Circular Economy – A Game Changer for the Wood Building Industry

Best Practices Report

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Content

1. Introduction

This report is a part of the project 'Circular Economy - A Game Changer for the Wood Building Industry', an Interreg project funded by the Botnia Atlantica program. The project partners are Tampere University, Seinäjoki University of Applied Sciences and Novia University of Applied Sciences in Finland. University of Umeå is a Swedish partner. Tampere University and Seinäjoki University of Applied Sciences are jointly implementing the work package 'Technical solutions', wherein this report has been written.

The aim of the project is to improve competitiveness of the regional wood product companies in the international market by promoting the emergence of new networks and business ecosystems, and by supporting the introduction of successful circular economy models. The main objective of the project is to support small and medium-sized enterprises operating in the region in their efforts to overcome the usual obstacles in the transition to a circular economy.

This report brings together a wide range of best practices related to a circular economy and low-carbon construction of the wood product and construction sectors from Europe's pioneering countries and Finland. The report also contains a section of new instructions and requirements, ensuing from Finland's renewed Land Use and Building Act and Waste legislation. Some results of the studies carried out during this project have been included as well. The best practices in Denmark and the Netherlands are based on the experience gained during the project's study visit. The material concerning Finland has been compiled mainly from seminar and webinar presentations of several different construction experts.

2. The use of recycling and by-products in building projects

2.1 Recycling of building materials in Denmark

Two Lendager Group's apartment blocks are being built in Ørestad, Copenhagen. Most of the building materials are recycled. Windows, wood, concrete and bricks have been obtained from old buildings.

Recycling of used windows and concrete

In a three storey building, Upcycle Studios, 75% of the windows are recycled and come from abandoned buildings in North Jutland. The wall elements of the first two storeys are made of recycled windows. The front of the third storey and the floors of the building are produced from offcuts from wood companies. In addition, 1400 tons of recycled concrete are casted from very durable concrete waste from the construction of Copenhagen Metro. (Palomäki and Lehtisaari 2018)

Pictures 1. Upcycle Studios in the Ørestad South district of Copenhagen, 75 percent of the windows come from abandoned buildings. (Picture by Virpi Palomäki, CE Wood -project)

Reuse of brick walls and wood

In the same area, a five-storey brick-paved apartment building, the Resource Rows, is also being constructed. The innovative concept in the project is to reuse entire brick walls from abandoned homes directly in the new building. By cutting the wall modules of the abandoned homes and installing them in steel frames, they can be used as wall modules in the new building. Brick modules are cut out from Carlsberg's historical breweries in Copenhagen. The rest of the bricks come from various old schools and industrial buildings around Denmark.

There are also recycled wood based materials from the Copenhagen Metro construction, which are being used on the Resource Rows outer coverage and on the interior surfaces. Remanufactured lumber has been treated to last and look beautiful.

Pictures 2. The bricks for The Resource Rows are cut out in modules and stacked up to create the new walls of the building. There are also recycled wood based materials from the Copenhagen Metro construction. (Picture by Virpi Palomäki and Paula Pihlaja, CE Wood -project)

2.2 Ambitious goals in the Netherlands

The Netherlands plans to shift completely to a circular economy by 2050. The first intermediate goal is 2030, the date by which half of the raw materials to be used are supposed to be recycled. In the construction industry, some municipalities already use the circular economy as one of the criteria in competitive tendering for public projects. To support the measurement of the degree of circular economy, material passports are also being introduced for buildings, with a view to improving the monitoring of the circulation of raw materials in the construction industry. Dutch independent research organisation, TNO, actively supports leading scientific institutes, companies, local communities and universities with their circular economy development projects. More information about CE- development projects from TNO website. (Palomäki and Lehtisaari 2018)

Picture 3. TNO is testing different wall elements made by fully recycled materials. (Picture by Virpi Palomäki, CE Wood -project).

The Dutch government strongly supports the circular economy strategy, and several provinces, e.g., Friesland, Groningen and Drenthe have launched large-scale circular economy projects. There is a building project starting in the City of Assen, Drenthe, with the aim of building 100 residential buildings from 100 % recycled materials. Funding has already been obtained, and construction work will start in 2019. In the Dutch provinces, the groundwork for a shift to a circular economy has already been done for a long time. In Assen and at the schools in the biggest cities in Friesland, school children are taught about circular economy and sustainable development, starting from elementary school. Find more information about these development projects on Circular Friesland and TNO.

3. Living labs

3.1 The Green Village in Delft

The Green Village is a living lab of the Delft University of Technology, which is a test platform in which all kinds of innovations related to the living environment can be researched. Themes range from research on applying new materials both in building components and interior, testing new services and installations, domotics and DC grids etc.

Figure 4. The Green Village in Delft (picture by Annika Glader, CE Wood -project)

The test houses in the Green Village have been inhabited by real inhabitants, assuring that the innovations are subject to real usage, real consumptions and real feedback. Having people living at the Green Village, is part of the Living Lab testbed, which forms a test facility for all kinds of innovations related to the living environment.

Woodyshousing have test houses in the Green Village and offers a housing solution based on a circular building system, technology and community platform. The WOODY is a prototype of the building development process that aims to start a wide-ranging production. The prototype in the Living Lab is the source for evaluation and connecting with end-users.

Figures 5-6. 5. The WOODY is the prototype of Woodyshousing. Figure 6. Prêt-à-Loger is a sustainable renovation concept (pictures by Virpi Palomäki, CE Wood -project)

The Sustainer Homes also have a test house 'Office Lab' in the Green Village. The Office Lab is designed to be flexible, adaptable and modular, so that different assemblies can be easily installed. The office space is used daily by real users, assuring that innovations are subject to real usage, consumptions and feedback.

Prêt-à-Loger is a sustainable renovation concept for which Delft University of Technology won awards at the international "Solar Decathlon Europe 2014" competition. The so-called "second skin" concept combines energy saving measures with adding extra living space by adding a smart greenhouse structure. The prototype in the Green Village is currently being used for further research on the concept and as a testbed for new technologies.

3.2 GreenLab Skive in Denmark

The municipality of Skive has published Strategic Roadmap 2017-2020 'A Business Park and Symbiosis Platform for Green Growth and Innovation' in July 2017. The roadmap sets out a series of strategic milestones, and presents combined knowledge about the organizational, financial and technological elements.

The idea is to create a business park that can accommodate more than 20 companies positioned around a central building, which is the core of the park. The central building is in shared use, and has educational and research facilities, demonstration areas, showrooms and meeting facilities.

The cornerstone in the GreenLab project is a power-to-gas plant, enabling large-scale conversion of wind power into energy, which is stored as gas. This makes GreenLab a natural choice for companies interested in renewable energy. GreenLab also invites companies that are able to utilize the excess energy to join the project.

GreenLab Skive supports the business, climate, energy and settlement policies of the municipality of Skive. At a national level, GreenLab Skive supports Danish efforts to create industrial symbioses that build on the green-transition initiative of the Danish Business Authority and the Central Denmark Region.

Figure 7. GreenLab Skive region (picture by Virpi Palomäki, CE Wood -project)

3.3 The Circularity City project in Denmark

The Circularity City project brings together actors from across the Central Denmark Region to create the circular cities of tomorrow and leverage circular construction and design to accelerate sustainable business growth. Cities are key in the transition to circular economy. Cities are undergoing extensive transformations, as a number of people are moving to urban areas, transforming businesses and the built environment. This provides new opportunities for rebuilding cities to accommodate circularity in all aspects of urban life, stimulating a transition to circular economy within the construction sector.

Circularity City is an engine for urban transformation and growth in the Central Denmark Region. Together, new urban solutions can be developed where resources and materials are designed for disassembly and embedded in closed loops, thus, making it possible to regenerate and reuse them again. Circularity City brings together those companies and municipalities that will take the lead and demonstrate how to shape our future circular cities.

