Antti Sirkka & Valtteri Pirttinen (ed.)

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CLT – versatile, fast and ecological construction material

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Foreword

Since the beginning of the industrial revolution greenhouse gas emissions of humankind have contributed to the warming of the climate. Initially the change was slow but in the latter part of 1990s, the pace have accelerated. The change begin to show for instance in the rise of global average temperature. The ongoing global warming will continue in the next decades. Now the question is how much and how long the warming will continue. Climate warming largely depends on the amount of greenhouse gas emissions. By reducing the greenhouse gas emissions, global warming can be slowed down, but the impact of emissions limitations will only be visible until the end of this century. (Ilmasto-opas 2017)

Climate change and concern for the environment have increased the demand for the use of renewable resources worldwide. The requirements imposed on resource efficiency in construction, as well as low carbon content and recyclable properties in construction products have contributed to expediting the development of wood structure innovations. Wood as a renewable raw material has emerged on a global scale as one of the construction materials with the most potential. Reasons why we should be interested in wood building is presented on the figure below.

Figure 1. Why we should be interested in wood?

In Finland, wood construction has been the most common method for implementing the frames of small residential buildings. Due to the large market share of these small buildings, some estimates have even stated that there is not growth potential in the sector. In large-scale industrial construction, however, wood-based solutions have the potential to bolster their market position. Karjalainen, M. 2014)

Among solid wood structures suitable for multi-storey buildings and other fast building production, CLT (Cross Laminated Timber) has been adopted at the fastest rate. The product has been refined to serve as a load-bearing structure in buildings by gluing together solid wood layers in a crosswise pattern. Primarily, CLT is used to manufacture frame plates as prefabricated wall units that are machined to be ready for installation, including all detail work. For the most efficient housing production, CLT panels are assembled and prefabricated as modular units, complete with everything including the interior. CLT has rapidly become more commonplace even though new suitable methods are required for all phases of the implementation process from design to finishing. CLT panels are manufactured in the following countries, for example: Austria, Switzerland, Germany, UK, Sweden, Norway, Latvia, Finland, Spain, Canada and the United States. (Tolppanen, J.; Karjalainen, Markku; Lahtela, Tero & Viljakainen, M. 2013)

This collection of articles highlights the growth potential of CLT construction as an ecological alternative for the construction sector. The articles cover CLT as a construction material and from the perspectives of design efforts, worksite operations and environmental effects. Sustainable construction is also an argument closely linked to CLT element construction, which is important to be considered now and in the future. Finnish CLT operators and reference projects have been collected at the end of the work. This knowledge base is intended for distribution to all construction field operators who are interested in the possibilities of CLT as a construction material. Within the RDI activities of the Lapland UAS, a CLT training document has also been prepared, which includes slightly more technical information on the use of CLT.

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Tytti Ahoranta, Mikko Vatanen, Valtteri Pirttinen & Antti Sirkka – Lapland UAS

Future possibilities for CLT-project

This collection of articles was prepared within the scope of the Future possibilities for CLT (Nya möjligheter för CLT) project. The Future possibilities for CLT (FCLT) is implemented as a ERDF-funded Interreg Nord research project involving the Luleå University of Technology, SP Technical Research Institute of Sweden, Centria UAS, Digipolis Oy and Lapland UAS. The project was initiated in September 2015 and will continue until May 2018. The primary objective is to promote the diverse use of CLT and increase awareness of the possibilities provided by CLT construction in the Interreg Nord region. Figure 1 presents the roles of the operators involved in the FCLT project.

ORGANISATION	ROLE IN THE PROJECT
LTU (Luleå University of Technology)	> Coordination > Solutions for structural and joint design > Assembling a CLT innovation network > FEM simulations
SP (Technical Research Institute)	> Product testing > Use class analyses > Use of CLT in external structures
LAPLAND UAS	> Construction process > CLT in the design process > CLT in worksite operations > Highly efficient construction
Digipolis	> Decentralised CLT production model > Assembling a CLT innovation network
Centria UAS	> CLT surface treatment > Composite structures > Fast prototypes

Figure 1. Party roles in the FCLT project

The responsibility of the work package coordinated by the Lapland UAS is to generate information for the project and interest groups involved on the design and worksite processes of CLT construction, and on analyses regarding sustainable construction. The tasks encompassed by the work package analyse the current practices of the region's construction sector and create example CLT integration strategies in co-operation with pilot companies based on the existing knowledge base and current situation. In addition to this, the benefits of CLT are evaluated in efficiency reviews, which include various methods developed for assessing the environmental effects, for example. Based on the results, examples are presented on how various companies can integrate CLT construction in their own operations. Core idea of Lapland UAS work package is presented in figure 2.

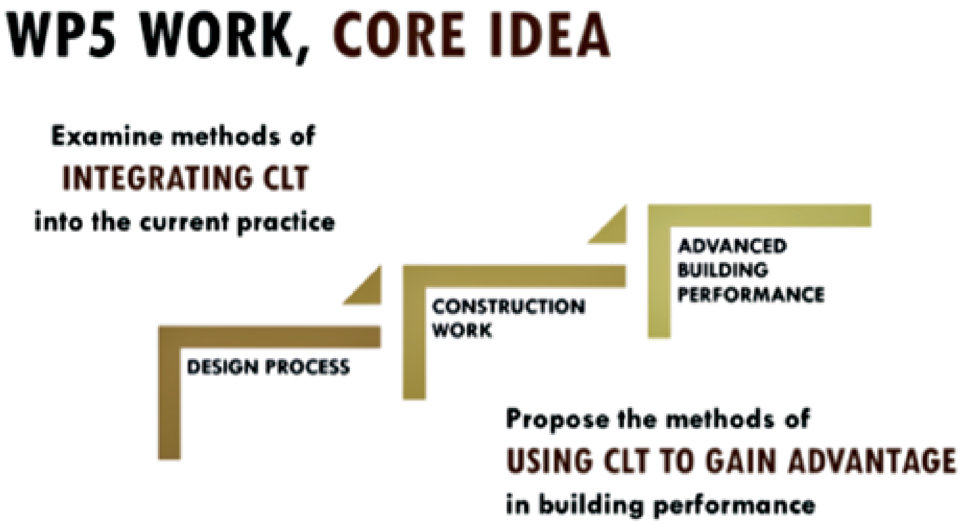

Figure 2. Core idea of Lapland UAS work package

The interview study conducted within the framework of the FCLT project in the autumn of 2016, provides an overview of the current state and future prospects of CLT construction. The goal of the interview study was to expand and supplement the previously collected knowledge base for the purpose of this publication. The study sought answers to the primary research question: *What kind of experiences have the various operators had with regard to CLT construction?* A total of 18 professionals working in CLT construction took part in the study. Based on the themes that emerged in the interview study, a collection of operating strategies was created, under the heading *Build using CLT*. Based on the study, we can conclude that CLT has a positive image and it is seen to have a great deal of potential to serve as an ecological alternative for future sustainable construction. Wood is seen as a valuable and aesthetically impressive material that has a positive effect on the quality of indoor environments. Active communication is required especially with regard to competence in the field and reference projects.

Studies related to CLT construction have also been previously conducted under a joint project between Digipolis Oy, Vocational College Lappia and Lapland University of Applied Sciences. Information on the special characteristics of solid wood element construction was received through the Lappia learning environment's R&D efforts, and follow-up studies of measurements related to building physics in a trial CLT building. Visits to production facilities, participation in domestic and foreign seminars and conferences, and study of written and visual material on CLT construction have also contributed to the process and provided additional information on solid wood element construction, which is rapidly gaining ground on global scale.

CLT is also rapidly entering the realm of log house production. Due to its non-settling properties, CLT log can be used to implement more and more demanding building projects, possibly even multi-storey buildings. As regards the integration of CLT to current construction methods, the existing methods available for the installation of wood-framed elements or large concrete elements can be applied. It is easier to obtain or use machines and lifting equipment that have been developed for these kinds of construction activities and used before in the field.

Antti Sirkka, Valtteri Pirttinen, Lapland UAS & Tytti Ahoranta, Digipolis

CLT as a construction material

PRODUCTION

MA solid wood CLT element consists of cross-glued layers of wood whose material thickness and number determine the strength and rigidity of the element (Figure 1). CLT panels are assembled from layers of timber, i.e. lamellas, between which formaldehyde-free adhesive is applied. In edge-glued CLT, the adhesive is also applied to the edges of the timber. After gluing, the panel is moved into a press, which joins the layers together. After pressing, the panels are machined as required by the element plans – e.g. corner and seam joints, window and door openings, and grooves and penetrations required by HPAC, electrical and buildings services installations. The size of the CLT panels may vary depending on the supplier, but usually the maximum dimensions are 12,000–16,000 mm in length, 2,900–3,500 mm in width and 300–400 mm in thickness. (Crosslam 2014) (Hoisko CLT Finland 2016) (Stora Enso 2013)

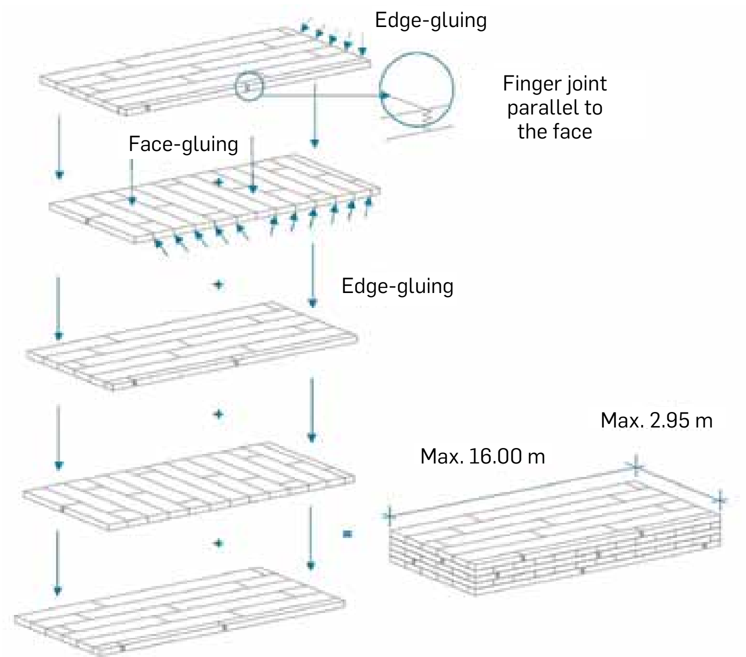

Figure 1. Structure of a five-layer CLT panel and finger joint (Stora Enso 2013)

CLT'S PROPERTIES

CLT panels are typically used as the buildings main loadbearing element. CLT is well-suited to the construction of buildings with more than six storeys and bridges, for example. Examples of various implementations can be found around the world. These examples are a testament to the versatile usability of the elements. Especially in mid-rise construction (e.g. 5 to 8 storeys), CLT's benefits include dimensional accuracy, easy handling during construction and a high level of prefabrication. This leads to significant time savings in worksite implementation and reduces the need for on-site storage space considerably. (Gagnon S, P. C. 2011.) The benefits of CLT construction are presented in Figure 2.

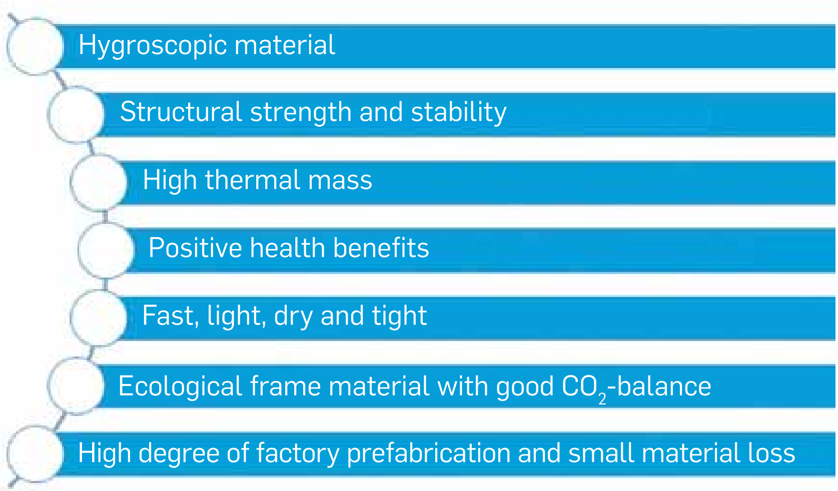

Figure 2. The benefits CLT construction (Crosslam 2014) (Hoisko CLT Finland 2016) (Stora Enso 2013)

CLT panels can be used to build all load-bearing structures above ground (walls, intermediate floors and roofs). In practice, the maximum span for intermediate floor structures is 6 m, due to the vibration dimensioning criteria applied in Finland. In roof structures, however, the span can be longer. CLT panels serve simultaneously as load-bearing and stiffening structures, which means that a separate stiffening structure is not required. Instead of CLT, a ribbed panel structure can also be used for horizontal elements. In addition to this, CLT elements can be used together with other construction materials to form hybrid structures (e.g. CLT-concrete, CLT-steel). (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

A CLT panel serves as a structural air and vapour barrier, which eliminates the need for a separate vapour barrier. The panel also insulates heat, meaning that a thinner layer of thermal insulation can be used than with other frame types.

