# The importance of characterisation and sampling of tropical wood species with regard to strength and durability classification

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**Strength class assignments and durability class assignments of wood species to be used in structures are necessary to make it possible for the engineer to design safe and durable timber structures. As a result of sustainable managed forests, more tropical wood species with relative small batch size, are coming on the market. In Europe, strength class and durability class assignments are allocated to wood species, identified by their botanical name. In practice this gives problems because the trade names may not represent the botanical wood species and the representativeness of the underlying tests is unclear. The objective of this paper is to start a discussion on the classification and sampling of structural timber for strength and durability. It is proposed to make classifications based on measurable characteristics of the timber, independent from tree species.**

***Key words: Tropical wood species, strength classification, durability classification***

## 1 Introduction

In Europe, strength class assignments for structural timber based on visual grading are listed in EN 1912 [1], for durability aspects so called 'Durability classes' have been established which are listed in EN 350-2 [2]. In these assignments it is assumed that the sampling is representative for the timber that is brought onto the market. In general, timber originates from tree species (= wood species) which are recognised by unique botanical names. It seems, that in practice it is very difficult to identify single wood species by anatomical features. In this publication wood species are defined by their botanical name. To deal with the problem of identification of a single wood species the term timber species has been introduced. A timber species is a single or a group of wood species from a defined origin which is marked with a trade name.

For example the trade name cumaru represents a timber species accordingly to the definition above. The trade name can vary by country. For instance the trade name 'cumaru' is used in Brazil whereas in Suriname the trade name 'tonka' is used for the same group of wood species.

A timber species has to be characterised by features which can easily be recognised on-site. Types of identification characteristics of a timber species may be different from wood species. In the case of cumaru anatomical features on genus level of *Dipteryx* and secondary features such as colour are suitable for the characterisation.

The allocation of the timber is related to its trade name and botanical name, and the area of origin of the wood species.

Since the Plant Systematic is based on morphological features of the tree such as flowers, leaves, fruits, etc., these features cannot be used in the later production chain of timber because of their absence. From the nineteen century plant anatomy has attracted attention in relation with wood anatomical features [3]. These anatomical features have been used to identify wood species as far they are distinctive enough. When timber has to be judged at the timber trader's storage or in a laboratory, the relation with a wood species can only be laid by comparison of wood anatomical features. In many cases trade names cover more than one botanical wood species which cannot always be distinguished by wood anatomical features. This common procedure has two drawbacks. Firstly, it is not always possible to identify the delivered timber on 'species' level, but only at a higher hierarchical level of the plant systematic such as 'Family' or 'genus'. Secondly, the origin and the definition of source area is often not clear. The questions raises, how representative the test results are for wood species which are widely spread over continents such as Latin America or Africa.

## 2 Identification and origin of wood material

At present wood properties are related to the wood species, therefore the identification of the wood species is still necessary.

### *2.1* ***Lesser-known wood species***

Most of the timbers from tropical forests (Asia, South America, Africa) for building applications enter the European Market as sawn timber. There are about 500 wood species which have commercially been used [4]. Almost 80% of these wood species belongs to the group 'lesser-known' species. That means that the identification characteristic and/or wood properties are hardly known by the market participants. Very often visual criteria such as colour, grain structure, density are governing the identification of a wood species in practice. Therefore it is likely that 'lesser-known' wood species could be mixed with a defined wood species in the same batch. Because properties are linked to the species, it would be necessary to identify the wood species of each piece of the timber batch.

### 2.2 *Trade names of timber*

Timber is delivered largely in batches under a 'trade name'. Trade names in particular are assigned by individual traders or common names are introduced by the wood industry of single countries.

After the tree is harvested, the trunk will be transported to a dispersal area or straight to a sawmill where the primary conversion takes place. Normally different wood species from different origins are processed at the same workstation. From this stage it is possible that the timber could be mixed because of the same secondary visual characteristics. The timber get a trade name which is used during the following process and transport stages until it arrives Europe.

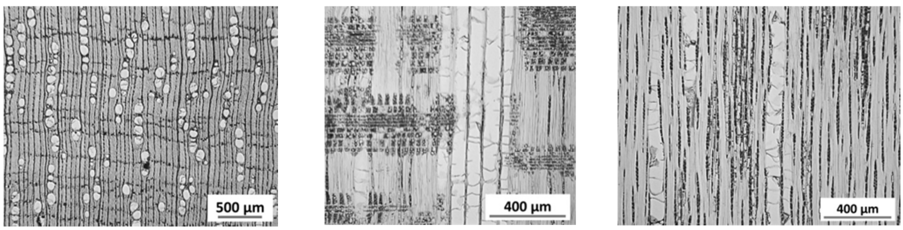
Several attempts have been made to constitute a tabulated overview of common timber trade names in standards with the accompanying scientific name of the wood species [5]. It seems that those lists have a limited validity because of the dynamics of the trade market which changes trade names of wood species and merges wood species under one trade name. The reason for this could be for example the use of secondary identification characteristics such as colour, density and grain texture of the timber but also the decline of availability of certain wood species and qualities .

During transportation of the timber in the countries of origin and/or regions (several countries) the timber can get a different trade names. For example the trade name 'cumaru' has been used in Brazil for an assortment of at least two distinctive wood species *Dipteryx odorata* (Aubl.)Willd. and *Dipteryx alata* Vogel, whereas in Venezuela the trade name 'sarrapia' is common [6]. To make sure that the assortments with these trade names consists of the same wood species, each piece/board should be identified. The common method for determining the wood species is based on wood anatomical characteristics.

In practice in many cases this is impossible because the anatomical features are not distinctive enough or the needed skills at site are not available. To a great extent this applies to assortments which consist of 'less known' wood species.

*2.3 **Wood characteristics***

Wood as a solid material consist of chemical constituents and is built up of elements such as fibres, vessels, parenchyma cells, etc.. These elements are in a certain order, which form different pattern at all three sections of the wood (transverse, radial, tangential) (see figure 1).




a) Transverse section  b) Radial section  c) Tangential section

*Figure 1: Three micro sections of Manilkara bidentata (A.DC.) A.Chev., trade name: Massaranduba [7]*

In some cases the pattern are not sufficient visible to the naked eye or with a magnification of a loupe to identify the wood at 'species' level. An example can be given by the timber species 'cumaru' which includes eight species, only two of them can be identified by small differences at micro scale with regard to the number of cell layers in rays (see figure 2). However a determination at a higher hierarchical level of the plant systematic such as 'Family' or 'genus' would be a reasonable approach for 'cumaru'.