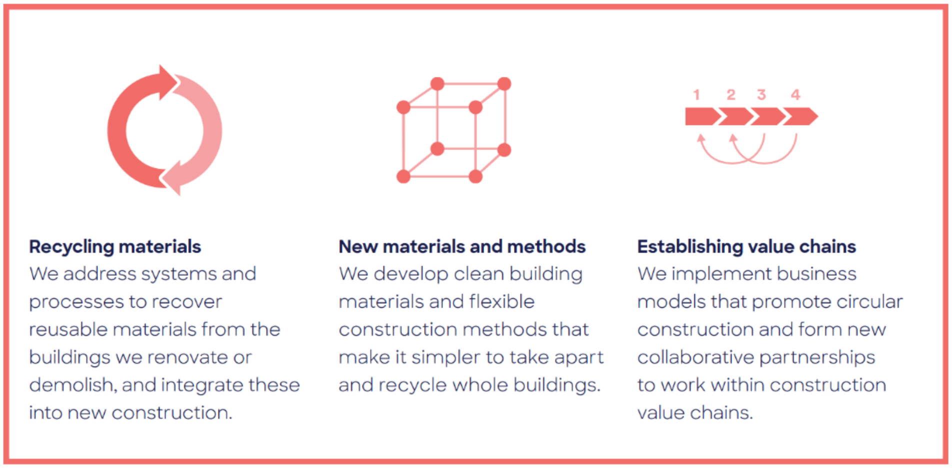


Figure 8. Original image published in Circularity City - Shaping Our Urban Future, Central Denmark Region

Figure 9. PhD Torsten Sack-Nielsen from VIA Centre of Research and Development – Building, Energy and Environment held a lecture at Skive's old town hall (picture by Lars Lindbergh, CE Wood –project)

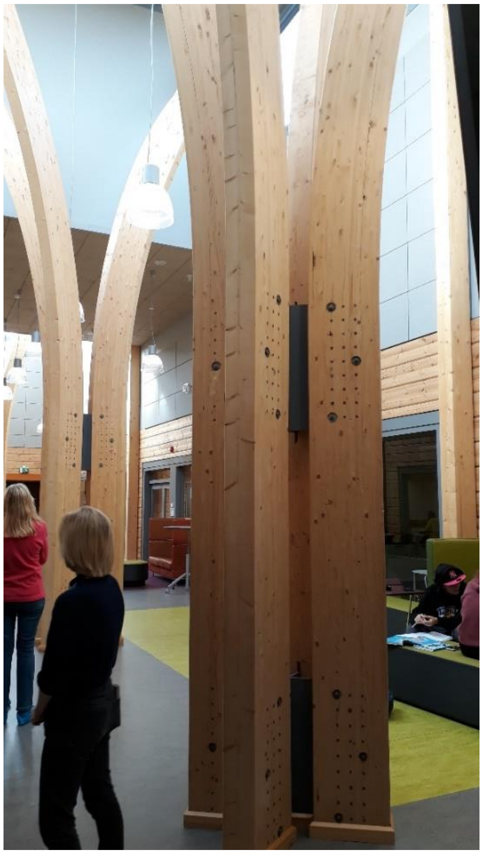
4. Life-cycle construction of logs

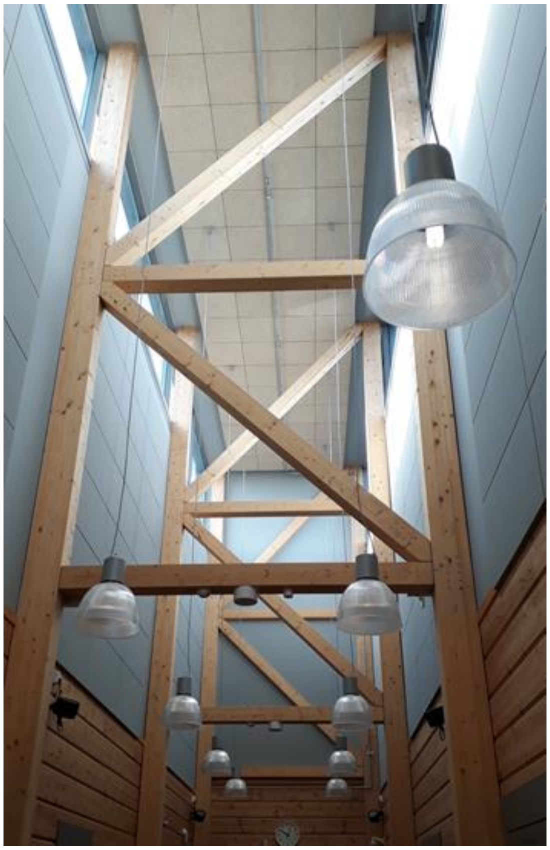
4.1 The building engineering solutions for log building at Pudasjärvi

The city of Pudasjärvi decided to bring its schools and community college to one location and have a new log-structured campus built. One aim in the use of timber was to prevent moisture and indoor air quality problems similar to those that the school buildings had previously experienced. It was also an eco-friendly choice. The campus was implemented as a life-cycle project.

The building consists of four sections in a setting of two wings. The frame of one section is made of reinforced concrete because it accommodates a civil defence shelter and kitchen facilities. The space is divided into small entities that children are able to comprehend. The regular classrooms are situated in two single-storey sections; the primary school in one, and the secondary school in the other. Between the two-storey sections, there is a central hall that also serves as the school canteen.

Except for the section with a concrete frame, all the walls of the building are made of logs: exterior walls of 275mm, and partition walls of 275mm, 205mm and 130mm laminated logs. The roofs of the main hall and of the roof lanterns are supported by glulam pillars with different shapes.

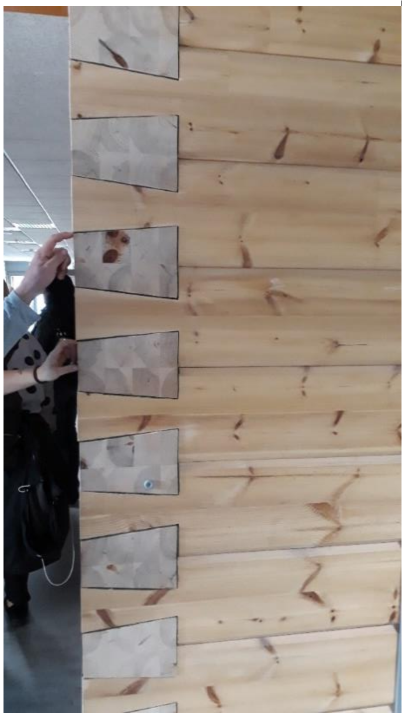




Pictures 10-12. Roof support structures of a log campus (pictures by Virpi Palomäki, CE Wood -project)

In the single-storey sections, the classrooms are small “log cottages” with windows and doors. The spaces between the cottages serve as open teaching and learning spaces. They receive natural light through large roof lanterns. Some of the teaching spaces receive natural light through floor-to-ceiling windows. The roof lanterns between the two-storey sections also provide light to the first-floor corridors.

A special aspect in the design of a log building is how to address the challenge of log settling. In particular, the question of how the roof shared by the concrete-structured and log-structured sections and the passageway between them would behave over the course of years required a great deal of consideration, but excellent solutions were found at the end. During the design process, another challenge was how fire safety regulations should be interpreted in the design of a log-structured school building. The positive attitude of the authorities helped to solve this problem. Cross-laminated timber elements were used in the intermediate floors and the banisters of the main hall stairways.



Pictures 13-14. Corner structures of a log campus (pictures by Virpi Palomäki, CE Wood -project)

4.2 Expected and actual measurement results of the life cycle model on the Pudasjärvi log campus

Ville Sormunen (2018) of YIT Talo Oy related that the Pudasjärvi log campus was implemented using a life cycle model in which the builder was partially responsible for in-service costs and services. The service period of the campus is 2016–2041, the building's area is 9,806 rm2 and the volume is 47,826 m3. The energy efficiency class is B / 129 kWh/ (m2 year). The builder bears the short-term and long-term (PTS) maintenance responsibility for energy consumption (excl. domestic water) as well as property maintenance and cleaning services.

The service promise listed in the life cycle contract for district heating was 1,293 MWh. The promise did not include the heating energy for domestic water and the district heating consumption in the kitchen. The actual value measured in 2017 was 1,228 MWh / 25.7 kWh / m3, and the weather-adjusted value was 1,328 MWh / 27.8 KWh / m3 (the heating degree day value for the realisation year was 3.6% lower than in the reference period).

The electricity consumption promise listed in the life cycle contract was 408 MWh. The actual consumption measured in 2017 was 747 MWh, of which 203 MWh was real estate electricity and 205 MWh lighting electricity.

Electricity consumption:
- Lighting 134 MWh / 18%
- Ventilation 141 MWh / 19%
- Other real estate electricity 82 MWh / 11%
- Consumer electricity 74 MWh / 10%
- Kitchen's electricity consumption 313 MWh / 42%

Indoor air analyses of the log campus

Concentrations of gaseous compounds (VOC, formaldehyde and ammonia) were measured at the Pudasjärvi log campus. Five different types of spaces were selected to represent different parts of the building. The total number of measurements was 21 for VOC, 17 for formaldehyde and 3 for ammonia (one measurement session in August 2016).

The indoor air concentrations of formaldehyde were below the limit of quantification for most measurements, which is not unusual in Finland. The low general level of the measurement results for the log campus is attributable to two causes: 1) the building does not include materials (e.g. glues) that could release significant amounts of formaldehyde, and 2) the formaldehyde concentration of outdoor air in Pudasjärvi is very low.

Based on the measurement results, the building does not contain movable property or materials that could release significant amounts of formaldehyde. Formaldehyde is also generated when terpene compounds react with ozone, but even this mechanism does not generate significant amounts of formaldehyde within the log campus.

In all analysed spaces the ammonia concentrations were below the limit of quantification (about 10 $\mu g/m^3$). The analyses were conducted to confirm the initial state and the possible effects of movable furniture and occupants on the indoor air.

