KTH Building materials, 2020-03-31

EnWoBio (2015-2019) - Slutrapport

Laboratoriet för ingenjörsdesignade trä- och biobaserade byggnadsmaterial.

EnWoBio

Engineered Wood and Biobased Building Materials Laboratory

Populärvetenskaplig sammanfattning

Det talas idag mycket om hållbar samhällsutveckling (sustainability), men vad betyder det? En enkel definitionen av hållbarhet är att inte använda mera idag än du kan ersätta i morgon. Detta är en av mänsklighetens största utmaningar och är högst relevant för byggsektorn som idag uppskattningsvis står för ca 40% av samhällets materialanvändning, energianvändning, koldioxidutsläpp och producerat avfall. Hur uppnår vi då ett hållbart samhälle? Är det genom att släcka lamporna när vi lämnar ett rum och att ta kortare duschar? Ja, det hjälper men vi måste även höja blicken och på ett övergripande sätt ta hänsyn till sociala, miljömässiga och ekonomiska aspekter. Alla är lika viktiga och alla måste vägas samman. Några viktiga komponenter i utvecklingen mot hållbarhet är att minska avfallsmängderna och användningen av icke förnybara råvaror, energi och vatten.

Hur passar detta projekt in i den bilden? Trä har spelat en avgörande roll i hela mänsklighetens historia, men nyligen har forskare, politiker och ekonomer förnyat sitt intresse särskilt för större träkonstruktioner, exempelvis för flervåningshus och hallar, men även i infrastruktur såsom vindkraftverk, gång- och cykelbroar. Bland de främsta fördelarna med trä kan nämnas dess förnybarhet och tillgänglighet, men även träets unika egenskaper till exempel hög styrka i förhållande till sin vikt, samt höga estetiska och känslomässiga värden.

Det övergripande syftet med detta projekt var att bedriva forskning kring ingenjörsdesignade trä- och biobaserade byggnadsmaterial för att bidra till en hållbar samhällsutveckling. Målet var att utveckla nya banbrytande biobaserade byggmaterial och koncept, framför allt med utgångspunkt från olika biomaterialflöden relaterade till den förnybara svenska skogsråvaran.

Projektet har bedrivits främst genom ett flertal doktorandarbeten, delvis samfinansierat med ett industriföretag. Forskningen organiserades i en så kallad matrisform för att öka möjligheten för tvärdisciplinära angreppsätt och överlapp mellan doktoranderna. Forskningsområdena har omfattat olika koncept att modifiera furu och gran och att även effektivt använda de olika materialströmmarna inom skogsindustrin, t.ex. som förnybar råvara i biokompositer. Ett exempel är studier kring nya typer av naturligt modifierat trä genom att utveckla koncept för att kombinera komprimering av trä med en värmebehandlingsprocess. På så sätt kan hårdheten ökas samtidigt som både dimensionsstabiliteten och motståndet mot nedbrytning av t.ex. rötsvampar förbättras. Moderna tekniker som tillämpats är t.ex. gaskromatografi och röntgenteknik vilket gett nya möjligheter att bättre förstå och utveckla trämaterialvetenskapen. Ett annat område gäller ny träarkitektur baserad på så kallad parametrisk designverktyg.

Några viktiga resultat kring projektets huvudforskningsfrågor har gett en ökad förståelse av de materialmekanismer som styr effekten av trämodifiering, t. ex. hur så kallad fuktsorption är kopplad till träets dimensionsförändring både på mikro- och makronivån och med vilka ”skräddarsydda” metoder som vi kan påverka detta. En central del av projektet har resulterat i ett proaktivt arbete för att utveckla en strategisk färdplan för hållbara innovationer för biobaserade byggnadsmaterial. I projektets slutfas har nya koncept för så kallad hybridisering identifierats som nya banbrytande biobaserade byggnadsmaterial och –system. Fortsatta satsningar föreslås framförallt att omfatta studier av nya innovativa träbaserade hybridkonstruktioner. Hybridtekniken bedöms vara särskilt intressant för lastbärande konstruktioner såsom takstolar, broar, golvbjälklag, högre byggnader och vindkraftverk. Denna utveckling bör också involvera samverkan mellan arkitektur, konstruktionsteknik och byggnadsmaterialvetenskap.

