Grading of timber for engineered wood products (Gradewood)

FINAL REPORT

Title of the research project	**Grading of timber for engineered wood products**
Coordinator of the project	**Tomi Toratti**

BASIC PROJECT DATA

Project period	[1.12.2007-31.8.2011]
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URL of the project	www.buildingwithwood.eu (internal site)

FUNDING

Total budget in EUR	1 420 000 EUR
Public funding from WoodWisdom-Net Research Programme:	Total funding granted in EUR by source:
Finland Tekes - Finnish Funding Agency for Technology and Innovation	150 000 EUR
Germany Federal Ministry of Education and Research (BMBF)/ Project Management Agency Jülich (PtJ)	140 000 EUR
Sweden Swedish Governmental Agency for Innovation Systems (VINNOVA)	170 000 EUR
France	

Ministry of Agriculture, General Direction for Forest and Rural Affairs (DGPAAT)	110 000 EUR
Technical Centre for Wood and Furniture (FCBA)	60 000 EUR
United Kingdom	
Forestry Commission (FC)	100 000 EUR

Other public funding:

Austrian Research Promotion Agency (FFG)	120 000 EUR
Slovenia, Ministry of Higher Education Sci. and Techn , Sci. and Techn. (MHEST)	30 000 EUR

Other funding:

CEI-Bois, Belgium	307 500 EUR
VTT, Finland	62 500 EUR
BRE, UK	20 000 EUR
University of Ljubljana, Slovenia	30 000 EUR
Swedish forest industries federation and Träcentrum Norr, Sweden	120 000 EUR

PROJECT TEAM (main participants)

Name, degree, job title	Sex (M/F)	Organization, graduate school	For a visitor: organization & country of origin	Funder
Ranta-Maunus A, D Tech, Professor emeritus	M	VTT		
Fonselius, M, Lic Tech, senior researcher	M	VTT		
Hofstetter K. PhD University assistant	F	TUW		
Bengtsson C, PhD, Professor	F	SP		
Ziethen R, Lic Tech, Senior researcher	M	SP		
Glos P, PhD, Professor emeritus	M	TUM		
Stapel P, dipl. eng Reasearch scientist	M	TUM		

Denzler J, PhD Research scientist	F	HfA
Turk G, PhD Professor	M	UL
Reuling D., Research scientist	M	FCBA
Holland C, degree, Senior consultant	M	BRE
Deublein M, Research scientist	M	ETH
Mauritz R, Dr. Chairman of Steering Committee	M	DOKA
Brännström M, PhD Chairman of Project Management group	M	Stora Enso Timber

The following five Grading machine producers were involved in the testing phase of the project:

Mr. Pieter Rozema, Brookhuis Micro-Electronics
Mr. Guillaume Roblot, Luxscan Technologies
Mr. Martin Bacher, MiCROTEC GmbH
Mr. Erik Eveborn, Rosen & Co Maskin AB
Mr. Yann Benoit, TRIOMATIC CBS

DEGREES
Degrees earned or to be earned within this project.

Year	Degree	Sex (M/F)	Name, year of birth and year of earning M.Sc.,	University	Supervisor of thesis, supervisor's organization
2010	Masters	F	Garcia, C.	Univ. Politec. Madrid, Spain	Karin Hofstetter, TUW

ABSTRACT

A summary of the project.

Joint analysis of 26000 old and 6000 new destructive tests has been carried out. Results give a unique basis for development of European standardisation leading to CE-marking of structural wood products. Coping with variability of raw material is the main challenge. Proposed new methods are a more robust method of prediction limits for determination of settings, and a method of dynamic production settings as response to quality shifts. Promising new methods have been developed for estimation of the effect of defects to mechanical properties and for definition of growth areas where same settings can be used. The objective to define borders where same settings can be used turned out to be multi-dimensional depending on species, loading mode and grading technology.

1.1 Introduction

1.1.1 Background

Describe the background of the project and the basic problem that it sought to address.

