# LOPPURAPORTTI

**Hankkeen nimi ja diaarinumero**
Click Design - Delivering fingertip knowledge to enable service life performance specification of wood – VN/4236/2018


## Contents

## 1. Tiivistelmä

## 1. Abstract


The general objective of ForestValue Click Design consortium project is to develop a performance-based protocol to provide a software tool for service life performance of wood for architects, planners and university students.

The consortium is composed of 26 partners including research organizations, industries, and administrations. The coordinator is Building Research Establishment (BRE, UK). In addition to VTT Technical Research Centre of Finland, the other scientific partners are University of Gottingen, Department of Wood Biology and Wood Products (Germany), Lund University (Sweden), Innorenew CoE (Slovenia), French Institute of Technology for Forest-based and Furniture Sectors (FCBA, France), Norwegian Institute of Bioeconomy Research (NIBIO, Norway), Insect Biology Research Institute (IRBI), University of Tours (France).

The other Finnish partners are Väylävirasto, Stora Enso, Puutuoteteollisuus ry, and Jartek Oy. The last one joined Click Design after the starting of the project.

The scientific and technical objectives of the whole project are: 1) to understand the link between the properties of wood material, the environmental exposure and the wood performance; 2) to collect European models and performances databases including decay and integrity, aesthetics and insect/termite performance; 3) to validate a set of models using real-case studies from across Europe; 4) to inspire new wood-based design solutions; 5) to deliver a software tool into pilot usage following the open source standard for BIM readiness. To reach these objectives, the project is composed of eight working packages (WPs).

VTT acts as leader of WP4 (Impact of decay on integrity) and participates in the other WPs, especially in WP6 (Validation of models and development of a specification tool).

The scheme on Click Design project is shown in Figure 1 and the details on the whole project can be found at the BRE link https://bregroup.com/services/research/clickdesign/

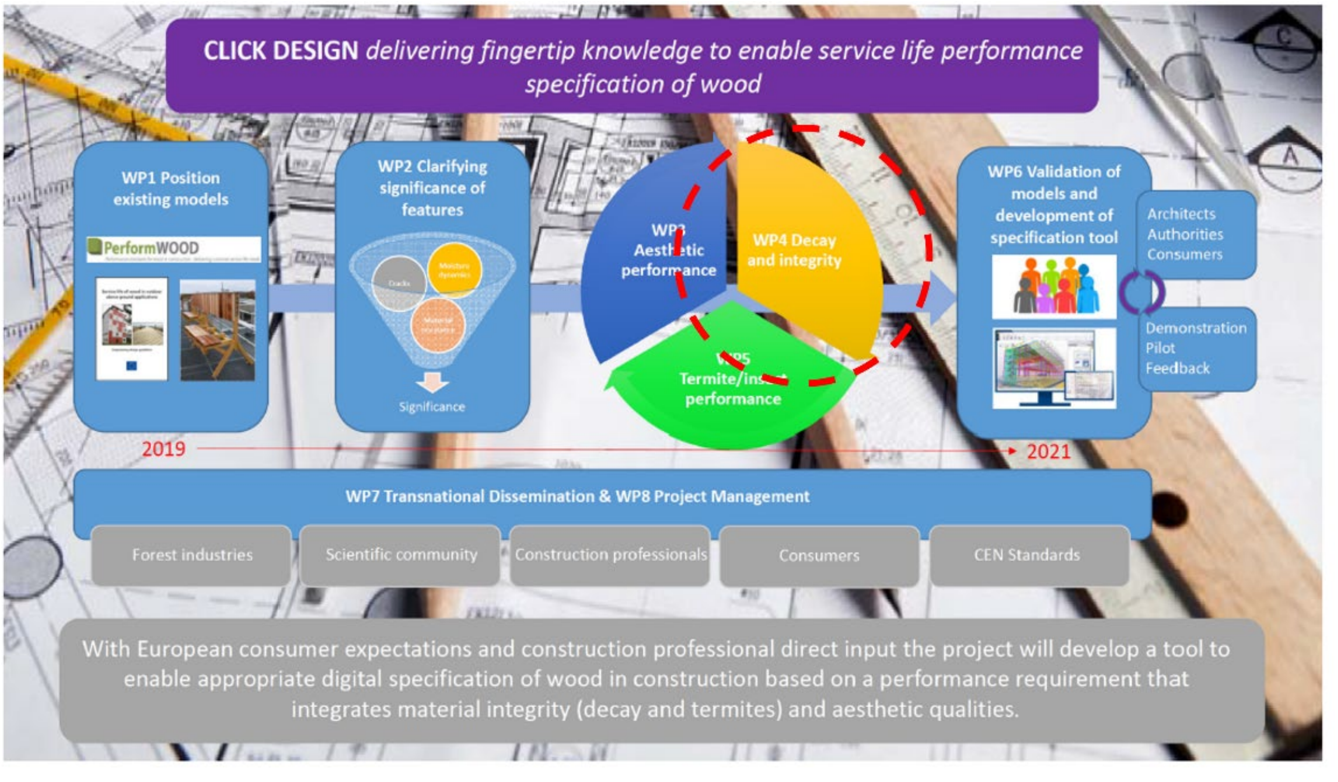




**Figure 1**. Scheme of Click Design project.

## 2. Hankkeen tausta ja tavoitteet

## 2. Project background and objectives

VTT has an internationally recognized experience in hygro-thermo-mechanical modelling of wood that was built in previous Era-Net projects such as "Modelling and Mitigation of Moisture Induced Stresses (Improved Moisture)", WoodWisdom-Net, 2008-2010 and "Durable Timber Bridges (DuraTB)", WoodWisdom-Net+, 2014-2017, as well as in the national project "A Digital end-user toolset for Moisture assessment in Wooden buildings - 1st part: Hygro-thermal database (DigiMoist1)", 2019-2020, within the Wood Building Programme. In those projects, simplified and advanced numerical models were developed to simulate the moisture transport in wood and the related mechanical effects, and the impact of moisture and moisture induced stresses on the crack risk in various wooden components. These competencies were considered relevant for the development of numerical tools in Click Design project, were the hygro-thermal response of wood is strictly related to its biological behaviour, that is the main focus of partners University of Gottingen (UGOE) and Lund University (LUND).