EnWoBio (2015-2019, Formas grant 2014-00172) - Final report
Engineered Wood and Biobased Building Materials Laboratory

Preface

The project has been conducted primarily by a number of doctoral students at KTH and LTU, co-financed by external partners and industrial companies, see attachment with a presentation of total project economy and achieved co-financing. 7 PhD students (4 with split positions with industry) have been involved in the project with significant funding from the grant; 4 of them have finalized their PhD exam (and 3 Lic. eng. exam), and 3 are expected to finish during end of spring or fall 2020.

Further information on the project can be found on the project leader's web page https://www.kth.se/profile/walinder, including a full list of publications and an extended project summary.

Extended summary

1. Introduction

The building sector in Europe accounts for approximately 40% of the total use of materials and energy, 40% of the greenhouse gas emissions, and 40% of the waste (the so-called 40-40-40 rule). These figures can also be related to the fact that the Swedish building material industry has a yearly sales of around SEK 170 billion and employs 53,000 people [1].

Despite this, today only a small fraction of the renewable Swedish forest biomass is used for production of biobased building and engineering materials and products, apart from traditional pulp-based, solid wood and panel products. It is argued here that a larger portion of the biomass should be used as a feedstock for further processing into recyclable building materials, which, in certain cases, could be used as an energy source at their end of life, or perhaps degraded to biobased building blocks for a new loop of processing into biobased materials.

Aim and over-all objective

The aim of this project was therefore to *conduct research with the highest international class to produce new knowledge* that will contribute to the development of production, use and further refining of renewable forest or agricultural biomass. In particular, this is of a strategic relevance for the present and future biobased building materials industry in Sweden.

The over-all objective was to *engineer innovative wood and biobased building materials for the future sustainable society*. New well-engineered and recyclable biobased building materials may replace on a large scale other materials which are both from non-renewable resources, such as concrete, steel and various plastics and whose production contributes strongly to current release of carbon dioxide

Project vision

Within ten years (by year 2025) the proportion of wood and biobased building materials used in the building sector, both in Sweden and globally, will increase to a level which supports a sustainable development of the society.

To reach this vision it is necessary to create long-term education and research links with essential groups of future decision makers. The target group in this project was engineering students and

[1] Based on the 800 member companies of the association Byggmaterialindustrierna, source: www.byggmaterialindustrierna.se

graduates within the Civil and Architectural Engineering programs at the Swedish Universities of the Built Environment (SBU).

Project strategies and main hypothesis

The main strategy to create these links was to increase the visibility of the wood and biobased building materials related industry at these programs which in this project was accomplished through:

- Split positions for 5-6 PhD students between universities and industry or institute (co-financed by the industry and institute). The goal is to reach engineering licentiate (Tekn. Lic.) examination for these students within the project period.
- Close links between the PhD student projects and the building material related classes within these programs.
- Close links between the PhD student projects and the building material related diploma works within these programs.

2. Materials and methods

The project was structured in two interacting research areas: I) biobased building material science, revolving around mainly wood material analyses and modification; and II) engineering and demonstration of the material systems, including life cycle and sustainability assessment as measures of e.g. environmental and socio-economic consequences. The work was executed by a multidisciplinary approach in six work packages fitted in a matrix structure, where material science meets the engineering and demonstration areas. Figure 1 presents an overview of the basic concept, activities, strengths, driving forces and vision of the suggested research project.

