Durable Timber bridges (DuraTB)

FINAL REPORT

Title of the research project	**Durable Timber Bridges**
Coordinator of the project	Kjell Arne Malo

BASIC PROJECT DATA

Project period	27.02.2014-30.04.2017
Contact information of the coordinator (institute/unit, address, telephone, fax, e-mail)	NTNU Norwegian University of Science and Technology/Department of Structural Engineering R. Birkelandsv 1a 7491 Trondheim +47 73 59 47 84 +47 73 59 47 01 Kjell.malo@ntnu.no
URL of the project	http://[-]

FUNDING

Total budget in EUR	2119521
Public funding from WoodWisdom-Net Research Programme:	Total funding granted in EUR by source:
<u>Austria</u> Federal Ministry of Agriculture, Forestry, Environment & Water Management (BMLFUW)	 [-]
<u>Finland</u> Tekes – the Finnish Funding Agency for Innovation Academy of Finland (AKA)	 245000 +115000? (lacking info from Aalto) [-]
<u>France</u> Ministry of Agriculture, Fisheries and Forestry Resources (MAAF) French Environment and Energy Management Agency (ADEME)	 [-] [-]
<u>Germany</u>	

Agency for Renewable Resources (FNR)	[-]
<u>Ireland</u> Department of Agriculture, Food and the Marine (DAFM - CoFoRD Programme)	[-]
<u>Norway</u> The Research Council of Norway (RCN)	600000
<u>Slovenia</u> Ministry of Education, Science and Sport (MIZS)	[-]
<u>Sweden</u> Swedish Governmental Agency for Innovation Systems (VINNOVA)	336151
<u>Switzerland</u> The Commission for Technology and Innovation (KTI; in the Federal Department of Economic Affairs FDEA)	[-]
<u>United Kingdom</u> The Forestry Commissioners (FC)	[-]

Other public funding:

NTNU ,Norway	150000
Norwegian public road authority, Norway	150000

Other funding:

Moelven Limtre, Norway	70000
Moelven Töreboda, Sweden	26926
Martinssons, Sweden	26926
Limträteknik, Sweden	46185
Swedish road authorities, Sweden	51663
VTT Technical research Centre of Finland Ltd	11000
Liikennevirasto, Finland	46000
Versowood oy, Finland	24000
Puutuoteteollisuusy (Finnish Wood Research), Finland	24000
Other Finnish funding: (Lacking detailed info)	196600

PROJECT TEAM (main participants)

Kjell Arne Malo, Dr. ing., Professor	Sex (M)	NTNU	Norway
Anna Posette, PhD, Researcher	Sex (F)	RISE (SP)	Sweden

Sven Thelandersson, PhD, Professor	Sex (M)	Lund University	Sweden
Stefania Fortino, PhD, Researcher	Sex (F)	VTT	Finland
Lauri Salokongas,PhD, Ass. Prof.	Sex (M)	Aalto	Finland
James Wacker, PhD, Researcher	Sex (M)	Forest Product lab	USA

DOCTORAL DEGREES
Degrees earned or to be earned within this project.

2017	PhD	Sex (F)	Anna Ostrycharczyk, 1987, 2017, PhD.	NTNU	Kjell Arne Malo, NTNU
2017	PhD	Sex (M)	Martin Cepelka, 1985, 2017, PhD.	NTNU	Kjell Arne Malo, NTNU
2018	PhD	Sex (M)	Francesco M. Massaro 1988, 2018, PhD.	NTNU	Kjell Arne Malo, NTNU
2019	PhD	Sex (F)	Katarzyna Ostapska-, Luczkowska 1987, PhD, 2019.	NTNU	Kjell Arne Malo, NTNU
2018	D.Sc.	Sex (M)	Jonas Niklewski, 1987 2018, D.Sc.	LUND	Eva Frühwald Hansson, LUND
2018	PhD	Sex (F)	Yishu Niu, 1989? PhD, 2019,	AALTO	Gerhard Fink? AALTO]

MASTER DEGREES (MSc)