As leader of the WP4 (Impact of decay on integrity, Figure 2), the objectives of the work carried out at VTT were the following:

1. ***To carry out studies on the spatial distribution of decay in timber under laboratory conditions***. This was aimed at performing studies on the spatial distribution of decay under laboratory conditions considering the distribution of moisture and temperature in wood in function of time and was carried out in collaboration with UGOE (Figure 3a).
2. ***To collect hygro-thermal properties of different wood species and treated wood through literature review and by carrying out few laboratory experiments***. The related work was finalized to collect hygro-thermal material properties needed to carry out the hygro-thermal analyses for the calculation of moisture gradients and the risk of crack in various wooden components, as well as the moisture contents to be used within the decay models of Click Design (Figure 3a). The work was done is strict collaboration with the national DigiMoist1 project, also funded by the Ministry of Environment. The aim was to collect hygro-thermal properties of different wood species and treated wood through literature review and by carrying out few laboratory experiments.
3. ***To conduct finite element analysis (FEA) for predicting the hygro-thermal effects in timber components as well as stiffness and strength evaluated as functions of material climate/exposure dose over time***. The related work was aimed at improving firstly the VTT hygro-thermal models including the levels of moisture above the fibre saturation point (FSP), i.e. moisture content MC≈30%. (Figure 3a). The work also included the collaboration with a project ordered by Väylävirasto about monitoring of relative humidity, temperature and displacements of Tapiola Bridge in Espoo (project leader: Keijo Koski, VTT). The inclusion of the biological deterioration in the numerical models and the stiffness and strength evaluation was done in collaboration with UGOE.

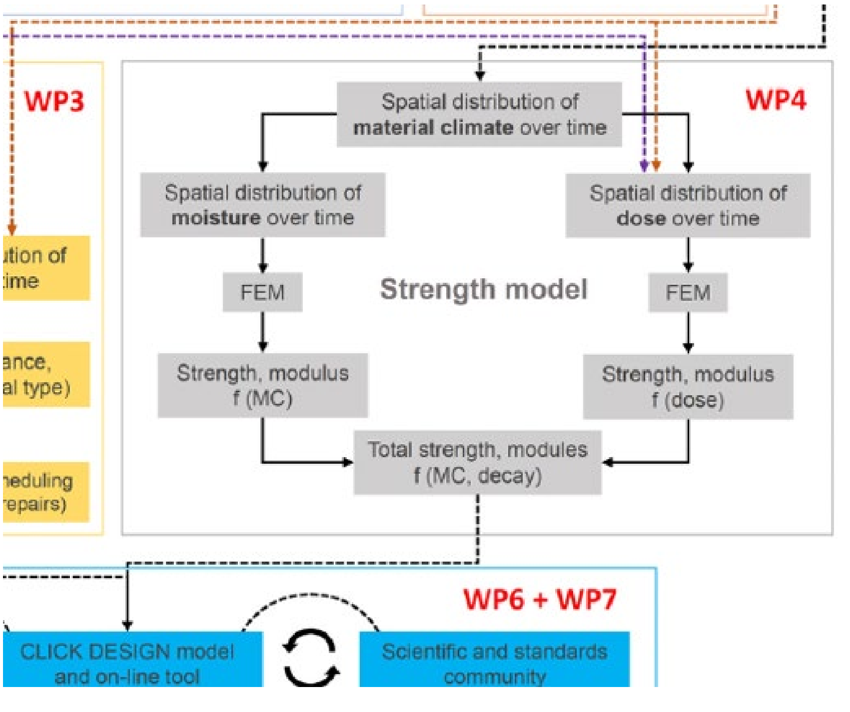



**Figure 2**. Working package WP4 led by VTT.

As collaborator partner in the WP6 (Validation of models and specification tools), VTT was the main actor in building the on-line Structural integrity tool in collaboration with UGOE for the part related to decay, stiffness and strength, and with LUND for the on-line issues (Figure 3b).

**WP 4: Impact of decay on integrity**

| Partner | BRE | UGOE | LUND | VTT | InnoRenew | FCBA | NIBIO | IRBI | HyOf |
|---|---|---|---|---|---|---|---|---|---|
| Person months | - | 7 | 2 | 5 | 4 | - | 2 | - | - |

**Objectives**

- To carry out studies on the spatial distribution of decay in timber under laboratory conditions considering material climate over time
- To collect hygro-thermal properties of different wood species and treated wood through literature review and by carrying out few laboratory experiments
- To conduct finite element analysis (FEA) for predicting the hygro-thermal effects in timber components as well as stiffness and strength evaluated as functions of material climate/exposure dose over time

| Deliverable | Title | Description | Month |
|---|---|---|---|
| D4.1 | Decay tests | Results for different input climates and wood species *(database)* | 18 |
| D4.2 | Hygro-thermal material properties | Hygro-thermal properties for different wood species (literature review and additional tests) for use by the hygro-thermal models in Task 4.3 and WP6 *(database)* | 12 |
| D4.3 | Hygro-thermal FEA | Results of hygro-thermal analyses and evaluation of stiffness and strengths as functions of material climate/exposure dose over time for various sections *(database)* | 24 |

**Figure 3a.** Partners, Objectives and Deliverables of working package WP4 led by VTT.

**WP 6: Validation of models & development of a specification tool**

| Partner | BRE | UGOE | LUND | VTT | InnoRenew | FCBA | NIBIO | IRBI | HyOf |
|---|---|---|---|---|---|---|---|---|---|
| Person months | 4 | 6 | 11 | 4 | 5 | 0.5 | 2 | 0.3 | - |

**Objectives**

- Develop, harmonize and integrate the various models into a superior performance model for wood products
- Validate the performance model against real performance data
- Design and build an easy-to-use open source design tool
- Provide information template and databook entry read across for BIM readiness

| Deliverable | Title | Description | Month |
|---|---|---|---|
| D6.1 | Model | A general design model consisting of a variety of sub-models *(model)* | 30 |
| D6.2 | Reality-checks | Comparison between projected performance vs. actual performance of existing structures, presented as a set of examples *(case studies)* | 33 |
| D6.3 | CLICK DESIGN tool | An open-source design tool for performance assessment of wood products/structures *(tool)* | 36 |

**Figure 3b**. Partners, Objectives and Deliverables of working package WP6 led by LUND.

## 3. Hankkeen osapuolet ja menetelmät

## 3. Project parts and methods

### 3.1 Part 1 – WP4 work

The Click Design project was particularly focused on the WP4 work during the 3 project years:

1. Collaboration with UGOE about decay tests (Deliverable 4.1) was aimed at developing studies on the spatial distribution of decay under laboratory conditions considering material climate vs time, i.e. the distribution of moisture content (MC), and temperature as functions of the time. The decay was studied through the UGOE's concept of Dose (Figure 4). The Dose as a function of the MC was assessed at UGOE and implemented in user subroutines of the Finite Element Method (FEM)-based code Abaqus at VTT.
2. Collection of hygro-thermal material properties for softwood and hardwood species was done in collaboration with the national project DigiMoist1 and the industrial partners Stora Enso and Jartek Oy

(Deliverable 4.2). Hygro-thermal material properties, such as moisture diffusion, permeability and sorption isotherms for softwood and Thermowood (TW) were used in the Finite Element Analyses (FEA) of Deliverable 4.3. The sorption isotherms for TW were measured at Aalto University by partner Jartek Oy.

