Service life and performance of exterior wood above ground (WoodExter)

FINAL REPORT

Title of the research project	**Service life and performance of exterior wood above ground – WoodExter**
Coordinator of the project	Mr Jöran JERMER

BASIC PROJECT DATA

Project period	01.10.2007- -28.02.2011
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FUNDING

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Kebony ASA, Norway	EUR 15 500
Association of the Austrian Wood Industries	EUR 100 000
Building Research Establishment, United Kingdom	EUR 30 000

PROJECT TEAM (main participants)

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Degrees earned or to be earned within this project.

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2009	BSc	F	Nives Salihodzic, Born 1982, BSc 2009	University College of Borås	Dr Jan Isberg, UCB Mr Jöran Jermer, SP
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ABSTRACT

Major contributions of WoodExter can be summarized as follows:

- A guidance document “Engineering design guideline for wood above ground applications” and related software – have been developed to serve as practical tools for engineers and architects for the design of wooden constructions with respect to durability and service life.
- New, important knowledge has been generated, in particular concerning exposure conditions and risk of decay, performance of coating systems, effect of decay on micromechanical properties of wood and the use of PCR (Polymerase Chain Reaction) techniques as early indicators of fungal colonization.
- A proforma for conducting systematic performance assessments of exterior wood cladding and decking has been prepared.

WoodExter has generated nearly 50 publications and results from WoodExter have been presented at numerous national and international events.

1.1 Introduction

1.1.1 Background

A key issue for the competitiveness of wood is the possibility to control durability, service life, maintenance and life cycle costs for constructions and components where wood is used.

Traditionally, durability design of wooden components and structures is based on a mixture of experience and adherence to good building practice, sometimes formalised in terms of implicit prescriptive rules. A modern definition of durability is: *The capacity of the structure to give a required performance during an intended service period under the influence of degradation mechanisms*. Conventional durability design methods for wood do not correspond to this definition.

The development of performance-based design methods for durability and service life requires that models are available to predict performance in a quantitative and probabilistic format for intended use condition. The relationship between product performance during testing and in service performance needs to be quantified in statistical terms and the resulting predictive models need to be calibrated to ensure that they provide a realistic measure of service life, including a defined risk level.

1.1.2 Objectives

The key outcome of WoodExter is a guidance publication with the provisional title “Engineering design guideline for wood in above ground applications”, targeted for specifiers, architects and qualified DIY builders, as a first attempt to introduce the core concept: performance based engineering design in practice for wood and wood-based building components in outdoor above ground situations. Focus is on cladding and decking.

Other objectives are to generate new knowledge on:

- How different climates end-use situations will affect the performance of wood.
- The role of surface coatings and their interactions with wood.
- Decay indicators from field tests to produce in-service performance predictions and related input to European standardization.
- The effect of decay on micromechanical properties of wood.
- The use of novel methodologies, quantitative real-time PCR Polymerase Chain Reaction (qPCR), for identification and quantification of early decay and conventional Polymerase Chain Reaction (PCR) for identification of early detection of colonisation by blue stain and mould.

Additionally, another objective is to develop a systematic approach for performance assessments of cladding and deliver a proforma for that purpose.

1.2 Results and discussion

Engineering design guidelines

Joint efforts from research partners of WoodExter have resulted in a breakthrough for design of wood constructions with respect to durability and service life. Thus, the main objective of the project has been fulfilled and a first draft of the guidance document "Engineering design guideline for wood in above ground applications" - a practical tool for engineers and architects for design of wood constructions with respect to durability and service life has been issued. The WoodExter approach is based on a similar approach as used in structural design which is familiar to engineers and architects. The expected service life is determined by available data of the resistance and exposure of the timber and expressed in a mathematical formula. Real building case studies have confirmed that this novel approach looks very promising.

Although is not possible to quantify all the factors in the design method on a scientific basis, the work within WoodExter has made it possible to determine a characteristic exposure index for a reference situation by using time series of climate data at different geographical locations (decay index mapping for Europe) together with the performance models for onset of decay for a reference material. Attempts have been made to make a relevant assessment of variability to achieve appropriate safety margins.

The system will give the designer a method to consider climate conditions at the actual site and also to some extent on the meso-level. A simplified way to account for the effect of coatings on exposure has also been introduced.