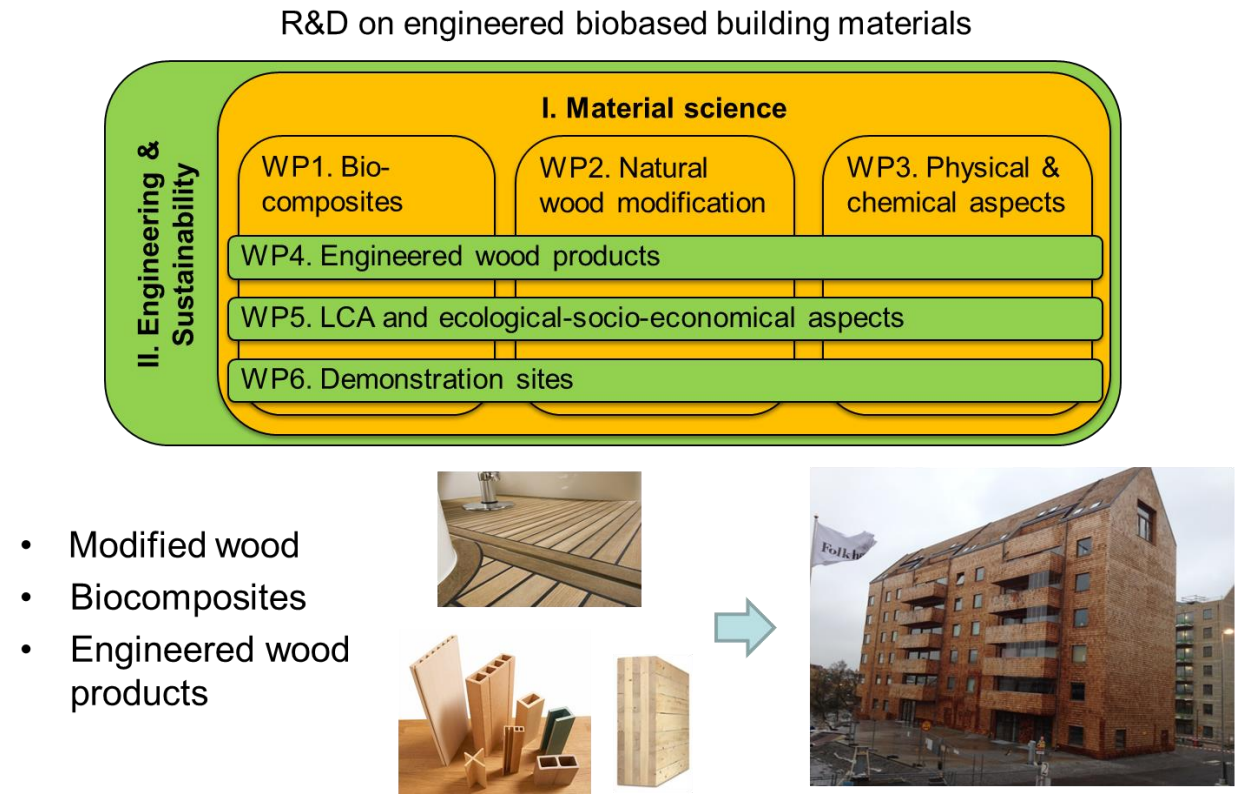

Figure 1. Basic project structure of EnWoBio

The specific objectives comprised the following interacting work packages:

WP1) ***New biocomposites***: a new group of building materials refined from renewable resources based on wood or natural fibres and biopolymers or recyclable thermoplastics with a high potential regarding both eco-efficiency and increased moisture resistance and extended service life

WP2) ***New natural wood modification:*** new concepts based on toxic free *combined mechanical-hydro-thermal procedure*. Such modified wood is expected to exhibit higher surface hardness, abrasion resistance, dimensional stability as well as increased decay resistance compared with unmodified wood.

WP3) ***Physico-chemical and moisture analysis of biobased building materials***: Moisture sorption is a particular critical feature of biobased materials. Fungal decay resistance, dimensional stability, mechanical performance and insulating capacity of biobased materials are examples of other properties which are affected by moisture.

WP4) ***Engineered wood products for the construction market:*** The contemporary construction market is facing new demands to obtain energy and cost efficient building processes. In sustainability perspective biobased products imply a potential alternative in many applications and so-called engineered wood products (EWP) show versatile properties and potential efficiency, which can support the needed societal development.

WP5) ***LCA and ecological-socio-economical aspects of biobased building materials***: A central part of the project also covered a proactive work to draw a strategic roadmap for sustainable innovations for biobased building materials.

WP6) ***Wood and biobased building materials demonstration sites***: Another central part of the project was to demonstrate different biobased material systems by exposing and monitor them in various experimental building materials sites.