With CLT, the load-bearing wood structure can be left visible or it can be covered. In most cases, however, fire regulations and technical factors related to sound necessitate protective cladding. On the grounds of functional fire design, the protective cladding can still sometimes be left out on a case-by-case basis, so that the quality of the CLT panel can be made suitable for exposed cladding. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

INDUSTRIAL WOOD CONSTRUCTION

The construction of wooden multi-storey buildings has made a clear transition towards industrial construction practices. Advanced industrial prefabrication and element structures are the shared characteristics of the currently available wood construction systems. (Figure 3). (Puuinfo 2015)

Figure 3. Ready-made wooden wall units (Lapwall 2016)

Wood and engineered wood products are well-suited to the industrial production of building components thanks to their dimensional accuracy, lightness, strength and easy workability. Due to their lightness, even large wood elements can be transported and lifted into place with truck-mounted cranes and stackers that are lighter than worksite cranes. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Industrial system construction differs in many ways from the conventional building practices from the perspectives of construction and design. The wood structure systems currently on the market are based on large components with a high degree of industrial prefabrication. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero; & Viljakainen, M. 2013.)

The new methods of industrial wood construction provide a variety of benefits over the current construction practices. Prefabricated elements can be installed quickly at the worksite – the process can take up to 50% less time than conventional implementations of a corresponding building. Additional time is saved thanks to simple jointing technology and dry construction conditions. Due to the shorter construction time, financing costs are also decreased, enabling an earlier start to the flow of rental income and a faster project cycle. The benefits of industrial wood construction are presented in Figure 4. (Tolppanen, J.;Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Fast installation of speed of prefabricated elements at the worksite	Consistent and documented quality of industrially manufactured components	Dimensional accuracy of factory-made components	Industrial construction increases the utilisation rate of materials
Opportunity to pay particular attention to joint tightness	Simple screw and bolt connections	Industrial construction alleviates labour shortage at worksites	Structures and the entire worksite can be protected against weather conditions until the building envelope is complete
	When construction is conducted in a location sheltered from the weather, work phases can be over-lapped more than usual	As regards work on the wooden frame, less time or no time at all is wasted on spent on waiting for the castings to dry	

Figure 4. Benefiots of industrial wood construction (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

CLT ELEMENT TECHNOLOGY

Figure 5. Small CLT element (Jalokivitalo 2016)

Among the element technologies currently in use, *CLT small element technology* involves the least prefabrication (Figure 5). Small CLT elements are CLT panels into which openings for windows and doors are cut at the factory, along with the necessary joints for attachment to adjacent elements. The width of small elements is usually 1,200 mm–16,000 mm (depending on the production line), and the height is 2,950 mm. Small elements are used for on-site construction, which means that features, such as insulation, windows and doors, are added to the frame elements at the worksite. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Prefabricated CLT wall units, are CLT panels that are manufactured to an installation-ready state at the factory (Figure 6). These units can be used in walls, base floors, top floors or balconies, for example. The elements are prefabricated according to the customer's needs, at times from the interior surface all the way to the exterior cladding. CLT wall units can be used in blocks of flats, public buildings or nursing homes, for example. Upon arrival at the worksite, the wall units are ready for installation. (Elementti Sampo 2017)

Figure 6. Prefabricated CLT wall unit (Stora Enso 2013)

In a CLT modular unit system, the elements are independent block structures with a high degree of factory prefabrication. At the worksite, the modular units can be connected together quickly, which shortens the worksite phase significantly compared to on-site construction, for example. Usually, all interior surfaces of the modular units are manufactured to completion at the factory. Windows, doors, fixtures and HPAC, electrical and building services installations are also normally included. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.) Figure 7 presents construction using CLT modular units.

Figure 7. CLT modular unit construction (Pinterest 2016)

It is beneficial for modular element construction for the production series of similar modules to be as large as possible, because the long series yield the highest financial benefits. Modular units are best suited for constructing housing units, residence halls and hotels with a large number of matching rooms and the number of varying modules needed to produce them is low. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Efficient use of modular units requires that the manufacturing dimensions of the elements are taken into account in the building layouts. Transport limitations must also be taken into account in the design of the modular elements. Special attention must be paid to rigidity during transport and installation, as well as the adequate weatherproofing of the elements. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

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Valtteri Pirttinen, Lapland UAS

CLT design process

INTRODUCTION

This article describes the design process of CLT construction. The interview study conducted under the Future possibilities for CLT project in 2016 collected information on CLT construction in Finland, with “CLT in the design process” as one of the themes. A total of five designers of CLT buildings were interviewed over the course of the study. Figure 1 presents the keyword cloud complied in conjunction with the interview study. The size of the words in the cloud was determined by their incidence in the interview material. The previously published interview study *Current state and future of CLT construction in Finland* presents the results of the study in more detail.

Figure 1. Keyword cloud on the theme of the interview study: CLT in the design process

DESIGN OF CLT BUILDINGS

General

From the perspective of design, using wood for the frame structure involves both unique freedoms and limitations, of which the designer should be aware. Instead of the frame material, the factors that affect the design of housing units the most are housing-related needs as well as aspects of the building that affect the cityscape. The system of choice must meet these in a reliable fashion. A system that imposes an excessive amount of technical or financial restrictions is not a feasible choice. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

The most important factors that affect the design of wood structure systems are as follows:

- Span lengths achieved with intermediate floors and the resulting need for load-bearing lines. In normal cases, the span lengths enabled by wood-framed intermediate floors cannot exceed 6–7 metres (Table 1).

Table 1. Maximum span lengths of the most common wood-framed intermediate floors (Tolppanen, J.;Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Intermediate floor type	Total thickness of intermediate floor [mm]	Span length [m]
Ribbed panel	450-500-550-600	5-6-7-8
The size	**400-450**	**5-6**
Wood-concrete composite	450-500-550-600	5-6-7-8

- Due to the span lengths, there are multiple load-bearing lines, as is the case with concrete buildings constructed from hollow-core slabs, for example.
- The structure thicknesses deviate from the norm. The separating walls and intermediate floors of a wooden housing unit with good sound insulation properties are thicker than their traditional concrete counterparts. On the other hand, the external wall structures of an energy efficient wooden building can be thinner than concrete structures with equivalent qualities in terms of energy efficiency.
- The type and placement of the load-bearing lines and the thicknesses of the structures affect the building's useful floor area and the room and/or floor height. In most cases, it is advisable to avoid placing load-bearing walls inside housing units due to fire design requirements and the principles of calculating useful area.

- When connecting wooden structures to concrete stairways and/or lift wells or brick facades, the possible differences in the structures' settling characteristics should be taken into account. The joints must be designed in such a way that they allow for the varying settling behaviours and elevations, and ensure that the components ultimately settle at the correct levels and meet the housing design guidelines' requirements on maximum threshold heights on access routes. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

CLT construction began in Europe some decades ago, and a variety of methods have been employed in the design process. Some of the calculation formulas used in the design are based on experimental tests, while some calculation methods are analytical. The other calculation methods include both experimental and analytical approaches based on model testing. In Europe, the most common theory used in the design of CLT structures is the theory of mechanically jointed beams, which can be found in Annex B of Eurocode 5: Design of timber structures. The theory presents the concept of effective bending stiffness and flexibility coefficient (γ_1), which is used to take account of the deflection of vertical layers due to shear stress. Value 1 of factor γ refers to a fully glued joint between the layers, whereas value 0 of factor γ refers to a joint with no attachment. The theory in question only provides a solution for the differential equation for sinusoidally loaded and simply supported beams/panels. However, the differences between an accurate solution and point loads or an evenly distributed load are minimal and acceptable in terms of engineer calculations. (Gagnon S, P. C. 2011.)

The websites of CLT panel manufacturers feature premade dimensioning cards and software for dimensioning CLT structures. For example, Stora Enso has released a free calculation service for the dimensioning of CLT structures. The dimensioning program can be found at https://calculatis.clt.info/, and it requires registration. The program can be used to dimensioning the following:

- Design of continuous beams
  - CLT panel, wood beam
  - Steel beam
  - Rib deck
  - Wood-concrete composite floor
  - Panel
- Pillar analyses
  - CLT panel
  - Wood beam
  - Steel beam
- Wall design
- Header analyses
- Miscellaneous analyses
  - Sequence analysis

- Rigid diaphragm analysis
- Load-bearing weight analysis (Stora Enso 2017)

In the software, the necessary data is entered for the design case in question, including the structure's dimensions, loads and service classes as well as other factors to be considered in the design process. The site also features a comprehensive manual that covers the use of the software. The results can be printed out from the software as a PDF file (Figure 2). (Stora Enso 2017)

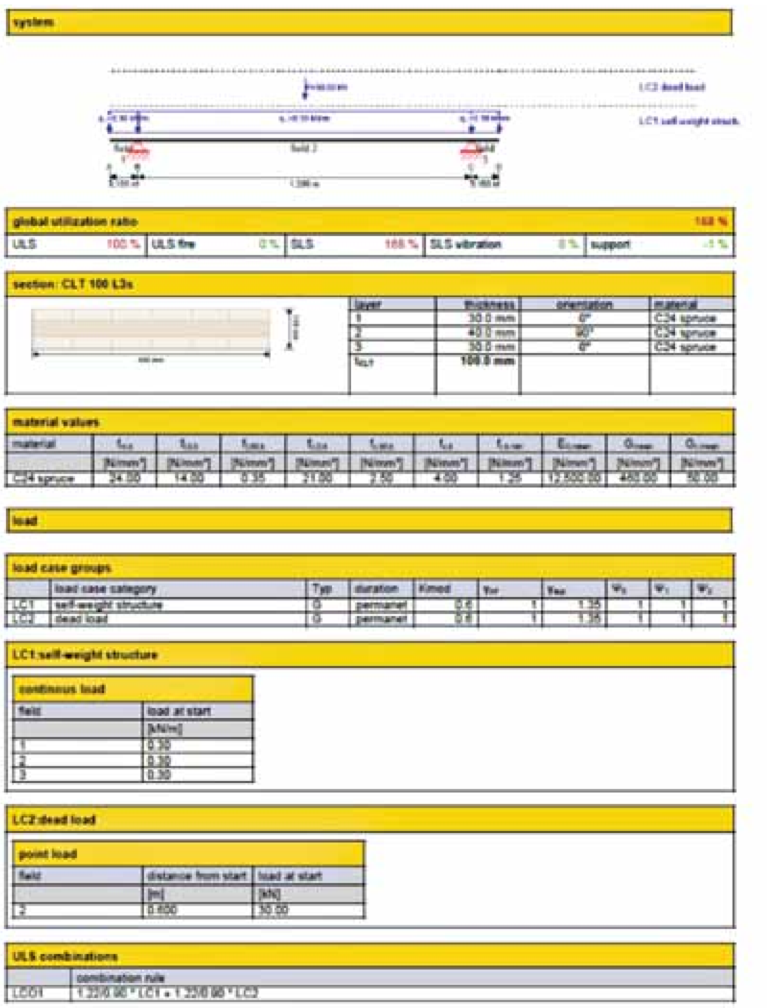


Figure 2. Example printout from Stora Enso's CLT-Calculatis software (Stora Enso 2017)

INFORMATION MODELLING AS PART OF CLT CONSTRUCTION

The term "information modelling" refers to the collection of life-cycle data on the building and construction process in digital format. The purpose of the model is to consolidate all the necessary information on the building into a single model. Each individual piece of information is recorded in the model to ensure availability to the entire design and implementation chain all the way to maintenance. Information modelling also enables the preparation of various analyses and simulations in early phases of the project. Among other things, the simulations and analyses can be used to ensure that the structures function appropriately and to compare the effects of the various solutions on the functionality of the building – e.g. energy analyses (Finnish Association of Civil Engineers 2017). Figure 3 presents the work flow of information modelling.