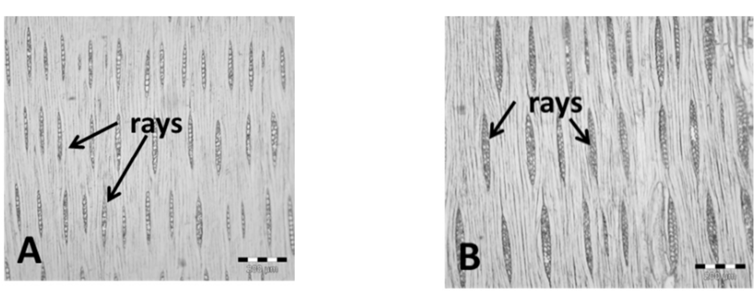



*Figure 2: Tangential micro-sections with rays. A: Dipteryx odorata (Aubl.)Willd. with single cell layer in rays. B: Dipteryx oleifera Benth with multi cell layers in rays. Both wood species belong to the timber species 'cumaru'.*

In addition to anatomical characteristics, chemical compositions could be used to identify wood species. The approach of chemotaxonomy [8] could make it possible to distinguish wood species where anatomical features are unclear.

Different methodologies have been investigated with regard of their sharpness and reliability in order to identify wood species. Because of the easy-to-use approach, near-infra-red (NIR) technology has been widely investigated for this purpose [9]. Other researchers have developed reagents for different wood extractives which leads to distinct colour reactions, which are unique for a single wood species [10,11]. These attempts needs further investigation to introduce these alternatives as a reliable methodology in industry. An advanced method to identify a wood species is based on genetics using DNA fingerprint [12]. This method has been progressing fast during the last decade. Currently several data bases are set up worldwide to collect DNA material of different wood species and growth areas. This method has a huge potential because of the reliability and the distinctiveness. At the moment a drawback of this method is the speed of the assessment. The assessment needs a laboratory environment and cannot be done on-site. However technology is developing and maybe these obstacles could be cleared away in the future.

### *2.4 **Representativeness of a test sample regarding its origin***

The timber species cumaru which consists of several wood species of the same genus, originates from tropical South America. It growths all over Brazil, Colombia, Peru, Venezuela, etc.. From the timber which arrives the European market it is not always possible to trace the source area because batches have been merged from different places. For both strength properties and natural durability testing, samples should represent a population. Currently a population is characterized by a wood species and a growth area confined by country borders. It is known that parameters of the forest stands such as soil, nutrition, micro climate and forest management have an essential effect on wood properties and durability [13,14].

For durability testing a minimum of 30 specimens should be used per wood species and fungus [15]. The minimum size of a sample for assigning a wood species to a strength classes is 40 [16]. In the latter case the strength value has to be downgraded by the application of the so called factor $k_s$ depending on the size and number of samples [16]. Keeping in mind that Brazil is twice of the area of the European Union, the question raises how representative test results are for a certain wood species or wood assortments (timber species), obtained from such small samples for both natural durability and strength values.

### 2.5 *Identification of a sample*

In general a sample should represent a defined population. For instance, actually a sample for strength grading and natural durability is characterised by the wood species and its origin. As discussed above, current procedures for wood identification are not always appropriate. Therefore it would be useful if instead of the botanical wood species other criteria should be introduced to characterise the population.

Beside the wood anatomical characteristics, parameters such as density, DNA fingerprint, NIR profiles, etc. could be brought in for the characterisation. See figure 3.

# 3 Strength class assignments

### 3.1 *Introduction*

For strength class assignments the test results of representative samples should be linked to a visual grade for a wood species. The visual grade is determined by giving limits for strength reducing characteristics. For tropical hardwoods the governing visual characteristics are knots and grain angle deviation. According to EN 5493 [17] these are limited to a knot ratio of 0,2 (diameter of the knot divided by the width of the beam) and a maximum grain angle deviation of 1:10. The representative samples must be tested on three properties according to the European standards EN 384 [16] and EN 408 [18] : The

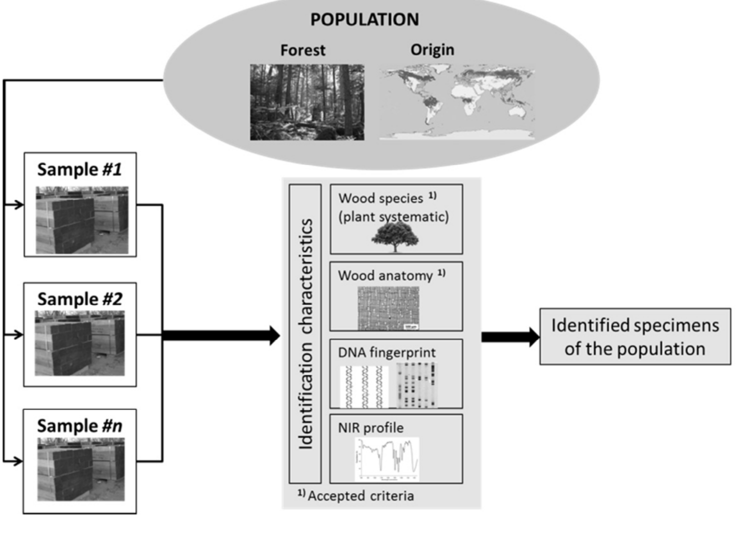



*Figure 3: Identification possibilities for specimens*

density, the modulus of elasticity and the bending strength. From the test results the characteristic values of the samples have to be determined for each property.
The European standard EN 384 [16] gives guidelines how to calculate the characteristic values of the three properties of a wood species for a defined growth area. All tested specimens of the different samples of a wood species, have to comply with the visual requirements of the visual grade. The characteristic values of the species are calculated as follows:

- For the density: the weighted average value of the 5%-values of the samples.
- For the modulus of elasticity: the weighted average value of the mean value of the samples.
- For the bending strength: the weighted average value of the 5%-values of the samples multiplied with a factor $k_s$ . The factor $k_s$ takes into account the number of samples and the number of specimens. The weighted average value of the 5%-values should not be greater than 1.2 times of the lowest 5%-value of a sample. When this is the case the value 1.2 times of the lowest 5%-value of a sample should be used as the characteristic value of the species. According to EN 384 [16] for individual samples the 5%-value has to be determined by the method of ranking. That means that when there are 40 pieces in a sample the 2nd lowest value is the 5%-value and for a sample with 50 pieces the average value of the 2nd lowest value and the 3rd lowest value.]