Year	Institution	Name	Title	Supervisor
2017	NTNU	Magnus W. Bast	Design of Network Arch Bridge in Timber (In Norwegian)	Kjell Arne Malo Haris Stamatopoulos
2017	NTNU	Jonas E. Tveter	Design of Network Arch Bridge in Timber (In Norwegian)	Kjell Arne Malo
2017	NTNU	Arild Kvittingen	Fatigue Strength of Lued-Laminated Timber loaded in Shear along Grain and Withdrawal of Threaded rods.	Kjell Arne Malo
2017	Univ. Brescia/VTT	Federico Ossoli	Effect of Northern European climates on the cupping of stress-laminated timber	Giovanni Metelli Stefania Fortino

			decks.	
2017	Aalto	Joonas Jaaranen	Timber.Concrete Composite Bridges	Lauri Salokongas Gerhard Fink
2016	NTNU	Hallvard Oltedal Veium	Axially loaded threaded rods in glulam splices. (In Norwegian)	Kjell Arne Malo
2016	NTNU	Nina Løkken	Fatigue of Threaded Rods Subjected to Axial Load	Kjell Arne Malo Haris Stamatopoulos
2016	NTNU	Morten Eilertsen	Long Span Network Arch Bridges in Timber	Kjell Arne Malo
2016	NTNU	Dag Erik Haddal	Long Span Network Arch Bridges in Timber	Kjell Arne Malo
2016	Univ. of Brescia (It) VTT	Alessandro Musci	Effect of moisture induced stresses on the mechanical performance of glulam beams of Vihantasalmi bridge	Giovanni Metelli Stefania Fortino
2015	Trento (It) NTNU	Giulia Devarda	Characterization of Timber Bowstring Bridge with inclined hangers.	Mauricio Piazza Kjell Arne Malo
2015	NTNU	Kasper van de Pontsele	Modelling of pedestrian Loading on Slender Footbridges	Kjell Arne Malo
2015	NTNU	Daniel Seides	Modelling of pedestrian Loading on Slender Footbridges	Kjell Arne Malo
2015	NTNU	Silje Borge Hovie	Design of Network Arch Bridge in Timber over river Orkla.(In Norwegian).	Kjell Arne Malo
2015	NTNU	Elen Katrine Skjerve	Design of Network Arch Bridge in Timber over river Orkla.(In Norwegian).	Kjell Arne Malo
2015	NTNU	Roger Håndlykken	Improvements of timber decks. (In Norwegian)	Kjell Arne Malo
2015	NTNU	Daniel Rønning	Improvements of timber decks. (In Norwegian)	Kjell Arne Malo
2014	NTNU	Ole Christian Sveen	Splicing of long timber areches in bridges. (In Norwegian).	Kjell Arne Malo

PROJECT SUMMARY REPORT

A summary of the project, preferably one page only

Most construction materials have a limited service life; concrete carbonates, steel corrodes and wood materials can be attacked by fungi and insects. Many of the built bridges in Europe over the past 50 years are characterized by decay and must either be repaired or renewed. Most of these bridges have fairly short spans in the range of 10 to 120 meters and enable crossing of rivers or plane less intersections. Bridges are important parts of our infrastructure and closure of bridges in connection with new constructions or repairs have high social costs. Timber bridges are very well suited to these ranges, allowing easy and quick installation and can in many cases use existing supports due to its low weight.

Wood is one of our oldest building materials for bridges, but has been replaced by steel bridges and later by concrete bridges for the last hundred years. It was assumed that steel and concrete bridges had less maintenance costs and longer life, but today's state of our bridges indicates that this does not have to be the case. The life span of wooden bridges are most related to how the climatic conditions affect the wood materials, and especially the moisture content and exposure time are important.

The project has focused on lifetime of wooden bridges, identification and classification of construction solutions with regard to service life and the development of new design and construction solutions with a long technical life.

A model has been developed for estimating the technical life of unprotected wooden bridges. The model compares climate exposure with resistance to rot development, and is based on quantification of both exposure and resistance in the form of doses. A dose is a measure of development of damage and depends on moisture content, temperature and time. The model has been verified through comparisons with the life of built bridges.