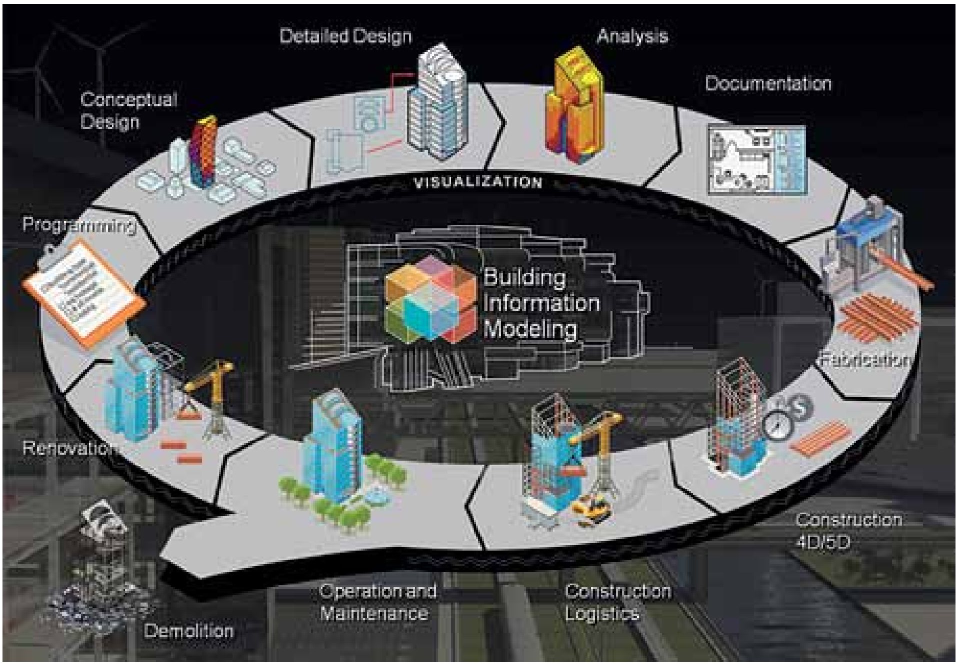


Figure 3. Overview of information modelling (Williams J. 2015)

In other words, a building information model (BIM) is a compilation of information covering the building's entire life span in the form of a single digital model. The IFC file format is used for transferring data in the context of the information modelling. IFC (Industry Foundation Classes) is an open manufacturer-independent file format, which enables the transfer of data on construction components between CAD programs (Figure 4). The design parties prepare their own information models using the IFC format, after which a combined model is created for the construction project. The combined model can be used to inspect the plans of the various parties through conflict analyses.

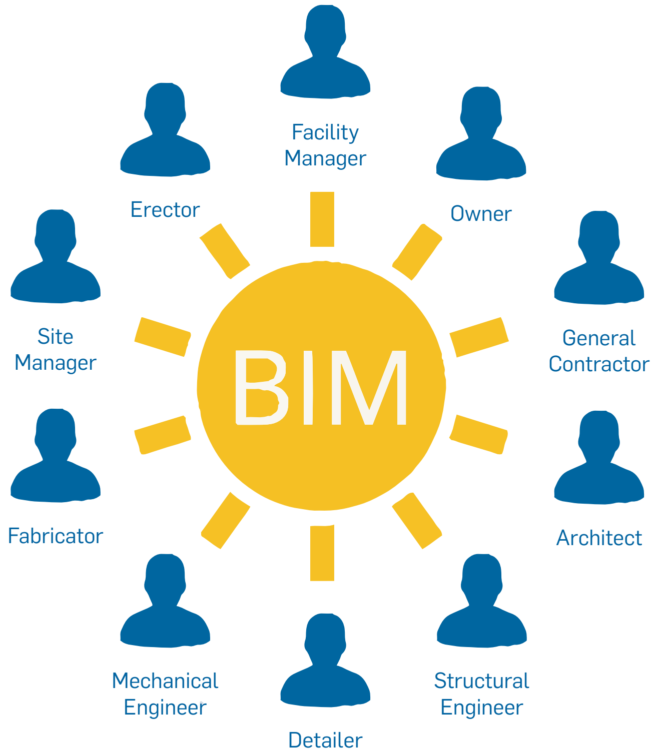
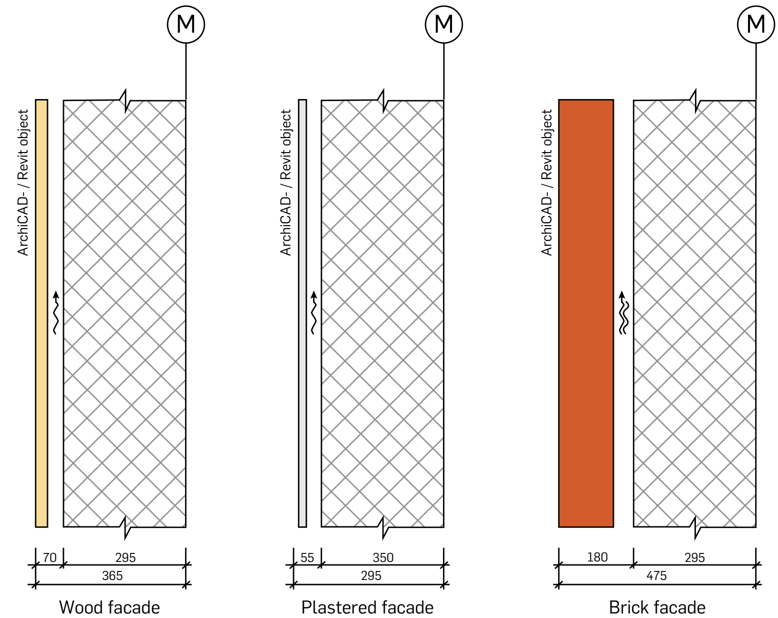


Figure 4. BIM work environment (Tekla 2017)

In short, the information model forms a shared knowledge base on which all plans are created. (Micro Aided Design 2013) (Tekla 2017)

As is the case with other materials, premade model libraries, which can be used for BIM-based design, are available for CLT. In addition to this, an open standard for industrial wood element construction, RunkoPES, has been developed in Finland to harmonise the construction of housing units using wood elements. The RunkoPES design principles are suitable for various kinds of buildings from single family houses to multi-storey buildings, regardless of their purpose of use, in accordance with the effective building codes. Among other things, RunkoPES standardises structural thicknesses, joint geometry and the location of the modular grids, which the head designers can use to formulate the frame of the building in the early design stages without the need to involve the element supplier. The full scope of the RunkoPES standard can be found on the Puuinfo website, where you can also download a structural object library for fire class P2 wooden residential multi-storey buildings, usable in ArchiCAD and Revit software (Figure 5). (Puuinfo 2012)

LOAD-BEARING OR NON-LOAD-BEARING EXTERIOR WALL
Fire design 3...4 floor / max 4 wood floors U



Facade type	Name of structure in object list
Wood	US4P4U17_365P
Plaster	US4P4U17_350R
Brick 130 mm	US4P4U17_475T

Figure 5. Example structural object RunkoPES: Load-bearing or non-load-bearing exterior wall (Puuinfo 2013)

A special benefit of information modelling for CLT is the ability to transfer the information to the machining equipment. The machining information required by a CLT element (e.g. window openings) can be transferred directly from the model to the machining tool's software. Figure 6 presents a CLT element flow chart from the designer's desk to the machining tool, as prepared by Project Manager Matti Yliniemi, who works for the CLT learning environment of the Lappia Vocational College.

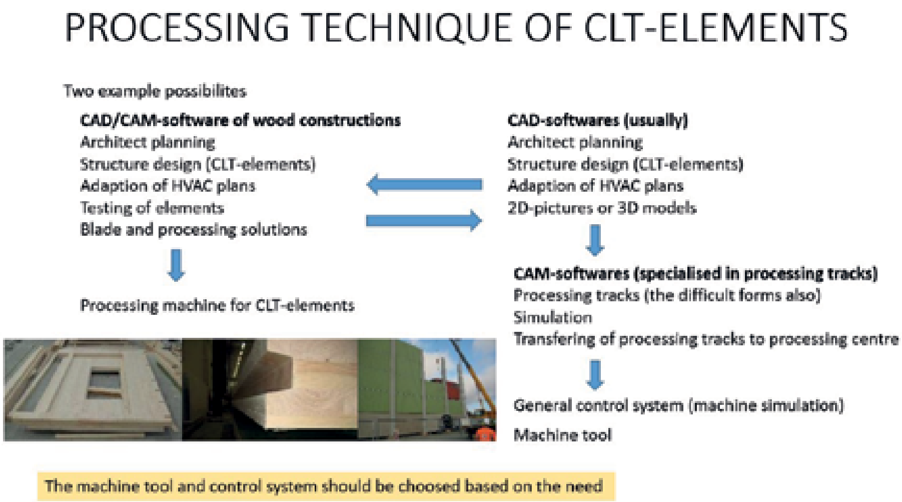


Figure 6. Machining methods of CLT elements (Yliniemi M. 2015)

FIRE DESIGN OF BUILDINGS

Fire regulations

Part E1 of the National Building Code of Finland was updated on 15 April 2011. The updates enable the construction of class P2 wood-framed and wood-cladded multi-storey buildings according to tabular dimensioning all the way up to eight storeys. A new addition to the building code are townhouses, which are buildings with 3–4 floors, all of which are part of the same housing unit. These buildings are subject to the regulations applicable to class P2 wooden multi-storey buildings, with the exception of the requirement to have an automatic extinguishing system. The updated fire regulations enable the use of D-s2, d2 – class wood solutions in the facades of class P2 stone multi-storey buildings with up to four floors – with due consideration to the requirements imposed in Part E1 of the National Building Code, this also applies to buildings with up to eight floors if an automatic extinguishing system is included. Concrete multi-storey buildings with up to seven floors can be expanded with an additional wood-framed floor featuring a wood facade without the inclusion of an automatic extinguishing system. Class D-s2, d2 wood materials can be used in the load-bearing structures, interior surfaces and facade cladding. Interior surfaces must be protected with class K2 protective covering. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Requirements of fire regulations for class P2 wood-framed multi-storey buildings:

- Wooden multi-storey buildings with more than 2 floors must equipped with an automatic water extinguishing system.
- Residential buildings with more than 3–4 floors must be equipped with an automatic extinguishing system that is in line with at least class 2 of standard SFS-5980.
- Residential buildings with 5–8 floors must be equipped at least
- in accordance with the requirements of class OH of standard SFS-EN 12845. The extinguishing systems of residential buildings must also be equipped with a secure water source.
- Residential buildings with 3–4 floors must also be equipped with class OH automatic extinguishing system, if the interior surfaces of the wood-framed building are intended to have wood cladding.
- The automatic extinguishing system of a class P2 employment building with 3–8 floors must also comply with the requirements of class OH.
- Buildings with 3–4 floors may not exceed an eave height of 14 metres – the corresponding limit for buildings with 5–8 floors is 36 metres.
- The classification requirement for load-bearing structures is 60 minutes (R 60).
- The classification requirement for the tightness and insulation of partitioning structures is 60 minutes (EI 60).
- The classification requirement for balconies and load-bearing structures is 30 minutes (R 30), and the partitioning requirement for balcony slabs is 30 minutes (EI 30).
- The load-bearing structures of the basement floor must be constructed from at least class A2-s1, d0 materials.
- The insulants and other fillers used in the building must meet the requirements of class A2-s1, d0, at minimum.
- More detailed information on the classification requirements for interior surfaces and protective cladding can be found in Part E1 of the National Building Code. (Tolppanen, J.; Karjalainen Markku; Lahtela Tero & Viljakainen, M. 2013.)

Preliminary information suggests that the requirements placed on constructors of wooden multi-storey buildings will be relaxed in the updated fire safety decree (E1) to be published in 2017. By virtue of the new decree, it will be easier than before to leave wooden surfaces exposed. The new decree will enter into force at the beginning of 2018. (Lehtinen T. 2016)

Functional fire design

Functional fire design based on expected fire development is a design method that ensures the fire safety of a building and has been approved in national and European regulations. Functional fire design takes into account *active and passive* fire protection methods as well as each building's individual properties, such as room height and geometry. Active fire protection measures include automatic extinguishing systems and smoke detectors, while structural protection solutions represent passive fire protection. (Puuinfo 2015)

Functional fire design determines realistic values for factors affecting fire safety in each specific location. These values can be used to form a truthful view of possible events during a fire, taking into account the effects of various factors on the safety of people and structures. (Puuinfo 2015)

Structural fire design can achieve a level of safety that is at least equal to that reached with tabular dimensioning based on Part E1 of the National Building Code. Among other things, the general rules based on tabular dimensioning limit the use of wood in load-bearing structures and visible surfaces (interior wools and ceilings). (Puuinfo 2015) Figure 7 presents the approaches to demonstrating the fulfilment of fire requirements.