The factor $k_s$ takes into account the accuracy of the 5%-value of the bending strength of the population, based on the number of samples and the number of pieces within each sample. When only one sample is tested, than the probability that the 5%-value of this sample is also the 5%-value of the population is lower than when the 5%-value of the population is based on more samples. Therefore, a larger reduction of the 5%-value from test that may be assigned to the population is necessary. When the population is perfectly normally distributed and the samples are drawn from this sample, then with statistical theory the $k_s$ factor can be derived exactly for any combination of number of samples and the number of specimen. However timber is a natural material with a large variability, that might not be totally reflected in a sampling with a low number of samples and a small quantity of specimens. It is also unsure if the samples can be regarded to come from one population. Therefore the $k_s$ factor should be calibrated with test results. Figure 4 presents the factor $k_s$ (taken from [16]) as a function of the number of samples and the amount of specimens within a sample. The factor $k_s$ is assumed to be 1, when 5 samples of 100 specimen are tested. However, the values for the $k_s$ factors are based on simulations only on softwood species [19]. It is questioned if these values are applicable for hardwoods. Arguments that the $k_s$ factor might be different for hardwoods is that the samples may come from a wider area, the samples may come from the same genus but from different species and the grade limits for visual characteristics are more difficult to evaluate than for softwoods.

The calculated characteristic values have to be compared with the standardised strength classes tabulated in EN 338 [20]. This table contains the mechanical strength and stiffness properties and the density of a strength class. When all three characteristic values, determined from the testing program are above the values of a strength grade, then this strength grade may be assigned to that wood species for beams fulfilling the visual requirements for the defined growth area. The strength classes are abbreviated with a 'D' (from deciduous) for hardwoods e.g. D50 where the number stands for the characteristic bending strength of that class.

The growth area to which the assignment applies to, is determined by the locations from where the samples were taken. It must be argued that they are representative for the growth area. The minimum growth area that should be applied is a country.

### 3.2 *Case studies with regard to sample number and size*

The case studies give an profound inside of the effect on characteristic strength values by sampling strategies and source area boundaries.

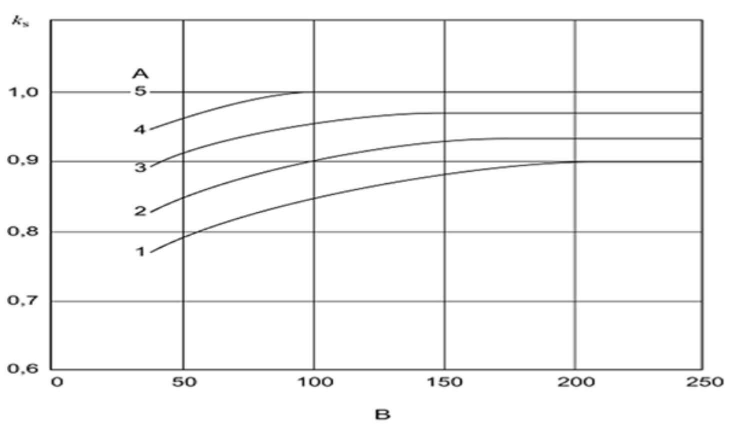



*Figure 4: The effects of the number of samples (A) and the lowest number of pieces within a sample (B) on the factor $k_s$ according to EN 384 [16].*

The influencing characteristics on strength properties should be covered by the samples. These characteristics  could be controlled by parameters such as genetics, growing conditions and processing. In the laboratory the genus (although the current assignment is on species level) and visual characteristics like knots and grain angle can be determined. The selected locations of the samples must take care of the representativeness for the stated source area. Figure 5 shows schematically the different layers of the identification of the wood species and the source area.

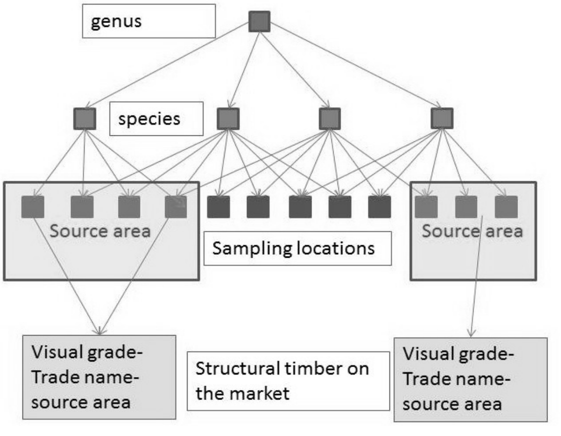



*Figure 5: Sampling strategy of timber considering different identification levels of the wood species*

In this case studies five samples of timber under the trade name cumaru and three samples under the name massaranduba were studied. As mentioned in paragraph 2.3, the timber species cumaru exists of a few wood species which cannot be distinguished so that the level of identification was limited to the 'genus'. The same was applied to the specimens from the timber species massaranduba. This was confirmed by microscopic investigation of the wood anatomical features. For both cumaru and massaranduba it could not be ruled out that more than one wood species was included. It was proven that all specimens from the sample cumaru belong to the timber species cumaru according to the definition above. This was also valid for  the specimens of massaranduba. Table 1 shows the locations and the grade determining properties of the samples of cumaru.  In table 2  the locations and the grade determining properties of the samples of massaranduba are given.  All samples consisted of approximately 50 pieces. All properties-values were adjusted to the reference

moisture content of 12%. The properties show huge variations within and between locations for both cumaru and massaranduba (see table 1 and 2).
Because all samples consist of approximately the same number of pieces the average 5% value could be calculated without weighting the samples When the growth area for cumaru is defined as Brazil, the average value of the 5%-values of the bending strength is 78,3 N/mm². However, the 5%-value of the lowest sample multiplied by 1,2 is 68,9 N/mm². This value determines the characteristic value that may be assigned to cumaru from Brazil. When the growth area would be defined as Brazil + Peru + Bolivia then the average value of the 5%-values of the bending strength is 67,2 N/mm² , but the leading characteristic value is the lowest multiplied by 1.2 that equals 55,9 N/mm². When Peru and Bolivia would be considered as growth area this would give an average 5%-value of 50,5 N/mm². For cumaru it could be economically worthwhile to define two growth areas: Brazil and Peru/Bolivia.