The development and utilisation of machine strength grading has been slow. One of the reasons for the slow progress in the past has been the existence of many national grading rules and practices, which differ from each other. Recently a European standard has been established for machine strength grading. In principle, the system now requires different machine settings depending on the “nationality” of the logs. To obtain new settings for all countries is very expensive, because it requires extensive testing. Historically based practises exist for acceptance of timber graded by the old system of manual visual grading. It is easier (especially for SME’s) to keep the old visual system, rather than to invest to a new grading machine, even if the old visual system is less accurate, more laborious and slower than machine grading. Machine strength grading has not yet been properly utilized in many European countries and most wood industries are not familiar with opportunities of it.

The grading equipment developers/manufacturers are small companies and do not have sufficient resources alone to develop the methods. This is a second reason for the slowness of the progress with machine grading. For example, the acceptance of a new machine requires the destructive testing of at least some 1000 pieces of timber.

Machine strength grading offers economic benefit to wood producers in the form of better yield to higher grades and consequently better competitiveness of timber as a construction material as well as improved and more efficient production process.

Many new machine technologies which are already available to the wood industry would offer great opportunities to optimise the use of raw material and to produce more competitive products for the construction market as well as enhance the production process.

1.1.2 Objectives

Describe the project objectives.

A breakthrough in technology and processing is needed to form an economic platform for SMEs and the whole industrial sector to take full advantage of the raw material properties through strength grading. This project aims to this development on a pan-European level. Developers and manufacturers of NDT equipment are involved in this project so that settings for many machines using different measurement techniques can be obtained from the same sample of timber. At the same time, harmonised data bank will serve as a test bench of grading equipment and as basis of checking of strength values of European timber in the standard EN338.
This project is to a large extent a development project with both scientific and practically applicable goals aiming to rise the level of strength grading in European wood industries by applying modern technologies. Project includes new scientific issues and a wide international cooperation is a prerequisite for success in the European standardisation. The project itself cannot produce new standards but will produce the background information for standardisation.

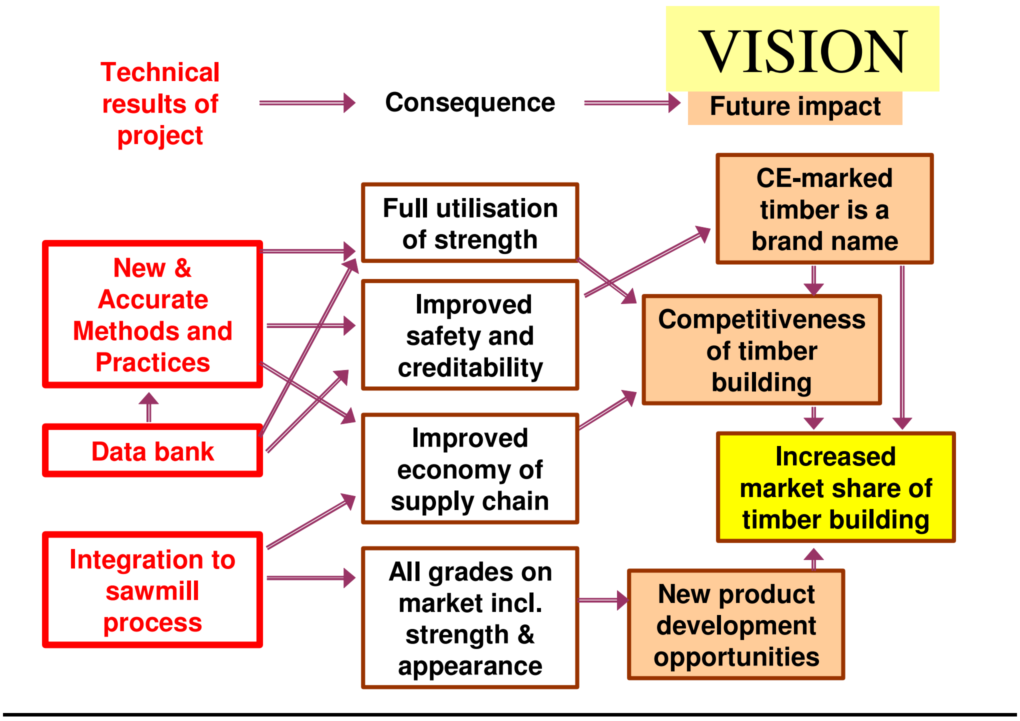

Figure 1. Vision of the results of the project

Project vision is illustrated in Figure 1, and industrial and scientific objectives listed in Tables 1 and 2.