Laboratory activities for characterization of "green" and biobased materials was focuses on "soft" and highly variable materials such as wood and biobased material systems. Access to databases and tools was also a key part of life cycle studies, and both IVL and SP were given access to licensed LCA tools such as SimaPro (SP) and GaBi (IVL), the most widely-used tools available. Both licenses included access to several databases with life cycle data for processes and materials relevant for the forest and the building sector.

3. Results and discussion

Main results involve increased understanding of the material mechanisms that control the effect of wood modification, eg. how so-called moisture sorption is linked to the wood's dimensional change at both the micro and macro levels and what methods that can influence this. A central part of the project has resulted in proactive work to develop a strategic roadmap for sustainable innovations for bio-based building materials. In the final phase of the project, new concepts for so-called hybridization have also been identified as new groundbreaking bio-based building materials and systems.

More specific results can be summerized as

- Development of experimental methods to determine surface and physico-chemical properties of modified wood and biocomposites
- Increased understanding of physico-chemical properties of modified wood and biocomposites
- Innovative means for continous surface densification wood by roller pressing technique and chemical modifiaction

- Conceptual and parametric design development combining engineering with architectural aspects for new applications of durability modified wood and engineered wood products (EWP), also including so-called hybridization concepts.

- Methodological development for analyses and predicting future scenarios for climate mitigation of new construction in Sweden, including evaluation of the effects of different technological pathways.

4. Conclusions

New innovative hybrid technology concepts, i.e. combining timber with both steel and concrete, is considered to be particularly interesting for load-bearing structures such as roof trusses, bridges, floor joists, taller buildings and bicycling and walking bridges. Future work is therefore proposed to primarily include studies of new innovative wood-based hybrid designs. This development should also involve collaboration between architecture, structural engineering and building materials science.

5. List of main publications within EnWoBio

In this case a significant part of the published work was financed by the Formas grant EnWoBio 2014-172.

Open access:

5.1 PhD Theses

Källbom, S. (2018). Characterisation of thermally modified wood for use as component in biobased building materials. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-233569

Neyses, B. (2019). Surface Densification of Solid Wood : Paving the Way Towards Industrial Implementation. PhD dissertation. Luleå University of Technology, Luleå, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-75794

Peñaloza D. (2017). The role of biobased building materials in the climate impacts of construction : Effects of increased use of biobased materials in the Swedish building sector. PhD dissertation. KTH Royal Institute of Technology, Stockholm, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-207130

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5.2 Licentiate Theses

Källbom, S. (2015). Surface characterisation of thermally modified spruce wood and influence of water vapour sorption. Licentiate dissertation. KTH Royal Institute of Technology, Stockholm, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-172989

Neyses, B. (2017). Surface-Densified Wood : From Laboratory-Scale Research Towards a Competitive Product. Licentiate dissertation. Luleå University of Technology, Luleå, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-60282

Peñaloza D. (2015). Exploring climate impacts of timber buildings : The effects from including non-traditional aspects in life cycle impact assessment. Licentiate dissertation. KTH Royal Institute of Technology, Stockholm, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-161193

5.3 Peer reviewed articles

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Källbom, S., Lillqvist, K., Spoljaric, S., Seppälä, J., Segerholm, K., Rautkari, L. (2020). Effects of Water Soaking–drying Cycles on Thermally Modified Spruce Wood–plastic Composites. *Wood and Fiber Science* 52 (1), 2-12. https://wfs.swst.org/index.php/wfs/article/viewFile/2761/2561

Larsson, M., Wålinder, M. and Falk, A. (2018). Teleodynamic Timber Façades. *Frontiers in Built Environment* 4(37): 1–16, doi: 10.3389/fbuil.2018.00037. https://www.frontiersin.org/articles/10.3389/fbuil.2018.00037/full

Neyses, B., Rautkari, L., Yamamoto, A., Sandberg, D. (2017). Pre-treatment with sodium silicate, sodium hydroxide, ionic liquids or methacrylate resin to reduce the set-recovery and increase the hardness of surface-densified Scots pine. iForest 10(5): 857–64. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-66300

