

Control of Grading Machine Settings

Commonly, grading machines are operating either machine controlled or output controlled. The output controlled grading system was developed in North America. Control is based on frequent destructive strength testing or proof loading of control samples of the machine graded timber. This system is relatively costly but it permits a modification of the machine settings in order to optimise the yield, i.e. the predictability of the properties of the graded timber material. This method requires large quantities of timber of similar dimension and origin, so that it can be assumed that the characteristics of the timber are stationary. These conditions rarely exist in Europe, where a variety of sizes, species and grades in small quantities are typical. For these conditions the machine controlled systems are developed. Machine control means that the settings are derived within a substantial assessment procedure prior to the operation phase of the machine. The settings are optimised to a representative un-graded timber population which might be typical for the daily use of the grading machine. In general these assessments are done for entire geographical regions, e.g. assessments for the gross supply in France or Scandinavia suggest common settings for certain grading machines used in these countries or regions.

Modeling the properties of strength graded timber material

As already discussed in the first part of this chapter it is the main requirement for the use of timber in load bearing structures that their strength, stiffness and density related material properties can be modeled with sufficient accuracy. This includes a sound representation of all uncertainties involved into these material models, i.e. uncertainties due to the natural variability of the natural grown timber, but also uncertainties due to limited information in form of data, and uncertainties due to mechanical and physical simplifications in the model. As discussed in several publications before [10], [11], [12] , a large part of the uncertainty can be controlled by proper schemes for quality control and grading. Existing schemes for timber grading, however, are not able to represent these uncertainties explicitly. These traditional schemes mainly focus on the qualification of timber in certain sub-populations, whereas the sub-populations are characterized in terms of minimum values of predefined characteristic values for some material properties of interest. The information which can be gained out of these procedures is not sufficient to derive efficient probabilistic models for the material properties of graded timber. As mentioned before, such an efficient probabilistic model for the strength, stiffness and density related material properties is the prerequisite for the safe and efficient use of building materials in load bearing constructions.

It can be seen as a major challenge for the timber producing industry (and the associated research community) to develop grading procedures that allow for an explicit utilization of information during the grading process and use this information for the probabilistic modeling for timber material properties. The method described in the following can be seen as a first step into that direction. Possibilities for its implementation in practice should be discussed in the near future. The COST Action E53 might be a proper platform for these discussions.

PROBABILISTIC METHOD

In the following the very basic principle idea behind the probabilistic modeling of graded timber material properties is outlined. The kernel of the method is a linear regression model of the following form:

$$y_i = \beta_1 + \beta_2 x_{i2} + \varepsilon_i \tag{1}$$

That is, simultaneous observations of the timber material property of interest x_i and the grading machines indicating property y_i are related to each other by Equation (1), where β_1 and β_2 are the regression parameters and ε is the error term.

The regression model can be used to predict the probability density function of graded timber material properties conditional on the settings of the grading machine; given by two limiting values of the indicative properties. The regression model is formulated that kind that new information can enter into the model continuously, i.e. information gained during the grading process can be used to improve the model and to refine its predictions.

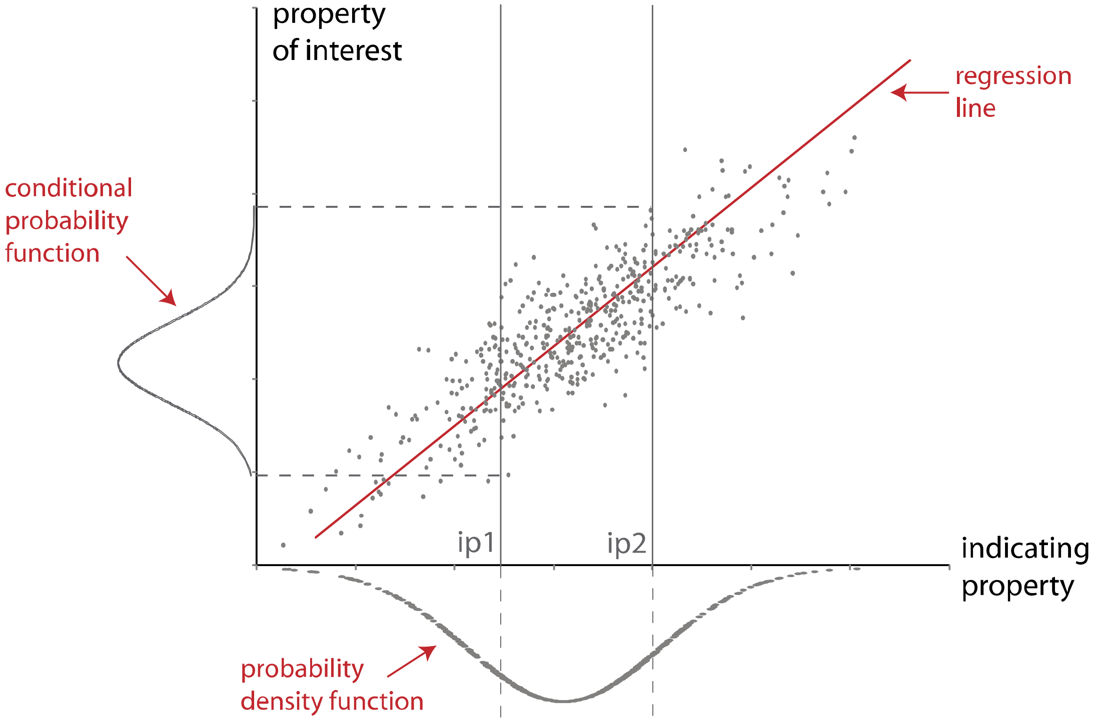

Figure 2: *Alternative approach for the control of grading machine settings, based on the regression analysis. Based on the regression analysis and the probability density function of the indicating property, first an conditional probability function and out of this an predictive distribution function of the property of interest can be assessed.*

CONCLUSION

The probabilistic modeling of timber material properties has been considered with special emphasis to the strength grading procedure of structural timber. The suggested probabilistic approach not only forms a very strong tool for the statistical quantification of the material characteristics of timber but furthermore provides a consistent basis for quantifying the efficiency of different quality control and grading procedures.

It is of utmost importance that the statistical characteristics of timber material properties are assessed and treated in consistency with the implemented quality control and grading procedures. Only then a consistent basis may be established for the quantification of the reliability of timber structures - the basis for codification of design and assessment.

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