Table 1. Goals set as to help the industry to improve business and sawmilling process

	GOAL (HELP FOR INDUSTRY)	MEANS (HOW?)
1	Improve the image of timber as a reliable material having predictable characteristics	by producing and publishing scientific data on timber properties.
2	Developing intelligent grading, which is economic and suits the production chain	by development of economic procedures for the supply chain, so that the 1st objective can be fulfilled within the economic constraints of a business. For example this could mean: - Grading as early as possible in the production chain to enable the economic utilisation of the resulting rejects (unavoidable when strength grading is made in a reliable way) - Machine strength grading combined with appearance grading
3	Taking full advantage of the strength potential of wood as accurately as possible	by promoting the use of state of the art technology in strength grading and ideas for development of new methods as well as renewing the strength profiles given in EN338 by checking the ratio of tension and bending strength values
4	Use of CE marking or other grading as positive brand indication for timber	by providing information needed for new generation of standards, for example user-specific grades based on stiffness rather than strength
5	Educating producers, distributors, users and designers to facilitate the adoption of the objectives by the industries	by organising seminars

Table 2. Goals set as scientific means to achieve the practical goals

	SCIENTIFIC GOAL	MEANS (HOW?)
1	Understanding the effect of growth irregularities on strength by means of physically based numerical simulations.	Realistic FEM calculations based on knot and other defect geometry and development of a model applicable for strength prediction based on morphological characteristics of the knots and defects
2	Verifying the strength properties and their dependence on growth characteristics of timber grown in different parts of Europe to set a scientific basis for the criteria of growth areas for determination of machine settings	Analysis of a combined data base of existing data available for the project and data produced in the project
3	Combining European growth areas so that advanced grading machines can be used in different countries, with the same reliable settings based on adequate and representative wood sampling	Development of scientific criteria for growth area definitions
4	Developing the accuracy and reliability of strength grading techniques to detect severe weaknesses in timber, such as local slope of grain	Analysis of the capability of different methods the find severe weaknesses
5	Scientific basis for combining strength and appearance grading	Analysis of appearance grading and strength grading on same samples of timber
6	Finding the best and practical combinations of measurements techniques to ensure highest possible outcome of strength grading without reduction of reliability	Analysis of combinations of measurement techniques for prediction of timber properties
7	Establishing grading methods that can be easily combined with the sawmilling process	Analysis of the effect of different strength grading strategies on the sawmilling process. Effect of log selection

1.2 Results and discussion

Main achievements of the project, quality, innovativeness, industrial relevance and contribution to competitiveness, environmental and societal impact.

A new basis for jugement of effects of defects to strength of wood has been developed based on the local fiber course around knots. The developed numerical simulation tool provides highly accurate estimates in tension and bending loading, as confirmed in various validation series of comparisons with experimental data. However, an accurate description of knot size and orientation of the knot axis turned out crucial in order to end up with suitable model predictions. Currently available grading machine data are not sufficient in this respect. However, future use of CT scanners in the grading process is expected to deliver data with acceptable accuracy.

The detection of severe slope of grain was studied by using a specific sample of reject grade material. It was concluded, not surprisingly, that E_{dyn} based methods can hardly detect such defects. Old static bending type machine is quite effective in this respect. A clear need for grading method which can detect large grain angles was identified.

Table 3. Number of new destructive tests made in Gradewood with source country.

country	pine		spruce		total
	bending	tension	bending	tension	
CH	-	-	-	442	442
FI	-	253	-	-	253
FR	-	239	119	-	358
PL	219	217	433	219	1088
RO	-	-	318	316	635
RU	-	171	-	-	171
SE	210	206	210	211	837
SI	-	-	1126	104	1230
SK	-	-	213	214	424
UA	-	-	315	328	643
total	429	1086	2274	1478	6083

To supplement the existing strength data new experiments were made as shown in Table 3. Full nondestructive and destructive tests were made as well as strength indicating properties were determined by use of five commercial strength grading equipment.

A new statistical criterion was developed for definition of an area where same settings of grading machine can be used. This is based on confidence interval of characteristic values and has been applied to existing and new test data as illustrated in Figure 2. The result was that characteristic strength values of spruce under tension are easily within confidence interval whereas bending strength of pine-results are quite different in different regions. Results will be used for development of standard.