Improved details have been developed with regard to moisture protection of wooden decks on bridges. This work has been carried out both in the form of experiments and numerical models. The tests carried out in the project gave new knowledge about durability of wooden details and the model of service life design of timber bridges that can be used to ensure the best performance. The numerical models have been validated with comparisons of measured climate and moisture content in some instrumented wooden bridges. Moreover, material data is provided for long-term behavior of stress-laminated wooden decks which takes into account the creep and moisture variation. This provides the basis for improved numerical models of wooden decks and a tool for further development of this type of decks. The project has contributed to a good step forward in the development of bridge details, not least with regard to the edge detail of stress-laminated decks

A parameterized model of network arch bridges has been developed for long spans especially suited for the use of timber in the main support system and decks. The model is optimized and provides an effective bridge type. Furthermore, jointing technique has been developed for large bridges, since bridges of greater length than about 35 meters are difficult to transport from factory to bridge site in one piece.

Bridges are exposed to fatigue and experimental tests have been made to determine the lifetime with regard to the fatigue of attachment of hanging rods and joints.

The project has prepared a joint report, where most of the results available at the reporting date are presented. Results that have been finalized afterwards are being published in scientific journals.

1.1 Introduction

1.1.1 Background

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

In the last decades, it is experienced that most materials used for construction of bridges have limited lifetime. Concrete is carbonized, steel corrodes and insects or fungi may attack timber. A large number of the concrete and steel bridges built after the Second World War was assumed to have little need for maintenance. However, the current state of many of these bridges does not support this assumption; and we now face a vast gap between the needs for maintenance and repair of these bridges and the work actually performed. In many cases the bridges are beyond repair and new bridges are needed. Consequently, the number of bridges in European infrastructure that needs replacement is large. Most of these bridges have quite small spans, in the range 10 to 120 m, crossing roads and rivers. Since the bridges are vital components of the transport infrastructure, the closing time in case of renovation or rebuild is an important issue. Timber bridges are well suited for this span range, they offer quick installation on site, and they can utilize existing foundation due to low weight. Hence, the market potential for timber bridges is significant.

It is a common perception that the expected lifetime of a timber structure is only a fraction of that of a concrete or steel structure. In spite of this, some of our timber structures like the Norwegian stave churches and the covered bridges in Switzerland are among our most durable structures. On the other hand, we do have timber structures that show serious decay after only a few years in service due to elevated levels of moisture and consequently growth of fungi and rot. This is also the case for many timber bridges in Europe. The proposed research aims to significantly improve the general standing and applicability of wood as a structural material in bridges and contribute to increased use and market shares for environmentally friendly timber bridges. The bridge design concepts to be developed shall be among the best alternatives with respect to environmental friendliness, initial costs and life-cycle costs, and they shall show excellent results in life-cycle analyses.

1.1.2 Objectives

Describe the project objectives.

Overall objective of the project:

- To develop durable timber bridges with a given estimated technical lifetime.

Scientific and technological objectives:

1. To develop an exposure model related to risk of decay validated for a given set of timber bridges.
2. To develop a performance model relating microclimate representative for wooden bridge elements to the risk of their decay
3. To develop a methodology to account for uncertainties in service life design of timber bridges
4. To develop a set of design concepts for durable timber bridges in the span 10 – 150 m.
5. To develop splicing technology for massive block-glued glulam cross-sections for bridges.

6. To improve the performance of stress-laminated wooden deck and details of wooden deck-plates.
7. To develop fatigue strength criteria for axial threaded rod (screw) connectors.
8. To develop design integrated maintenance concepts for timber bridges.

1.2 Results and discussion

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

The overall objective:
The project has focused on lifetime of wooden bridges, identification and classification of construction solutions with regard to service life and the development of new design and construction solutions with a long technical life. The project content and results corresponds well with the overall objective stated in the project application.