*Table 1: Characteristic values of 5 cumaru samples at 12% moisture content*

| sample | location | 5%-value of the density (kg/m³) | Mean-value of the Modulus of Elasticity (N/mm²) | 5%-value of the bending strength (N/mm²) |
|---|---|---|---|---|
| 1 | Brazil | 933 | 20700 | 76.8 |
| 2 | Brazil | 880 | 20600 | 58.7 |
| 3 | Brazil | 919 | 22200 | 100.9 |
| 4 | Peru | 829 | 19000 | 46.0 |
| 5 | Bolivia | 843 | 19000 | 56.0 |

*Table 2: Characteristic values of 3 massaranduba samples at 12% moisture content*

| sample | location | 5%-value of the density (kg/m³) | Mean-value of the Modulus of Elasticity (N/mm²) | 5%-value of the bending strength (N/mm²) |
|---|---|---|---|---|
| 1 | Brazil | 932 | 23500 | 86.2 |
| 2 | Brazil | 938 | 18900 | 68.4 |
| 3 | Brazil | 934 | 12900 | 44.1 |

For massaranduba the situation is different. There are 3 samples from Brazil with an average value of the 5%-values of the bending strength of 66,2 N/mm$^2$, but the 5%-value of the lowest sample multiplied by 1.2 equals 52,9 N/mm$^2$.
There are big differences in the 5%-values of the bending strength between the sample .
Possible explanations for this could be:

- The growing conditions are varying at the different locations, resulting in specific growing characteristic. It happens that specimen from different locations have a different kind of grain deviation, one more "straight" and the other more "curly", which might influence the strength properties, although both fulfil the visual requirements of the grade.
- Characteristic grain angle deviation is not always easy to determine by visual means. The modulus of elasticity of sample 3 of massaranduba is remarkable low since the density is in line with samples 1 and 2. An explanation might be a different grain angle deviation pattern, which is not good visible to the naked eye.
- The sample could be a mix of different species but from the same genus.
- "Bad luck" of the number of weak specimen within a sample. The method of ranking to determine the 5%-value is sensitive for low number of specimen. A larger sample size might give different results.

The results from these case studies give evidence that the variation within the sample does not cover the natural variation of parameters such as locations, number of species from the same genus, growing conditions, etc.. This ask for a more specific approach.
In the next paragraph possible approaches will be discussed.

### *3.3* ***Possible classifications***

*Identification of a sample*

Part of the classification method for timber consists of the identification of the wood species and the origin of the timber. For practical reasons it would reasonable to leave the identification level on which it coincides with the timber species (trade name). This could be the genus level (see figure 5). However, in many cases a genus is diffused over countries and even continents, therefore the growth area has to be limited to the origin of the samples. This might depend on the method of determining the characteristic strength values as will be explained in the next section.

*Determination of characteristic strength values*

There are two approaches to determine characteristic strength values for visual grades:

- Derivation of the strength values from full size data.
- Derivation of the strength values from small clear data

Another possibility to obtain characteristic strength values is, using instead visual characteristics, non-visual properties such as modulus of elasticity to grade the timber, this is called machine strength grading.

In the next paragraphs these approaches will be addressed. The focus will be on the bending strength, because this is considered to be the most important property.

*3.3.1 Derivation of characteristic values from full size data for visual grading*

As is shown in the two case studies (see paragraph 3.2) there can be a large variation at the 5%-level values of the bending strength between different samples.

The $k_s$ factor (see figure 4) is an important factor to incorporate the expected variation between samples for determining the characteristic strength value. This factor has been based on the assumption that the samples belongs to a well identified wood species. This applies mostly for softwood species but seldom for tropical hardwood species. Even for the same wood species but for samples from different origins the correctness of the $k_s$ factor was questioned in [21].

On the basis of the samples from the case studies (see paragraph 3.2) it will be studied how to determine a $k_s$ factor which correctly addresses the 5%-value for hardwoods.

The $k_s$ factor is incorporated as follows in [16]:

The characteristic value $f_k$ based on a number of N visually graded samples of a wood species should be calculated with equation (1):

$$f_k = \bar{f}_{05} k_s \qquad (1)$$

where $\bar{f}_{05}$ is the weighted mean of the 5%-values of all samples, with the restriction that $\bar{f}_{05}$ may not be higher than 1,2 times the lowest 5%-value of a sample. For N samples with all the same number of specimen this becomes:

$$\bar{f}_{05} = min\left[\frac{\sum_{i=1}^{N} f_{05,i}}{N}, 1.2 * f_{05,i,min}\right] \qquad (2)$$

Where $f_{05,i}$ is the 5%-value of a sample, and $f_{05,i,min}$ is the lowest 5%-value of the samples in the test programs. Now the value of $k_s$ can be determined by evaluating performed test programs by calculating:

$$k_{s,est} = \frac{f_k}{\bar{f}_{05}} \qquad (3)$$

When there is only one sample tested the 5%-value of this sample will also be $\bar{f}_{05}$ and the 1.2 restriction has no meaning. That means that the $k_s$ factor will be the lowest when there is only one sample tested. To make a good comparison on the influence of the number of samples in this paper the 1.2 restriction will not be taken into account.

The following procedure was followed:

- For the timber species massaranduba (genus *Manilkara)* and cumaru (genus *Dipteryx)* testing programs were simulated, based on tables 1 and 2. It could be that instead of 5 samples cumaru only 3 samples were tested. Those 3 could be randomly taken from the 5 possible samples. That means that for cumaru in total there are $2^5$-1 =31 combinations in which the samples could be tested. For instance, there are 5 different combinations possible of 4 samples to be tested in a testing program, 10 different combinations possible of 3 samples to be tested etc. For massaranduba there are $2^3$-1=7 combinations. Then the average value of the 5%-values were calculated for every testing program combination.
- For the testing program combination with the maximum number of samples the average 5%-value of the samples is assumed to be the "true" average 5%value for the timber species.
- The average 5%-values for all combinations for massaranduba and for cumaru in the test program are plotted against the number of samples in the test program in figure 6. For 1 sample in the testing program combination the variation is of course the highest, since the 5%-value of 1 sample is also the average 5%-value, leading to 5 different average 5%-values. When there are more samples in the test program the variation decreases.
- For every combination the ratio between the "true" average 5%-value for the timber species and the average 5% of the combination was calculated. This is the value for $k_{est}$ for every combination. In figure 7 all these ratios are plotted against the number of samples in the test program. It was found that the lowest ratio was 0.67 (For 1 sample of massaranduba, see figure 1) .