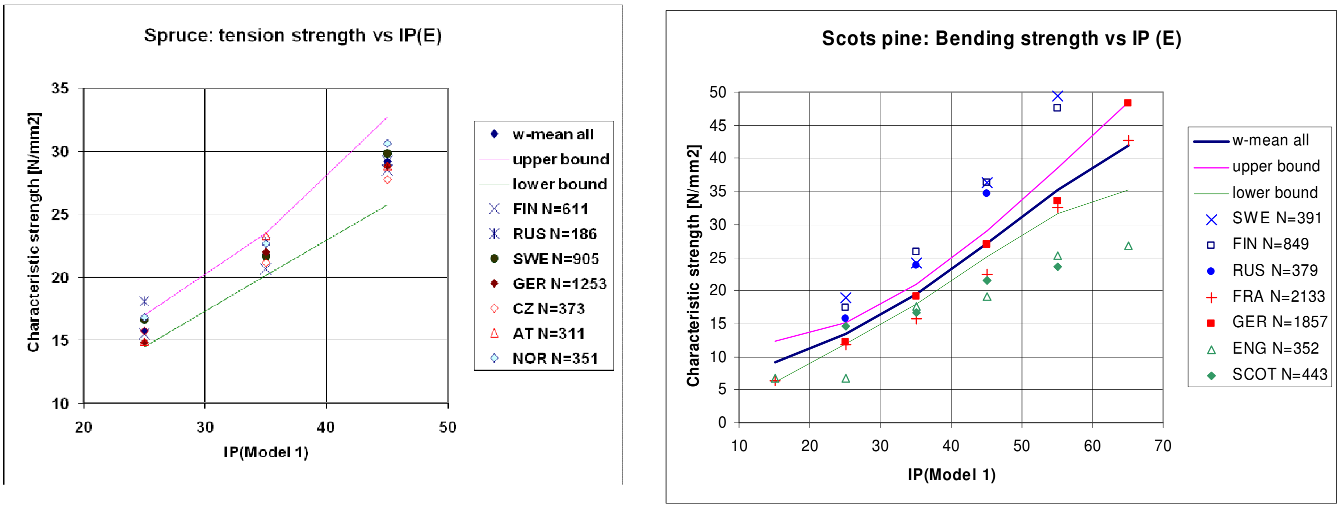

Figure 2. Characteristic strength-IP(E) relation of full national samples. Left: spruce in tension, rigth: pine in bending

Analysis of the experimental results (26000 old, 6000 new) reveals the inherent problem of variability of wood material: testing with any practical sample size cannot predict properties of population with high precision. Therefore it is not possible to conclude if observed different values of two samples are result of different populations or just signal of statistical error. Conclusion of this is that strength grading system (determination of settings) should not be sensitive to quality of a limited sample. Furthermore, a question can be asked on which confidence level requirements need to be fulfilled in test sample and in production.