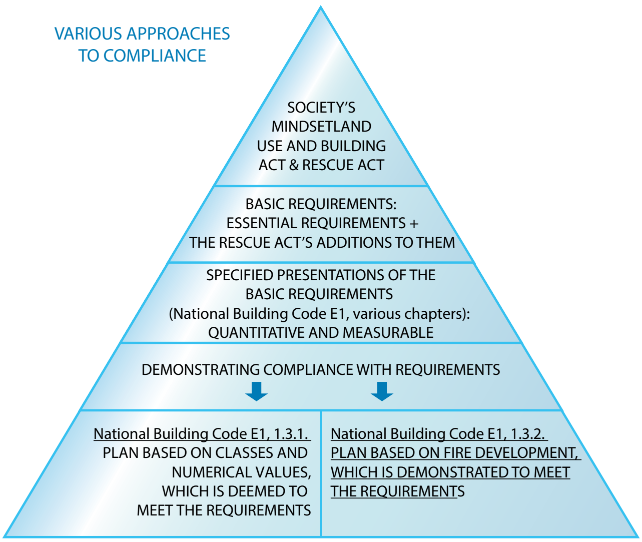


Figure 7. Approaches to demonstrating compliance with the fire requirements (Puuinfo 2015)

Section 1.3 of the Part E1 of the National Building Code of Finland states that the fire safety requirement is deemed to be satisfied if the building is designed by applying the fire classes and numerical criteria presented in Part E1 or, alternatively, if the building is designed and executed based on design fire scenarios. When planning a project on the basis of tabular values, all properties cannot be taken into account. As a result, tabular design is sometimes cumbersome and is not always well-suited to modern diverse construction activities. The method is sufficient for the fire design of houses, halls with standard design, and conventional multi-storey buildings. For diverse projects and wood structures in particular, functional fire design has proven to be an excellent method of design. For example, it enables the appropriate consideration of the operation and efficiency of automatic fire extinguishing equipment and the combined effect of the extinguishing equipment and smoke extraction. (Puuinfo 2015)

When using functional fire design, the values in the E part tables of the National Building Code are not observed. The dimensioning utilises the essential technical requirements of fire safety as its starting points. (Outinen J. 2009) Section 1.2 of Part E1 of the National Building Code presents the areas of the essential technical requirements for fire safety as follows:

- *"the load-bearing structures of the building shall sustain in case of fire for the imposed minimum duration of time;"*
- *"the generation and spread of fire and smoke in the building shall be limited;"*
- *"the spread of the fire to neighbouring buildings shall be limited;"*
- *"the occupants in a building shall be able to leave or be rescued by other means;"*
- *"the safety of rescue teams in building shall be taken into consideration."*

Functional fire design involves determining the probable threats and design fires of the building, creating a risk analysis and preparing a calculation analysis of temperature development, smoke formation and evacuation safety. (Puuinfo 2015)

The functional fire design of structures must be planned in co-operation by the various design parties. Collaboration is required particularly between the structural engineer, fire technical engineer and the construction and rescue authorities when the initial data is being determined (Outinen J. 2009). Figure 8 presents the design process of functional fire design, while Figure 9 presents software co-operation model developed in the Natural Fire Design project.

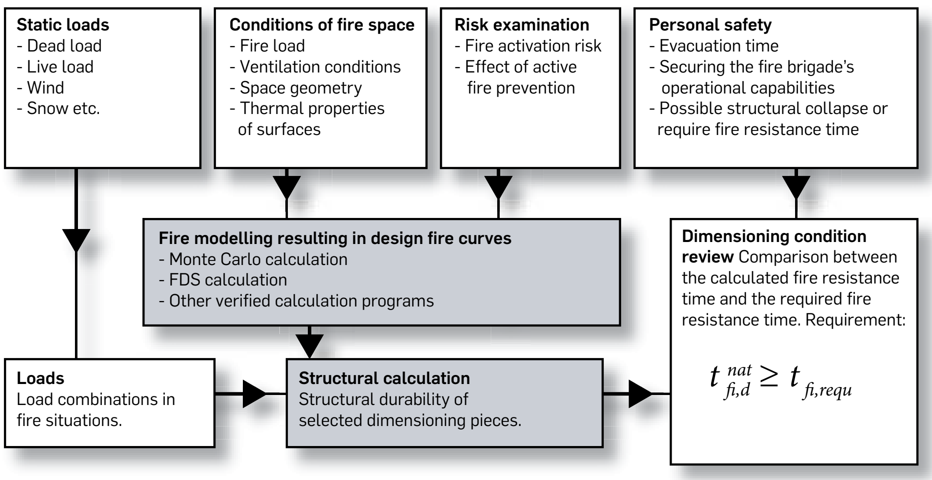
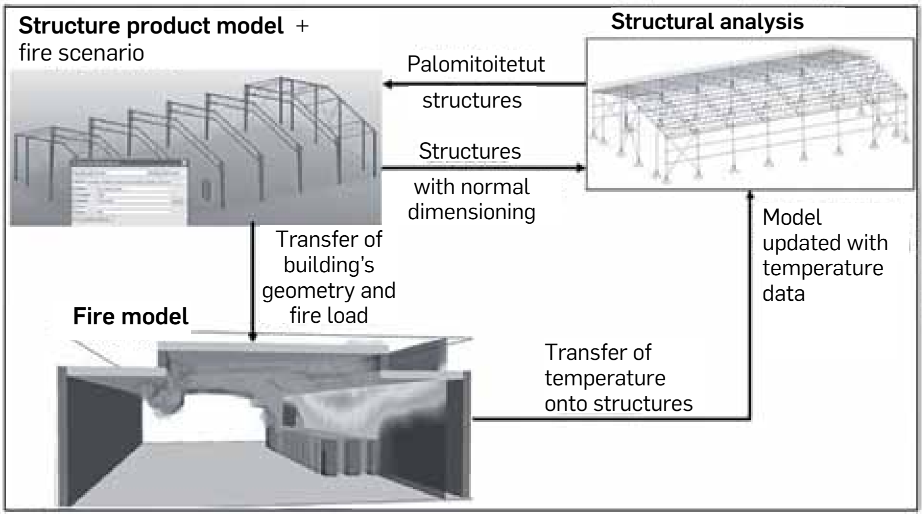


Figure 8. Flow of the functional fire design process (Outinen J. 2009)



Kuva 9. Natural Fire Design- projektissa kehitetty ohjelmistojen yhteistoimintamalli (Outinen J. 2009)

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CLT worksite operations

INTRODUCTION

TThis articles covers worksite operations in CLT construction. The article describes the special characteristics of CLT construction and presents the most common operating methods. The interview study conducted under the Future possibilities for CLT project in 2016 collected information about worksite operations and interviewed a total of 6 contractors with experience in involvement with the implementation of CLT-framed buildings. The interview study served to bolster prior views of CLT construction. The method was deemed to be very similar to other element-based construction systems, and ensuring sufficient weatherproofing was highlighted as the most important aspect to consider in construction. A keyword cloud created based on theme 4 “Observations based on the construction phase” Interview study is presented in Figure 1.

Figure 1. Keyword cloud on the interview study theme “Observations based on the construction phase”

The site layout plan is a written presentation of the placement of worksite operations in the construction location. In element construction, it is particularly important that the movement of element transport equipment in the worksite area is arranged to be as smooth as possible. In addition to this, the element storage locations and lifting equipment must be taken into account. (Building Information Foundation 2007)

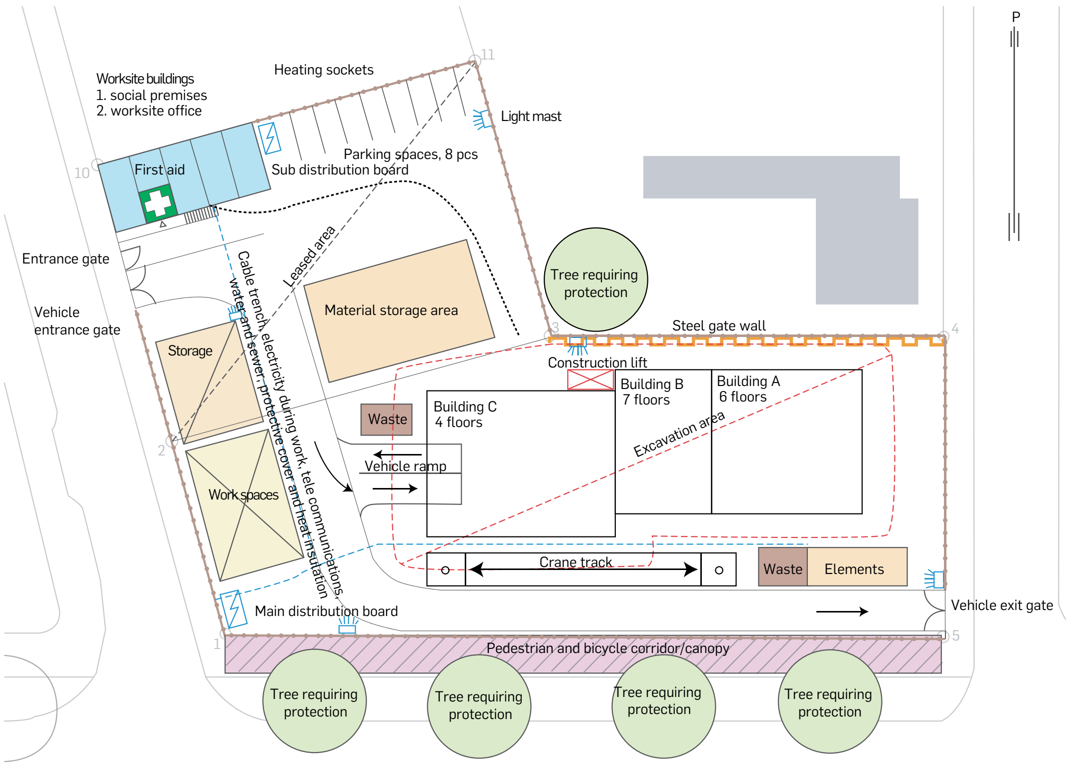

Figure 2. Example of a site layout plan in the framework construction phase. (Building Information Foundation 2007)

Before installation, it is important to ensure that the CLT load and the crane can be driven to the site without any hindrances (roads, on-site paths, sufficient vertical and horizontal space, load-bearing capacity of bridges, overhead cables). The official permits for possible special transport arrangements must be applied for beforehand to ensure timely delivery to the worksite. The order for the CLT panels must list the loading order and account for the worksite scheduling. A single load can be have a maximum of 50 m^3/25 t of CLT panels. The panels are stored either vertically or horizontally at the factory, and the aim is to take the installation order into account in the loading phase. During transport, the panels are usually stacked horizontally in such a way that a sufficient number of wood blocks is placed under the bottom layer and the subsequent layers are placed directly on top of the previous ones. When transporting the panels over short distances, they can also be placed vertically with the appropriate supports. If the CLT panels are not installed into place directly off the lifting equipment, they are placed in intermediate storage and protected in accordance with the supplier's instructions. The CLT panels must be protected against rain with plastic sheets or tarpaulins during transport and installation as well as after installation before the protective exterior walls and top floor structures are in place. A screw-fastened hoist is commonly used for lifting. Two lifting points are normally used to lift wall elements, while four lifting points are used to lift floor, intermediate floor and top floor elements. CLT elements must be visually inspected in conjunction with installation or intermediate storage, especially with regard to surfaces that will remain visible. Water-induced discolouration and other visual blemishes should be avoided in elements that will remain visible. The technical properties of CLT elements do not suffer from short-term exposure to water. (Helamo, M. 2014) (Stora Enso 2013)

LIFTING OF ELEMENTS

In construction, CLT is a relatively new type of solid wood structure. So far, little experience has been accumulated with regard to the design and implementation of CLT structures, and their functionality as load-bearing structures in a building envelope. For this reason, there is also relatively little technical documentation available on the erection of large CLT structures. There are some similarities between concrete element construction based on sizeable concrete panels and the current CLT construction techniques. Since the methods and tools of concrete element construction have been developed over a long period of time, it is currently easier to use them. (Gagnon S, P. C. 2011)

