Trip Report

Sweden, Norway and France - November 1 to November 11, 2007

SP Tratek and Växjö University, Sweden, 1-2 November, 2007
Moelven Massivtre Mill and SINTEF Byggforsk, Norway, 4 to 7 November 2007
Batimat, France, 8-9 November 2007

By

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1 Objectives

1.1 Sweden

The main objectives of the trip to Sweden were:

- Meet and discuss with Research Scientists from SP Tratek, the Swedish Research and Testing Institute on Wood Technology;
- Meet and discuss with Professors and Ph.D Students from Växjö University and Lund University;
- Visit Växjö University laboratories (civil engineering and wood science);
- Visit two 8-storey buildings made of wood currently in construction (Glulam, cross-laminated wood panels for walls and floors);
- Visit two 5-storey buildings made of wood built in 1995 (light-framed building).

1.2 Norway

The trip to Norway had several objectives:

- Visit Moelven Massivtre Plant, one of the two Norway Cross-laminated wood panels producers;
- Meet and discussion with engineer from Moelven Massivtre;
- Meet and discussion with Research Scientists from SINTEF Byggforsk, the national research institute for building and construction in Norway (similar to CCMC);
- Visit two single family houses made of cross-laminated wood panels;
- Visit a 4-storey office building made of cross-laminated wood panels and glulam;
- Visit a 2-story multi-family building made of cross-laminated massive wood panels;
- Find partners that could supply cross-laminated wood panels for the two research projects launched this year and that are related to massive wood constructions: 1) Construction Solutions for Wood-based Floors in Hybrid Building Systems (550-5755) and 2) Wood Alternatives for Concrete-Steel Assemblies in Non-Residential Buildings (550-5906)

1.3 France

The trip to France had two main objectives:

- Visit BATIMAT, a construction show on construction and building products;
- Meet with Dr. Jean-Luc Kouyoumji from CTBA, a specialist in Acoustic and Energy in wood construction.

2 Sweden

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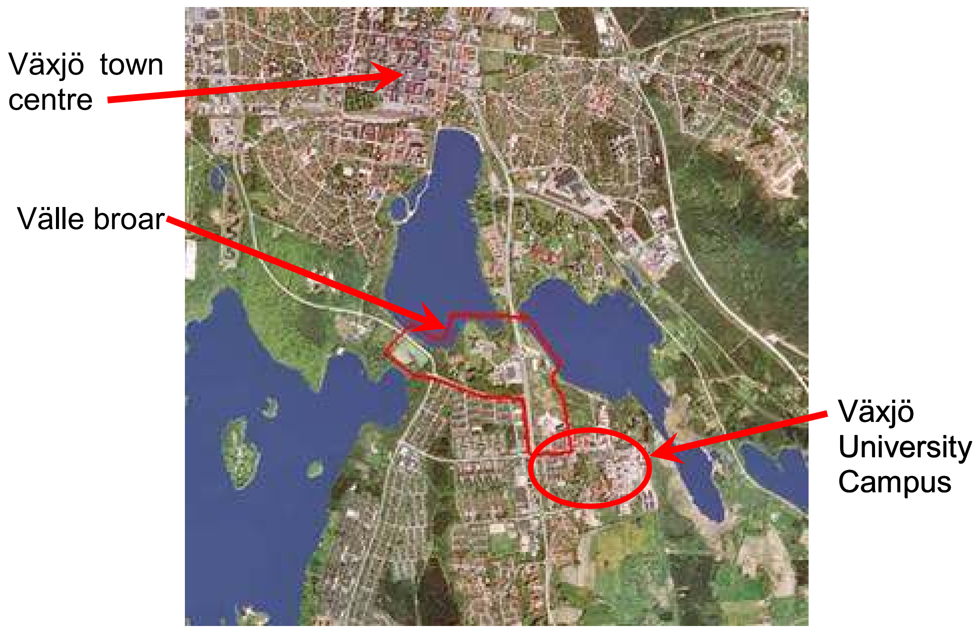
2.3 National Building Code in Sweden

Until 1994, it was forbidden in Sweden to build timber buildings above two storeys. Due to large fires that occurred in mid 19th century, the Swedish building authorities decided to limit wood in low-rise buildings. However, a new building code was introduced in 1994 with a performance-based format. It is now permitted to use wood in almost any building construction and this without the prior storey restriction, provided that any technical issues are met. Finally, there is no building official in Sweden. It seems that builders take the full responsibility of the construction.