One advantage with the system is that the user will have to think about the consequences of violation of the limit state. Another advantage is that in applying the method the designer will go through a check list where he/she becomes aware of the importance of appropriate detailing solutions. Even if the factors describing effects of detailing, contact zones, coating systems and maintenance are difficult to quantify in a reliable way the use of the method should generally lead to better solutions.

Building professionals normally have limited understanding of the concept durability by design for wood. Direct descriptions (pictures) of so called best practice solutions are quite difficult to use because the designer does not understand what happens if the solution is modified, which is most often necessary. As a complement to the guidance publication a special software based on MS Excel has been developed to serve as a practical help for design for durability.

End-use situations and performance

The effect of design on the microclimate and on wood moisture content was studied on decking with three different designs. Decking N°1 had a conventional design, decking N°2 included improvements of the fixations to reduce moisture ingress and decking N°3 included further improvements to avoid water traps.
The wood species selected was poplar. Poplar is not used for decking but was chosen because it is non durable. Therefore early degradation was expected when exposed outdoors. Two sets of these three designs were made. One was exposed and assessed in Bordeaux (France) and the other one in Göttingen (Germany).
Moisture measurements were performed on these uncoated and untreated decking during field trials with a non destructive moisture meter measuring the humidity of the wood by contact.
For both exposures sites, from April 2009 to end of 2010, results show that there are no significant differences in wood moisture content amongst the three objects studied. The increase in moisture content is especially linked to the duration of rainfall. No decay was observed during this period. Only some blue stain was noticed.

Surface coatings and interaction with wood

Interactions of wood and coatings were studied in a collaborative approach by the research partners based on a systematic sample plan. This plan included 12 different coating systems, 2 wood species, variations in growth ring orientation, wood density and surface preparation (planed, sanded, sawn) as well as five types of modified wood produced in commercial processes. In total approximately 900 wood panels with selected properties were produced and coated for different experiments. The objective of this work was to study the influence of several types of modification (acetylation, furfurylation, thermal modification) and other parameters of the wood substrates on coatings performance.

Physical properties like water and water vapour permeability, adhesion in dry and wet conditions and UV-light protection were studied in laboratory trials with different methods. A comparison of two methods of assessing the adhesion has shown that the pull-off test is more sensitive than the cross-cut test and gives more information about the influence of the substrate. Under wet conditions adhesion was generally lower than dry adhesion. Compared to the reference, there was no improvement in the dry adhesion due to the different modifications, treatments or variations of the substrates. It was found that by increasing the coating film thickness, the coating permeability decreased and also less solar radiation transmitted through the coating film. This indicates the higher barrier properties of a coating film with higher thickness.

Artificial weathering and 24 months natural weathering at six sites in Europe were carried out with coated panels and uncoated references. In the natural weathering trials data on wood moisture content fluctuations in the panels was recorded and assessed to quantify the influence of coatings systems and exposure sites. Parts of this data were used to assess the risk of decay of these panels by previously published models. Fluctuations in wood moisture content were influenced by the film thickness, moisture protection and colour of the coating systems used. Degradation phenomena led to decreasing moisture protection of less durable coating systems over time of exposure. Differences between the exposure sites were relatively low, except for the site in the UK where moisture conditions were higher. The data of wood moisture content gives evidence on coating durability and its moisture protection. It was used to estimate the influence of coatings on durability design for the guidance document "Engineering design guideline for wood above ground applications". It may also contribute to future modelling of decay risk and service life estimation of coated wood constructions on a European level.

Results of weathering performance in artificial and natural exposure indicated that on one hand higher film thickness can result in improved durability of the coating and thus longer maintenance intervals but on the other hand very low permeability of the coating can enhance the risk of moisture trapping in the wood at defects or joints. Acetylated Radiata pine wood revealed outstanding performance in colour stability and as coating substrate in all weathering trials. The performance of thermally treated pine sapwood was comparable to the unmodified reference. Its colour change was characterised by bleaching. Uncoated furfurylated pine sapwood samples showed strong colour change with extensive bleaching, whereas coated furfurylated wood showed good colour stability. Coated Cr-free impregnated pine sapwood showed sensitivity to mechanical defects of the semi-transparent coating film, leading to strong discolouration. These results indicate the possible influence of preservative impregnation on coating performance of semi-transparent stains.