Usually, CLT panels are lifted off the transport platform directly into place in the building. The worksite must have sufficient space for the preparatory work before the installation of the CLT panels – e.g. sorting the panels into the correct lifting order. The installation of frame elements with no prefabrication or cuts is rare. In Finland, the most common practice is to prepare the CLT elements as either prefabricated wall units or modular units at the factory and install them directly into the building off the transport platform without intermediate storage at the worksite. (Gagnon S, P. C. 2011)

The base of the storage location must be sufficiently even and firm. A sufficient quantity of wood blocks should be reserved for placement under the materials that require storage. There must be enough space next to the foundation for the vehicle carrying the elements and the crane used for lifting, taking into account the boom length and lifting capacity. When unloading the elements, special attention must be paid to maintaining the balance of the load. Vertically positions CLT panels must be prevented from falling. Unloading elements in rainy and windy weather should be avoided. (Gagnon S, P. C. 2011)

The lifting method for complete CLT panels is always selected based on the panel type (vertical, horizontal) before the lifting required for the work phase. Disposable lifting equipment (screws, straps) can be used for the lifting work. A screw hoist system is most commonly used for lifting CLT panels. There are many lifting techniques based on counter-rotary fastening. Although these methods are simple and efficient, they require precise control during use. The benefit of this method is that it does not harm the wood surface when the intention is to leave it visible. (Gagnon S, P. C. 2011)

The method widely used in Europe is based on a screw hoist combination, which is used in concrete element production. The original method involves concrete-embedded anchors with protruding ends that enable attachment to the lifting ring. The hoist's roller latch is attached to the bases of the self-tapping screws fastened to the CLT panel. Self-tapping screws are recommended to be used only once. The lifting rings must be inspected regularly to ensure safety. The lifting equipment can be installed on the face or side of the panel. It is recommended to check the allowed loads from the manufacturer's technical information and the instructions for use and installation. (Gagnon S, P. C. 2011)

Figure 3. Screw hoist combination for CLT panels (Rothoblaas 2013)

If the element features large openings, special care must be taken during lifting to ensure that the top or bottom of the panel does not give out. If the section above or below the opening is very thin, it must be supported during the lifting with suitable wood pieces, for example. (Stora Enso 2013)

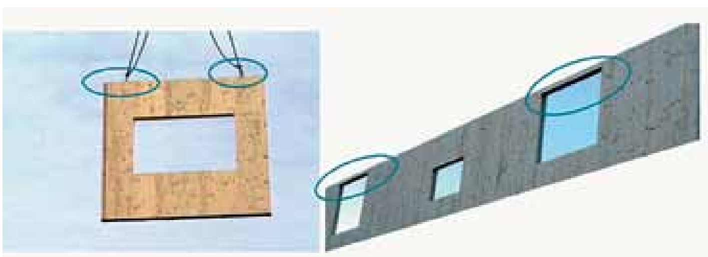

Figure 4. Taking lifting points into account. (Stora Enso 2013)

All lifting tasks, including the monitoring and inspections of the necessary equipment (crane and all lifting equipment), are the responsibility of the authorised lifting contractor. Occupational safety is the responsibility of all those working at the site (= obligation to provide information and warn others of hazardous situations). The lifting work must always be planned with care. The planning of the lifting process is related to the safety planning of the construction work, the planning of the worksite use and various task-specific plans, such as the element installation plan. The lifting plan is normally prepared under the guidance of the main implementer. The characteristics of the piece to be lifted, the lifting environment, the external conditions and the lifting equipment and tools must be taken into account in the planning of the lifting work. (Gagnon S, P. C. 2011)

The lifting points must always be inspected. Broken walls (e.g. fractures, knot holes or knots in the lifting positions) must not be hoisted under any circumstances. The worksite manager or installation supervisor checks the damaged lifting points and specifies the necessary changes. In most cases, it is enough to move the lifting point. Intermediate floor and top floor panels are usually lifted into place with a lifting screw, which is connected at four points, and a lifting hook attached to it. The angle between the lifting chains may never exceed 90°; which also applies when lifting wall panels correspondingly using two-point attachment. The lifting capacity is heavily dependent on the lifting angle (= screw loading direction), which is why the lifting screws are generally drilled into the wood parallel to the direction of the lifting chains. When lifting wall panels, it must be considered that the lifting screws should not be attached to the riser. Instead, they must be drilled into the CLT's horizontal layers. The capacity data for the lifting screws can be obtained from the manufacturer. For the lifting of top floor panels, the chain lengths must be adjusted to suit the roof pitch. (Stora Enso 2013)

Figure 5. Lifting of intermediate floor and top floor panels (Stora Enso 2013)

Figure 6. Lifting of modular units (Puuinfo 2017)

SEALING, ATTACHMENT AND SUPPORT

Jointing tape or jointing compound is recommended to be used in the joints of CLT panels. The tapes and compounds ensure tight structures. A wide variety of jointing products is currently available on the market. The products commonly used in CLT construction include EPDM rubber seals, expanding sealing strips, elastic polyurethane foam and elastic sealing compounds The most important purpose of the sealing products is to improve the airtightness of the structure, but they also contribute to thermal insulation, weatherproofing and sound insulation. (Illbruck 2016)

Retrofitted sealing with tape is also possible, but it may be time consuming, resulting in additional costs. However, construction joints are recommended to be taped in low-energy construction in order to ensure the airtightness. (X-lam alliance 2014)

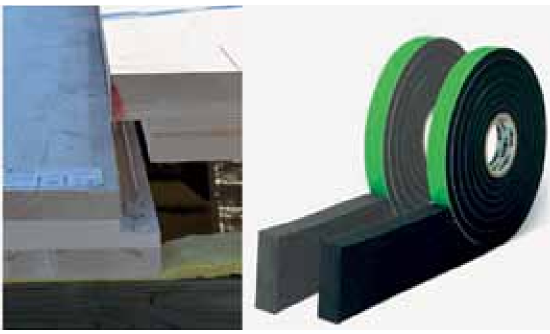

Figure 7. Sealing compound and expanding insulation tape. (Illbruck 2016)

Tongue and groove joint

Before connecting the CLT panels, it must be ensured that the joint is free of dirt and sawdust. The joint is fastened with wood screws and sealed appropriately (with sealing tape or adhesive compound). (Stora Enso 2013)

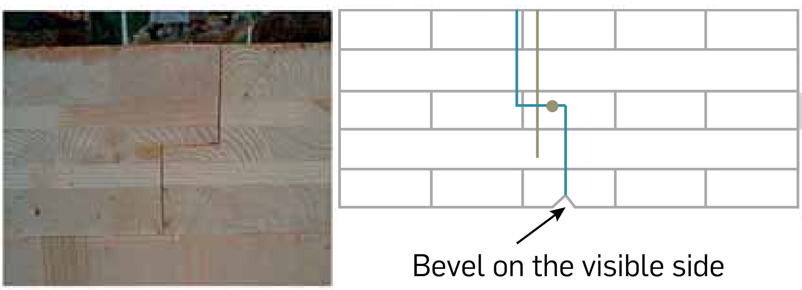

Figure8. Tongue and groove joint (Stora Enso 2013)

Board joint

The jointing board is fitted into place and screwed or nailed for attachment. The joint must be sealed with sealing tape. In order to prevent fitting errors, the panels are recommended to be attached to each other with fully threaded screws installed at an angle. Board joints can also be implemented with internal boards. (Stora Enso 2013)

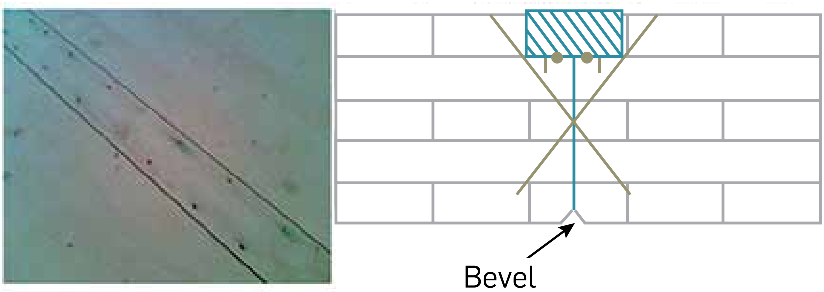

Figure 9. Board joint (Stora Enso 2013)

Butt joint

A butt joint does not include a tongue and groove fitting or similar jointing profile. The joint is made fully threaded screws installed at an angle, as with the board joint. Vertical wall corners are usually implemented with butt joints. (Stora Enso 2013)

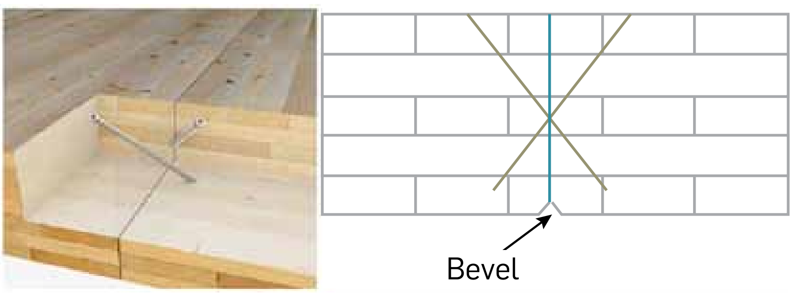

Figure 10. Butt joint. (Stora Enso 2013) (Naskali, J. 2015)

Screws and fasteners

Figures 11 and 12 present the most common attachment points, methods and screws in CLT construction.

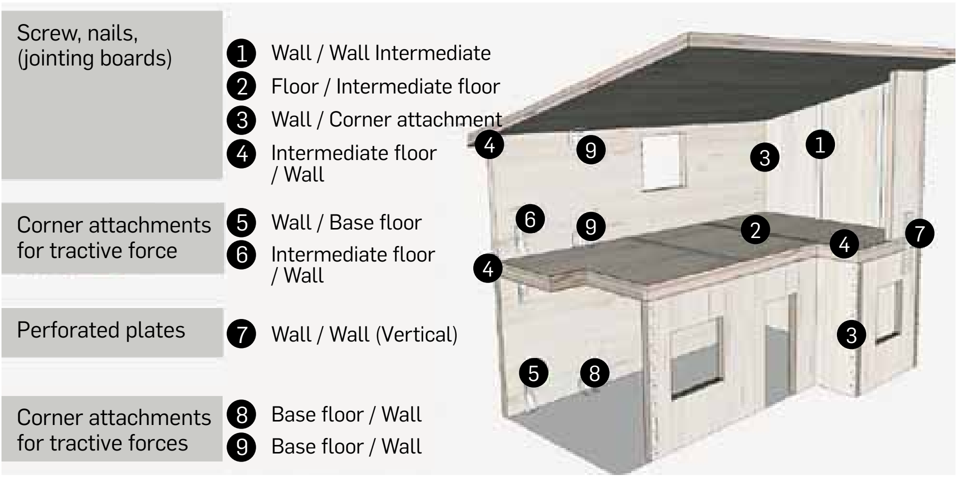

Figure 11. Illustration of joints in a CLT building (Naskali, J. 2015)

Figure 12. Screw joints with self-tapping wood structure screws (Naskali, J. 2015)

If jointing boards have been designed for the intermediate floor/top panels, it is important to ensure that the joints are flush. The intermediate floor must be checked from below. If necessary, the intermediate floor must be supported with suitable support solutions. Once the supports are in place, the panel joints are fastened with fully threaded screws installed at an angle at suitable intervals. The supports can then be removed. (Stora Enso 2013)

Figure 13. Installation of an intermediate floor element (Stora Enso 2013)

Support

Timber or adjustable element installation supports can be used for support purposes. In order to protect the visible surfaces, the supports are attached to the openings. To expedite the installation work, the supports can be attached to the panels before beginning element installation. The supports must be installed at suitable intervals to ensure sufficient support. The supports must not be removed before the other supporting and stiffening structures have been installed and fastened into place. (Stora Enso 2013)

Figure 14. Support examples. (Rothoblaas 2013) (Niemelä A. 2013)

MOISTURE CONTROL IN THE CONSTRUCTION PHASE

Moisture control in the construction phase must be implemented in accordance with the contractual terms in such a way that the end result meets the necessary requirements regarding use and maintenance. The aspects presented in the following figure are taken into account in the construction phase. (Ministry of the Environment 2015)