Results of the log campus user survey

In May 2018, a user survey covering the entire staff of 90 people was conducted. The response percentage was about 31%, evaluation scale 1–7.
- Average grade 5.71 (previous 5.60)
- Satisfaction with the property's indoor temperature 5.0 (5.11)
- Satisfaction with the property's lighting 5.38 (5.72)
- Satisfaction with the property's acoustics 6.25 (6.0)
- Satisfaction with the property's indoor air quality 6.21 (5.56)

5. Special features of wood construction

5.1 Carbon footprint assessment in building regulations

According to the Hirsitaloteollisuus ry association, carbon footprint calculation will be included in Finnish building regulation in 2025 at the latest (Romppainen, 2018). After this, a total carbon footprint assessment must be conducted on construction projects. Finland is currently keeping an eye on models that are already or will soon be in use in other EU countries. In the Netherlands, CO_2 calculation became mandatory in 2018 and emissions have limit values. France requires mandatory environmental reports, and CO_2 emission limits were adopted in 2020. Sweden instituted the obligation to report CO_2 emissions in 2020, and Norway is also about to make CO_2 calculation mandatory for all state construction projects.

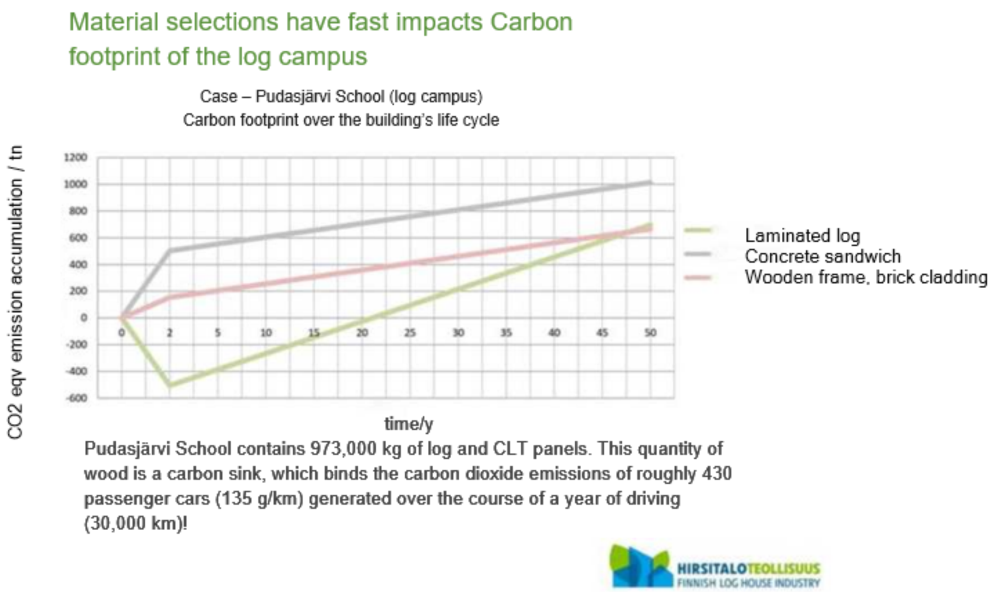


Figure 15. Carbon footprint of the log campus in the seminar presentation of Seppo Romppainen from Hirsiteollisuus ry.

5.2 E-value exceptions and fire regulations in the context of solid wood buildings

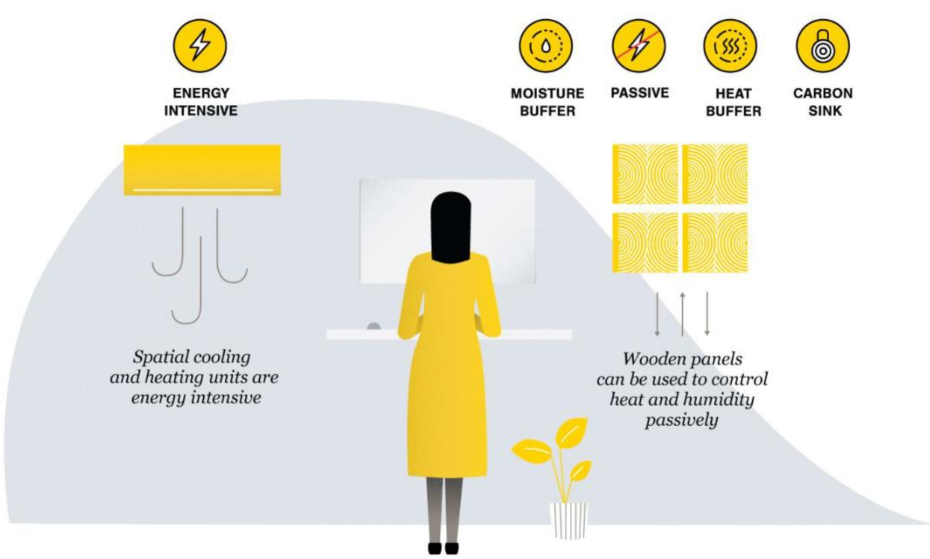
There are some E-value exceptions and fire regulations that apply to solid wood buildings. In the teaching building and day care centre, the E-value limit can be exceeded by 5 $kWh_E/(m^2a)$, if the heated net area is no larger than 1,000 m^2. As regards solid wood buildings, the E-value limit can be exceeded by 20% in separate small buildings and linked houses where the heated net area is 50–150 m^2, by 15% in separate small buildings and linked houses where the heated net area is larger than 150 m^2 and by 10% in other purpose of use categories. (Romppainen, 2018)

As regards terraced houses and residential blocks of flats with no more than two residential floors, the aforementioned E-value limits can be exceeded by 5 kWhE/(m2a) when the building is connected to a heating system in which the heat is led from a shared heat exchanger or heating device to three or more buildings through external heating pipes.

The new fire regulations permit more wood to be uncovered on the surfaces of blocks of flats, too. Moreover, wooden-framed accommodation and care facilities can now be up to eight storeys high. This change is due to the results of internationally notable fire tests conducted by the wood product industry. The Ministry of the Environment has published a decree regarding the fire safety of buildings. The decree entered into force at the beginning of 2018 and replaced the previous E1 fire regulations and the relevant instructions released in 2011. From the perspective of using wood, the decree includes numerous significant improvements. In wooden blocks of flats, the interior surfaces of wooden structures can be left without protective cladding, which means that up to 20% of the wooden wall and ceiling surfaces remain visible. By increasing the load capacity requirement to 90 minutes, up to 80% of the wooden surface can be left uncovered. In addition to this, non-load-bearing partition walls and floors can have wooden surfaces. (Romppainen, 2018)

5.3 Can wood improve the indoor environment and energy-efficiency of buildings?

According to Mark Hughes (2018) of Aalto University, the material properties of wood can be used to control indoor air and improve energy efficiency. In addition to being a good structural material, wood has a relatively low thermal conductivity, a moderately high heat capacity, a relatively low effusivity and is hygroscopic.



Picture 16. Original image in Mark Hughes' presentation in the VAIN HYVIÄ SYITÄ –seminar at Pudasjärvi.

The properties of wood can be used to passively influence or control the interior environment of a building, which can then have an effect on comfort and health. The amount of wood, the orientation of the exposed surface, the species and whether it is coated or not all play an important role in determining the magnitude of the effect. The hygrothermal properties of wood can influence the energy efficiency of a building.

5.4 The superpowers and wellness value of wood

Wood boasts antimicrobial properties. This is due to the extractives contained by wood which are highly antimicrobial. Removing the extractives from the wood weakens the antimicrobial properties of the surfaces. Lignin, too, affects the capacity to stave off bacteria. Some extractives can vaporise, decay, wear out or otherwise disappear from the wood surface over time, but this aspect requires further study. (Vainio-Kaila, 2018)

International studies have been conducted on the impacts of wood on people's well-being and measurable physiological changes (Muilu-Mäkelä, 2018). A study involving 20 test subjects compared the effects of a basic room and various wooden furnishings on the subjects by means of a 60-minute test. Differences were found in a variety of feelings, such as tension, vitality and despondency. More feelings of fatigue were experienced in spaces with no wood. The test subjects found the colour, smell and lighting more pleasant in wooden rooms. Another study compared the impacts of plasterboard and spruce panel on test subjects. The study included 102 volunteers. Based on the relevant questionnaire, a wooden interior had a statistically significant positive impact on the test subjects' assessments based on touch, hearing and smell. In tests focusing on emotional states, the room with a wooden interior elicited more positive feelings than its painted counterpart. On the other hand, another study indicates that wood materials in combination with other interior materials are found more pleasant than interiors featuring wood or other materials only (Figure 17).