Objectives 1, 2 and 3:
The project has worked on quantification of risk of decay related to moisture traps in timber bridges. Available experimental data from many European countries on material pieces have been collected and forms the empirical basis for a model for decay. Comprehensive tests of typical bridge detailing have been set-up and instrumentally monitored. The relations between climate condition and moisture content for these details have been determined and classified. By combining data from material pieces, bridge details, existing instrumented bridges, statistical methods, analytical methods and numerical models of moisture transport in wood, a model has been developed for estimation of the technical life of unprotected wooden bridges. The model compares climate exposure with resistance to decay, and is based on quantification of both exposure and resistance in the form of doses. A dose is a measure of development of damage and depends on moisture content, temperature and time. The model has been verified through comparisons with the lifetime of built bridges. The project fulfills the expectations set in objectives 1 and 2, and partly 3, but the latter only with respect to the uncertainties in expected service life time.

Objective 4:
The development of a long spanning timber bridge is based on the network arch concept. A special concept of arch bridges with self-stabilizing arches using hangers in so-called spoked wheel configuration has been developed. A parameterized computer model of the conceptual network arch bridge has been developed for long spans (50 – 150 meters). The concept bridge is especially suited for the use of timber both in the main support system and the deck. The model is optimized and provides an effective tool to document the design of a very efficient bridge type. The structural properties has been studied in detail using a parameter study and documented for all relevant types of loading. For short spans the Timber-Concrete Composite bridge have been studied and investigated with respect to long term properties. Objective 4 is achieved in a satisfactory manner.

Objective 5:
Jointing techniques have been developed for large bridge cross-sections, since bridge components of greater length than about 35 meters are difficult to transport from factory to bridge site in one piece. The work has been performed by a combination of numerical models and experimental testing in a laboratory. A satisfactory method for splicing has been developed, but some practical aspects need further attention before the splicing method becomes a standard method.

Objective 6:
The phenomenon of crack development, caused by gradients in the moisture distribution in large block-glued glulam members, has been explored. This work has been carried out combining experiments and numerical models. The numerical models have been validated with comparisons of measured climate conditions and moisture contents in some instrumented wooden bridges.
Improved details have been developed with regard to moisture protection of wooden decks for bridges.
The structural behavior of stress-laminated decks has been studied by long-term creep and relaxation tests under controlled conditions in the laboratory. Material data for use in mathematical models is determined for the long-term behavior of stress-laminated wooden decks (which takes into account the creep and moisture variation). This provides the basis for improved numerical models of wooden decks, and is a powerful tool for further development of this type of decks.

Objective 7:
Bridges are exposed to fatigue and experimental tests have been performed to determine the lifetime with regard to the fatigue of typical attachments of hanging rods and joints. The data is collected and supplies the data base of fatigue resistance in the next European design standard EN 1995-2.

Objective 8:
After some discussions, the consortium agreed to put the emphasis on maintenance and repairs, and inspection techniques of timber bridges. In addition, life cycle evaluations (LCA and LCC) on the performance of timber bridges has been performed, considering also the effect of maintenance.

1.3 Conclusions

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

The project is deemed to satisfy all the objectives quite well.

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.

Five PhD Thesis will be available to the public from the project, they will in due time appear in open sources (e.g. NTNU Open). Two of the five theses are already submitted for evaluation and dissertation.

About 20 master students have been connected closely to the project and they have worked out their master theses on a topic of great interest for the project.

A pre-processor for generating automatic numerical models for timber arch bridges has been programmed using Python scripting.

Improved approaches for numerical simulation of moisture transport and distribution in wood has been worked out.

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.

The project results is available in a common report from the project;

Durable Timber Bridges Final Report and Guidelines.

The final report can be obtained from any of the project partners. It can also freely be downloaded from the DIVA portal from RISE Sweden; RISE Research Institutes of Sweden SP Rapport 2017:25 ISSN 0284-5172 Skellefteå 2017.

New instructions in the Swedish AMA, based in part on the performed tests of waterproofing and bridge details, will contribute to good constructions and details in timber bridge building.