Long term experience was gained from assessment of old weathering trials that were started up to 15 years ago including cladding samples of Scots pine, Norway spruce and thermally modified wood. It was found that the coating system has a great influence on the performance of wood. With two or three layer systems the best performance was obtained and wood species had minor effect on the performance. The wood species had a greater importance in case of "low performing" coatings.

Definitions of a series of limit states for coating systems on wood were published including aesthetical limits and three levels of durability limits. Film forming coatings can reach two durability limits, i.e. the maintenance interval and the renovation interval. For non film forming coatings there is only one limit state of coating durability where maintenance is needed. Experience on coating durability and maintenance intervals of different wood coating systems was collected among the research partners to gain information on coating durability in real situations and in different regions of Europe. A Top Five list of recommendations to obtain good coating performance on cladding was generated, with an appendix of a few more items with lower priority.

An overview of present evaluation procedures for coatings on exterior wood on European and national levels was compiled and summarised. The collection of methods was categorised in those assessing weathering performance, moisture related failure and susceptibility to biological attack. A range of well-defined and standardised assessment methods is available from European standardization. A summarizing report was submitted to CEN/TC 139 WG2.

Decay indicators
A critical assessment has been conducted of approaches for determining durability and thus for providing durability indicators. Mass loss is the durability indicator that CEN standards uses, the work of this task has looked at other means of recording durability such as change in mechanical properties and biochemical changes. These could provide in the future more reliable or earlier indicators for durability for all durability enhancing technologies. An analysis of existing CEN/TC 38 standards and their usefulness for informing on expected service life of products was conducted has fed into CEN committee activity.

Field data has also been reanalysed to see if more information in performance (service life) can be gained. In the Nordic countries field trials (EN 252) have been going on for more than 60 years, and more than 20 000 field test stakes have been installed and evaluated since 1968. Results from these trials have been the main source for the database developed in this project. These in-ground data have been compared and analysed together with different "above-ground" field tests data in order to develop durability indicators that can that can be used in the service life design model developed. The interpretation of the data also reflects the impact of several other factors like temperature, humidity, and soil, and how they all affect the rate of deterioration.

Reflecting the wide variation in both exposure situations and wood treatment, Scots pine sapwood obtained an average life of 3.5 years at a Swedish test site, while the same wood material obtained an average life of 4.5 years when exposed in a Norwegian test field. For one type of preservative-treated wood the corresponding figures are 21 years in Sweden and more than 35 years in Norway. The correlation found for decking situations based on trials with small test decks and standard methods for above ground testing (ENV 12037), was roughly a factor 3, implying that it takes 3 times as long to reach the same decay rating above ground, compared to in ground.

Durability indicators I_{Rk}, to be used in the design model are calculated from Characteristic values X_{Rk} which were produced by ranking of resistance against rot decay given the same exposure conditions for different materials, species, treatments and products, correlated to a use class in accordance with EN 350 part 1 and 2.

This work will be of importance for the standardization work within CEN/TC 38, and its new Working Group (WG 28) with focus on service life prediction, and in particular how present test decay test methods can be used for that purpose. WG 28 was established following an initiative by, among others, the WoodExter coordinator.

The effect of decay on micromechanical properties of wood
Fungal decay causes changes in the wood microstructure, expressed by decomposition or degradation of its components, and consequently a decrease of macroscopic mechanical properties. Consideration of these alterations in the framework of a multi-scale model for wood allows predicting changes in the macroscopic mechanical properties. For the purpose of model validation, an extensive experimental programme was carried out, in which changes in chemophysical properties and corresponding changes in the mechanical behaviour were examined. In particular, pine (*Pinus sylvestris*) sapwood samples were measured in the reference condition as well as degraded by brown rot (*Gloeophyllum trabeum*) or white rot (*Trametes versicolor*). Stiffness properties of the unaffected and the degraded material were measured, not only in uniaxial tension tests in the longitudinal direction, but also in the three principal material directions by means of ultrasonic testing.