2.4 Välle Broar Project

A few years ago, Sweden initiated a national policy that stipulates that wood products should be used as much as possible in new buildings. The city of Växjö decided to follow this national policy by creating a sector in the city where "almost" all buildings would be made of wood. This project was called "Välle Broar". This area is near the campus university. Next Figure illustrates the project.



Source: Växjö University

Figure 1 Välle Broar project

2.5 Limnologen Project: Four 8-Storey Buildings

Following the Välle Broar initiative, an impressive construction project of four 8-Storey buildings was launched. The project was called Limnologen and started in 2006. The first floor is made of concrete while the remaining are made of wood (i.e., 7+1 Storey).

Figure 2 8-Storey building under construction

2.5.1 Construction team

2.5.1.1 Structural design and wood systems supplier: Martinsons

Martinsons is one of the largest timber industries in Sweden. The group is composed of seven companies, each one specialized in its own field. The group comprises everything from the most modern sawmill in Europe, Sweden's largest manufacturer of glulam to the leading company in the Nordic countries for wooden bridges and solid wood frames. Martinsons has 400 employees.

Website: http://www.martinsons.se/

2.5.1.2 Builder: NCC

NCC is one of the leading construction companies in the Nordic region. The Group had sales of SEK 56 billion in 2006 ($900 M CAN) and has 22,000 employees.

Website: http://www.ncc.se/

2.5.1.3 Fire engineering consultant: Tyréns

Tyréns is one of Sweden’s leading consulting companies in the urban development sector. The company has more than 600 employees and offices in some 20 locations all over Sweden. The company provides services in the fields of structural planning and design, infrastructure, IT, property development and management consulting.

Website: http://tyrens.se/

2.5.2 Building systems used

In the recent years, the European wood industry has developed innovative wall, floor and roof systems. A brief literature review exercise by Forintek listed over fifteen different types of European timber wall/floor/roof systems. It is usually mentioned in these research studies that wall/floor/roof assemblies are cost-effective and meet national codes and standards requirements (i.e., fire and structural safety, vibration, acoustic performance, etc). Moreover, it is indicated that the prefabrication of these building systems accelerates the construction process and larger spans than typical joists can be achieved.

Martinsons developed innovative building systems that include framed structures made of both glulam and cross-laminated systems made of planks and thicker lumber (3 plies and more). Next Sections illustrate the concept developed by Martinsons.

2.5.3 Construction of the buildings and protection against bad weather conditions

Solid timber walls, floors and ceilings are often used in Europe with the interior face apparent. The product shall then be well protected during the construction (rain, ice, snow, undesirable prints/marks, etc.) and damages that could occur during the construction. A movable tent system was used to protect the workers and the structure of the elements during the construction process. This process also accelerates the building erection.