The studies in the project about design concepts, design methods, moisture calculations and LCA have contributed to increasing the overall knowledge regarding timber bridges. In the three Nordic countries national seminars have been arranged for dissemination of the project results; Sweden in January 2017, Finland in March 2017 and Norway in June 2017. In addition, most of the scientific results was presented on the 3rd International Conference on Timber Bridges in Skellefteå, Sweden, June 2017.

There will be 5 PhD degrees awarded connected to the project; Sweden – Jonas Niklewski, Finland – Yishu Niu and Norway – Francesco Mirko Massaro, Martin Cepelka and Anna

Ostrycharczyk. The dissertations will take place from November 2017 and probably be finalized in 2018.

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

1.1. Brischke C, Meyer-Veltrup L (2015) Moisture content and decay of differently sized wooden components during 5 years of outdoor exposure. European Journal of Wood and Wood Products 73(6), 719-728. 10.1007/s00107-015-0960-7

1.2. Brischke C, Meyer-Veltrup L (2016) Modelling timber decay caused by brown rot fungi. Materials and Structures 49: 3281–3291. 10.1617/s11527-015-0719-y.

1.3. Brischke C, Meyer-Veltrup L, Goritzka C, Tammen B, Hundhausen U, Mahnert K-C, Gellerich A (2016) Rissbildung in Holzbauteilen – Bewertung materialspezifischer Unterschiede und Einfluss auf Holzfeuchte und Oberflächenqualität. Holztechnologie 58 (3): 5-13.

1.4. Cepelka M, Malo KA (2017) Moment resisting splice of timber beams using long threaded rods and grout-filled couplers – Experimental results and predictive models, Construction and Building Materials155: 560-570. doi.org/10.1016/j.conbuildmat.2017.08.089

1.5. Meyer-Veltrup L, Brischke C, Alfredsen G, Humar M, Flæte P-O, Isaksson T, Larsson Brelid P, Westin M, Jermer J (2017) The combined effect of wetting ability and durability on outdoor performance of wood – development and verification of a new prediction approach. Wood Science and Technology 51(3): 615-637. doi:10.1007/s00226-017-0893-x

1.6. Niklewski J, Fredriksson M, Isaksson T (2016) Moisture content prediction of rain-exposed wood: Test and evaluation of a simple numerical model for durability applications. Building and Environment 97:236-246.

1.7. Niklewski J, Isaksson T, Frühwald Hansson E, Thelandersson S (2017) Moisture conditions of rain-exposed glue-laminated timber members: the effect of different detailing. Wood Material Science and Engineering. Accepted for publication. http://dx.doi.org/10.1080/17480272.2017.1384758

1.8. Cepelka M, Malo KA, Stamatopoulos H (2017) Effect of rod-to-grain angle on capacity and stiffness of axially and laterally loaded long threaded rods in timber joints, Under review in an international scientific journal.

1.9. Cepelka M, Malo KA (2017) Moment resisting on-site splice of large glulam elements by use of mechanically coupled long threaded rods, Under review in an international scientific journal.

1.10. Ostrycharczyk AW, Malo KA (2017) Parametric study of radial hanger patterns for network arch timber bridges with a light deck on transverse beams. Submitted to Engineering Structures in February 2017

1.11. Ostrycharczyk AW, Malo KA (2017) Parametric study on effects of load position on the stress distribution in network arch timber bridges with light timber decks on transverse crossbeams, Submitted to Engineering Structures in July 2017

1.12. Ostrycharczyk AW, Malo KA (2017) Network arch timber bridges with light timber decks and spoked configuration of hangers – parametric study. Submitted to Structural Engineering International in July 2017

1.13. Meyer-Veltrup, L.; Brischke, C.; Niklewski, J.; Frühwald Hansson E. 2017: Design and performance prediction of timber bridges based on a factorization approach. Wood Material Science and Engineering. Submitted for publication

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

2. CONFERENCE PAPERS

2.1. Malo KA, Ostrycharczyk AW (2014) Durable Timber Bridges. COST FP1004 Timber Bridge Conference - CTBC 2014, Proceedings, Bern University of Applied Sciences Biel/Bienne, Switzerland, 25.09.14 - 26.09.14, pp 81-86.