Peñaloza, D. Erlandsson, M., Berlin, J., Wålinder, M. (2018). Future scenarios for climate mitigation of new construction in Sweden : Effects of different technological pathways. *Journal of Cleaner Production* 187: 1025–1035, doi.org/10.1016/j.jclepro.2018.03.285. https://www.sciencedirect.com/science/article/pii/S0959652618309661?via%3Dihub

Sedighi Moghaddam, M., Van den Bulcke, J., Wålinder, M.E.P., Claesson, P.M., Van Acker, J., Swerin, A. (2017). Microstructure of chemically modified wood using X-ray computed tomography in relation to wetting properties.. ISSN (Online) 1437-434X, ISSN (Print) 0018-3830, DOI: 10.1515/hf-2015-0227, October 2016. *Holzforschung* 71(2): 119–128. https://www.degruyter.com/view/journals/hfsg/71/2/article-p119.xml

5.4 Proceedings, international conferences, (underlined presenting author)

Falk, A. and Wålinder, M. (2015). Bio-based material hybrids seeking new applications in construction Conference Paper. In: Proceedings of the IASSWORKING GROUPS 12 + 18 International Colloquium “Bio-based and Bio-inspired Environmentally Compatible Structures”, A. Falk, P. Vegh and J. Chilton (eds.), 10-13 April, Tokyo Denki University, Tokyo, Japan. https://www.researchgate.net/publication/276272818_Bio-based_material_hybrids_seeking_new_applications_in_construction

Falk, A., Dietsch, P., Schmid, J., (editors). Proceedings of the Joint Conference of COST Actions FP1402 & FP1404 Cross Laminated Timber : A competitive wood product for visionary and fire safe buildings [Internet]. Stockholm: KTH Royal Institute of Technology; 2016. 195 p. (TRITA-BYMA). http://www.diva-portal.se/smash/get/diva2:951846/FULLTEXT01.pdf

Frisk, O., Segerholm, B.K., Wålinder, M.E.P. (2016). Fibre damage in WPC for two different compounding processes. In: proceedings of 12th Annual Meeting of the Northern European Network for Wood Science and Engineering (WSE2016). Andersons, B., Kokorevics, A, (eds), ISBN 978-9934-14-981-8 Printed, ISBN 978-9934-14-982-5 PDF, September 12-13, Riga, Latvia, pp 230–232. http://www.kki.lv/old/dokumenti/WSE2016.pdf

Källbom, S., Altgen, M., Segerholm, K., Jones, D., Militz, H. and Wålinder, M. (2017). Water vapour sorption characteristics of thermally modified Norway spruce particles. In: Book of Abstracts of the COST Action FP1303 meeting “Design, Application and Aesthetics of biobased building materials”. ISBN 978-619-160-758-7. 2017, Feb 28 – March 1, Vitosha Park Hotel, Sofia,

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Källbom, S., Rautkari, L., Johansson, L.-S., Wålinder, M.E.P., Segerholm, B.K., Jones, D. and Laine, K. (2015). Surface chemical analysis and water vapour sorption of thermally modified wood exposed to increased relative humidity. In: Proceedings of the Eight European Conference on Wood Modification (ECWM8). Hughes, M., Rautkari, L., Uimonen, T. and Militz, H. eds., October 26-27, Helsinki, Finland, pp 241–247. http://costfp1303.iam.upr.si/en/resources/files//past-events/ecwm8-conference-2015/proceedingsofecwm8.pdf

Källbom, S., Sedighi Moghaddam, M., Segerholm, K., Jones, D., Wålinder, M. (2016). Extractives influence on the wettability and swelling of thermally Scots pine. In: proceedings of 12th Annual Meeting of the Northern European Network for Wood Science and Engineering (WSE2016). Andersons, B., Kokorevics, A, (eds), ISBN 978-9934-14-981-8 Printed, ISBN 978-9934-14-982-5 PDF, September 12-13, Riga, Latvia, pp 152–157. http://www.kki.lv/old/dokumenti/WSE2016.pdf