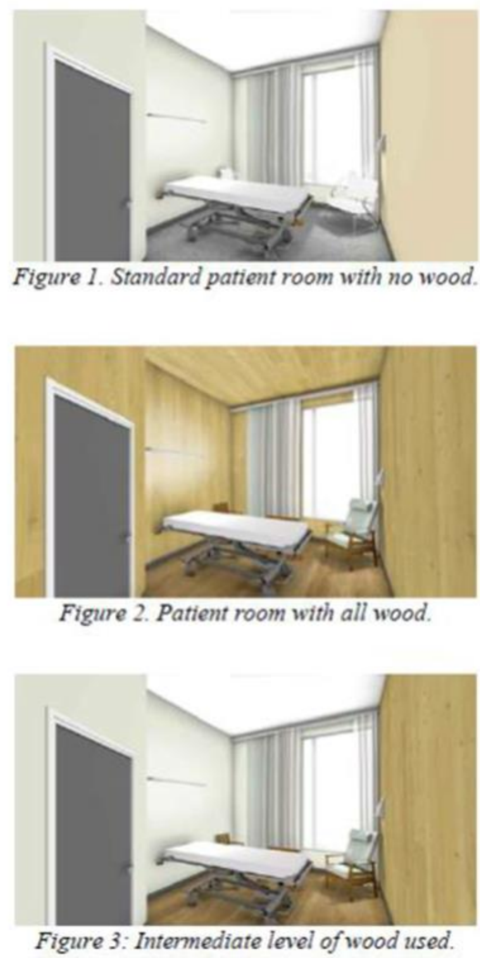


Fig. 17. Patient rooms from Muilu-Mäkelä's presentation.

Researchers in Finland have also begun studying the effects of wood on people's well-being. The aim of Natural Resource Institute Finland's (Luke) SuperWood 2017–2018 project was to build a testbed for studying whether or not wood materials can be used to influence the physiological stress and recovery of people in work environments. The studies monitor physiological parameters: blood pressure, heart rate, skin conductivity, stress hormones. The psychological assessments are based on tests of alertness, cognitive load and creativeness as well as opinion polls. Luke's Wood for Good research project will provide Finnish material on the health and wellness effects of wood (Muilu-Mäkelä, 2020). The University of Eastern Finland, VTT Oy and XAMK (Paajanen, 2020) are also conducting a multidisciplinary study on the cleanability and antibacterial properties of wood surfaces. In the future, these studies will provide more detailed information on the impacts of using wood.

5.5 Acoustic special properties and impact damping in wooden buildings

Wood and wood products are excellent materials for surfaces that reflect sound in spaces intended for speaking or musical performances, for example. They can also be used to produce sound-scattering surfaces for spaces such as recording and music rooms, as well as perforated panels that absorb sound. Wood can be easily combined with other acoustic solutions (Jokitulppo, 2018).

However, the coincidence cut-off frequency of wood and many wood-based panels falls within a challenging range, which is why wood in panel form is largely unsuitable for soundproofing structures. Wood features fairly low density and, based on mass law, the mass of panel structures is not sufficient to insulate sound. As a result, wooden structures must be double or triple structures and the flanking transmissions must be managed by means of structural partitions.

According to an analysis by A-Insinöörit, the intermediate floor is the primary element in terms of the competitiveness of wood construction. For acoustics, impact damping is the dimensioning factor. According to the analyses, the most important factors affecting impact damping are the ceiling and its fastening method, the mass of the load-bearing structure's ceiling board, flooring, wool quantity in the air gap and the floating floor. Minor impacting factors are the joist loading width, span, joist type and height, and ceiling mass, if the panels are fastened directly to the joists.
A-Insinöörit's conclusions regarding the impact damping of the intermediate floor (Jokitulppo, 2018):

- A floating floor is not mandatory, as a flexibly suspended ceiling is more important.
- The development efforts produced a wooden intermediate floor with acoustic properties close to its concrete counterparts.
- The same flooring products used for concrete intermediate floors can be used for the newly-developed floor solution.

5.6 Wood construction – fasteners and connectors

Among other projects, design firm Toni Kekki (2019) has been designing the award-winning Puukuokka wooden blocks of flats built in Jyväskylä. The buildings are made of modules which, according to Kekki, ensures more consistent quality than on-site construction. According to him, modular construction is an industrial process instead of a construction process. It is easier to control quality (e.g. joints, airtightness and material quality) since the industrial process involves a high degree of prefabrication.

The modules are usually attached to each other with horizontal and vertical connection plates, which can be either metal or wood. In buildings with multiple floors, the modules must be fastened with both horizontal and vertical plates since it is necessary to transfer the forces affecting the building to the foundation from all modules. A dowel solution can also be used for the joints. The joints must be “loose” to ensure appropriate soundproofing. Rubber insulation is used for this purpose. Rubber anti-vibration strips or friction insulation solutions are used in the module joints to prevent vibration.

Figure 18. Example of wood structure fastening from the presentation of Konepuristin Oy’s Antero Kujala at the Puurakentaminen – kiinnikkeet ja liittimet event in Ähtäri on 29 October 2019. The figure features hidden joint components.

6. Flexibility and versatility

6.1 Convertible and ecological Townhouse

Marko Simsiö (2019) designed an urban residential building, Townhouse, which gained him the shared first place in the 'Hirsirakenteinen kaupunkiasunto' (Urban log house) idea competition. Built from logs, the Townhouse building organically blends modern wood construction and comfortable, healthy and ecological living with a form of living that is new to Finland. The Townhouse concept involves small urban houses that are connected to the adjacent homes, feature two or three storeys and each have their own plot of land.

According to Simsiö, 35% of greenhouse gas emissions in Finland are caused by construction and buildings, 40% of waste generation in Europe is caused by buildings and demolition, and 1 million Finns are exposed to low-quality indoor air on a daily basis.

Simsiö's views on the benefits of wood construction:

- healthiness: fewer indoor air issues in new wooden buildings
- renewable material: binds carbon dioxide, recyclable, bioenergy production, new trees bind carbon dioxide
- the carbon footprint of a wooden block of flats is 75% less than that of a concrete building

Hopes for the future of wood construction:

- building sustainably, extending the life cycle of buildings
- building from high-quality materials and in simpler ways
- building for people: healthiness, high-quality architecture, new living solutions

The needs of residents change with age and as their children grow. Modifiability ensures that people can live in the housing units for as long as possible. The floors of the log Townhouse are divided into three zones. Utility spaces, such as bathrooms, are in the middle of the building frame and the actual living areas are at both ends of the building. Openings can be made in the intermediate floor which enables creating a high space in the living room, for example.

Since the outer walls serve as the building's load-bearing frame, the spaces can be modified for a variety of purposes. These interior spaces can be divided into smaller sections with partition walls. Alternatively, an entire floor can be left as an open space. A space reservation for a lift enables older residents to live in the building for as long as possible. A part of the first floor can be sectioned off as a separate housing unit for a grandparent or teenager, or as an office space for personal use or letting.

https://www.honka.fi/fi/blog/2018/02/22/townhouse-uusi-tapa-rakentaa-kaupunkiasuntoja/

Figure 19. Illustrative image of the Townhouse building from Marko Simsiö's 12 February presentation materials.

6.2 Modifiable Eco School concept

Futudesign Oy has developed the use of wood in schools. Research indicates that wooden interior decoration can improve students' focus. For example, the number of errors made in mathematical exercises was measured to decrease, indicating an improvement in focus (Niemeläinen, 2019).

According to Niemeläinen, modular wood construction can ideally reduce construction time, general worksite costs and financial administration expenses, compared to conventional construction. The shortened construction time in the project's production phase is one of the main reasons for favouring wood in construction. The method can result in up to 30% faster construction compared to more site-intensive options. The flexibility and precision enabled by modern CNC processing technology enables the production of customised panels, which in turn enables flexible and cost-efficient design and construction.

Niemeläinen talked about the Eco School concept based on a school module of approximately 600 m2, which can house about 100–150 pupils or 5–8 classes. The module was designed in accordance with the modern Finnish curriculum, but it is also highly adaptable for a variety of educational needs. The ample size of the school module enables simultaneous use by different age groups and classes with different learning needs. The open learning environment version features open and closed learning spaces of varying sizes. Positioning the closed group work spaces in the centre of the module divides the space to offer more options for different kinds of learning situations.

6.3 Movable TeijoTila modules

Teijo-Talot Oy manufactures high-quality premises for commercial and public sectors. Sustainable, eco-friendly and energy efficiency are values in their business. The quality of the indoor air, the safety of used materials and care for the environment are very important aspects of constructing different premises. Teijo-Talot Oy offer turnkey solutions from design to implementation, from groundworks to assembly on site.

Fig. 20. The modules are removable with the foundation. Photo by Teijo-Talot Oy

Teijo-Talot takes into account the changing needs of construction and renews traditional construction with movable space solutions. Teijo-Talot manufactures removable buildings and space solutions, such as schools, day care centres and health centres, as well as office and production buildings. Portable solutions allow for rapid construction and low disruption at the construction site.

The concrete foundation is an integral part of every TeijoTila module. The modules are removable with the foundation and fixtures. All premises are delivered completely ready, including electricity, plumbing and interior decorations. For example, the city of Järvenpää bought a 2100 m^2 school for 288 students from Teijo-Talot. The school contains 30 space element modules. (https://www.teijotalot.fi/)

Fig. 21. In addition to the classrooms, the school has a spacious two-story high hall. Photo by Teijo-Talot Oy.