- As a next step a regression line was fitted to find a formula for $k_{s,est}$ based on the number of samples. This regression line was fitted through the lowest $k_{s,est}$ values for every number of samples. Equation (4) for $k_{s,est}$ was found, where $N$ is the number of samples for sample sizes of approximately $n$ = 50. The factor $k_s$ is called $k_{s,timber}$ (from the term timber species) to distinct it from the $k_s$ in EN 384 which could in fact be called $k_{s,species}$ (from the term wood species)

$$k_{s;\text{timber}} = 0.083 * N + 0.60 \qquad (4)$$

In table 3 the lowest $k_s$ values for the number of samples are compared with the calculated values with equation (4).

In figure 7 the regression line for $k_{s,timber}$ is plotted against the number of samples with sample size $n$ = 50. The current $k_s$ line according to EN 384 for sample size $n$ = 50 is plotted for comparison. This shows that on timber species level a more conservative $k_s$ factor has to be used. Of course the strength class allocation is only valid for the area where the full size samples originate from.

### *3.3.2 Derivation of characteristic values from small clear data for visual grading*

The samples described in paragraph 3.2 consist of specimen of structural sizes, that means the sizes that are normally used in structures. There are however several databases with strength data for small clear specimen. Cross sections for small clear specimen can be 20 mm x 20 mm, whereas specimen of structural sizes could be 65 mm x 150 mm. Another

*Table 3: Comparison of lowest $k_s$ values with equation (4)*

| Number of samples $N$ | Lowest $k_s$ values for the number of samples | $k_{s,timber}$ = 0.083 * $N$ + 0.60 |
|---|---|---|
| 1 | 0.67 | 0.68 |
| 2 | 0.76 | 0.76 |
| 3 | 0.86 | 0.84 |
| 4 | 0.93 | 0.93 |
| 5 | 1.00 | 1.01 |

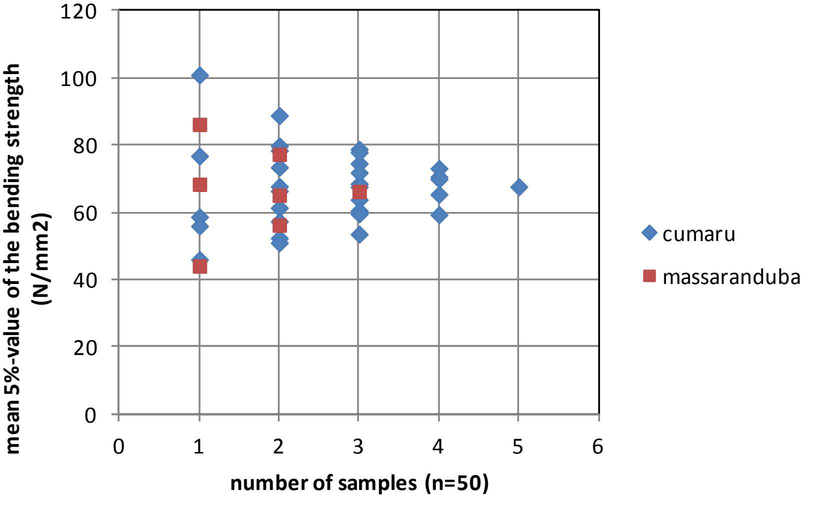



*Figure 6.The mean 5%-values of all combinations of samples depending on the number of samples*

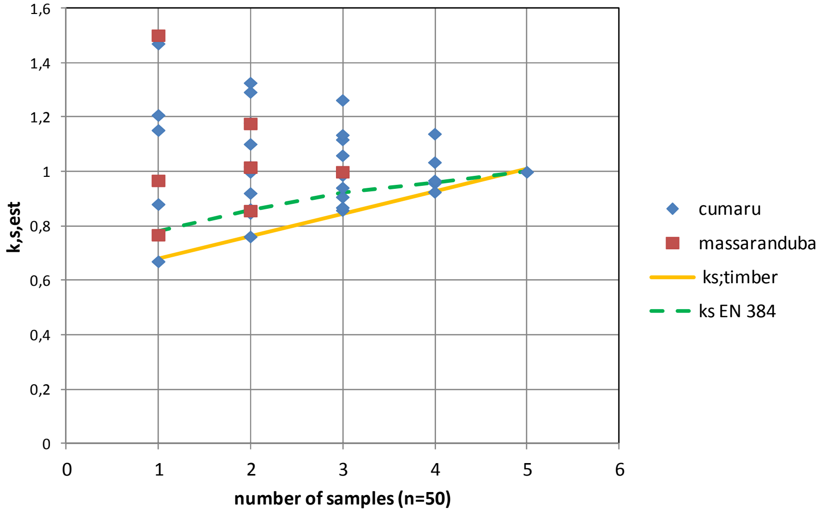



*Figure 7. The $k_{s,est}$ values for every test program combination plotted against the number of samples in the test program. Also added the current $k_s$ ratio according to EN 384 and the found $k_{s,timber}$ according to equation (4). of the minimum 5%-sample value the mean 5%-value of the samples depending on the number of combinations*

difference is that small clear specimen for example do not have knots and have a straight grain (no grain angle deviation).

In a research project assigned by the European Timber Traders Federation, a research group consisting of the Dutch Delft University of Technology and the French research institutes FCBA and CIRAD, was studied if a relation could be found to predict the 5%-value of a wood genus (defined by the trade name) out of the mean value of a sample of 40 specimen of small clear specimen from the genus. This is allowed according to EN 384 when a relation can be proven. The resulting values are referred to as $f_{mk,full\ size}$.