3. The numerical analyses carried out in Click Design included 2 topics:
    a. Based on the hygro-thermal properties of Deliverable 4.2 for the so-called single-phase moisture transport models, computational tools to assess the moisture gradients and the risk of decay in glulam and CLT components, as well as in TW, were built. Hygro-thermal FEA analyses were also improved in order to work for levels of moisture above the fibre saturation point (FSP), i.e. MC≈30% (Deliverable 4.3). The single-phase models are based on Fick's diffusion equation and have the MC as the only variable of the related differential problem. The calculation of Dose and the related decay risk in double layered decking tested at VTT during 2004-2010 were carried out (Figures 5-6). Numerical tools to evaluate decay rating in wood were prepared and validated against measurements carried out in Slovenia by University of Ljubljana and UGOE on single-layer decking components (Figures 7-9).
    b. The hygro-thermal properties of Deliverable 4.2 for multi-phase models were used to numerically model the hygro-thermal response of Tapiola Bridge in Espoo, whose monitoring started in October 2019 within a monitoring project ordered by Väylävirasto about monitoring of relative humidity, temperature and displacements of the bridge. The monitoring is currently on-going. The numerical results of a multi-phase model assessed within Click Design in terms of distribution of moisture content, vapour pressure and temperature, were recently published in several peer-reviewed journal paper (Figures 11-13). The multi-phase models for moisture transport, based on the multi-Fickian theory, are able to model the various phases of water in wood, i.e. the water vapour in the lumens, the bound water in wood cell walls and the free water in lumens, as well as the temperature in wood, see Publication [10].

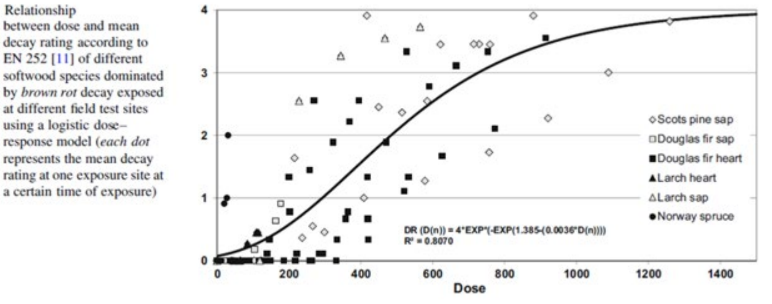



**Figure 4.** Dose model from Brischke C. and Meyer-Veltrup L. (2016) Modelling timber decay caused by brown rot fungi. Materials and Structures (2016) 49:3281–3291.

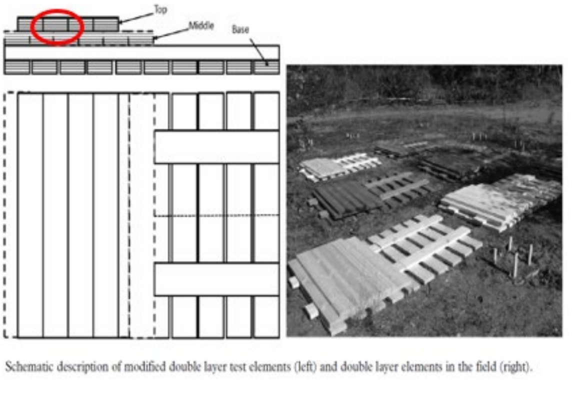
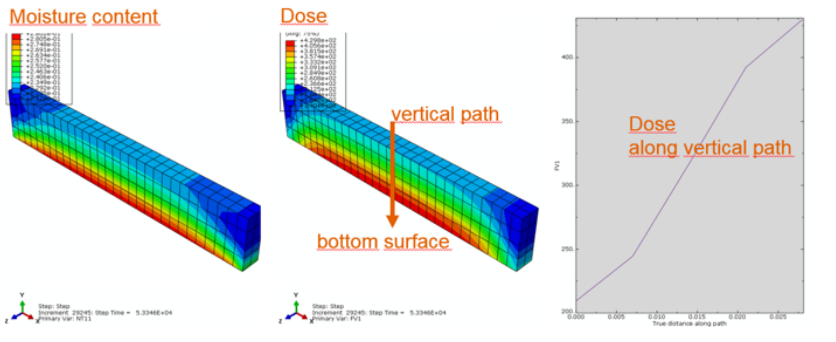



**Figure 5**. Double layered decking boards tested at VTT during 2004-2010. In the red circle the analysed decking cross section. Figure from Metsä-Kortelainen, S., & Viitanen, H. (2017). Durability of thermally modified sapwood and heartwood of Scots pine and Norway spruce in the modified double layer test. *Wood Material Science and Engineering*, *12*(3), 129-139. https://doi.org/10.1080/17480272.2015.1061596




| | |
|---|---|
| | Decay rating (EN 252) |
| | Untreated wood, bottom face |
| 1 year | 0.2 |
| 6 years | 1.5 |
| | |

**Figure 6.** Distribution of Moisture content and Dose (left), Dose along a vertical path (centre and decay rating (right) in untreated wood of a double layered decking (Publications [11] and [13]).

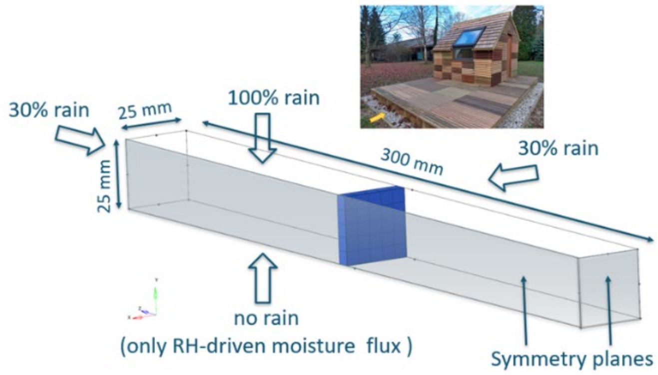



**Figure 7**. Abaqus model for the Model House (small image on the top) studied in Slovenia by partner UGOE in collaboration with University of Ljubljana (Publication [4]).