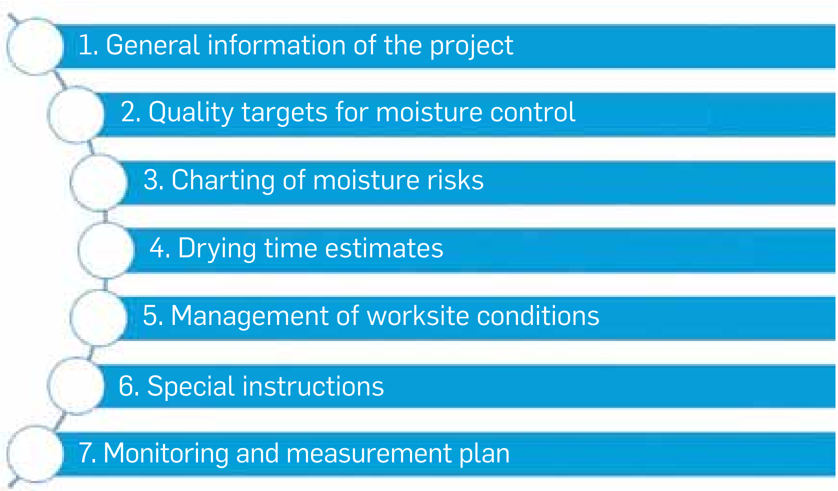

Figure 15. Content of the construction phase moisture control plan (RIL 2011)

The protection of the CLT panels against moisture must be carefully considered. According to the requirements placed on the product, the moisture content must not exceed 11% +- 2% for grades to be cladded (not visible q) and 9% +- 2% for grades that will remain visible as interior surfaces, for example (visible q) – the moisture content must remain largely constant throughout the construction process. The most important factors in moisture control are bringing the product to the worksite in accordance with the delivery schedule, minimising the time spent on construction and using temporary shelters during construction. As is the case with other wood products, CLT panels must always be protected against rain, snow and ground moisture. CLT panels are particularly sensitive to moisture damage due to the laminated structure and their capacity to absorb large quantities of water through the faces and the crosswise cut surfaces. (Gagnon S, P. C. 2011)

Figure 16. Weather protection (Ramirent Finland Oy 2017)

Compared to plywood and standard sawn timber, CLT is much more massive. If the panels get wet, they will take a long time to dry. For this reason, the moisture protection of the CLT panels must be a priority at the worksite. The applicable product standard requires a specific moisture content of CLT panels. According to the National Building Code, the moisture content may not exceed 19% (surface, core, edges) in any part of the panel structure before it is covered. It is also important to maintain a constant moisture level for the duration of the construction work as moisture expansion and shrinkage due to drying may damage the gluing and lead panel deformation. (Gagnon S, P. C. 2011)

In the construction phase, the CLT panels must be protected temporarily with a waterproof canopy, tarpaulin or other efficient method to prevent them from absorbing moisture from the environment before the roof of the building is complete. Temporary moisture protection can also be installed on the panels during the manufacturing phase, and it may not be removed during panel storage. The temporary protection should not be removed before the panels have been installed into the building and the roof is ready, or the panels have otherwise been permanently protected against moisture. In modular unit construction, movable roof elements are used to protect the block immediately after installation. (Gagnon S, P. C. 2011)

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Sustainable wood construction

INTRODUCTION

This article describes sustainable wood construction, particularly from the perspective of CLT. One of the themes in the interview study conducted under the Future possibilities for CLT project in 2016 was CLT as part of business strategy. Based on the study, we can conclude that CLT has a positive image and it is seen to have a great deal of potential to serve as an ecological alternative for future sustainable construction. Wooden surfaces are seen as valuable and aesthetically impressive enablers of high-quality indoor environment. One of the most important themes highlighted in the interview study was "Use the value of the material", which refers to emphasising specific aspects of CLT as a material in communications – e.g. its domestic origin, renewability and recyclability. A keyword cloud based on theme 6 of the interview study "CLT as part of business strategy" is presented in Figure 1.

Figure 1. Keyword cloud on the interview study theme "CLT as part of business strategy"

DEFINITION OF SUSTAINABLE CONSTRUCTION

Buildings consume 40% of the energy used in Finland, in addition to which 30% of emissions are attributable to buildings. Population growth, migration and increased standard of living will increase construction, which is why it is extremely important to ensure its sustainable implementation. Even in welfare states such as Finland, 16,000 new housing units a year are required to replace old ones to maintain the total number at the current level. The building stock is renewed at an annual rate of approximately 1%–1.5%, which means that repair construction and the use of properties are important themes in the context of sustainable construction. (Puuinfo 2014)

Social, ecological and financial aspects are always considered in sustainable construction (Figure 2). The purpose of sustainable construction is to produce buildings and structures with long service lives, high material efficiency and low energy consumption. However, mitigating climate change must not be the only goal – instead, the buildings must be constructed for people and use, which is why they must be safe, healthy, comfortable, modifiable, easy to maintain and value-retaining. (Puuinfo 2015)

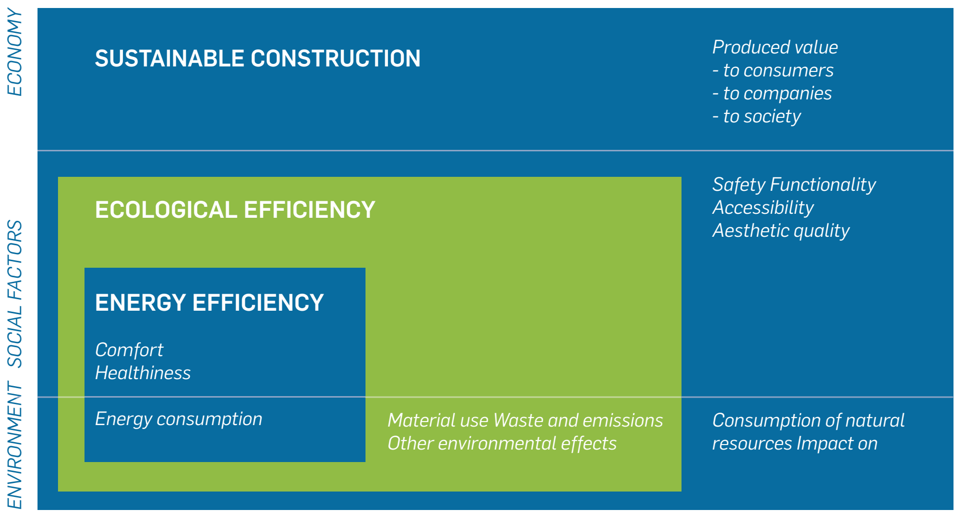

Figure 2. Sustainable construction. (Puuinfo 2015)

In sustainable construction, the environmental and cost-related effects are examined for the building's entire life span. The building life span presented in Figure 3 covers construction all the way from land use planning to the demolition of the building. (Puuinfo 2015)

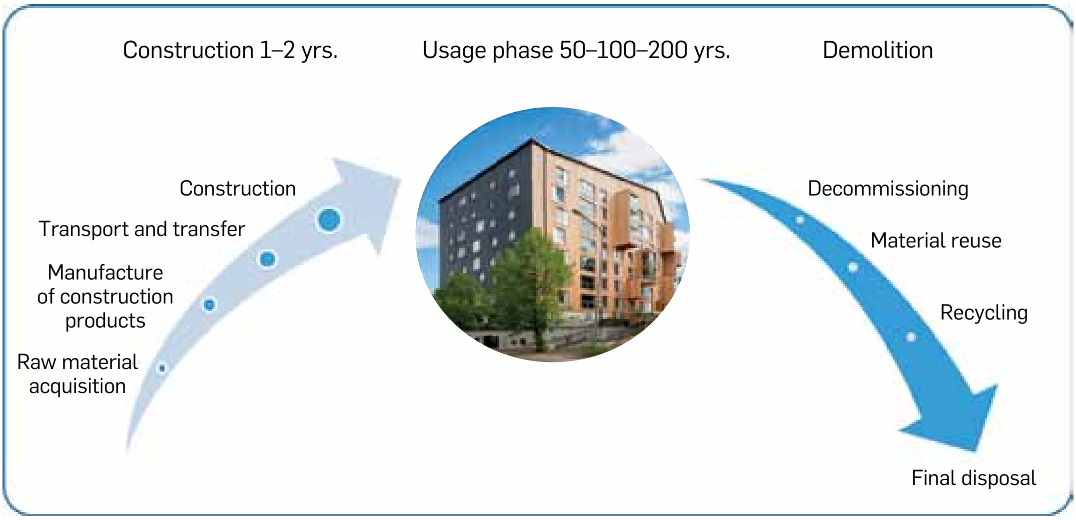

Figure 3. Building lifespan (Puuinfo 2015) (Puuinfo 2017)

The most important decision for the building's entire lifespan are made early on in the project, at which point the purpose of the building and the construction solution are determined (Figure 4). (Puuinfo 2015)

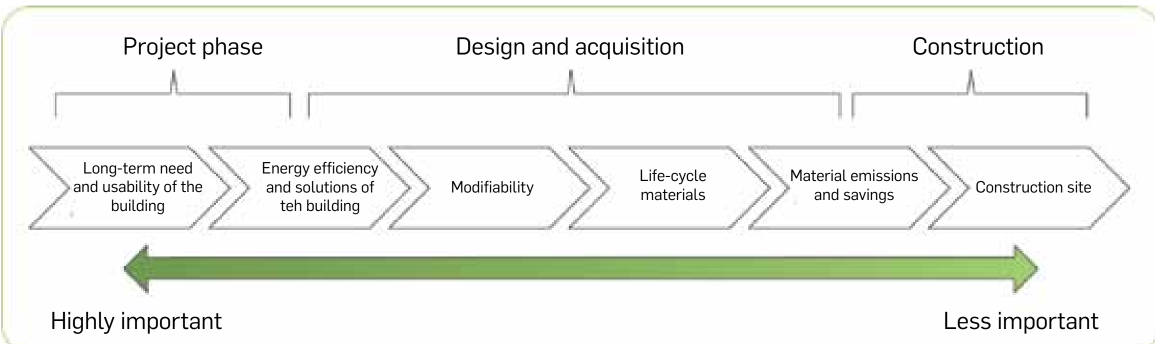

Figure 4. Impact of the construction phases on the life-cycle environmental effects (Puuinfo 2015)

A European standard, CEN/TC350, has been developed for the assessment of sustainable construction and environmental effects. The standard package has been created as a transparent assessment and calculation method for sustainable construction. As regards the CEN/TC350 standard family, the matters covered are the production of environmental data on construction products, which are required as initial data, and the assessment of life-cycle sustainable construction. In addition to the procedures for assessing environmental aspects, European assessment principles have also bee drawn up for social and economic sustainability. Standardised information is used as a basis for international and national environmental classification systems. On an international level, the most widely-spread environmental certification systems are the LEED system developed in the United States and the British BREEAM scheme, which is covered in greater detail in the article *CLT construction and environmental certifications*. In Finland, the Construction Products Industry association carries the responsibility for the field under CEN/TC 350 SFS, Green Building Council Finland has developed life-cycle metrics for the project and usage phases of buildings, and the Building Information Foundation published a Finnish RTS environmental classification system for buildings at the end of 2016. (Puuinfo 2015)

CLT – ECOLOGICAL ALTERNATIVE

The ecological qualities of CLT as a material were also brought to the fore in the interview study conducted in an earlier phase of the project. The study indicated that, due to CLT ecological qualities and small carbon footprint, the positive image of wood construction is seen as important for future competitiveness. Thanks to its environmental sustainability and increased domestic production, CLT is regarded as a structural alternative with significant potential for the future.