2.2. Massaro F M, Malo KA (2014) Review of pre-stressed timber bridge decks: durability, lay-out and structural systems, COST FP1004 Timber Bridge Conference - CTBC 2014, Proceedings, Bern University of Applied Sciences Biel/Bienne, Switzerland, 25.09.14 - 26.09.14, pp. 9-15.

2.3. Cepelka M, Malo KA (2014) Review on on-site splice joints in timber engineering, COST FP1004 Timber Bridge Conference - CTBC 2014, Proceedings, Bern University of Applied Sciences Biel/Bienne, Switzerland, 25.09.14 - 26.09.14, pp. 1-8.

2.4. Fortino S., Hradil P., Sippola M., Toratti T. (2014) Hygro thermal numerical models for stress-laminated timber decks. Proceedings of CTBC 2014 Timber bridge conference, Cost action FP1004, 25-26.9.2014, Biel, Switzerland, 8 p.

2.5. Ostrycharczyk AW, Malo KA (2014) Experimental evaluation of timber network arch bridge. COST FP1004 Experimental Research with Timber: Enhance mechanical properties of timber, engineering wood products and timber structure, Proceedings, University of Bath. Prague, Czech Republic, 21.05.2014-23.05.2014, pp 150-154

2.6. Pousette A, Gustafsson A, Fjellström P-A (2014) Moisture monitoring of beam and pylon in a timber bridge, COST FP1004 Timber Bridge Conference - CTBC 2014, Proceedings, Bern University of Applied Sciences Biel/Bienne, Switzerland, 25.09.14 - 26.09.14, pp. 125-131.

2.7. Brischke C, Meyer-Veltrup L, Thelandersson S, Malo KA (2015) Wood protection by design – concepts for durable timber bridges. In: Waldemar Perdoch, Magdalena Broda (Eds.) Proceedings of the 11th Meeting of the Northern European Network on Wood Science and Engineering, Poznan, Poland, 13-14th September 2015, pp. 156-162.

2.8. Cepelka, M.; Malo, K. A. (2016): Experimental study of end grain effects in timber joints under uniaxial compression load, *CD-ROM Proceedings of the World Conference on Timber Engineering (WCTE 2016)*, August 22-25, 2016, Vienna, Austria, Eds.: J. Eberhardsteiner, W. Winter, A. Fadai, M. Pöll, Publisher: Vienna University of Technology, Austria, ISBN: 978-3-903039-00-1

2.9. Brischke C. (2016) Design guidance for timber structures based on long-term field monitoring. 27th International Conference on Wood Science and Technology 2016. Implementation of wood science in woodworking sector. Zagreb, October 2016: 15-22.

2.10. Brischke C, Meyer-Veltrup L, Hundhausen U, Goritzka C, Ossanna D, Tammen B, Gellerich A (2016) Rissbildung in Holzbauteilen - materialspezifische Unterschiede und ihr Einfluss auf Holzfeuchte und Dauerhaftigkeit. Deutsche Holzschutztagung [German Wood Protection Conference] 22-23 September 2016, Dresden, Germany: 95-117.

2.11. Niklewski J, Frühwald-Hansson E, Brischke C, Kavurmaci D (2016) Development of decay hazard maps based on decay prediction models. The International Research Group on Wood Protection, IRG/WP/16-20588.

2.12. Meyer-Veltrup L, Brischke C, Goritzka C, Hundhausen, U (2016) Formation of cracks in wooden elements – design, moisture and durability aspects. COST Action FP 1303 4th Conference 'Designing with bio-based building materials – challenges and opportunities'. 24-25 February 2016, Madrid, Spain.

2.13. Brischke C, Frühwald Hansson E, Meyer-Veltrup L, Thelandersson S, Isaksson T, Niklewski J (2017) Design and service life prediction concept for timber structures - Part 1: A factorization approach based on dose-response models. XIV. Conference on Durability of Building Materials and Components, Ghent, Belgium.