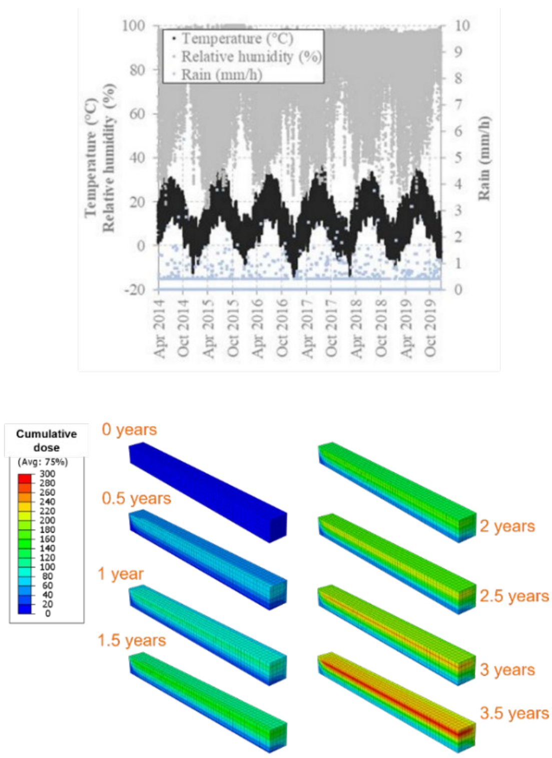



**Figure 8.** Top: Slovenian weather. Bottom: Distribution of Dose in a spruce decking component of the Slovenian Model House (Publication [4]).

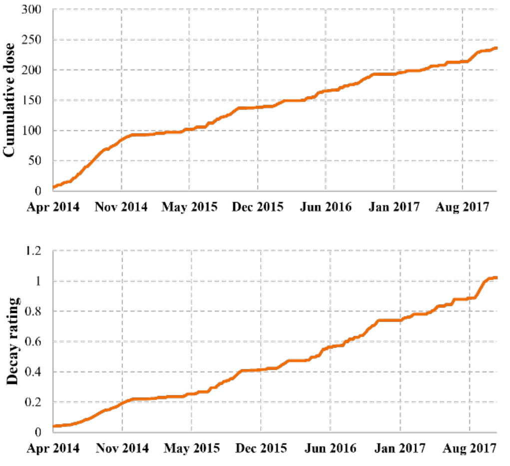
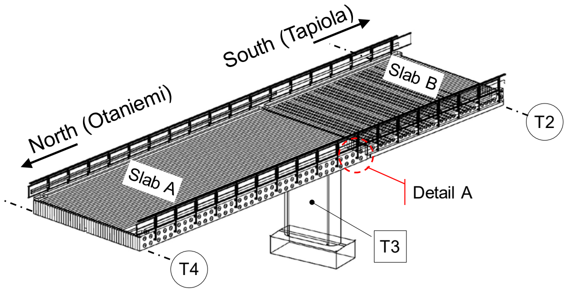
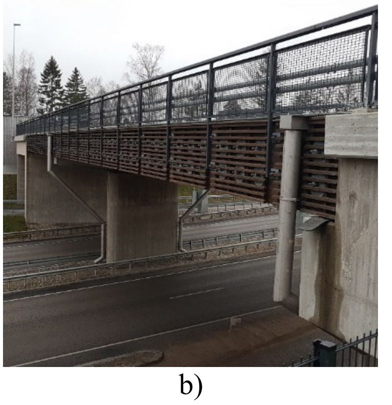



**Figure 9**. Model House in Slovenia. Cumulative dose and decay rating in a spruce decking component of the Slovenian Model House at 10 mm from the top (Publication [4]).




a)



b)

**Figure 10**. Tapiola Bridge. a) The scheme of the transverse prestressed glulam wooden slabs of the bridge where T2, T3 and T4 indicate the supports (Publication [10]). b) A picture with the view of the bridge.

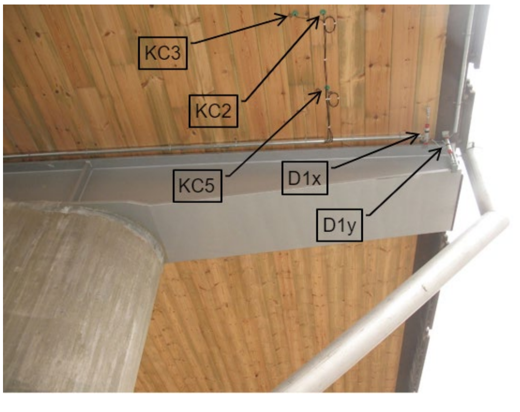



**Figure 11**. Tapiola Bridge. Photos of the sensor locations: from the bottom; b: from the lateral side (Publication [10]).

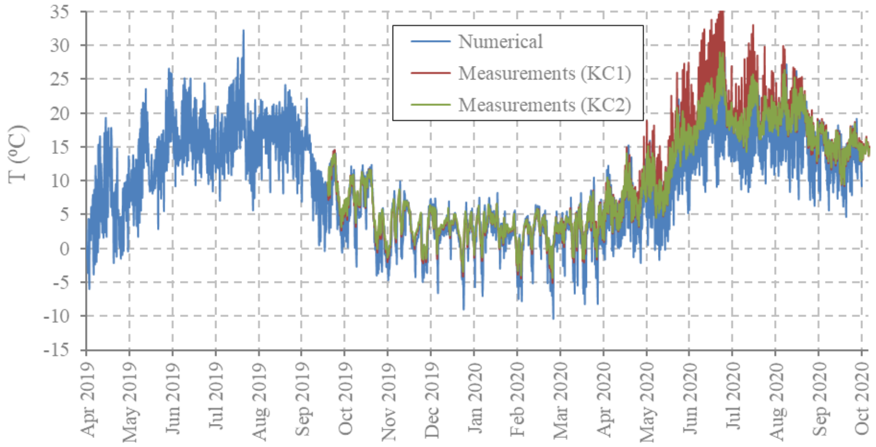



**Figure 12.** Tapiola Bridge. Comparison between numerical temperatures in wood and measurements in sensors KC1 and KC2 at 60 mm from the surface (Publication [10]).