Figure 3 System of tent used during the construction

2.5.4 Floor systems

2.5.4.1 Interior floors

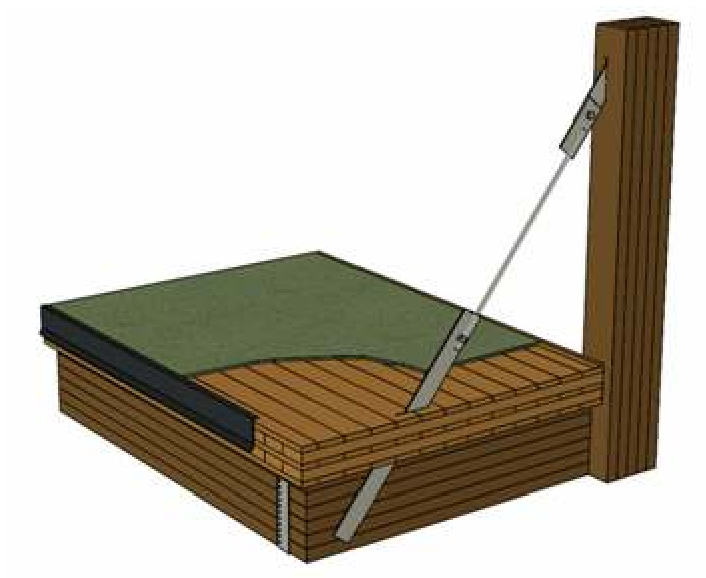
The floor system developed by Martisons consists of a composite floor made of Glulam beams and cross-laminated panels. Two elements of glulam are connected together using adhesives. The cross-laminated timber panel acts as the top plate and is glued and screwed to the glulam web elements. The floor system is similar to typical North American joisted wood floor system but using glulam as joists and cross-laminated wood panels as sub-floor. Comparing with North American joisted wood floor system, one may think this floor system is not the most efficient system. However, one advantage of this floor system in this building is the radiate heating floor system embedded with hot water pipes. The use of thick wood panels for the sub-floor can provide sufficient thickness for embedding the pipes. This construction solution, for the installation of a wood radiate heating floor system, may be more efficient than that used in North America. In North America, we first install the sub-floor of 5/8” (or 3/4”) wood panels. Then we add wood radiate flooring with pre-cut groves for hot water pipes into the sub-floor.

Source: Martinsons

Figure 4 Interior floor system

2.5.4.2 Balconies

Balconies are made of cross-laminated timber panels and glulam beams. The top side of the panel is covered by a non permeable layer.



Source: Martinsons

Figure 5 Balconies

2.5.5 Wall systems

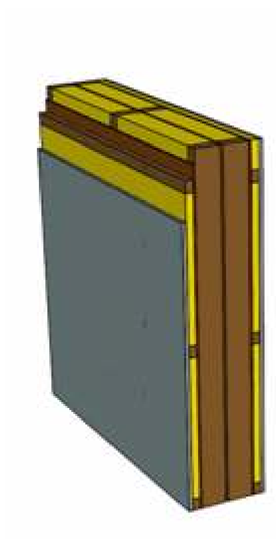
2.5.5.1 Interior walls

Solid lumber walls such as cross-nailed boards and glue-laminated walls were increasingly studied for a few years in Europe and Japan. Several research studies on the shear capacity of these building systems when used as shear walls have been undertaken. These wood systems show numerous advantages including the possibility to use low grade lumber, good seismic performance, reduced construction time due to the prefabrication process, light weight, good fire performance, etc. The load bearing solid lumber wall system has been initially developed with the principal objective of substituting masonry and concrete walls in countries were these materials are commonly used in residential buildings.

Martinsons developed different concepts of wall systems. In the Limnologen project, partition walls installed in the same unit are made of cross-laminated timber and gypsum boards on each side. For walls between units and for increasing the acoustic performance, a system made of studs and insulation material were used. Both sides are covered of gypsum boards.