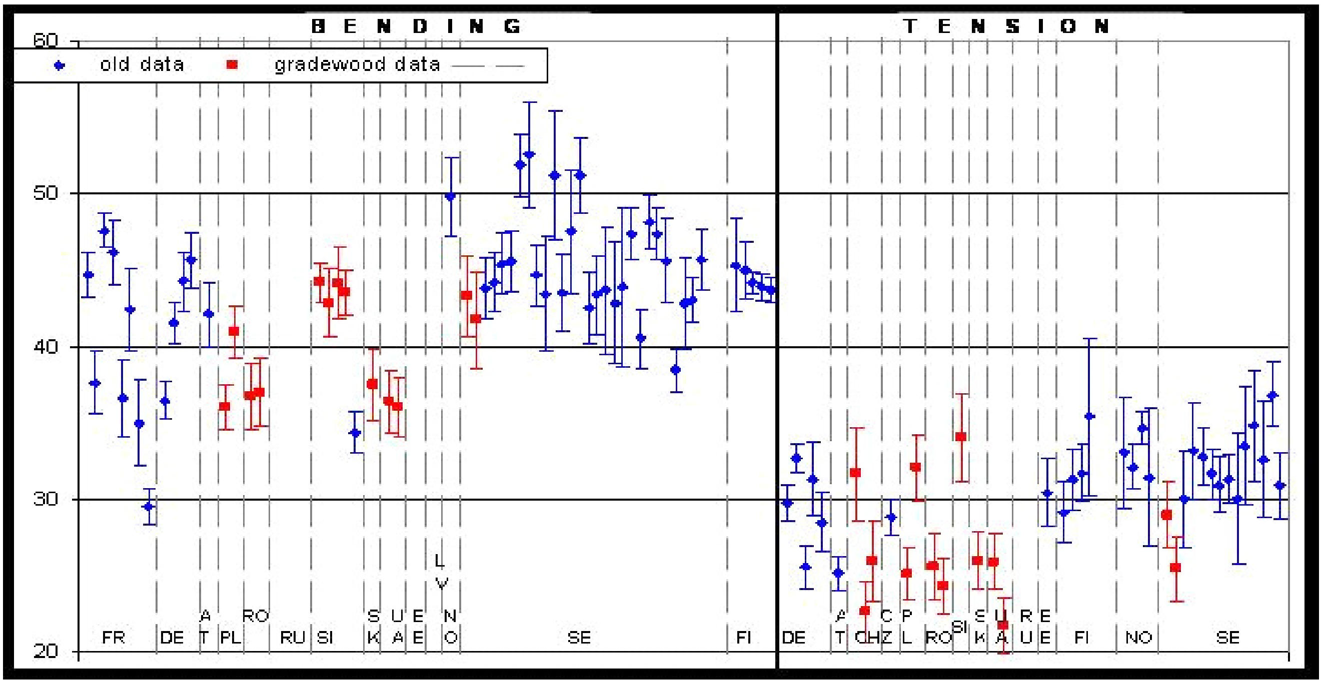

Figure 3. Variability of bending and tension strength of spruce of samples.

Growth area definition of European standard is based on difference between countries. The results show that variability of mechanical properties inside a country is as important as variability between countries. However, we have the statistical justification to separate Nordic area and other European growth area. This is especially clear for pine.

Determination of settings by the use of the Prediction limit method has been evaluated by the use of the simulated data sets. Data fitted to the same regression line are not sensitive to different mean value. A poor correlation gives more conservative settings. The Gradewood test results have been used to verify the results from the simulated data sets. The results from these verifications show differences of the settings between different parts of Europe. The difference between different parts within a country is of approximatively of the same size.

Further evaluation on the prediction limit method has shown that the settings obtained are depending on the variance of the residuals. This means that the settings are independent on mean values for different sub-samples. The only critical parameters are slope and intercept of the model and the deviations between model and observations. Examples based on the test results verify this. The independency from mean values of the sub-samples may have a major influence on the possibility to establish common grading areas for larger areas in Europe.

Within the area where same settings are used, timber properties were observed to have quality shifts depending for example on harvesting area. These quality shifts were seen also in mechanical values of in-grade timber. A grading system adaptive to the quality of the incoming material is developed using real grading machine IP-values from one sawmill combined with simulated values for the grade determining properties. Adaptive dynamic settings are illustrated in Figure 4. Results for grade determining properties were highly promising.

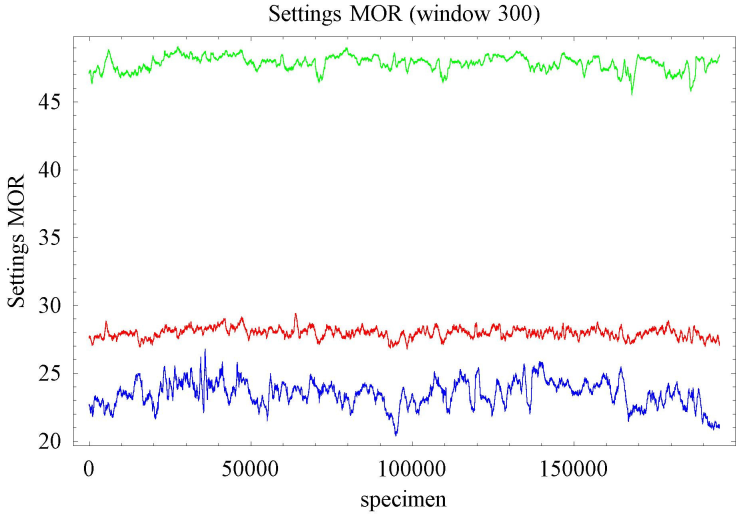

Figure 4: *Illustration of dynamic adaptive production settings of when grading to C40-C30-C18*

Variability of properties of visually graded timber was by use of indirect means observed to be larger than variability of machine graded timber.