2.14. Brischke C, Frühwald Hansson E, Kavurmaci D, Niklewski J (2017) Design and service life prediction concept for timber structures - Part 2: Climate effects. XIV. Conference on Durability of Building Materials and Components, Ghent, Belgium.

2.15. Meyer-Veltrup L, Brischke C (2017) Design and performance prediction of timber structures based on a factorization approach. The International Research Group on Wood Protection, IRG/WP/17-20603.

2.16. Hradil P., Fortino S., Salokangas L., Musci A., Metelli G. (2016) Effect of moisture induced stresses on the mechanical performance of glulam beams of Vihantasalmi bridge., Proceedings of World conference in Timber Engineering (WCTE 2016), August 22-25 2016. Vienna, Austria, 9 p.

2.17. Fortino S. Hradil P., Genoese A., Genoese A., Pousette A., Fjellström P.A. (2016) A multi-Fickian hygrothermal model for timber bridge elements under Northern Europe climates. Proceedings of World conference in Timber Engineering (WCTE 2016), August 22-25.2016, Vienna, Austria, 8 p.

2.18. Niklewski J, Frühwald Hansson E, Pousette A, Fjellström P-A (2016) Durability of rain-exposed timber bridge joints and components. Proceedings of the World Conference on Timber Engineering (WCTE) August 22-25, 2016 in Vienna.

2.19. Cepelka M, Malo KA (2017) Effect of on-site splice joints for timber network arch bridges, Proceedings 3rd International Conference on Timber Bridges (ICTB 2017) 26 - 29 June 2017 Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.20. Stamatopoulos, H. and K. A. Malo (2017). Fatigue strength of axially loaded threaded rods embedded in glulam at 45º to the grain. Proceedings of the 3rd International Conference Timber Bridges (ICTB), 26 - 29 June 2017 Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden

2.21. Fortino S., Hradil P., Metelli G., Ossoli F., Pousette A., Toratti T. (2017) Effect of Northern European climates on the cupping of stress-laminated timber decks. A numerical study. Proceedings of the 3rd International Conference on Timber Bridges, ICTB 2017, 26 - 29 June 2017, Skellefteå, Sweden. SP Technical Research Institute of Sweden; Luleå University of Technology, 9 p.

2.22. Hradil P., Fortino S., Metelli G., Musci A., Dohnal J. Fredriksson M. (2017) Simulation of moisture diffusion in timber bridges exposed to rain. Proceedings of the 3rd International Conference on Timber Bridges, ICTB 2017, 26 - 29 June 2017, Skellefteå, Sweden. Luleå University of Technology. SP Technical Research Institute of Sweden, 10 p.

2.23. Pousette A, Jacobsson P, Johansson E, Nilsson L-O, Warg C (2017) Improved edge design for stress-laminated decks made of spruce. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.24. Ostapska-Luczkowska K., Malo K.A. (2017): Parallel splitting mode of failure in dowel type connection with chamfered cuts. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.25. Ostrycharczyk A., Malo K.A. (2017): Comparison of network patterns suitable for timber bridges with crossbeams. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.26. Massaro F.M, Malo, K.A. (2017): Anchor plates for pre-stressing rods and compression orthogonal to grain of timber. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.27. Jaaranen J., Salokangas L., Fink G. (2017): Short-term analysis of timber-concrete composite bridges. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.28. Jaaranen J., Salokangas L., Fink G. (2017): Long-term analysis of timber-concrete composite bridges. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

2.29. Yishu Niu, Salokangas L., Fink G. (2017): Life-cycle assessment on two design alternatives of the Driva Bridge. ICTB 2017 - 3rd International Conference on Timber Bridges, 26-29 June 2017, Skellefteå, Sweden. Luleå University of Technology. RISE Technical Research Institute of Sweden.

3. Articles in national scientific journals with peer review

Not monitored

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

Not monitored

5. Scientific monographs

There will be 5 PhD Theses. About 20 Master are available.