In the first stage of the project a database with strength values from small clear specimen was connected with a database with available strength values from full size specimen. Since the database with strength values from small clear specimen is much larger the idea was that by finding a relation the full size strength values of the remaining data could be derived from the found relation. After this first step where data from about 15 timber species was analysed a relation between the mean value of the small clear bending strength and the 5%-value of the full size bending strength was found. [25]

In a second stage, the database was extended with 6 full size and 6 small clear samples, where the small clear specimens were cut from the same full size specimen. This was in contradiction to the data used from the two databases in the first stage of the project. The reason for this approach was to investigate the basic relation of the small clear specimen of a batch of a species to predict the strength of the full size specimen of the same bacth of these species. One would expect that this relation would be better than the relation found in the first stage, since for each full size specimen, the small specimen was cut from it. Two samples were from the timber species cumaru, one from Brazil and the other from Peru (samples 1 and 4 from table 1). The result is plotted in figure 8. On the horizontal axis the mean values of the bending strength of the small clear data and on the vertical axis the 5%-values of the bending strength of the full size samples ( $f_{mk,full\ size}$). The figure shows the regression line expressed by Y=0.42 X. In figure 8 the data point in the upper red circle represents cumaru from Brazil whereas the data point in the lower red circle cumaru from Peru. The mean values of the small clear samples for the two samples are very close to each other whereas there is a big difference in the 5%-values of the full size data, as was also seen in the previous section. It is important to state that the small clears were cut from the full size pieces for these to samples. The variation in the 5% values between the full size samples therefore could not be explained by the difference in mean values of the small clear samples. To be able to predict the 5%-value of the full size timber a prediction line has to be chosen that takes the variation between the full size samples into account. Since the differences in variation for the 5%-value of full size samples from the same timber species (consisting of possibly more than one wood species) is not known when an assignment based on small clear data is done, a safe prediction line has to be chosen. Based on figure 8 a prediction line of Y=0,30X seems to be safe to ensure this, because in this case there is only one datapoint for which the predicted full size 5%-value of the bending strength is slightly lower than the 5%-value Because the variation in location can also not be proven the connected source area could be the growth area on a continent where the timber species occurs. So for instance the Amazonas in South-America.

It may be clear that this method gives more conservative values for most timber species than if data from full size tests have been used. At least, it would be possible to use a large number of timber species with conservative strength values, with as a benefit that a large growth area can be defined. In a later stage, when the wood species is commercially successful, more accurate strength value based on full size specimen could derived. However, then he source area has to be limited to the area that that comprises samples for full size testing.

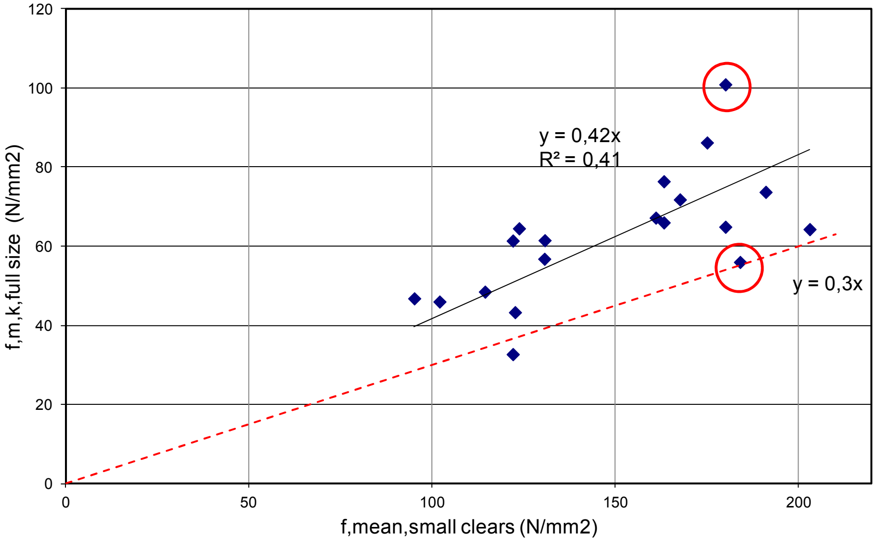



*Figure 8. Relation between the mean value of small clear samples of cumaru and the 5%-values derived from full size specimens of the same timber species*

*3.3.3 Derivation of characteristic values by machine grading*

With visual grading the differences in strength values between the samples cannot be detected as explained in the previous sections The specimen have to fulfil the requirements for the visual grade (knot ratio < 0.2, grain angle deviation < 1:10) but the values for these characteristics are not spread enough to be able to make strength predicting models for it. They therefore have the function of a threshold value. It turns out that the modulus of elasticity for the same specimens has much better strength predicting capabilities. The modulus of elasticity can (apart from a static bending test in a laboratory) also be determined by the frequency response from stress waves, a well-known method in practice currently in use for grading softwoods. This is called machine grading since the measurements are made automatically by a machine. Machine grading is currently accepted for softwoods, but not yet for hardwoods. In figure 7 the potential for machine grading of tropical hardwoods is shown. For the 3 samples from the timber species massaranduba the bending strength of each specimen is plotted against the mechanically measured modulus of elasticity, which is called the dynamic modulus of elasticity.

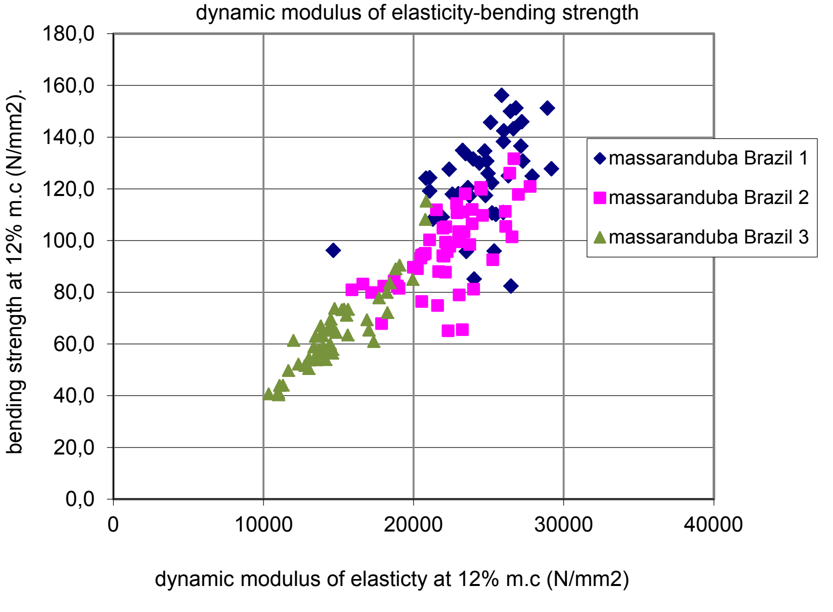



*Figure 9. Relation between the dynamic modulus of elasticity and the bending strength for all specimen of the three massaranduba samples*

Figure 9 shows that the difference in bending strength between the 3 samples can be explained by the relationship with the dynamic modulus of elasticity of each specimen. That means that by using the dynamic modulus of elasticity as a grading parameter the identification of the wood species becomes less irrelevant. When for instance a limit value of 20000 $N/mm^2$ is used for the dynamic modulus of elasticity as grade limit, all specimens that have a higher value are selected. In this case none of the selected specimens has a value for the bending strength lower than 60 $N/mm^2$. Taking into account the scatter around the regression line the exact limit values for the dynamic modulus of elasticity can be found for which the assigned specimen will have a probability of 5% that the bending strength will be lower than 60 $N/mm^2$. Consequently, the yield for grades of strong material can be optimised by machine strength grading.