6.4 Sydänpuu concept

Lakea Oy has developed its Sydänpuu concept for the construction of wooden blocks of flats. The company is a pioneer in wood construction and invests particularly in ecologically sustainable and responsible construction. The company is continuously developing methods for wood construction and sees its national and international potential. For the purposes of modular wood construction, Lakea Oy has developed its own Sydänpuu concept and applied for a patent. The concept involves assembling wooden modular units around concrete wet room modules. The concept yields savings in construction costs and enables later modification of the housing units. The wet rooms are constructed from modular units that are separate from the dry room elements and can be installed on top of each other without a separate frame. (Mantila, 2019)

According to Mantila, future climate policy will push developers towards more energy-efficient and carbon-neutral construction. Mantila particularly emphasised the necessity to develop industrial construction to ensure competitiveness in the construction field.

6.5 Development of the Vuores and Hiedanranta areas in Tampere

The City of Tampere has entered into a cooperation agreement lasting until 2020 with the Ministry of Economic Affairs and Employment, Tampere University of Technology, Tampere University of Applied Sciences and Natural Resources Centre Finland to promote wood construction. The city aims to develop itself into an internationally-known hub of wood construction. The Isokuusi neighbourhood in the Vuores district is the most significant area for the programme to promote wood construction.

The plan for Isokuusi is to construct an architecturally harmonious neighbourhood of wooden buildings, including blocks of flats, small urban house concepts, detached houses, terraced houses, and a school and day care centre building. Wood will also be used in infrastructure construction, such as marketplace, bridge, park and yard structures. Upon completion, the area will be one of the largest modern urban environments in Finland to be made out of wood. Another objective is to make Isokuusi a carbon-neutral area where energy and material efficiency, energy systems, life cycle thinking and ecological ways of life are considered from the very start. Isokuusi is being profiled as a Finnish model neighbourhood for new industrial wood construction, renewable energy and smart solutions.

Important aspects for Tampere:

- Diversity in family types
- Modifiability and systems for adjusting the spatial features of housing units
- Communality and new kinds of social environments
- Impact of digitalisation and sharing economy on living; smart built environment
- Fitting together work and living; “new urban work”
- Typological diversity

Solutions that provide the opportunity to section off a smaller dwelling through minor modifications improve usability during the life cycle and ensure that people do not need to leave their homes, or at least their blocks, when their situations in life change. The goal was to create a communal block with a small-town feel.

Attractive social spaces and shared yard areas provide an environment for people to meet, get to know each other and do things together, regardless of their age and situation in life. Furthermore, high-quality common spaces generate added value for living: for example, the spaces can contain equipment that would be too expensive to purchase for each housing unit. Areas such as work spaces can also be shared.

Figure 22. Vuores district's wooden blocks of flats in an illustrative drawing

Hiedanranta area

In the future, Hiedanranta will feature homes for 25,000 residents and 10,000 jobs. Together with the Lielahti district, it will form the appealing centre of western Tampere and provide an excellent place for living, working and engaging in leisure activities. New ideas, trials and urban culture in general are flourishing in Hiedanranta. Smart and sustainable solutions make residents' daily lives easier. The future lakeside district will be quickly accessible from the city centre via a tram line and other transport links.

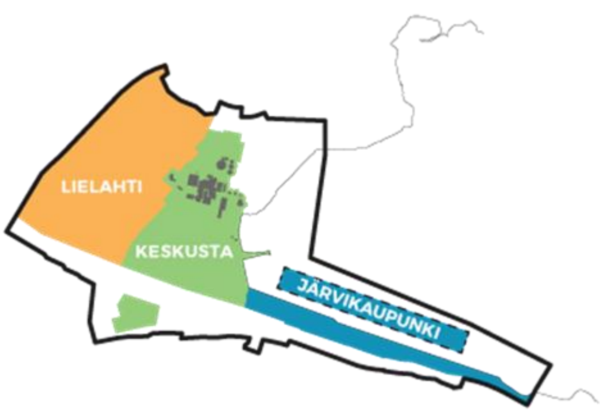


Figure 23. The future Hiedanranta district will consist of three areas: New Lielahti, Centre (Keskusta) and Canal City (Järvikaupunki). The aim for the entire area is to provide homes for 25,000 residents as well as 10,000 jobs. https://www.tampere.fi/asuminen-ja-ymparisto/kaupunkisuunnittelu-ja-rakentamishankkeet/hiedanranta/suunnittelu.html

Hiedanranta serves as a development platform for trials and projects that promote smart and sustainable solutions and the circular economy. The developers are cooperating with city residents, businesses, research bodies and other organisations. Even during its construction, Hiedanranta will serve as a development and business platform for numerous energy-related projects, trials and business operations. The aim is to create a separate digital energy market for Hiedanranta and ensure that the area becomes a new kind of smart and sustainable operating environment for the energy business. Energy production in the area is based on renewable energy sources. Among other ventures, a new energy retention trial is under way, which involves binding heat in a bed of sand from which it can be gradually released for use. Another plan is to use the heat energy collection system to be linked to the foundation piles in the construction of the residential area.

The Hiedanranta district aims for a “blue-green” infrastructure that increases natural diversity and mitigates the risks caused by climate change. The solutions utilise natural processes and view water as a resource instead of a risk. Examples of the blue-green infrastructure include green roofs, permeable surfaces, channelling rainwater into the substrate of street trees, urban agriculture, and stormwater basins and trenches. As regards urban agriculture, cultivation trials are under way in the area, involving growing herbs, strawberries and similar plants in vertical cultivation pipes with fully artificial light. Allotments have also been created and small greenhouses have been constructed in the area for residents to grow their own produce.

https://www.tampere.fi/asuminen-ja-ymparisto/kaupunkisuunnittelu-ja-rakentamishankkeet/hiedanranta/innovaatioiden-hiedanranta.html

7. Platforms and marketplaces

7.1 Netlet Oy

Netlet Oy https://www.netlet.fi/ is an example of an interesting new venture in the construction field. The company's business idea involves two kinds of operations:

Raksanouto (construction pick-up) is a service concept developed for construction professionals, which aims to alleviate the worksite pressure to meet ever-tightening waste management requirements. The service picks up usable surplus materials from the worksite for no charge. Raksanouto prevents the disposal of viable materials on waste skips and leads to direct savings in the worksite's waste management and logistics costs.

Rakennusoutlet.com is a portal for selling usable surplus materials held by construction companies. The concept includes both an online shop (www.rakennusoutlet.com) and warehouse outlet, which is located in Vantaa.

7.2 Verte Oy

Verte Oy coordinates the development of the ECO3 Platform for the bio and circular economy business area in Nokia. The City of Nokia owns the business area where companies producing various kinds of circular economy solutions will be collected; https://www.verte.fi/, https://kolmenkulma.fi/. The ECO3 business area was selected as the winner of the circular economy market category of the national 'Kuntien kiertotalouden kiinnostavimmat teot' (Municipalities' most interesting circular economy measures) competition.

The Platform services include the following:
- Collecting new bio and circular economy companies and water management companies and rooting them in the area.
- Developing, acquiring and innovating the demo and pilot environments of the ECO3 technology companies together with businesses and research bodies.
- Identifying the national and international market demand and integrating it into the business, visibility and value chains of the companies in the area.

7.3 Materiaalitori

Materiaalitori (Material marketplace) is intended for the professional exchange of waste and by-products generated by companies and organisations. The service can also be used to find related services, such as waste management and expert services. Materiaalitori is open to all operators in the field and can be used free of charge. The digital service was established by the Ministry of the Environment and Motiva.

From the beginning of 2020, holders of waste must seek market-based waste management services for their waste through Materiaalitori before they can request the service from the municipality based on a market gap. The lack of private services is a precondition for the municipality's secondary waste management services. To determine whether or not there is a deficiency, the holder must submit a notice of the required waste management service to Materiaalitori. The secondary services can be requested from the municipal waste management facility if a reasonable market-based service cannot be found within 14 days of submitting the notice.

The obligation to use Materiaalitori does not apply to municipal secondary waste management services falling short of €2,000 in annual value or situations where waste management services are needed with unexpected urgency. The obligation will cover public holders of waste, i.e. procuring entities, from the beginning of 2021.