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

3. CONFERENCES WITH (EXTENDED) ABSTRACTS AND/OR POSTERS:

3.1. Meyer-Veltrup L, Brischke C (2017) Durability-based design of timber structures – Quantifying design, exposure, and resistance on the basis of dose-response relationships. COST Action FP 1303 Workshop on 'Design, application and aesthetics of bio-based building materials. 28 February – 01 March 2017, Sofia, Bulgaria.

3.2. Fortino S., Hradil P., Sippola M., Genoese A., Genoese A. (2015) A multi-Fickian model to simulate the hygro-thermal behaviour of stress-laminated timber decks. Proceedings of Euromech 556 Colloquium - Theoretical, Experimental and Numerical Analyses in Wood Mechanics .Technical University of Dresden, 27-29 May 2015, 2 p.

3.3. Fortino S., Hradil P., Pousette A. (2017) A numerical approach to study the effects of coatings on the moisture gradients and moisture induced stresses in glulam beams of timber bridges. Proceedings of ECCOMAS Thematic Conference on Computational Methods in Wood Mechanics - from Material Properties to Timber Structures, CompWood 2017, 7 - 9 June 2017, Vienna, Austria.

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.

4. BOOKS, REPORTS:

4.1. Malo, K.A.: Timber Bridges. Chapter 11 in: Innovative Bridge Design Handbook – Construction, Rehabilitation and Maintenance, edited by Alessio Pipinato, Elsevier 2016, ISBN: 978-0-12-800058-8

4.2. Pousette, A., Fjellström, P.-A., Experiences from timber bridge inspections in Sweden – examples of influence of moisture, SP Rapport 2016:45, ISSN 0284-5172, SP – Sveriges Tekniska Forskningsinstitut, 2016

4.3. Pousette, A., Tätskikt och kantlösningar på tvärspända brobaneplattor av trä, SP Rapport 2016:90, ISSN 0284-5172, SP – Sveriges Tekniska Forskningsinstitut, 2016

4.4. Fortino S. (2017) Hygro-thermal models. Article in Chapter 8 in: Performance of Bio-Based Building Materials. Woodhead Publishing (2017). pp 495-502. https://www.elsevier.com/books/performance-ofbio- based-building-materials/jones/978-0-08-100982-6

4.5. Pousette A., Malo K.A., Thelandersson S., Fortino S., Salokangas L. Wacker, J. (2017): Durable Timber Bridges. Final Report and Guidelines. SP Rapport 2017:25, ISSN 0284-5172, SP – Sveriges Tekniska Forskningsinstitut, 2017

5. POPULAR SCIENCE PAPERS

5.1. Malo KA (2014) Renaissance for Timber Bridges. Pan European Networks: Science and Technology 12.

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.

The project had a consortium with 20 partners from four countries, with NTNU in Norway as coordinator. The twenty partners have been gathered on 7 plenary meetings, lasting approximately three days each and organized on a regular basis every 6 month. The agenda of the meetings has been almost fixed with focus on the progress of each work package. Each work package have prepared a progress report in advance of the regular meetings.

The participation from the industry has been good. The meeting locations have been circulating among the partner countries, and the number of participants on the plenary meetings has been approximately 25. In addition, there have been telephone and Skype meetings mainly on work group level. A common E-room has been provided by NTNU and all material has been made available there.

The economy in the project has been managed on a national level, and has developed according to the project plan.

The work was divided into five work packages with several tasks, where researchers, companies and road/traffic authorities participated in several parts. Exchange between work packages took place mainly at joint project meetings twice a year, as well as by E-mail and E-room. The project worked quite well; one key to moving forward in the project was that there were not too big task groups in the different work packages. The cooperation between the partners have also worked very well. Sometimes it was a challenge to collect all necessary information from all the partners in time, but taking the large number of partners into account it is deemed to have been satisfactory.

An interesting outcome of the project is that the Nordic project participating countries appear to be well prepared for the work with the next generation of European standard for timber bridges – EN 1995-2. All the three Nordic project countries participates in CEN/TC250/SC5/WG6 Timber Bridges and the results of the project have generated important documentation for the standardization process taking place on the European level.