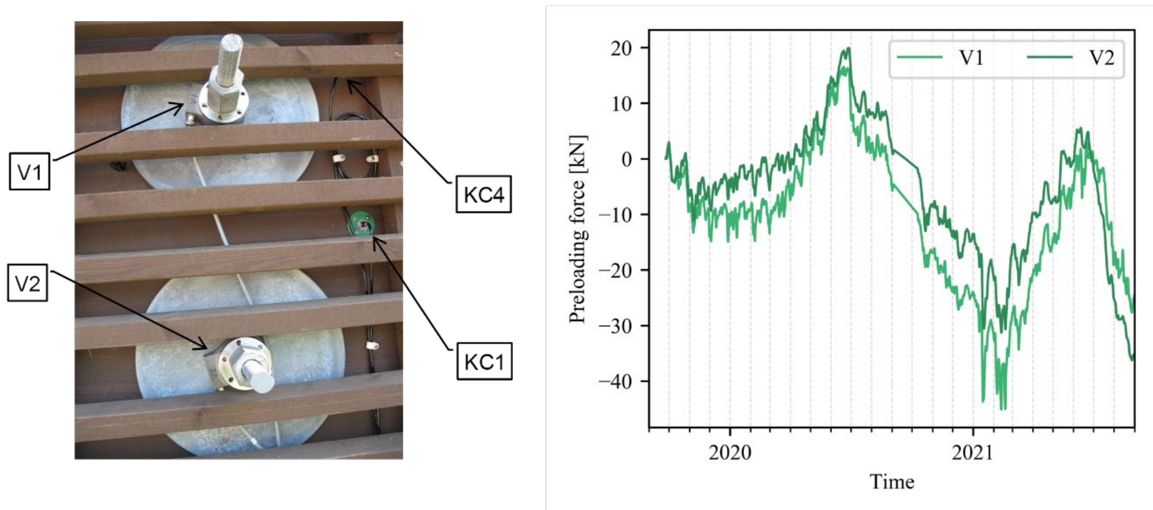



**Figure 13**. Left: Sensors V1 and V2 in Tapiola Bridge (Publication 5). Right: monitored preloading forces in sensors V1 and V3 (Publications [6] and [7]).

**3.2 Part 2 – WP6 work**

The work on WP6 issues for creation of the on-line Click Design tool for Structural integrity started during the second half of 2021 and continued until the end of the project (Deliverable 6.3).

A methodology to predict bending or compression resistance of structural wooden elements during the onset and development of the material decay was assessed in collaboration with UGOE. Two methods to calculate remaining bending and compression resistance under the attack of brown rot and white rot were presented: reduction of material strength or reduction of the cross-section of the wooden element. The methods are based on UGOE's bending and compression tests of material exposed to extreme moisture and are demonstrated as a part of the Structural integrity online calculation tool implemented in the Modelling Factory environment at VTT ClickDesign Structural Integrity Calculator (simupedia.com), see Publication [1]. The methods are applicable to wood components where the decay is expected to progress from the surface inwards. It should be noted that the prediction of bending or compression resistance is in the present state limited to specific loading conditions and decay mechanisms. However, the estimation of the remaining structural integrity of the material may be very important for the planning of maintenance actions in the structures, such as bridges, where the immediate replacement is not possible or for better safety measures in removing, renovating or demolishing decaying wooden construction.

Some examples of results are shown in Figures 14-16. VTT's tool is currently embedded in the main digital tool of Click Design project that includes all digital tools generated in the project WPs, i.e., the Fungal decay (UGOE, Germany), the Aesthetics (Innorenew, Slovenia), the Termite mapper (FCBA, France) and the Structural integrity

(VTT, Finland), see Figure 17. The organization of the on-line digital tools was managed by LUND. The final version of the tool will be available at the BRE website.

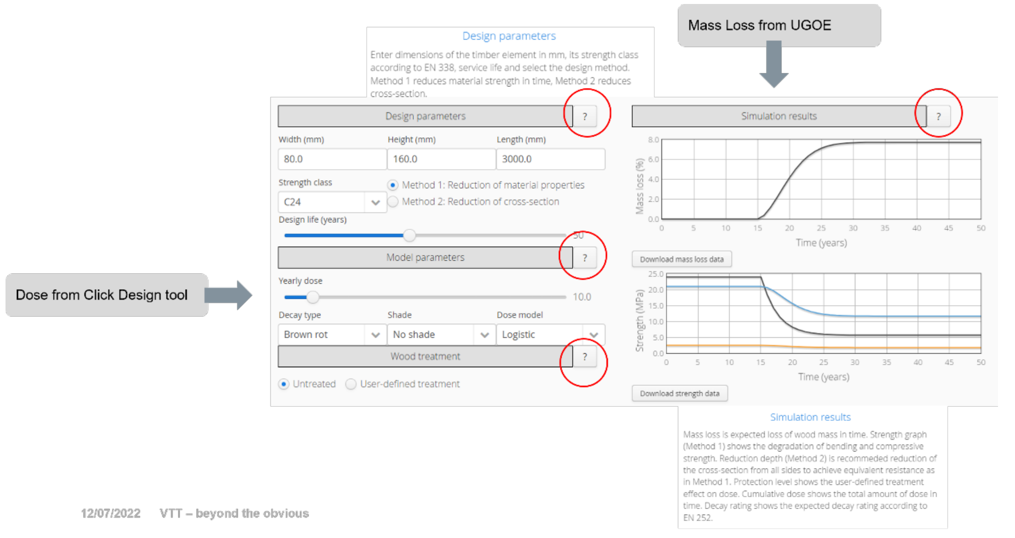



**Figure 14.** VTT's Structural integrity tool for untreated wood. Instructions are displayed by clicking the red circles (Publication [1]).