In present standard, "output control method" (CUSUM) is intended to cope with timber quality shifts. CUSUM method was analysed by simulation and it was observed that it requires a lot of testing when a variation of grades and grade combinations are produced, and it has a too slow response for variation of quality of incoming material. The number of extra tests required and thus additional production cost is increasing more or less linear with reduced settings. Further evaluations had shown that the method is coarse and that it is insensitive to changes of the incoming ungraded material.

1.3 Conclusions

The most important contributions to the state-of-the-art, derived from the results and discussion.

In Europe, strength, stiffness and density are considered as grade determining properties, and characteristic values of all of them need to fulfil requirements. The most commonly used indicating properties (IP) do not have high correlation with all three properties, and consequently such IPs cannot result in grading with high accuracy. In order to have a European strength grading machine working on wide area we need to use separate IP-functions for three grade determining properties:
- One for MOR (measurements of knots and material quality)
- One for MOE (measurements of dynamic MOE)
- One for density (measurements with Xray or mass of timber).

Gradewood material is a good basis for determination of an area where same settings can be used, and this area needs to be determined separately for each grading method and species.

As solution to the quality variability problem two new methods are proposed to be used:

1. the application of Prediction limit method to all three grade determining properties for determination of initial settings.
2. use of adaptive dynamic settings based on cumulative information of wood properties what a modern grading machine can have.

It is also concluded that Output control method in the present European form should be withdrawn.

1.4a Capabilities generated by the project

Knowledge generated in the project / outcomes of the project, such as unpublished doctoral theses, patents and patent applications, computer programs, prototypes, new processes and practices; established new businesses; potential to create new business opportunities in the sector.

1. New experiments of 6000 specimens were made and this data base is available for participating institutes and 5 grading machine manufacturers for future development work.
2. New settings of participating grading machines can now be based on same timber specimens which enhance transparency of the system
3. Data base is being used in 2 doctoral thesis which are under work

1.4b Utilisation of results

Give a brief description of how the results of the research and development have been used and/or what is the exploitation plan or plans for transferring the results into practice.

1. 5 grading machine manufacturers have access to data base of 6000 specimens and they will use it for development of their business.
2. Proposal for renewal of EN 14081-2 has been drafted and will be submitted to CEN 2011.

1.5 Publications and communication

a) Scientific publications

For publications indicate a complete literature reference with all authors and for articles a complete name. Indicate the current stage of the publishing process when mentioning texts accepted for publication or in print. Abstracts are not reported. Indicate the five most important publications with an asterisk.

1. Articles in international scientific journals with peer review

Buksnowitz C, Konnerth J, Hackspiel C, Hofstetter K, Müller U, Gindl W, and Teischinger A (2010). Knots in trees – strain distribution in a naturally optimized material. Wood Science and Technology 44: 389–398.

Two publications under submission.

2. Articles in international scientific compilation works and international scientific conference proceedings with peer review

Ranta-Maunus A (ed) (2009). Strength of European Timber, Part 1: Analysis of growth areas based on existing test results. VTT Publications: 706 (105 p + app 63p) http://www.vtt.fi/inf/pdf/publications/2009/P706.pdf

Ziethén R, Bengtsson C (2009). Machine Strength Grading – a New Method for Derivation of Settings. CIB W18-meeting, paper 42-5-1,12 p. Zurich, Swizerland

Ranta-Maunus A, Denzler J.K. (2009) Variability of strength of European spruce. CIB W18-meeting, paper 42-6-1,10 p. Zurich, Swizerland

Ranta-Maunus A (2009) Comparison of four basic approaches in machine strength grading. COST E53 Conference, Lisbon, Portugal

Stapel P, van de Kuilen J.W.G. (2010): Growth areas in Europe with regard to different wood species and grading principles. WCTE 2010. Riva del Garda, Italy.