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Markström, E., Bystedt, A., Sandberg, D. (2017). Prospects for an Increased Use of Bio-based Building Materials in Sweden. In: Book of Abstracts of the COST Action FP1303 meeting "Design, Application and Aesthetics of biobased building materials". ISBN 978-619-160-758-7. 2017, Feb 28 – March 1, Vitosha Park Hotel, Sofia, Bulgaria. http://costfp1303.iam.upr.si/en/resources/files//past-events/sofia-meeting/book-abstractssofiadjfinal.pdf

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Neyses, B., Hagman, O., Nilsson, A. Sandberg, D., Sundqvist, B. (2016). Continuous Wood Surface Densification – Chemical Treatments to Reduce the Set-Recovery. In: Proceedings of The 13th Pacific Rim Bio-Based Composites Symposium – Bio-based composites for a sustainable future (BIOCOMP 2016), November 13-15, Conceptión, Chile, 66-70. https://www.diva-portal.org/smash/get/diva2:1045754/FULLTEXT02.pdf

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6. List of additional publications related to EnWoBio

In this case a minor part of the published work was financed by the Formas grant EnWoBio 2014-172, whereas a major part was financed by agreed industry co-funding, as well as other additionial funding (from both industry and universities).

Open access:

6.1 PhD Thesis

Sjökvist, T.. (2019). Coated Norway Spruce : Influence of Wood Characteristics on Water Sorption and Coating Durability. PhD dissertation. Linnaeus University ,Växjö, Sweden. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-80768

6.2 Peer reviewed articles

Frolovskaia, A.V., Deordiev, S.V., Falk, A., Klinduh, N.Y., Terehova, I.I. (2018). Experience of light thin-walled structures improvement in construction. In: 6th international conference on mechatronics and control engineering (ICMCE 2017). IOP Conf. Series: *Journal of Physics: Conf. Series* 1016 012004, doi :10.1088/1742-6596/1016/1/012004. https://iopscience.iop.org/article/10.1088/1742-6596/1016/1/012004/pdf

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Sjökvist, T., Blom, Å., Wålinder, M. (2019). The infuence of heartwood, sapwood and density on

moisture fuctuations and crack formations of coated Norway spruce in outdoor exposure. *Journal of Wood Science* 65(45). https://link.springer.com/content/pdf/10.1186/s10086-019-1825-1.pdf

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Sjökvist, T., Wålinder, M. and Blom, Å, (2017). Liquid sorption and swelling behaviour of Norway spruce heartwood and sapwood veneers studied by the multicycle Wilhelmy plate method. In: Proceedings of the 13th annual meeting of the Northern European Network for Wood Science and Engineering (WSE2017), Engelund Thybring, E. (Ed), University of Copenhagen, Denmark, September 28-29, p. 140. http://kth.diva-portal.org/smash/person.jsf?pid=authority-person%3A31335&dswid=4841

Yin, H., Sedighi Moghaddam, M., Wålinder, M., Swerin, A. (2019). Fabrication of superamphiphobic wood surface based on silicone nanofilaments. In: Proceedings of the 15th annual meeting of the Northern European Network for Wood Science and Engineering (WSE2019), Fredriksson, M. (Ed.), Lund University, Lund, Sweden, 9-10 October, pp. 135-137. http://kth.diva-portal.org/smash/person.jsf?pid=authority-person%3A31335&dswid=4841

Not open access:

6.4 Peer reviewed articles

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6.6 Popular science articles and other dissemination

Crocetti, R., Erlandsson, M., Nygren, J., Westin, M., Wålinder, M. (2017). Ställ krav på fler hus byggda i trä. *Dagens Samhälle* 16 mars. https://www.dagenssamhalle.se/debatt/staell-krav-pa-fler-hus-byggda-i-trae-32298

Kvint, A. (2016). Hög tid för trä? *Arkitektur*, 17 mars. https://arkitektur.se/tema/hog-tid-tra/

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Seminars and workshops

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Seminar on Mechanisms of brown-rot fungal attack on wood by Roger M. Rowell, Professor Emeritus, Biological Systems Engineering, University of Wisconsin, Madison, WI USA, Tuesday October 8 2019, KTH Department of Civil and Architectural Engineering.

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