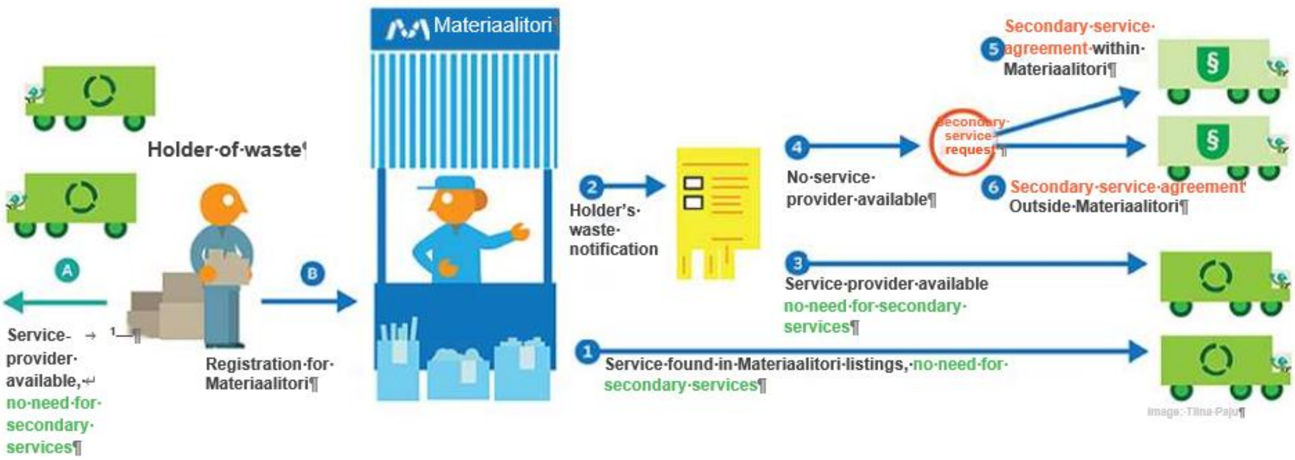


Fig. 24. Operational diagram of Materiaalitori www.materiaalitori.fi

Materiaalitori expedites the circular economy and increases transparency

The circular economy aims to keep materials in circulation and retain their value as long as possible. The consumption of natural resources can be reduced by using recycled materials. Materiaalitori's essential goal is to promote the circular economy and the reuse of waste and by-products by providing operators in the field with a meeting place where those who have recyclable materials and those who need them can find each other. The creation of these kinds of industrial symbioses is a precondition for the circulation of materials. Materiaalitori aims to collect material streams generated in Finland to a single visible location in order to ensure the emergence of new utilisation methods around them and an increase in the reuse of materials. The development of these kinds of recycling markets is key for increasing the value of recycled materials. For recycled materials to remain in circulation for as long as possible, they should be seen increasingly as valuable raw materials.

8. Development and use of assessment and calculation tools

8.1 Developing a green profile assessment tool

Various tools have been developed for assessing the business opportunities related to the circular economy. By commission of the CESME project operating in South Ostrobothnia, VTT Oy developed and tested a green profile evaluation tool. The aim was to create an operating model for applying the tool and thereby promote the transition of regional businesses towards a green economy. The tool was tested among companies in the region together with economic development operators.

The tool offers the following:

- Various ways to assess business operations from a circular economy perspective
- Information on more environmentally and socially sustainable operations and the opportunities of the circular economy
- Promotes the circular economy transition among companies

Goal of using the tool:

- Helps to understand value creation in the circular economy and responsible business operations, and to illustrate the new opportunities provided by the circular economy
- Assessing the impacts of the circular economy on business and the new business opportunities it provides (e.g. new products or services)
- Helps to take the circular economy into account better in current operating methods, products or services

The tools support the emergence of new operator networks: e.g. industrial symbioses, circular economy collaboration between operators/fields, and the production of operator-specific information on waste and by-products and their opportunities, companies and other operators linked to the activities.

8.2 CE Wood project workshop assessment regarding the functionality of circular economy business models

The CE Wood project organised a virtual workshop in September 2020, in which Maria Antilainen of VTT Oy presented the circular economy operating models used in the assessment tool. In conjunction with the workshop, the participants were asked which circular economy business models would best suit the wood product and construction industries.

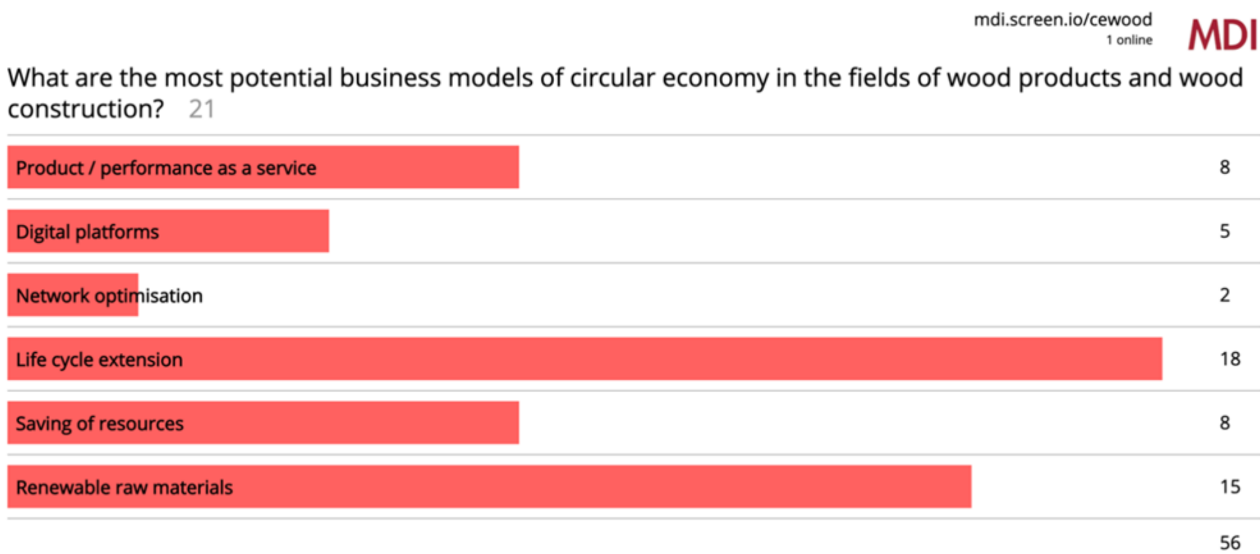


Fig. 25. The participants felt that extending the life cycle of products and buildings was the most important circular economy business model. The use of renewable materials was deemed as the second most important model.

8.3 Bionova Ltd

Bionova Ltd has developed a life cycle calculation software in the form of the One Click LCA software, which adheres to the Ministry of the Environment's plan for carbon emission assessment. It separates the various life cycle phases from raw material acquisition and the production of construction materials to demolition. (Bionova 2020)

In the calculation method developed by the Ministy of the Environment (https://elinkaarilaskenta.fi/), the carbon footprint and handprint are calculated and reported separately. Carbon footprint means the negative climate impacts that are generated by a construction project. Carbon handprint refers to the positive climate impacts that would not be generated without the project. For example, carbon handprint assessment covers the impacts of using recycled materials and wood-based carbon stores.

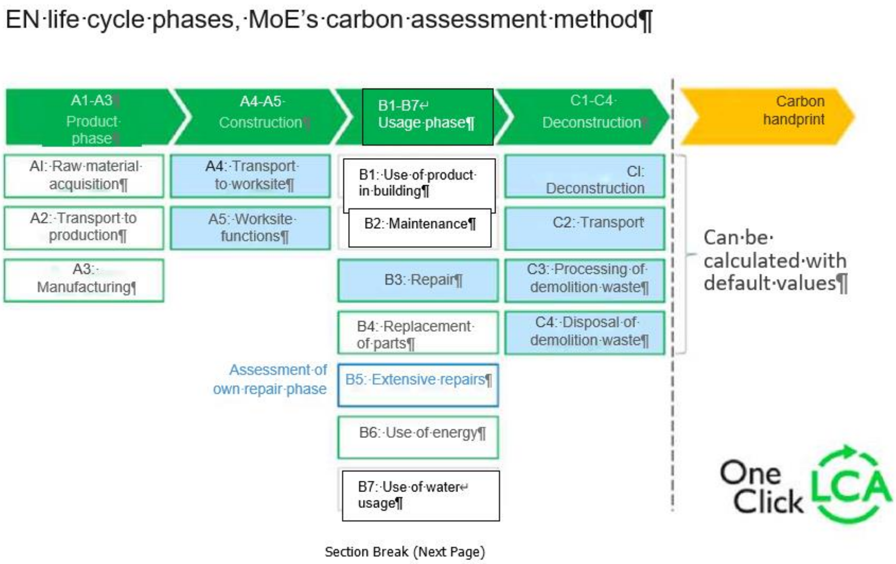
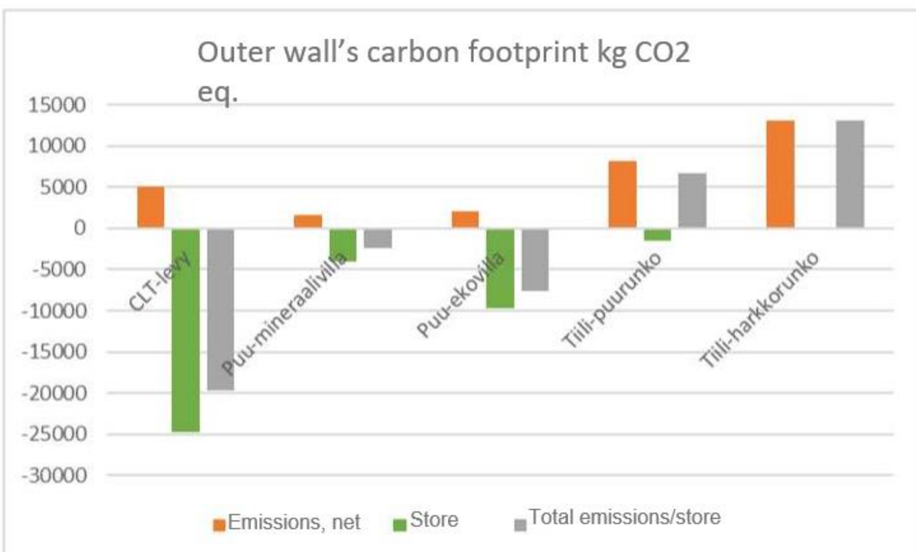