Experiments and modelling results revealed transversal stiffness properties to be much more sensitive to degradation than longitudinal stiffness properties. This is due to the degradation of the polymer matrix between the cellulose fibres, which has a strong effect on the transversal stiffness. On the contrary, longitudinal stiffness is mainly governed by cellulose, which is more stable with respect to degradation by fungi. Consequently, transversal stiffness properties or ratios of normal stiffness tensor components may constitute suitable durability indicators.

qPCR for identification and quantification of early decay
A novel methodology, quantitative real-time PCR Polymerase Chain Reaction (qPCR) has been utilised for identification and quantification of early decay and proven very useful in:

- monitoring of fungal colonization in laboratory and field trials
- insight in mode of action of modified wood against decay fungi
- as a tool for early estimation of service life

An interdisciplinary approach has given new insight in the effect of fungal decay on micromechanical and chemical properties. The use of Thermo Gravimetric Analysis (TGA) has proven to be a fast and useful tool for estimation of chemical changes during decay for brown rot fungi, see above.

PCR for early detection of blue stain and mould
The aim of this research was the early detection of fungal attack on the surfaces of modified and unmodified wood after natural weathering. The investigation was carried out by molecular techniques and the development and establishment of genus/species specific PCR for important moulds and sapstain fungi was part of this work. After adaptation of the method, a monitoring of the succession of *Ascomycetes* on surfaces of modified wood with and without coatings after natural weathering started. During the investigation, this method turned out to be a very useful tool for monitoring the surfaces of wood in service concerning the attacks by moulds and sapstain fungi.

Performance assessments of exterior wood cladding and decking
A proforma for gathering data in a consistent and systematic way on the performance and service life of existing cladding and decking installations was agreed and issued. It was then tested in reality and a total of 74 completed proformas for wood cladding on buildings and 15 for decking were gathered from across Europe. This brought together data on materials, design (water shedding, ventilation), exposure (climate, orientation, height above ground), installation and details of the project and images of the products. An excellent database now exists for testing the engineering model and advising on best practice. In addition, a Top Five list of tips for extending service life of exterior wood cladding by design has been agreed across the partnership and is published for wide circulation.

1.3 Conclusions

From the results reported above it can be concluded that WoodExter has succeeded to deliver in accordance with the objectives with the most important contributions as follows:

- The guidance document "Engineering design guideline for wood in above ground applications" and the related software - practical tools for engineers and architects for design of wood constructions with respect to durability and service life.
- New, important, knowledge generated, in particular concerning exposure conditions and risk of decay, performance of coating systems, effect of decay on micromechanical properties of wood and the use of PCR techniques as early indicators of fungal colonization.
- The development of a proforma for systematic performance assessment of cladding and decking.

WoodExter has generated nearly 50 publications and results from WoodExter have been presented at numerous national and international events, e.g. at the 39th, 40th and 41st Annual Meetings of The International Research Group on Wood Protection, the 5th European Conference on Wood Modification, the 7th Wood Coatings Congress and Wiener Holzschutztage.

1.4a Capabilities generated by the project

Main knowledge generated in WoodExter:

- The practical tool for engineers and architects for design of wood constructions with respect to durability and service life, see above. After further development and improvements of the tool, including software, there is a potential for new businesses in the wood building sector.

Furthermore, improved knowledge on

- Exposure conditions in Europe with focus on decay hazard for wood (decay index mapping).
- The relationship between exposure conditions and risk of decay.
- The influence of sites on coating system performance.
- The influence of wood modification on coating performance and fungal colonization.
- The influence of detailing and coatings on moisture conditions in wood
- Indicators of fungal colonization (qPCR+micromechanical properties +field test evaluation)
- A critical analysis of the use of existing CEN standards for informing on service life

A number of young scientists have been engaged in different WoodExter projects and two young scientists have been working in WoodExter projects as part of their doctoral studies. This will be beneficial for future research in the areas of wood durability, wood protection and service life prediction to support the European Research Area and the wood industry sector.

1.4b Utilisation of results

- The Guidance document and related software will now be tested in practice on a national level. There are plans for capturing feedback in order to further improve the technique, e.g. by professionals or in future research projects.
- Work on early indicators for decay from various test procedures will continue to accommodate requirements for performance data expressed in the CPD. This work will also give useful input to standardization work within CEN/TC 38 WG28.
- The proforma for systematic performance assessments of cladding and decking will be further used and tested in practice and improved.
- A number of field tests started within the WoodExter project will continue and generate important data for future assessment and evaluation and input to CEN/TC 38 and CEN/TC 139.
- Research work on micromolecular techniques will continue within the framework of other projects.