When constructing building components from wood, the carbon contained by the wood is stored in the structures, which then serve as long-term carbon repositories. A conventional Finnish single family house with a wooden frame, binds approximately 30 tonnes of airborne carbon dioxide in its structures. This amount of carbon dioxide is equal to the average driving emissions of a single consumer over a period of 10 years. (Construction Industry 2013)

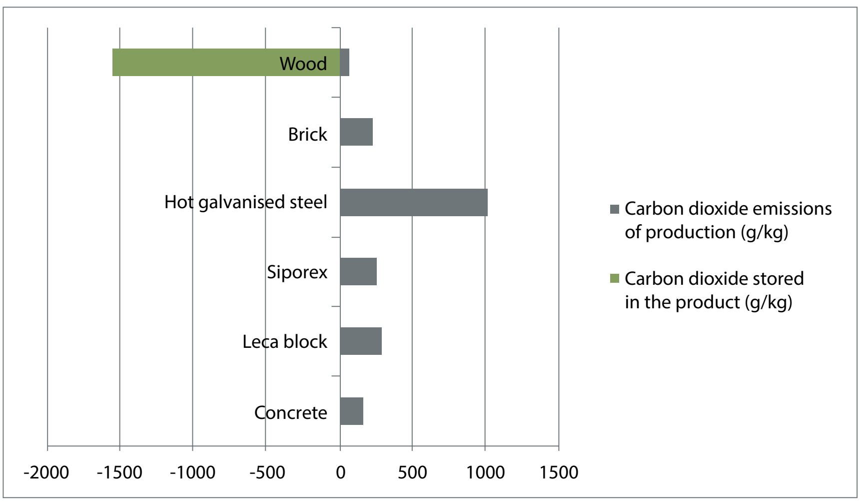

Figure 5. The carbon dioxide emissions caused by the manufacture of various construction materials (Construction Industry 2013)

The manufacture of wood products generates less carbon dioxide emissions, compared to the production of other construction materials. (Figure 5). (Construction Industry 2013)

The manufacture of wood products and structures consumes less energy compared to the manufacture of products and structures made from other materials. The majority of the energy used to make wood products comes from renewable energy sources. A significant portion of the required energy comes from the by-products, such as bark, gained in connection with the production (Figure 6). (Construction Industry 2013)

Figure 7 presents the life cycle of a wooden building and the utilisation opportunities in the demolishing phase. Wood products at the end of their life span can be recycled or used for energy production. (Puuinfo 2015)

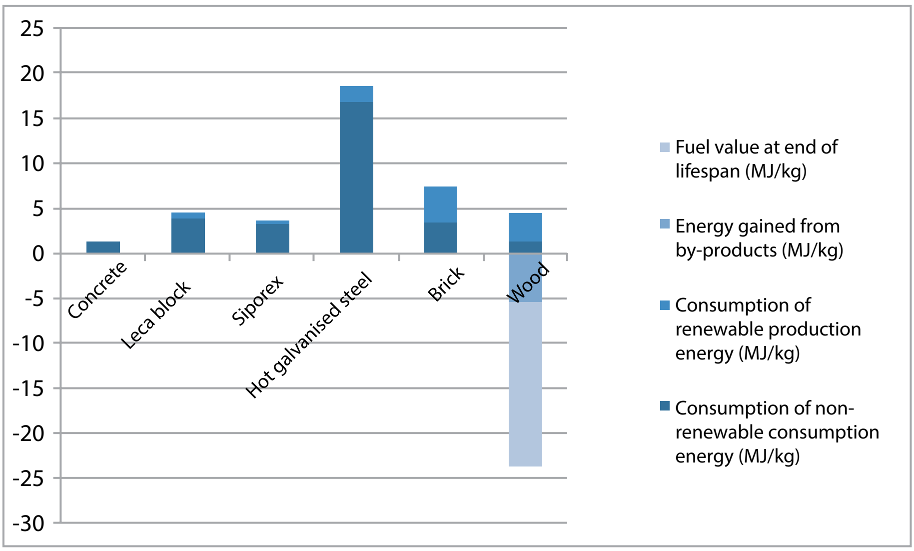

Figure 6. Energy consumption caused by the manufacture of various construction materials (Puuinfo 2015)

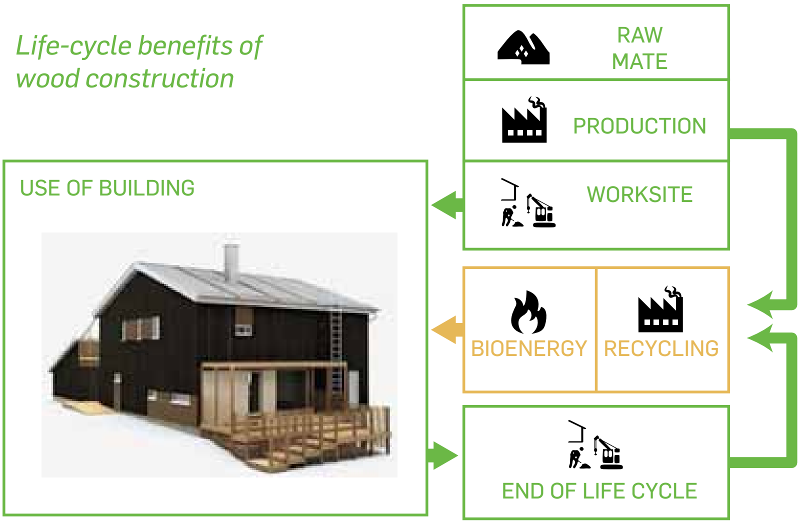

Figure 7. Life cycle of a wooden building (Puuinfo 2015)

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CLT construction and environmental certifications

International certification standards are being used more and more widely in the examination and assessment of ecological construction. How does the increasingly popular CLT construction fare in scoring based on the LEED and BREEAM systems?

NEED FOR ENVIRONMENTAL CERTIFICATIONS

Environmental management and life-cycle expertise is becoming one of the core areas of expertise in modern construction. Terms such as *sustainable construction, ecological construction* and, for example, *green construction* are used with increasing frequency in the context of construction projects. Even more terms are used to describe the energy efficiency of buildings: in EU Member States alone, there are more than 20 terms in common usage (Erhorn, H. & Erhorn-Kluttig, H. 2011). The varied definition practices obfuscate the matter, and even professionals in the field find it difficult to compare building efficiency based on the different methods in practice. Furthermore, it should be noted that key figures indicating energy efficiency, for example, are only one part of the actual environmental effects of a construction project. Environmental certification systems are tools that have been developed to meet this need. The certifications aim for reliable and transparent assessment of environmental effects that is eligible for generalisation and accounts for all of the important aspects of construction project. (Green Building Council Finland. 2015)

On the other hand, large numbers of certifications have been developed all over the world. The benefit of local certifications is that they can be used to easily account for regulations and standards applied in the area, for example. The weak point in local considerations is that it sometimes complicates international comparison. Among international certification systems, the LEED system developed in the United States and the British BREEAM system have gained substantially more popularity than their counterparts. Between the two, popularity is, at least at present, relatively equal, with LEED being clearly more popular in its native country, the United States, while BREEAM has a stronger foothold in European construction. The basic principles in both systems are very similar, but there are differences as well. The LEED system evaluates a construction project by awarding points to it based on categorised areas. In BREEAM, the evaluation method is the same, but there are some differences in terms of the content and weightings of the categories. (Triple E Consulting. 2014) Among the currently available methods, the voluntary certification systems are the most suitable for describing the environmental effects of construction projects, and the use of these systems is likely to become more commonplace in Finland, too, in the coming years. The challenge in applying the systems to Finnish construction is finding the appropriate practices to ensure operational fluency. For example, the international systems do not contain references to very many of the construction standards commonly used in Finland. In more detailed examination, however, it is often found that the standards applied by Finnish operators are at least as demanding as the equivalent foreign standards required by the certification systems. Still, early on in the process, each requirement must be compared individually. (Vierinen A-M. 2015)

In the future, it would be important to find ways to utilise as much of the existing information on construction projects in the certification process. There is already a wealth of good practices in Finnish construction, and their utilisation should be optimised. That said, the certification process has an impact on the implementation of a project, and rightly so. In order to achieve a good score, many decisions regarding environmental effects must be made during the implementation of a project. In practice, this will lead to a pursuit of a project-specific "cost optimum" – i.e. the investment that is required to reach a result that is as good as possible while still remaining cost efficient. The end results will hopefully be additions to our built environment that are of a higher quality than before and also more energy efficient and environmentally friendly.

BENEFITS OF CLT CONSTRUCTION IN THE LEED CERTIFICATION SYSTEM

CLT construction and wood construction in general are marked as low-carbon construction solutions. Wood as a construction material is a carbon sink, meaning that it binds carbon from atmospheric carbon dioxide up to an amount equal to half of its weight. This process releases the oxygen from the carbon dioxide back into the atmosphere, and the amount of stored carbon dioxide can be determined with the formula: *trapped CO_2 = 2x wood weight*. (Puuinfo Oy. 2010) Other possible benefits of wood construction are the low energy used for production and the local origin of the products. This article assesses the possible effects of CLT construction on the certification scores.

LEED *(Leadership in Energy & Environmental Design)* is a certification system for green construction. The aim of the system is to affect the steering of construction in such a way that the best solutions to promote ecological construction are evaluated in a reliable and transparent manner. On the basis of project type or life-cycle phase, the LEED system is divided into subordinate scoring systems, which retain the basic principle but allow for better consideration of the various characteristics of different project types. There are currently five subordinate scoring systems:

- LEED for Building Design + Construction (BD+C)
- LEED for Building Operations and Maintenance (O+M)
- LEED for Interior Design and Construction (ID+C)
- LEED for Homes (HOMES)
- LEED for Neighborhood Development. (ND) (U.S. Green Building Council. 2017)

In addition to this, the subordinate systems can account for various building or project types to improve the accuracy of the assessment. The following lists examples of the building types that can be selected in the LEED BD+C system:

- New construction & major renovation
- Core & shell development
- Schools
- Retail
- Data centers
- Warehouses & distribution centers
- Hospitality
- Healthcare
- Homes & multifamily lowrise
- Multifamily midrise. (U.S. Green Building Council. 2017)

In other words, the range is wide and varied, and a generally applicable interpretation of the results is surely impossible. The actual assessment requires project registration, which is subject to a fee, and requires the collection of detailed evidence of the project in question. The points gained by the construction project in the actual classification process determine whether or not the project is accepted in one of the four LEED certification categories.

- Certified 40–49 pts;
- Silver 50–59 pts;
- Gold 60–79 pts;
- Platinum +80 pts.

Figure 1. LEED certification categories (CleanTechnica. 2015)

As an example, we will select the New construction & major renovation category of the LEED BD+C system to assess the effects of CLT construction. The category can be selected for new construction projects or projects that involve significant renovation. Table 1 presents the system criteria and estimates the possible effects of CLT on point accrual. The example is not intended as a detailed assessment.

Table 1. Assessment of the effects of CLT construction/LEED (U.S. Green Building Council. 2009)

CLT assessment to "LEED for Building Design + Construction v3"			
Criterion	**Description**	**Opportunities of CLT construction**	**Additional points (CLT)/ Total points**
Sustainable sites	The purpose of the criterion is to consider the aspects, such as location, traffic links, preservation of nature, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 / 26**
Water efficiency	The main principle of the criterion is to ensure a holistic examination of matters pertaining to water.	The assessment does not include elements especially applicable to CLT construction.	**0 / 10**
Energy & atmosphere	The purpose of the criterion is to examine aspects such as the optimisation of energy consumption, the use of renewable energy sources, and the environmental friendliness of refrigerants.	The assessment does not include elements especially applicable to CLT construction.	**0 / 35**
Material & resources	The criterion aims to affect the reuse of materials, the use of local material, the use of certified timber, etc.	CLT construction can achieve benefits in the following aspects of the criterion: MRc5: regional materials**/ 1–2 points** MRc7: certified wood/**1 points**	**2–3 / 14**
Indoor environmental quality	This criterion is used to assess factors related to indoor environment quality, such as air quality management, material releases, management of temperature and lighting, etc.	CLT construction can achieve benefits in the following aspects of the criterion: EQc4.1: low-emitting materials - adhesives and sealants**/1 point**	**1 / 15**
Innovation	The criterion enables the consideration of innovative solutions that are not encompassed by other assessed areas. The solutions' positive impact on the environmental effects of construction must be demonstrated.	The assessment does not include elements especially applicable to CLT construction.	**0 / 6**
Regional priority credits	The points awarded through this criterion are, in a way, bonus points that are determined by the local Green Building Council. This serves to emphasise the assessed aspects with the most regional significance.	The materials used, for example, could yield **1–2 additional points.**	**1–2 / 4**
TOTAL POINTS			**4–6 / 110**
SUMMARY/ ANALYSIS	The "additional points" gained through CLT construction would be around 4–6 points out of 110 total points. This would mean an added benefit of 3.6%–5.5% in the assessments, which is a moderate gain and seams reasonable in terms of its scope. However, the matter is not quite this clear-cut as the CLT frame is only one part of the total structure. It may be possible to gain at least some of the "additional CLT points" with other frame alternatives if local materials and certified timber are used in the structures, for example. In other words, the genuine difference (or added benefit) is far from certain and depends entirely on the point of comparison.		