Fig. 26. Diagram of the phases of the One Click LCA software (workshop presentation, 6 February 2020)

8.4 CE Wood project's comparison study regarding the carbon footprint of wall structures

The analysis conducted under the CE Wood project compared the carbon footprints caused by a variety of outer wall structures. The impact of insulants was compared by calculating the effects of mineral wool and ecowool. (Palomäki, 2018)



CLT panel, Wood – mineral wool, Wood – ecowool, Brick – wood frame, Brick – block frame

Figure 27. Comparison of the carbon footprint of a CLT panel wall, wood-framed wall cladded with wood and insulated with mineral wool, wood wall insulated with ecowool, wood-framed wall cladded with brick, and block-framed wall with brick cladding.

The CLT walls and wood-framed walls with wood cladding resulted in the lowest emissions. The use of timber and solid wood in construction generates less emissions compared to other materials. The carbon store impact of the ecowool insulation is significant in terms of the total carbon footprint. Generally speaking, wood materials serving as carbon stores in wooden walls (carbon handprint) generates a significant carbon sink.

8.5 A comparative study of the carbon footprint and energy consumption of a wooden and concrete school.

Within the scope of the CE Wood project, a comparison of the carbon footprint and energy consumption of a wooden school and a concrete school was conducted as part of the Purkuko research project commissioned by the Ministry of the Environment from Tampere University, using Bionova Oy's One Click LCA calculation method (Huuhka et al., 2021). The carbon footprint calculation covered all life cycle phases: product phase, construction, utilisation phase and end of life cycle. The actual carbon footprint calculation was conducted using an analysis period of 50 years. The calculation takes into account in-service energy consumption as well as the carbon footprint (kgCO_2e) of materials used throughout the analysis period. The material emission details were selected from emission databases to correspond as well as possible with solutions commonly used in Finland. (Moisio and Huuhka, 2021)

The model for the school buildings included in the case study was the new building constructed for Tesoma School in Tampere. For the purposes of the calculation, two separate school buildings were formed based on Tesoma School's geometry: a large version and a smaller version for calculation. The structural types of both cases were adjusted to match typical and commonly-used structures.

The concrete school structures are from the existing Tesoma School building. The structures of the wooden school were selected in cooperation with CLT Finland Oy's experts from among the CLT structure types implemented by the company. For the wooden school, the structural types were changed to wooden structures only to the extent that this was justified and possible without modifying the original plan. The load-bearing structures, such as the exterior wall, columns, beams, intermediate floors and roof structures, were implemented as wooden, CLT or glulam structures. As regards partition walls, plasterboard partition walls were replaced with CLT walls containing a wooden structure. Other partition walls, such as concrete load-bearing stairwells, sand lime masoned wet room walls and load-bearing walls of exterior platforms, were kept intact.

The results of the carbon footprint calculation are formed by the itemised results of the energy calculation and the results of the life cycle carbon footprint calculation. The results also separate the carbon handprint, which in the comparison is formed by the reuse of materials and the organic carbon bound to construction materials. The energy efficiency (E-value) of the small wooden school is lower than that of the small concrete school. The wooden school's E-value and consumption of delivered energy are 5% and 8% higher, respectively, than for the concrete school. This is primarily due to the lower U-values of the wooden building's exterior walls. Despite the better energy efficiency, the total carbon footprint of the small concrete school over a 50-year analysis period is about 10% higher than of the wooden school.

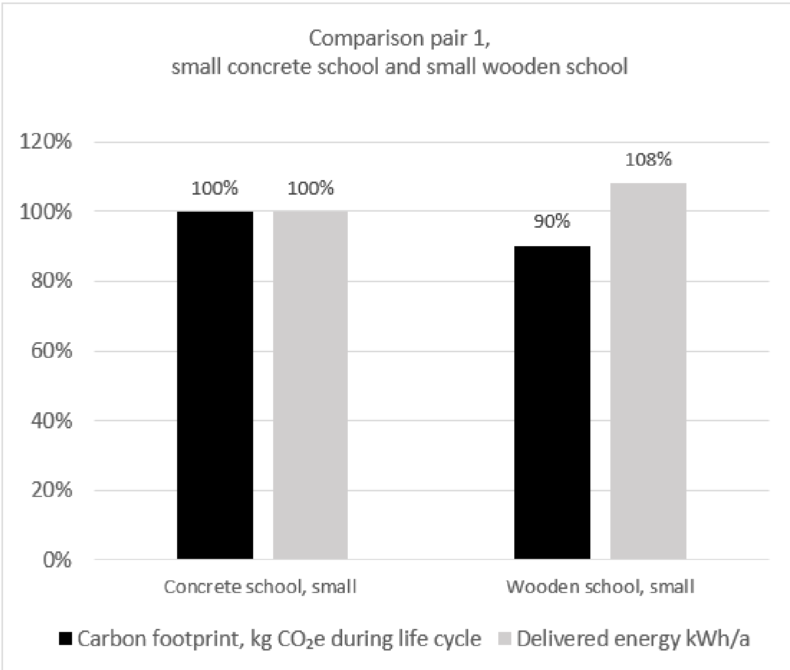


Figure 28. The total carbon footprint of the small concrete school over a 50-year analysis period is about 10% higher than of the wooden school.

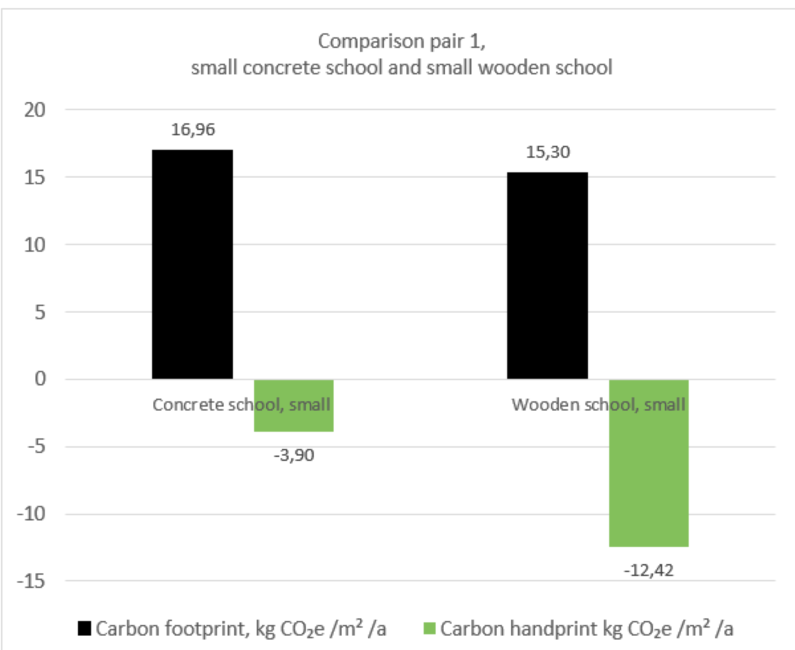


Figure 29. The small wooden school's carbon handprint is substantially larger than that of the small concrete school.

9. Regulation and legislation of sustainable development

9.1 Sitra's circular economy roadmap

Sitra published Finland's circular economy roadmap in 2016. The 'Leading the cycle – Finnish road map to a circular economy 2016–2025' roadmap details the steps towards sustainable success. According to Sitra's estimate, the circular economy would create 2–3 billion euros in added value by 2030. The Club of Rome estimates that it would create more than 75,000 new jobs. The national circular economy roadmap was created under the leadership of Sitra in cooperation with the Ministry of the Environment, Ministry of Agriculture and Forestry, Ministry of Economic Affairs, business sector representatives and other important interest groups.

The roadmap emphasises concrete measures from the perspective of growth, investments and export. The measures are divided into five groups based on Finland's existing strengths. The groups are 1) a sustainable food system, 2) forest-based loops, 3) technical loops, 4) transport and logistics, and 5) common actions.
'Leading the cycle' road map can be found at: https://media.sitra.fi/2017/02/28142644/Selvityksia121.pdf

In March 2019, Sitra released an updated 2.0 version of the circular economy roadmap. The 2.0 roadmap updated the solutions to a new level and specified the vision and strategic goals.

The transition to the circular economy requires strategic objectives that span through the entire society and that the roadmap presents. The map describes in detail the circular economy visions of various social sectors and lists the concrete measures to the promotion of which Finnish operators have committed to enable the change in the national economy. In addition to this, the roadmap presents necessary measures that are currently not in place.