1.5 Publications and communication

a) Scientific publications

1. Articles in international scientific journals with peer review

Grüll G, Truskaller M, Podgorski L, Bollmus S, Tscherne F. (2010). Maintenance procedures and definition of limit states for exterior wood coatings. European Journal of Wood and Wood Products 30 July 2010 (online).

Pilgård A., Alfredsen G., Hietala A. (2010). Quantification of fungal colonization in modified wood – qPCR as a tool for studies on *Trametes versicolor*. Holzforschung 64.

Pilgård A., Alfredsen G.; Björdal C G, Børja I, Fossdal C G (2010). qPCR – a molecular tool to study fungal colonization pattern in wood field stakes. Will be submitted in January 2011.

Viitanen H, Toratti T, Makkonen L, Peuhkuri R, Ojanen T, Ruokolainen L, Räisänen J. (2010). Towards modelling of decay risk of wooden materials. European Journal of Wood and Wood Products. Vol 68. No 3.

Podgorski L, Grüll G, Georges G, Truskaller M, Bollmus S. Coating performance on different types of modified wood: natural and artificial weathering results. Submitted to Surface Coatings International in December 2010.

Bader T K, Alfredsen G, Bollmus S, Hofstetter K (2011). Changes in microstructure and stiffness of Scots pine (*Pinus sylvestris*) sapwood degraded by *G. trabeum* and *T. versicolor* – Part I: Physicochemical alterations. Will be submitted to Holzforschung in February 2011.

Bader T K, Alfredsen G., Bollmus S, Hofstetter K (2011). Changes in microstructure and stiffness of Scots pine (*Pinus sylvestris*) sapwood degraded by *G. trabeum* and *T. versicolor* – Part II: Anisotropic stiffness properties. Will be submitted to Holzforschung in February 2011.

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

Viitanen H, Peuhkuri R, Ojanen T, Toratti T, Makkonen L. (2008). Service life of wooden materials – mathematical modelling as a tool for evaluating the development of mould and decay. Proceedings
COST Action E37 Final Conference. Bordeaux, 29-30 September, 2008

Viitanen H, Toratti T, Peuhkuri R, Ojanen T, Makkonen L (2009). Durability and service life of wood structures and components -State of the art. Proceedings COST Action E25 Workshop Integrated approach to life-time structural engineering. Timisoara, 23-24 October, 2009.

Viitanen H, Toratti T, Makkonen L, Thelandersson S, Isaksson T, Früwald E, Jermer J, Englund F, Suttie E (2011) Modelling of service life and durability of wooden structure. Paper to be presented at NSB, Nordic Building Physics Conference 2009 in Tampere, Finland.

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
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5. Scientific monographs
Forslind I, Salihodzic N (2009). Durability of cladding – Evaluation of proforma for inspections. Univ College of Borås BSc Thesis.

Schlotzhauer P (2010) Vergleichende Untersuchungen von Fassaden aus thermisch modifiziertem und unmodifiziertem Holz. University of Göttingen BSc Thesis.

6. Other scientific publications, such as articles in scientific non-refereed journals and publications in university and institute series
Alfredsen G, Pilgård A, Hietala A (2008). A step towards a better understanding of fungal colonization of modified wood - QRT-PCR studies. The International Research Group on Wood Protection, IRG/WP 08-10653.

Bader T K, Hofstetter K (2010). Pilzabbau von Holz: Quantifizierung des Steifigkeitsverlusts auf Basis von mikromechanischen Überlegungen. Proceedings of Wiener Holzschutztage 2010, Vienna, 25-26 November.

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Bollmus S, Gellerich A, Krause A, Dieste Märkl A (2011). Electric moisture measurements of untreated and modified wood during outside exposure Paper to be presented at IRG 42nd Annual Meeting, Queenstown, New Zealand.