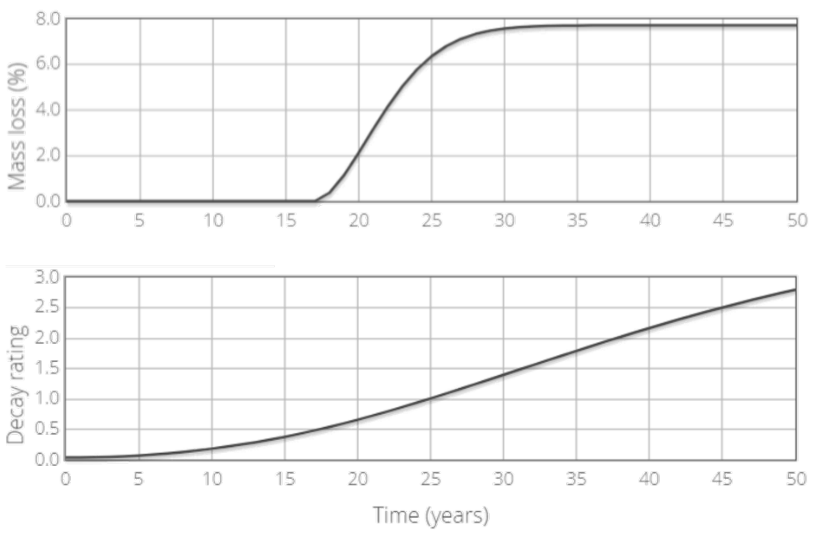



**Figure 15.** Example of mass loss (top) and decay rating (bottom) prediction due to brown rot in softwood based on a constant dose of 10 points per year (Publication [1]).

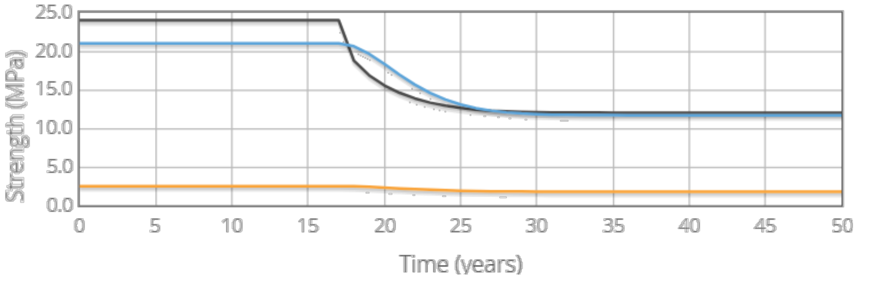



**Figure 16.** Example of predicted material characteristic strength degradation in bending (black line), compression parallel to the grain (blue line) and perpendicular to the grain (yellow line) of 80x160 mm member from C24 grade wood (Publication [1]).

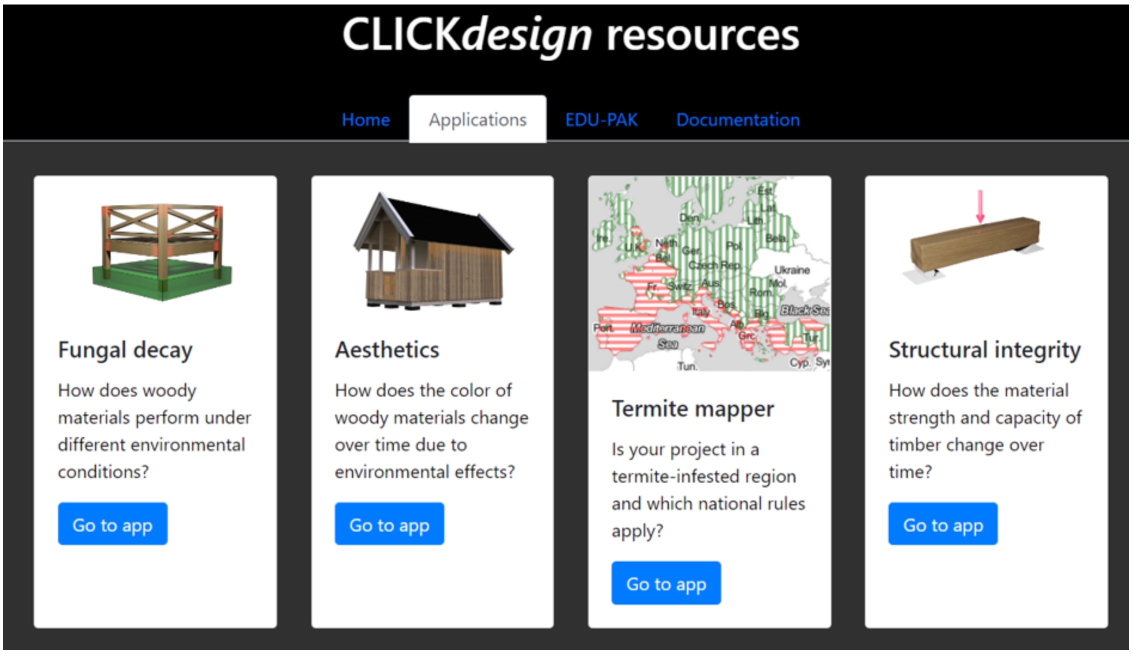



**Figure 17**. VTT's Structural integrity tool included in the main tool of Click Design project.

## 4. Hankkeen tulokset
## 4. Project results

### 4.1 Hankkeen tavoitteiden ja suunniteltujen tulosten toteutuminen (mahdolliset mittarit)
### 4.1 Fulfillment of goals and planned results (possible metrics)

As described in the previous sections, the last year of Click Design project was particularly focused on the completion of the WP4 work on decay as well as on the contribution to the WP6 for the development of the Structural Integrity digital tool. In the summary below, the Deliverables are considered as metrics and are marked in bold:

***Deliverable 4.1* -** The collaboration with UGOE about decay tests (Figure 3a) was successfully completed. The decay in wood was studied by using the UGOE's concept of Dose (Figure 4). The novelties compared to the second year of the project were the following:

- The final results on the bending and compression tests of decayed wood were completed at UGOE.
.
- The results of the bending and compression tests on decayed sample, provided by UGOE were used to implement at VTT the spatial distribution of Dose as a function of the moisture content within the FEM code Abaqus (Publication [4]).

***Deliverable 4.2***
- The collection of further sorption isotherms for softwood and TW, provided by University of Ljubljana in a study for decking modelling, integrated the hygro-thermal material properties already collected in the Report of national project DigiMoist1, funded also by the Ministry of the Environment and available in the Hankeportaali website: https://www.hankeportaali.fi/hankkeet/216-digimoist1-a-digital-end-user-toolset-for-moisture-assessment-in-wooden-buildings-1st-part-hygro-thermal-database

- Hygro-thermal material properties, such as moisture diffusion, permeability and sorption isotherms for softwood and TW were used in the FEA analyses of *Deliverable 4.3*.

- Active collaboration with partners Stora Enso and Jartek Oy allowed to send wood samples to partners UGOE and NIBIO and to use the related decay tests for 2 joint journal papers on decay (Publications [8-9]).