BENEFITS OF CLT CONSTRUCTION IN THE BREEAM CERTIFICATION SYSTEM

BREAAM is the world's first environmental certification system for buildings, and it has a wide user base. Since its implementation in 1990, more than 556,700 buildings have been certified according to the BREEAM system. Similarly to LEED, the BREEAM system examines construction projects in a comprehensive manner and strives to steer them towards the best practices. Another aim is to encourage the project parties to be more active in terms of energy efficiency, low-carbon solutions, efficient use of water and low emissions, for example. (BRE Global. 2017a)

There are numerous country-specific variations of BREEAM, but the actual international BREEAM system is divided into five main categories:

- BREEAM Communities (Masterplanning)
- BREEAM Infrastructure (CE & Public Realm)
- BREEAM New Construction (Buildings)
- BREEAM In-Use (Buildings)
- BREEAM Refurbishment and Fit-out (Buildings) (BRE Global. 2017b)

Within these categories, the assessment can be focused according to the type of building or project in question. For example, the BREEAM New Construction category can be used to analyse following types of buildings:

- Residential
- Offices
- Industrial
- Retail
- Community
- Residential instututions
- Public. (BRE Global. 2012)

This shows that the BREEAM system is very versatile in meeting a variety of needs. The high number of different combinations complicates the process of interpreting the benefits of CLT construction, as there can be significant variation in the information on buildings intended for different purposes. As regards the actual assessment process, the BREEAM system utilises assessment categories that have specific weightings with regard to the whole. The end result is a five-tier classification system for certified buildings (Table 2).

Table 2. BREEAM classification (Vierinen A-M. 2015)

BREEAM -rating	% score	Stars
Outstanding	**≥ 85**	*****
Excellent	**≥ 70**	****
Very Good	**≥ 55**	***
Good	**≥ 45**	**
Pass	**≥ 30**	*

In the following example, a general assessment process based on the BREEAM category International New Construction is used to evaluate the possible effects of using CLT in a construction project. Table 3 presents the assessment categories and the "additional points" that CLT construction may bring to the certificate.

Table 3. Assessment of the effects of CLT construction/BREAAM (BRE Global. 2013)

CLT assessment in accordance with "BREEAM International New Construction 2013"			
Criterion	**Description**	**Opportunities of CLT construction**	**Additional points (CLT)/ % in system**
Management	The purpose of the criterion is to draw attention to, among other things, procurement principles, consideration of interest groups in the design process, worksite conditions, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Health & Wellbeing	This criterion is used to assess factors related to indoor environment quality, such as air quality management, material releases, management of temperature and lighting, etc.	CLT construction can achieve benefits in the following aspects of the criterion: VOC emission levels/ **2 points**	**3 %**
Energy	The purpose of the criterion is to examine the optimisation and monitoring of energy use, the utilisation of energy sources, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Transport	This criterion is used to assess traffic links, support of low-emission traffic, parking space, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Water	The principle of the criterion is to ensure a holistic examination of matters pertaining to water.	The assessment does not include elements especially applicable to CLT construction.	**0 %**

Materials	The criterion aims to draw attention to the materials' life-cycle carbon balance, sustainable production, durability in use, etc.	CLT construction can achieve benefits in the following aspects of the criterion: Life cycle impacts / **3–4 points** Responsible sourcing of materials / **1–2 points**	**4–6 %**
Waste	The purpose of criterion is to affect, among other things, the arrangement of worksite waste management, in-service waste management and material efficiency.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Land use & Ecology	The purpose of the criterion is to consider the aspects such as location, responsible land use, preservation of nature, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Pollution	The principle of the criterion is to ensure that building emissions are minimised with regard to refrigerant releases, water or heating system releases, light pollution, noise pollution, etc.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
Innovation	The criterion enables the consideration of innovative solutions that are not encompassed by other assessed areas. The solutions' positive impact on the environmental effects of construction must be demonstrated.	The assessment does not include elements especially applicable to CLT construction.	**0 %**
TOTAL POINTS			**7–9 / 100 %**
SUMMARY/ ANALYSIS	The "additional points" gained through CLT construction would be around 7–9 per cent of the full 100 per cent. This would mean a moderately significant gain in the assessment, which seams reasonable in terms of its scope. It should be noted that, in the BREEAM system, the weightings would seem to focus slightly more on the materials than those of the LEED system. Therefore, the additional benefit gained through CLT would appear to be greater. As was the case with LEED, it may be possible to gain at least some of the "additional CLT points" under the BREEAM system with other frame alternatives if materials with low VOC emissions and material that have been procured in a responsible manner are used, for example. In other words, the genuine difference (or added benefit) is far from certain and depends entirely on the point of comparison.		

SUMMARY

The significance of environmental certifications in the construction field is increasing by virtue of the environmental effects of construction rising to the fore as an essential topic of discussion. The international certification systems LEED and BREEAM are the by far the most popular assessment methods for environmental effects even though the may countries utilise their own local systems. As a result, the implementation of generally applicable and transparent system in Finnish construction is also under way.

The rise of CLT in the Finnish construction sector seems to be occurring at the same time. CLT construction is marketed as a low-carbon construction solution, which it undoubtedly is. Alongside this, the assessment of environmental effects should aim to determine the significance that the various solutions involved have on the big picture. The LEED and BREEAM systems provide a welcome perspective for this very purpose.

This article assessed the added benefit that may be achieved through CLT construction in the scoring schemes of the LEED and BREEAM systems. Under the LEED scoring system, some 3.5–5.5% of the points would seem to be of the nature that could be affected by using CLT. For BREEAM, the added benefit stood at 7–9%. The BREEAM system would seem to focus slightly more on assessing materials whereas the LEED system aspects such as energy use have a more prominent role.

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CLT operators and references in Finland

CLT OPERATORS IN FINLAND

Stora Enso has been working to promote CLT construction in Finland for quite some time. Stora Enso's CLT panels are manufactured at factories in Austria, where the production capacity is approx. 140,000 m3 a year. Stora Enso has developed wood construction solutions all over the world, and November of 2016 saw the release of the new free-of-charge Calculatis dimensioning software, which supports CLT design, static design, fire design, building physics design and the dimensioning of the most common joints. (Stora Enso 2013)

Oy CrossLam Kuhmo Ltd, which began its operations in December 2014, manufactures and supplies CLT elements. The CrossLam CLT element factory is located in Kuhmoa, and Finnish PEFC-certified timber from the area area for element production. The maximum length of CrossLam's CLT elements is 12,000 mm, the maximum width is 3,200 mm and the thickness can vary between 60–300 mm. Crosslam Kuhmo Ltd Oy has set 8,000 cubic metres of CLT panel as the production target for 2017. CrossLam is strongly involved in the operations of Kuhmo Woodpolis, and the Elementti Sampo, which manufactures prefabricated CLT wall units and modular units is also located in the same Kantola industrial area. (Crosslam 2014)

Elementti Sampo manufactures prefabricated CLT wall units and CLT modular units. The company's factor lies in the Kantola industrial area of Kuhmo. The company has its own multi-storey building concept, *Suomi Kerrostalot*, which provides assistance to clients in the completion of multi-storey building projects involving large panels. The concept is suitable for constructing up to six-storey buildings, and it includes six standard dwelling types in size categories 28 m2–80 m2. (Elementti Sampo 2017)

Hoisko CLT Finland Oy began production in Alajärvi in January 2017, producing small panels, prefabricated wall units and modular units from CLT material. Hoisko CLT manufacturer's edge-glued CLT panels with a maximum length of 12 000 mm, maximum width of 3,500 mm and and maximum thickness of 60–400 mm. The CLT is made from Finnish PEFC-certified wood. Hoisko's annual production capacity will start at 40,000 m3 and increase to 70 000 m3 by 2018, thanks to the planned investments. (Hoisko CLT Finland 2016)

Lappia Vocational College's CLT learning environment is a learning environment for CLT element production and CLT construction, which is located in Kemi. It provides students of the wood and construction sectors with modern facilities and equipment, develops education in the field and forges co-operation with companies. (Lappia Vocational College 2017)

Pyhännän Rakennustuote purchased Stora Enso's modular unit factory in Hartola in the summer of 2016. The 200,000 m3 production facility produces various types of modular units and prefabricated wall units under the PRT-Pro brand. The company provides prefabricated frames, roofs, wall elements, intermediate floors and balcony solutions for wooden buildings, which are installed on-site. The modern production lines of the Hartola factory enable more diverse structural solutions than ever before. In addition to the new factory in Hartola, the company has production facilities Pyhäntä. (Rakennuslehti 2016)

REFERENCE PROJECT IN FINLAND

The Finnish Nature Centre Haltia is located in Espoo, in the immediate vicinity of Nuuksio National Park. Haltia, shown in Figure 1, is the first public building in Finland made fully from massive wood. The building's load-bearing frame, i.e. the walls, roof and intermediate floors, is made up of CLT elements. With the exception of the basement floor, the entire building is wood all the way to the exterior cladding. Haltia's aim is to serve as a flagship of wood construction and, by example, inspire Finnish developers and the construction industry to increase the amount of wood construction in public structures and multi-storey buildings. The construction of the building began in November 2011, and the opening was celebrated in June 2013. The building was designed by Arkkitehtitoimisto Lahdelma ja Mahlamäki Oy, Stora Enso provided the wooden structural solutions, and YIT handled the construction. (Finnish Nature Centre Haltia 2017)

Figure 1. Finnish Nature Centre Haltia (2017)

Puukuokka 1 is the first 8-storey wooden building completed in the Kuokkala district of Jyväskylä towards the end of 2014. Two corresponding buildings developed by Lakea Oy will be erected at the same site. The structure in Figure 2 was designed by OOPEAA Office for Peripheral Architecture and constructed from CLT modular units supplied by Stora Enso. An individual housing unit is formed by two modular units: one includes the entrance hall, kitchen and bathroom, while the other contains the living room, bedroom and balcony. A parking garage with a concrete structure, along with storage and utility space, has been constructed under the site. As Oy Jyväskylän Puukuokka 1, the housing company that owns the buildings, was granted the 2015 wood architecture award. (Puuinfo 2015)

Figure 2. Puukuokka 1 (Puuinfo 2015)

The Rajamiehentie care home in Kajaani is 1,200 m2 4-storey building, which was developed by the Kainuu Social and Health Care Joint Authority. The load-bearing structures are made of massive CLT. Elementti Sampo will supply the prefabricated CLT wall units, Rakennusliike Halonen Oy will serve as the main contractor, Rakennussauma Komulainen Ky will provide element installation services, and Timber Bros Oy will handle the design. Scheduled for completion in January 2017, the care home will be a sheltered housing unit for 15 persons with developmental disabilities. The draft drawing is presented in Figure 3. (Puuinfo 2017)

Figure 3. Rajamiehentie nursing home (Elementti Sampo 2017)

The seating section in Sauvosaari Kemi was constructed as a combination of various wooden structures, with CLT having a key role. The CLT elements were manufactured as a student exercise in the Lappia CLT learning environment – up to 15 students took part in the production, element assembly and surface treatment. The seating section shown in Figure 4 was erected by the City of Kemi. (Lappia Vocational College 2017)

Figure 4. Seating section in Sauvosaari Kemi (Pohjolan Sanomat 2016)

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This collection of articles examines CLT as a construction material and its characteristics from the perspectives of worksite operations and the design process, along with exploring the related environmental effects. The articles also present Finnish CLT operators and reference projects. Finnish CLT operators and reference projects have been collected at the end of the work. This knowledge base is intended for distribution to all construction field operators who are interested in the possibilities of CLT as a construction material.

Studies related to CLT construction have also been previously conducted under a joint project between Digipolis Oy, Vocational College Lappia and Lapland University of Applied Sciences. Visits to production facilities, participation in domestic and foreign seminars and conferences, and study of written and visual material on CLT construction have also contributed to the process and provided additional information on solid wood element construction, which is rapidly gaining ground on global scale.

The "CLT – versatile, fast and ecological construction material" collection of articles was authored and compiled under the Fugure possibilities for CLT project. The Future possibilities for CLT (FCLT) is implemented as a ERDF-funded Interreg Nord research project involving the Luleå University of Technology, Technical Research Institute of Sweden (SP), Centria UAS, Digipolis Oy and Lapland UAS. The project was initiated in September 2015 and will continue until October 2018. The primary objective is to promote the diverse use of CLT and increase awareness of the possibilities provided by CLT construction in the Interreg Nord region.

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