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De Windt I, Van den Bulcke J, Van Acker J (2010). Impact of wood species on the performance of exterior wood coatings. The International Research Group on Wood Protection, IRG/WP 10-40519

Englund F (2010). Standardization related to Service Life Planning. State-of-the-art . SP Report 2010:37

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Grüll G, Truskaller M, Podgorski L, Bollmus S, De Windt I, Suttie E (2010). Moisture conditions in coated wood panels during 18 months natural weathering at five sites in Europe. Proceedings of the 7th International Woodcoatings Congress, 12-13 October 2010, Amsterdam

Grüll G, Truskaller M, Podgorski L, Georges V, Bollmus S, Jämsä S, Viitanen H, Jermer J (2010). WOODEXTER Work Package 3 Interaction of wood and coatings – effect on the performance of wood products. Report on Laboratory Results. HFA Nr FFG 436.

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Pilgård A, Alfredsen G, Børja I, Björdal C. (2009). Durability and fungal colonisation patterns in wood samples after six years in soil contact evaluate. The International Research Group on Wood Protection, IRG/WP 09-20402.

Podgorski L, Grüll G, Truskaller M, Lanvin J D, Georges V, Bollmus, S (2010). Wet and dry adhesion of coatings: comparison of the pull-off test and the cross-cut test. The International Research Group on Wood Protection, IRG/WP 10-40524.

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Sivertsen M, Alfredsen G, Westin M (2009). Ultrasound - A feasible tool for decay detection? WSE conference – Nordic Baltic Network in Wood Material Science & Engineering. September 2009 Copenhagen.

Steitz A, Schmöllerl B, Pfabigan N, Bollmus S, Grüll G (2010). Early detection of colonisation by blue stain and mould on modified wood using PCR technique. The International Research Group on Wood Protection, IRG/WP 10-10730

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Suttie E, Englund F (2010). Service life prediction for exterior timber cladding. The International Research Group on Wood Protection, IRG/WP 10-20460

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Suttie E (2010). Sustainability in the built environment. Public Service Review 2/2010

Toratti T, Viitanen H, Peuhkuri R, Makkonen L, Ojanen T, Jämsä S (2009). Modelling of durability of wooden structures. Proceedings 4th International Building Physics conference IBPC, Istanbul, 15-16 June, 2009.

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b) Other dissemination

Conferences, workshops
Results from WoodExter have been presented at the following international conferences:

- COST Action E37 12th workshop, 21-22 April 2008, Heraklion, Greece
- 39th Annual Meeting of the International Research Group on Wood Protection, 25-29 May 2008, Istanbul, Turkey
- 40th Annual Meeting of the International Research Group on Wood Protection, 24-28 May 2009, Bejing, China
- 4th International Building Physics Conference, 15-18 June 2009, Istanbul, Turkey
- 5th Meeting of the Nordic-Baltic Network in Wood Material Science and Engineering, 1-2 October 2009, Copenhagen, Denmark
- COST Action E25 workshop, 23-24 October 2009, Timisoara, Romania
- 41st Annual Meeting of the International Research Group on Wood Protection, 9-13 May 2010, Biarritz, France
- 5th European Conference on Wood Modification, 20-21 September 2010, Riga, Latvia

- 7th International Woodcoatings Congress, 12-13 October 2010, Amsterdam, The Netherlands
- Wiener Holzschutztage, 25-26 November 2010, Vienna, Austria
- 42nd Annual Meeting of the International Research Group on Wood Protection, 8-12 May 2011, Queenstown, New Zealand (upcoming)

In addition, WoodExter related material has been presented at approximately 20 national workshops, seminars and information meetings.

1.6 National and international cooperation

There is presently a growing interest in service life issues and activities are running or planned in Europe and elsewhere. From WoodExter point of view the following collaboration/networking should be mentioned:

- Collaboration between WinFur and WoodExter on material properties and durability of furfurylated wood. For Norwegian partner NFLI this project has established new links and additional cooperation with other projects based on the WoodExter contacts.
- In Sweden the WoodExter project has fed useful input to a national project with a similar focus – WoodBuild. Through WoodBuild further collaboration with other international partners has been established.
- In Belgium the WoodExter project gained input to a national project Optiwoodcoat with focus on the performance assessment of wooden window joinery. WoodExter gave the opportunity to gear results to one another and to establish further collaboration with international partners. Later on results of the WoodExter project will be implemented in Belgium.