The numerical tools developed in Click Design included the following topics:

***Deliverable 4.3***

- The computational tools for single-phase hygro-thermal modelling under rain developed for 3D slices of wood components during the second year of the project, were further assessed for full scale wood components. The results of the new numerical analyses were validated against old measurements carried out at VTT (Figures 5-6 and Publications [11] and [13]) and measurements carried out in Slovenia by University of Ljubljana and UGOE and used to evaluate decay ratings in wood (Figures 7-9 and Publication [4]).

- The work in collaboration with VTT internal projects for wood helped to create an on-line tool (Hygro, Publication [2]) for moisture modelling in wood within the VTT Modelling Factory workspace. The related simplified algorithm is implemented in Python and uses the properties assessed in Click Design. This algorithm was used to prepare a paper about the monitoring and modelling of Tapiola Bridge, that was accepted for publications in Proceedings of IABMAS2022 conference (Publication [6]). As described previously, the monitoring started in October 2019 within a project ordered by Väylävirasto about monitoring of relative humidity, temperature and displacements of Tapiola Bridge in Espoo. Further work, related to the state of art of the monitoring, was reported Publication [7].

***Deliverable 6.3***

- The calculation of dose and the related mass loss for the decayed wood specimens under bending and compression were implemented in an online tool of the VTT Modelling Factory workspace (ClickDesign2, Publication [1]). This tool belongs to the VTT contribution provided to WP6, see Figures 14-17.

### 4.2 Poikkeamat verrattuna suunnitelmiin

## 4.2 Deviation compared to the plan

During years 2020-2022, due to the covid-19 pandemic, the project meetings and the planned collaboration with international collaborators, were only possible in on-line or hybrid form:

- The Click Design Steering Group national project meetings and the international ones (2 national SG project meetings /year and 2 international project meetings/year) were held remotely by using the programs Microsoft Teams or Zoom. The last project meeting and the ForestValue conference in June 2022 were held in hybrid form.
- Regular meetings organized by the coordinator BRE by Teams, allowed continuous communication among partners.
- The planned stage of PhD student Yatong Nie, University of New South Wales (UNSW), Australia, at VTT was cancelled and the collaboration was carried out via Skype or Teams.
- The collaboration with prof. Miha Humar (University of Ljubljana) for the Slovenian case-study described in the previous sections, was possible only via Teams.

### 4.3 Poikkeamien syyt

## 4.3 Deviation cause

The covid-19 pandemic was the cause of the on-line project meetings and the remote work with collaborators Yatong Nie and Miha Humar. In spite of the remote work, the research results were in very good agreement with the plans.

### 5. Hankkeen vaikuttavuus/vaikutukset

## 5. Project impact/effects

The impact of VTT publications and digital tools created in Click Design project is relevant from both the scientific and the engineering point of view. The scientific publications have increased the understanding about fundamental research questions related to the risk of crack and decay in wood components and the created digital tools are easy to use for architects, planners and students. The results are listed in Section 6.

### 5.1 Hankkeen positiivinen ja negatiivinen vaikuttavuus/vaikutukset puurakentamisen edistämiseen

### 5.1 Positive and negative impact/effects of the project on the promotion of wood construction

The positive impact of Click Design results achieved at VTT are relevant for the promotion of wood construction in Finland and internationally. This is especially due to the created digital tools (see previous sections) that can concretely assist the design of wood components for buildings.

The scientific impact of Click Design results achieved at VTT are relevant since the scientific articles can be considered as an important contribution in the field of wood science and engineering. In particular, the scientific papers present the validation of methods used in the created user-friendly digital tools for wood construction, as well as their applications in engineering problems.

No negative impact can be found.

### 5.2 Muut vaikutukset (positiiviset ja negatiiviset)

### 5.2 Other effects (positive and negative)

Other important effects of Click Design project at VTT were the creation of a strong background for the generation of new projects in the field of wood science and engineering. Also thank to Click Design, VTT recently won the following projects:

- **Secure 5G-Enabled Twin Transition for Europe's TIMBER Industry Sector (5G-TIMBER)**
  - HEU call: *CL4-2021-TWIN-TRANSITION-01-08: Data-driven Distributed Industrial Environments (IA)*. Coordinator: Tallinn University of Technology, 16 partners. Duration: 2022-2025.
- **Image-based Modelling of Water Transport In Wood including material biodegradation (WaterInWood)**
  - Project funded by the Academy of Finland. Coordinator: VTT, partners: Luke and University of Jyväskylä. Duration: 2022-2025.

## 6. Viestinnän toteutuminen ja tulokset

## 6. Implementation of communication and results

The VTT results of Click Design project were mainly disseminated through scientific publications and on-line digital tools and communicated in conferences and seminars.

### 6.1 Viestinnän pääasiallinen sisältö, määrä, laatu, kohderyhmät

### 6.1 Main content, quantity, quality, target groups of communication

The main content of results communicated by VTT regards computational models and digital tools for moisture transport, biological deterioration and structural integrity in wood components.

The quantity of communicated results is described in the following. The quality is ensured by the publication in peer-reviewed journals and international conferences. Target groups of communication are researchers, architects, engineers, representatives of industries and administrations, and university students.

The results of the project are reported in 3 user-friendly digital tools, built within VTT's Modelling Factory environment, and 11 scientific articles or abstracts, see the List of Publications below. Digital tools Hygro (moisture content calculations by using a simplified single-phase model) and HygroViz (DigiMoist1 project's results online, based on FEM pre-calculations) were built in VTT internal projects in collaboration with Click Design. The ClickDesign2 tool is the Structural integrity tool embedded in the main Click Design tool. In addition, 2 scientific abstracts were submitted for presentation at the WCTE 2023 conference (Oslo, Norway, June 2023):

- 1 abstract about the multi-phase model for moisture transport in wood including the effect of solar radiation;
- 1 abstract about VTT's Structural integrity tool.

The work on the above presentations will be continued within HEU project 5G-TIMBER.