# 4 Durability class assignments

### *4.1 Introduction*

Wood durability has been classified in so called Durability Classes (DC) [2]. Durability concerns natural durability against micro-organisms such as fungi. In general, natural durability is strictly connected to the heartwood of the wood species independent from their origin. Usually natural durability has been determined by field or laboratory testing against fungi which take several month or even years. To today there is no method available where natural durability of a single piece of timber can be determined at that moment. Therefore the wood species of the timber has to be known. For tropical timber, wood anatomical features are often not distinctive enough to identify the wood species. Another important aspect of durability assignment of wood species is the representativeness of the population and the reliability of the classified values. Both aspects have been intensively discussed by the members of the European Standardisation Committee CEN TC38 WG21. Research has shown [22] that durability of a wood species can have large scatter which is not taken into account in the classification system. This scatter could be explained by a mix of wood species in the sample or the variation of natural durability within the same species. In order to investigate this, large samples would be necessary to get reliable test data. Statistical sampling is concerned with selecting a subset of individuals from a defined population in order to estimate the characteristic of the whole population [22]. However this is not appropriate for wood species which are spread over continents.

### 4.2 *Natural durability*

Natural Durability of wood is defined in EN 350-1 [23] as 'The inherent resistance of wood to attack by wood-destroying organisms'. The same standard describes the test procedure for determining the resistance against fungi. This procedure is based on field tests [26] in soil contact where test stakes are used made of the wood which has to be tested. The field test last at least five years. The classification of the natural durability is built on the average life of the reference stakes. Since the field test takes a quite long time, a provisional classification may be given, based on short term (16 weeks) laboratory tests mentioned in EN 350-1 [23]. In this regard the classification is determined by the relative average mass loss of the samples after the test period. As soon as the field test results are available, the allocation of the durability class has to be aligned to if necessary.

CEN/TS 15083-1 [15] describes a differing procedure whereby the classification is based only on laboratory tests. The classification has been taken from the EN 350-1 where the higher median mass loss is decisive.

The different test procedures, such as field and laboratory tests, and the inconsistency of the statistical analysis (mean or median value) might lead to different results regarding the allocation of the durability grade of the same wood species. In EN 350-2 [2] the wood species are listed with the allocated durability class. There is no information given about the applied test method and the number of samples of the tested material so that the durability grades of the different wood species are not always comparable. Neither the reliability nor the confidence level of the natural durability of the wood species have been reported. Many assignments of natural durability to wood species in that table relies on historical assessments based on practical experience. This has been applied mainly to tropical hardwood species.

Keeping the durability grades meaningful, it might be necessary to define a laboratory test with regard to wood-destroying fungi which could be used to compare the natural durability of wood species relatively to each other. The results of that test should be recorded as the basic natural resistant against wood-destroying fungi of a wood species and determine the durability grade. Depending on the application, supplementary tests could be applied in order to get a better inside of the natural resistant capacity of the wood species. Additional tests could be related to different soil qualities or joint geometries. In this regard several test setups have been designed such as the lap-joint test [29], double layer tests [30]. In both setups capillary gaps between single wood elements were created where moisture accumulation is excited.

The grades of the durability or in particular the resistance of wood against wood-destroying fungi do not consider safety or serviceability aspects deliberately. A relationship between durability grade of the wood and service life of the structures or products could hardly be established. Low natural durability of the wood could shorten the service life of a structure or even lead to structural strength failure, when the surrounding conditions e.g. climate, are stimulating growth of fungi in the wooden members.

It could be questioned if the natural durability grade of a timber species shouldn't be adjusted by a factor or that a low percentile-value should be used, depending on the application in order to ensure the intended service life. The durability grade for timber in load bearing structures where safety aspects govern, could be treated like strength graded timber, where the 5%-percentile value determines the characteristic strength value. However, the results of the durability tests should undergo a statistical analysis where probability aspects and the variability of the results have to be taken into consideration to allocate a durability grade. This would allow a more pronounced use of durability grades towards the service life prediction of the concerned structure.

### *4.3* ***Sampling***

European standards such as Eurocode 5 and national building legislations refer to the natural durability grades of timber species in [2] to stipulate the treatment of the timber. For example timber in durability class 3 has to be treated with wood preservatives when used under wet conditions, in contrast to timber of class 2 it mustn't. In this regard it is important to derive the durability grades from reliable test results and statistical analyses. The samples for testing should represent the intended population which could be characterised by its origin. In CEN/TS 15083-1 [15] a guidance on sampling is given where distinction is drawn between sampling from logs and commercial supplies of timber. It has been shown that the natural durability of the heartwood will vary both along the length and across the diameter of the tree [27]. Therefore the sampling regime for trees should take this into consideration. In EN 350-1 [23] a sampling procedure for trees is given. Normally tropical timber arrives at the European market not as round wood but as sawn timber. In that situation it is almost not possible to verify the location of the boards within the original tree. For sawn timber it has been agreed that randomly 2 specimens from each of 20 boards will be tested per fungus [15]. Unfortunately the statistical reason for this approach has not been described.

However, the number of test samples and specimens should be derived from the variation of the expected test results. Up to now little research has been focused on statistical measures for analysing test results regarding natural durability of wood [22] [28]. Investigations have shown that the spread in test results is not only based on natural variation in durability of the timber but also might depend on different laboratories [22]. This may be caused by a lower reproducibility of the tests and/or the slightly latitude of interpretation.

The quality of tropical timber which enters the EU market can vary after years and decades, because the timber undergoes pre-selection procedures in the country of origin depending on the market needs. The pre-selection criteria are usually based on visual features of the timber which normally cannot be linked with the natural durability of it. That means that the variation of the durability within a timber species could fluctuate. The extent of fluctuation could be captured by sampling the timber species coming on the market in reasonable time segments (3-5 years) to ensure that the current durability has not been changed significantly.

This approach makes it possible to get a reliable insight of variation in natural durability of the different timber species.