Stapel P, Denzler J.K. (2010). Influence of the origin on specific properties of European spruce and pine. The Final Conference of COST E53. Edinburgh, UK.

Stapel P, Rais A, van de Kuilen J.W.G. (2010). Influence of origin and grading principles on the engineering properties of European timber. Council for research and Innovation in Building and Construction, Working Commission W18 -Timber Structures, Meeting 43, Nelson, New Zealand.

Ranta-Maunus A (2010). Variability of strength of in-grade spruce timber . COST E53 Conference, Edinburgh, UK

Ranta-Maunus A,Turk G (2010). Approach of dynamic production settings for Machine strength grading. WCTE 2010, Riva del Garda, Italy

Ziethén R, Lycken A, Bengtsson C (2010). Machine strength grading – "output control" as a method for production control. WCTE 2010, Riva del Garda. Italy

Ziethén R, Bengtsson C (2010). Machine strength grading – prediction limits – evaluation of a new method for derivation of settings. WCTE 2010, Riva del Garda, Italy

Ziethén R, Lycken A, Bengtsson C (2010). Development of a simulation-evaluation program for introducing and using output control in the sawmill industry. COST E53, Edinburgh, UK

Ziethén R, Bengtsson C (2010). Machine strength grading – prediction limits – evaluation of a new method for derivation of settings. COST E53, Edinburgh, UK

3. Articles in national scientific journals with peer review

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4. Articles in national scientific compilation works and national scientific conference proceedings with peer review

Lycken A, Oja J, Lundahl C G (2008), Kundanpassad optimering i såglinjen - Virkeskvalitet On-line. SP Rapport 2008, SP Technical Research Institute of Sweden

Stapel P (2010): Auswirkung der Herkunft auf die Festigkeit bei verschiedenen Sortierverfahren. Doktorandenkolloquium Holzbau Forschung + Praxis. Stuttgart, Germany. pp.43-48

Denzler, J.K. (2010): Grading of timber for engineered wood products - Europäische Herkunftsgebiete – erste Ergebnisse. Wiener Leimholzsymposium. Vienna, Austria 2010. pp 42-55.

5. Scientific monographs

-

6. Other scientific publications, such as articles in scientific non-refereed journals and publications in university and institute series

Garcia C (2010) Numerical Simulations on the Strength Reducing Effect of Knots in Wooden Boards. Master Thesis, TU Vienna.

a) Other dissemination

Such as text books, manuals, user guidelines, newspaper articles, TV and radio programmes, meetings and contacts for users and results.
Dissemination of results to industrial partners and industrial partners dissemination within the company.

Project web page has been used of communication between participants from research and industry (total of 86 documents, www.buildingwithwood.eu)

Project has organised one day seminars to industry: Växjö 2009, Edinburgh 2010, Munich 2011, additionally several presentations in symposiums.

1.6 National and international cooperation

Give a brief description of the cooperation/ networking (partnership between the project participants and how this has developed; industrial involvement; synergies of industrial and research expertise; Has the project collaborated with similar projects in the WW-Net countries or other regions, or established new links with/ between local or

international organisations involved in the respective research field? Describe how these partnerships have supported the project.
National vs. transnational aspects in the project; added value for the project and its impacts which result from transnational cooperation.

This project was unique in the area of strength grading of timber in following aspects:

1. Large amount of existing confidential data (26000 specimens) was jointly analysed
2. New experiments of 6000 specimens were made and this data is now available for participating institutes and grading machine manufacturers
3. New settings of participating grading machines can now be based on same timber specimens

All this form a solid and transparent unique basis for European standardisation.

Industry has submitted confidential data for analysis which was the only practical way for researchers to find out the variability of timber material.

Project included research participants from Austria, Slovenia and Switzerland. Their contribution was crucial in statistical expertise and in testing of Central and Eastern European timber.

Collaboration with industry was part of project plan: grading machine developers were invited to participate by change of information. Industry measured project test material by use of their equipment, and gave the results (indicating properties) to project participants. In return they received results of destructive tests. It was a real win-win deal.

In addition, industry gave their grading machine data for analysis in the project, which was the first time when researchers could analyse a data base of hundreds of thousands timbers, and see the variability of timber source.