## 6.2 List of Publications

### 6.2.1 Digital tools

1. Petr Hradil (2022). ClickDesign2 ClickDesign Structural Integrity Calculator (simupedia.com)
2. Petr Hradil (2021). Hygro https://modellingfactory.org/content/hygro
3. Jukka Aho (2021). HygroViz hygro.ptaas.ad.vtt.fi

### 6.2.2. Published/submitted scientific articles and abstracts

4. Fortino S., Hradil P., Korkealaakso A., Avikainen T., Humar M., Nie Y., Niekerk P., Brischke C. A 3D numerical framework for the spatial simulation of decay risks in decking boards. Manuscript. *To be submitted to a selected MDPI journal.*

5. Fortino S., Hradil P., Avikainen T., Koski K., Fülöp L. Hygro-thermal modeling of timber bridge decks considering the effect of solar radiation. *Abstract accepted for presentation at Forum Wood Building Nordic, 28-30.9.2022, Helsinki, Finland.*

6. Hradil P., Fortino S., Koski K., Mäkinen J. Fülöp L. Smart monitoring system for stress-laminated timber bridges. Invited full paper. To be published *in Proceedings of IABMAS 2022 conference, 11-15 July 2022, Barcelona, Spain.*

7. Hradil P., Fortino S., Koski K., Fülöp L. Health monitoring of stress-laminated timber bridges. Bridge Maintenance, Safety, Management, Life-Cycle Sustainability and Innovations - Proceedings of the 10th International Conference on Bridge Maintenance, Safety and Management, IABMAS 2020. H. Yokota, D.M. Frangopol (Eds.), pp. 407-416. ISBN 978-0-429-27911-9.

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The Click Design project and the related VTT plans and results were/will be presented in:

- 7 international conferences (see the List of Publications);
- 1 national seminar: Wood Days and Wood Bridge Days, 4.11.2021, Helsinki (Presentation on "Tapiola Bridge's monitoring and Click Design") https://puuinfo.fi/tapahtuma/puupaiva-4-11-2021/;
- 3 ForestValue conferences (Helsinki, Finland, 2021; Skellefteå, Sweden, June 2022; Final ForestValue conference in Madrid, Spain, September 2022) https://forestvalue.org/.

### 6.2 Arvio viestinnän onnistumisesta, viestintäsuunnitelman toteutumisesta

### 6.2 Evaluation of the success of the communication, the realization of the communication plan

The published scientific papers and the participation in international conferences represent successful results from the scientific point of view.

The impact on the wood industrial community is also relevant as there were several industrial workshops organized in the international project meetings where the industry representatives had the possibility to give comments and suggestions on the on-line tools under development.

## 7. Tulosten kestävyys ja hyödyntäminen

## 7. Durability and utilization of the results

### 7.1 Arvio tulosten kestävyydestä ja konkreettisuudesta ja siihen liittyvistä riskeistä

### 7.1 Assessment of the sustainability and concreteness of the results and the associated risks

During the last ForestValue conference in Skellefteå (June 2022), the industrial representatives were very satisfied about the presented final tools, including VTT's Structural integrity tool, and their potential applications in concrete wood engineering activities.

There are not specific risks related to the achieved results at VTT.

### 7.2 Ehdotukset hankkeen tulosten hyödyntämiseksi, ml. liiketaloudelliset ja lainsäädännölliset näkökohdat

### 7.2 Proposals for utilizing the results of the project, incl. business and legislative aspects

Some of the published computational tools at VTT can be used to solve various customer projects, such as the risk of crack and decay in various wooden components under different climates (by using VTT's hygro-thermo-mechanical analyses including decay) and the related structural integrity (by using VTT's Structural integrity tool).

## 8. Talouraportti (kustannuserittelylomakkeen liitteeksi, ei raporttiin)

## 8.1 Budjetin ja rahoitussuunnitelman toteutuminen ja esiin nousseet ongelmat

**ClickDesign VN/4236/2018**

Toteutuneiden kustannusten ja toteuman vertailu kustannusarvioon (kustannusarviolomake) 1.1.2019-30.06.2022

| Kustannuslaji | YM budjetti | Toteuma 1/2019-06/2022 | Jäljellä budjetista | Kust.toteuma% |
|---|---|---|---|---|
| Palkat | 28 209 | 29 529 | -1 320 | 104,68 |
| Henkilösivukulut | 17 207 | 18 169 | -962 | 105,59 |
| Matkat | 6 857 | 2 285 | 4 572 | 33,32 |
| Julkaisukustannukset | 1 143 | 1 313 | -170 | 114,90 |
| Yleiskustannukset | 43 144 | 45 272 | -2 128 | 104,93 |
| Tutkimusympäristökustannukset | 3 440 | 3 089 | 351 | 89,81 |
| **TOTAL** | **100 000** | **99 658** | **342** | **99,66** |

## 9. Suositukset tulevia hankkeita ja ohjelmia varten

## 9. Recommendations for future projects and programs

### 9.1 Esiin nousseet ja jatkohankkeita koskevat ideat ja tarpeet

### 9.1 The ideas and needs that emerged and concern further projects

Referring to the new HEU project 5G-TIMBER, mentioned in Section 5.2 and based also on Click Design background, it is suggested that in future projects or programmes, it would be relevant to focus on the digitalization of wood construction in the various phases of the product life, from the manufacturing, to the construction, to the service life of buildings.

### 9.2 Mitä vastaavissa hankkeissa tulisi välttää, mitä suositellaan

### 9.2 What should be avoided in similar projects, what is recommended

In future projects focusing the digitalization of wood construction, issues similar to the ones developed in HEU 5G-TIMBER are recommended, e.g.: development of numerical models to predict the performance of selected timber components; use of internet of things live data for predictive machine maintenance and structural health monitoring; development of methodologies for construction, renovation and waste valorisation.

## 10. Johtopäätökset/Yhteenveto hankkeesta ja päätuloksista

## 10. Conclusions/Summary of the project and main results

In ForestValue Click Design consortium project, VTT acted as leader of WP4 (Impact of decay on integrity) and has collaborated in the other WPs, with special focus on WP6 (Validation of models and development of a specification tool).

The main results planned and successfully reached at VTT are:

- an input database for hygro-thermo-mechanical analysis of wood components;
- a numerical tool to monitor the hygro-thermal response of timber bridges during their service life;
- a numerical tool to simulate the development of decay in wooden components under moisture and temperature variations;
- a structural integrity on-line tool for wood components embedded in the Click Design software tool.

The results were or will be reported in 11 scientific articles, 3 on-line tools, and presented in 7 international conferences, 1 national seminar and 3 ForestValue international conferences. The impact of the results is relevant from both the scientific and the industrial point of view, as pointed out during the last ForestValue conference in Skellefteå, Sweden, June 2022, were the project results (including VTT's Structural integrity tool) were highly appreciated by both the research and industrial representatives.

During the last national Steering Group meeting of Click Design project, it was suggested to present the Structural Integrity tool at the Puupäivä seminar (3rd of November 2022) and in other national events.

The details on the results of the whole consortium project will be reported in the final report of Click Design, that will be available at the BRE website https://bregroup.com/services/research/clickdesign/