### *4.4* ***Possible classifications***

The current classification of natural durability is connected with the wood species and standardized in EN 350-1 known as Durability Classes 5 to 1 whereas 5 refers to the lowest resistance and 1 to the highest [23]. This classification is based on absolute or relative weight loss of decayed wood specimens in comparison to the reference pieces. By applying an ordinal value scale which is based on continuous test data might lead to alienation effects at the classification borders. A continuous scale could provide a better see into the distance of natural durability between timber species. As discussed in paragraph 4.2, so called 'characteristic' values might be defined as average, median or another percentile values. This should depend, for instance on the application of the timber.

According to the standards [2],[15],[23] at least one sample is required for the classification of a wood species. The characteristics of a sample have not been defined in the standard. Also the statistical treatment of different samples from the same wood species has not been described. Consequently the responsibility of interpretation and merging test data has been left to the testing institution.

In order to get more transparency how the durability grades of the different wood species have been established, it would be advised to define the procedure of statistical analyses and the characteristics/parameters of a sample.

A first attempt has been taken by the Work Group 21 from CEN TC 38 (European Committee for Standardization) to describe a statistical procedure how to analyse test results with regard to their variation. The possibility has been discussed to introduce the median value and a confidence level of the durability class of a wood species. For small samples the non-parametric methodology would be suggested. Samples with a huge number of specimens (>100) could be approached by deriving parametric probability distribution functions. From these, characteristic values for natural durability could be determined. On-going discussions are still about confidence level and sampling strategies.

Leaving for a moment the current classification system which is related to wood species and extensive fungi tests, and turn to an ideal and user friendly classification procedure. From practical point of view it is not necessary to identify the tree/wood species when the natural durability of the timber could be determined at each piece in situ. Then the name of the timber species would not be relevant anymore. In this case also the origin of the timber could be neglected.

Extractive configurations in the wood are governing to great extend the natural durability of wood [24],[27]. By sophisticated methods such as Near Infra-Red (NIR), a fingerprint of the chemical formation could be taken from each piece of timber. However, these fingerprints have to be tested against fungi resistance. Finally a database would be set up over time where 'fingerprints' will be related to durability 'classes' or levels (figure 10B) For example when tannins configurations at a certain concentrations have a particular resistance against fungi, then all timbers with this configuration could be supposed as having the same durability grade and can be assigned to the durability classification system. If so, the classification system is no longer established on wood species (figure 10A) but derived from characteristics such as chemical constituents. In this case the NIR spectrogram could be used for the allocation of the piece of wood to the durability grading system. The identification of the wood species would be expired which would be an improvement especially for tropical wood species because of the difficulty of identification (see paragraph 2).

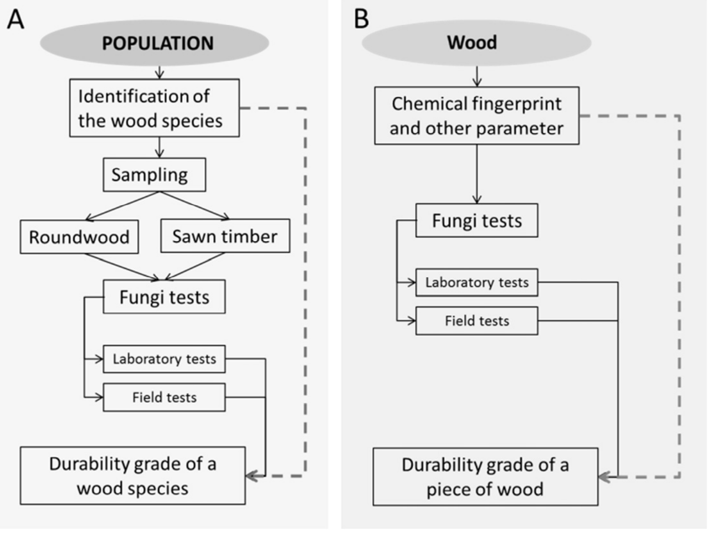



*Figure 10 Accepted route to determine the durability grade (A), new approach to determine durability grades (B).*

## 5 Conclusions

This paper addresses the existing praxis of sampling wood species for strength grading and natural durability of wood and the consequences of this.

***Identification of wood species***

Currently for both, strength grading and natural durability assignments, the identification of tropical wood species is necessary. This causes uncertainty because the available characteristics are not distinctive enough for a clear identification of the wood species. In this context there are different approaches proposed:

- Introduction of the term timber species which allows a mixture of different wood species which cannot be determined by wood anatomical features. This makes it possible to identify a timber species (e.g. cumaru) on genus and not on wood species (*Dipteryx odorata* (Aubl.)Willd.) level.
- A novel approach for both strength grading and natural durability assignments should be by using only characteristics which can be measured or determined at single piece of timber in situ such as dynamic modulus of elasticity. In addition

to anatomical features, chemical configurations could be determined by NIR or other methods used in the research field of chemotaxonomy and/or more sophisticated methodologies based on DNA fingerprints.
In this case a new systematic could be introduced which would not necessarily be related to the botanical systematic.

***Sampling with regard to strength grading***

- In the sampling of a timber species, commercially traded by one trade name, there can be a high variability in strength properties for visually graded timber.
- Since it is not possible to distinguish the samples on a species level when they are coming on the market it is recommendable to determine the strength values on a timber species level for visually graded timber.
- The number and size of samples of a timber species have considerable influence on the allocation of strength class.

***Classification regarding strength classes***

- To determine the strength values on a timber species level for visually graded timber based on full size specimen the $k_s$ factor that brings into account the variation between the samples has to be adjusted for tropical timber to $k_{s,timber}$ for which the equation is derived in this paper.
- To predict the 5%-bending strength of a genus of full size timber for visual grading out of the mean values of small clear specimens a large reduction factor has to be applied, because the variation in full size timber is not reflected in the small clear specimen.
- When machine grading, based on the dynamic modulus of elasticity, is used, the grading can take place on the basis of individual pieces of full size timber, instead of sample level. This makes the identification on a species level irrelevant, and groups of timber pieces with different strength properties can be distinguished.

***Classification regarding natural durability***

Natural durability of timber has been considered as governing property for a lot of structural applications. The current classification methodology and criteria need to be revised.

- Durability grades should reflect the distribution and the confidence interval of the durability of the single wood species or timber species. This is not covered by the current classification system.
- The reliability of the test results have to be argued by statistical analyses such as repeatability.
- Requirements on the representativeness of the samples have to be sharpened.
- New approaches have to be developed to define characteristics of natural durability by for example chemo-IDs for different resistance levels against micro-organisms which can easily be determined at each single timber piece. For this NIR techniques are very promising.

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