1. Reforming the foundation of competitiveness and vitality: Our goal is to develop the economy in such a way that Finland shifts the focus to circular economy solutions in the context of competitiveness and economic growth strategies.
2. Transitioning to low-carbon energy: In the circular economy, energy will still be required to maintain our well-being. The energy must be produced sustainably and with low carbon emissions. It must also be possible to promote the efficient use of energy.
3. Regarding natural resources as a scarcity: The processing of natural resources and material and the manufacture of products cause a significant portion of global climate emissions.
4. Driving change through day-to-day decisions: The economy will not rise to the next level required by the circular economy unless we all make changes in our day-to-day choices. As much as 70% of Finland's climate emissions are related to housing, transport and food.

Businesses

Companies must change their operating methods and earnings models. A transition must be made from the old ways of making a profit to business models that are aligned with the circular economy. They will enable the more thorough utilisation of materials and deeper customer relationships – the circular economy is the basis for productive business. Business operations that comply with the principles of the circular economy can be divided into five business models: 1) renewability, 2) sharing platforms, 3) product as a service, 4) extending product life cycles, and 5) resource efficiency and recycling.

Administration and legislation

The circular economy must be integrated in the central government's structures. The circular economy is a phenomenon comparable with digitalisation, which requires an approach that crosses the boundaries between administrative branches and levels. Addressing the issues separate in an individual sector is not enough – all administrative branches must be committed to the circular economy.

The implementation of administrative guidance to promote the circular economy is still in its infancy and, thus far, legislation and steering have not been viewed as a single whole. In Finland, efforts have been made to remove the legislative obstacles to the circular economy, especially with regard to the construction industry. However, much work remains to be done in relation to utilising the waste materials of industrial facilities, for example.

As regards various industrial sectors, it is evident that there is legislation that hinders the circular economy and legislation that will further it upon implementation. For example, the construction product legislation requires CE-marked products to be used in certain parts of buildings. On the other hand, the EU-level goal is to ensure that 70% of construction and demolition waste is recycled by 2020. Products gained from decades-old buildings in the demolition phase are not CE-marked, which makes it more difficult to use them for construction purposes.

9.2 Ministry of the Environment's regulation of sustainable construction

In Finland, the energy efficiency of construction has been the clear focus of steering construction activities. In years to come, steering will be changed to ensure that any steering arrangements related to the built environment supports the EU's climate goals.

- The climate impacts of social structures guide zoning
- The energy requirements of new construction will be near zero
- The improvement of energy efficiency of the existing building stock will continue
- The land use and building legislation will be updated

In the future, the steering will be more widely focused on the entire life cycle of buildings. A transition to regulating the life cycle carbon footprint of buildings will be made in the context of new construction by 2025. In the first phase, an obligation to report may be implemented with regard to the carbon emission of buildlings, followed by limit values before 2025. (Kuittinen, 2019)

The Ministry of the Environment's website features a calculation method that can be used for the life cycle calculation of a building if a commercial calculation program is not available. The calculation program can be found at https://elinkaarilaskenta.fi/. Matti Kuittinen (2020) has steered the development of a carbon footprint calculation tool for buildings at the Ministry of the Environment. The tool can be used to assess both the carbon footprint and carbon handprint. The calculation's limit values apply to aboveground structures and building services, and the calculation uses a life cycle of 75 years and takes the building's climate impacts throughout its service life into account. The calculation makes a distinction between the carbon footprint and the carbon handprint, which refers to carbon stores and sinks, for example. More calculation methods will be made available later on: a simplified model using partial tabular values, a precise calculation model, and a calculation model for the carbon footprint of basic renovation. For example, 63% of the carbon footprint of a block of flats is attributable to energy consumption and 37% to other life cycle phases, of which construction supplies account for 26%. The rest is attributable to construction and repairs.

According to Kuittinen (2020), construction materials impact a building's carbon footprint, which is why the Ministry of the Environment is in the process of compiling a database on the typical emissions generated by the production of construction materials. This information can be used to calculate the carbon footprint, if manufacturer-specific product information cannot be obtained. Typically, the carbon footprint of wood materials is small, and wood also serves as a carbon store, which is taken into account in calculating the carbon handprint. Carbon handprint refers to the positive climate effects of housing and construction materials. In seeking to achieve carbon-neutral construction, the aim is to find a balance between the carbon footprint and carbon handprint. However, the term 'carbon-neutral' has not yet been specifically defined. The process of establishing a more specific definition is currently under way to enable comparing different types of buildings and construction projects.

Considering circular economy principles in construction

The Ministry of the Environment aims to promote the consideration of circular economy principles through the life cycles of buildings. Within the EU, the goal was to achieve a 70% recycling rate for construction materials by 2020. This goal has not been reached. In Europe, 50% of the building demolition materials are recycled on average. For Finland, the recycling rate is roughly 25–35%.

Key areas of recycling construction materials:

- The end of a building's life cycle: demolition and the utilisation of the demolition waste
- Design phase: flexibility, versatility, ways to demolish the building and ways to reuse the components
- Sharing economy

An obligation to report construction and demolition waste was already instituted in legislation in 2011, but the role of demolition will grow in years to come. Demolition will become more systematic and guided, and the recycling of materials will be considered better than before. Digital marketplaces have been developed to expedite recycling, including the materiaalitori.fi service by Motiva and the Ministry of the Environment, through which holders of waste must offer their demolition materials on market terms before they can request waste management services from the municipality based on a market gap.

Construction challenges in Finland and the EU:

- Qualification for recycled materials and components in new building materials and construction
- The supply and demand of materials
- Recycling, reuse and flexibility in the design of a new building
- Insufficient knowledge of building waste statistics on building stock materials

Reducing the environmental impact of construction plastics

9.3 CE Wood project workshop results on the use of circular economy solutions in construction

The CE Wood project organised a virtual workshop in September 2020. The workshop participants were asked to state the most important factors that promote the circular economy in the construction sector. The figure below shows the importance of the various recycling options from the perspective of the workshop participants.

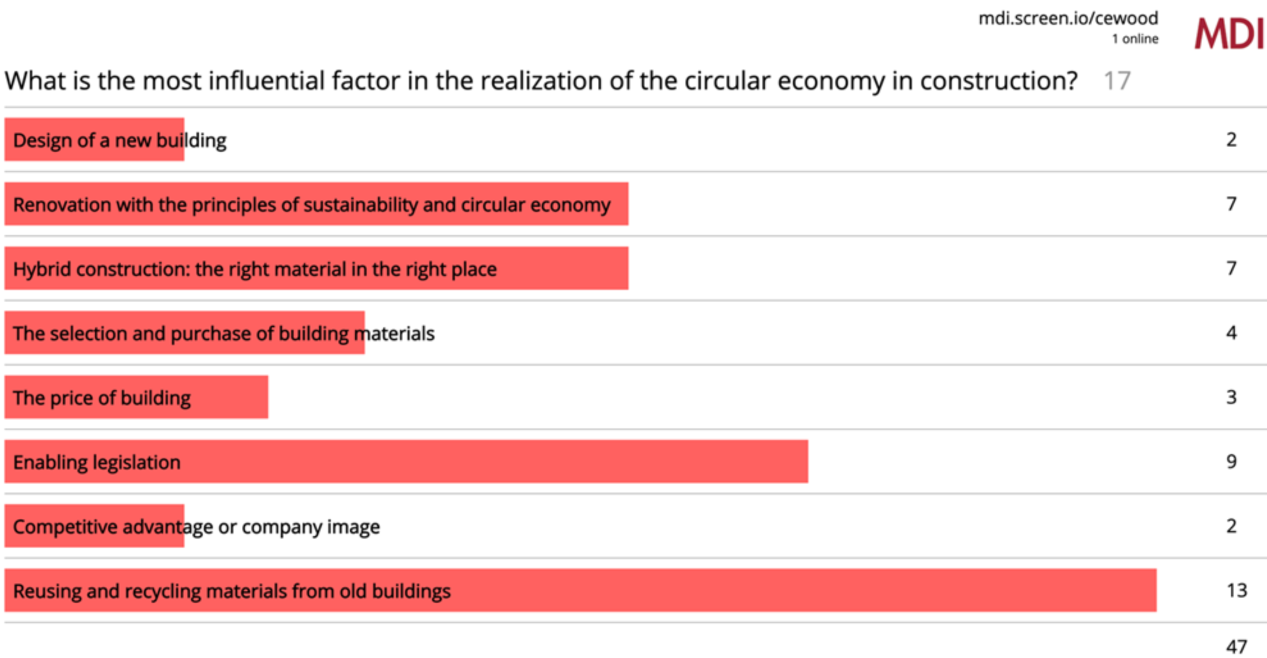


Fig 30. The workshop participants felt that the reuse and recycling of old construction materials is among the most impactful measures in promoting the circular economy in the construction sector. Favourable legislation was listed as the second most important factor.

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