Source: Martinsons

Figure 6 Partition wall system in the same unit

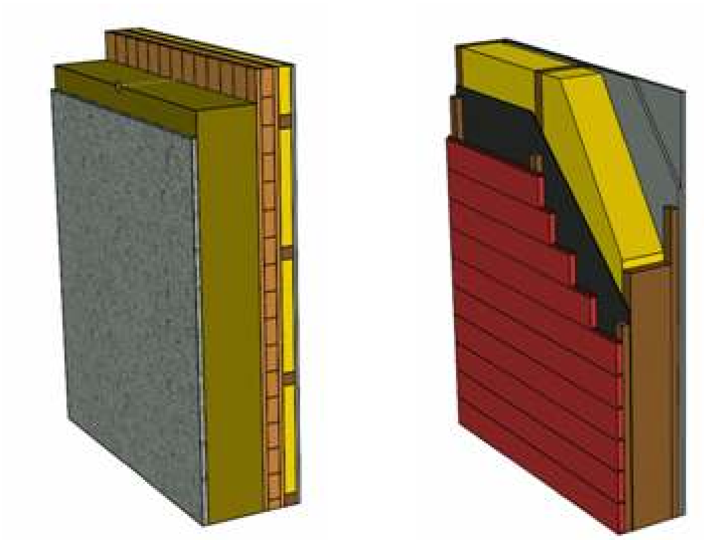


Source: Martinsons

Figure 7 Partition wall system between units

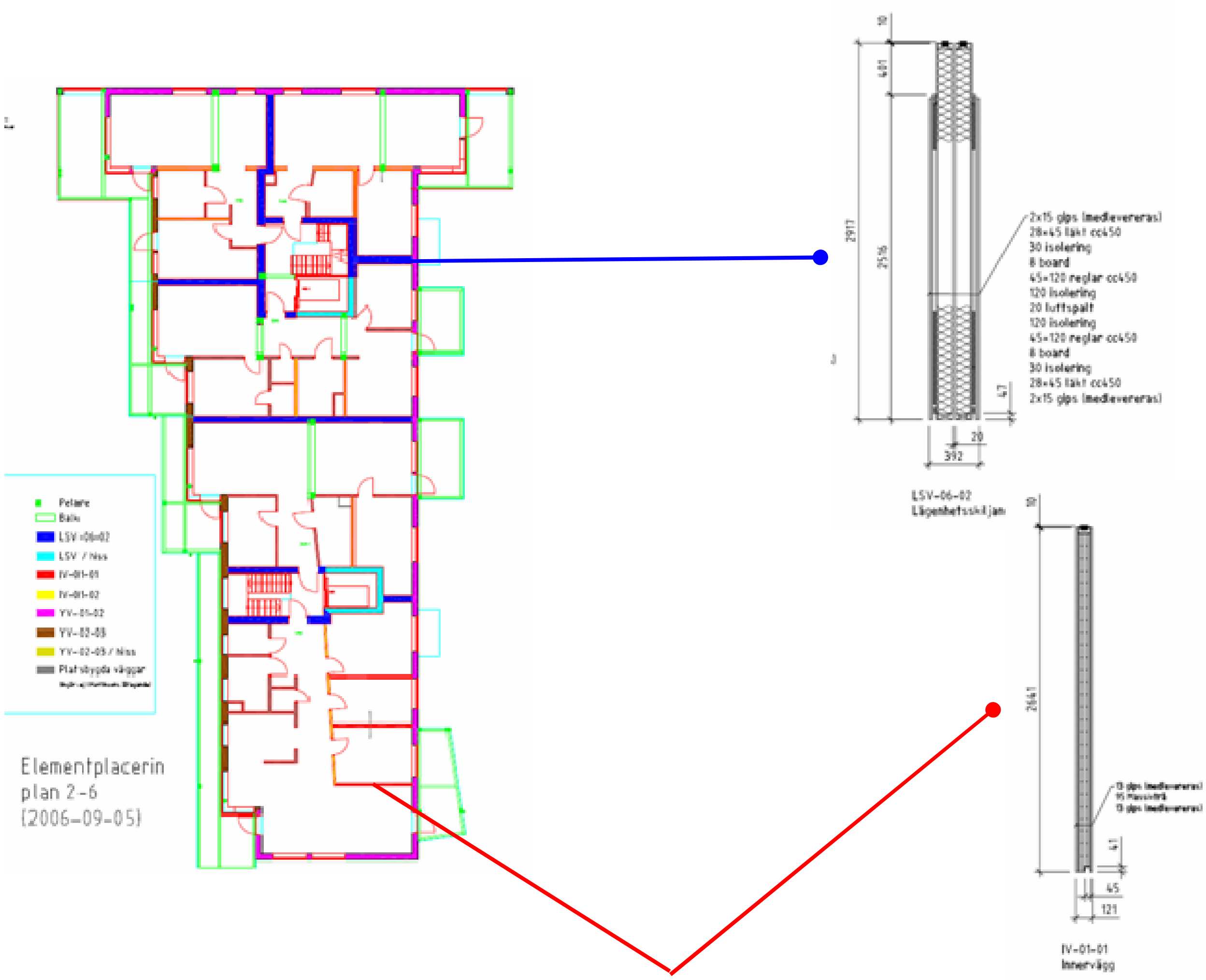
2.5.5.2 Exterior walls

Two different wall systems were used in this project. Due to fire requirements, only one façade of the building could have used wood cladding. The three other façades were built using non flammable materials for cladding. The system used with wood cladding was built using stud elements and insulating material. The wall system with a non flammable material was built with cross-laminated timber panels and insulating material.



Source: Martinsons

Figure 8 Exterior wall systems



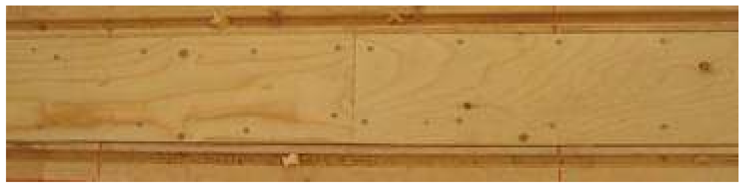
Source: Växjö University

Figure 9 Plan view of one storey

2.5.6 Connections

2.5.6.1 Floor-to-floor connections

The connection between the composite panels was achieved by a plywood strip screwed to the wooden panels. The number of screws was optimized following the calculation of shear stress all along the panel.

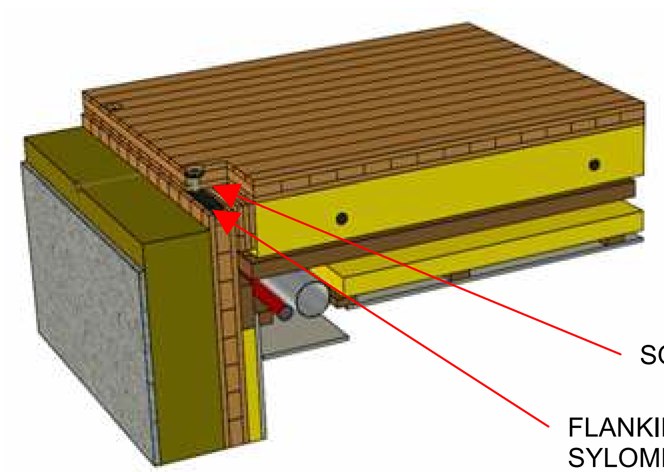


Source: Växjö University

Figure 10 Connections between floor panels

2.5.6.2 Floor-to-wall connections

To connect the floor element to loadbearing walls, Martinsons decided to use the top plate made of cross-laminated planks as bearing support. Sound-insulated screws where used to connect the two elements. Finally, insulation material was put between the supports for reducing flanking sound transmissions.



Source: Martinsons

Figure 11 Connections floor-to-wall

2.5.6.3 Wall-to-wall connections and Lateral load resisting system

A good system of connections between adjacent walls shall assure the load transfer due to wind and earthquakes. In Scandinavian countries, seismic loads are not important. Wind loads usually control the design of the lateral load resisting system.

To resist the wind loads, a system of steel rods was used. Those rods were installed at different locations in the building to assure a good transfer horizontal efforts to the concrete foundations. Steel rods were anchored to the foundations and then passed though all cross-laminated walls at each storey. The lateral load resisting systems where located either in interior partition walls and exterior loadbearing walls.

Figure 12 Connections wall-to-wall for lateral load resisting system

Elevator cage frame does not participate to resist the lateral loading due to wind and earthquake. To connect the walls together, steel plates with pre-drilled holes and European nails is used. Note that a power gun is employed for nailing.

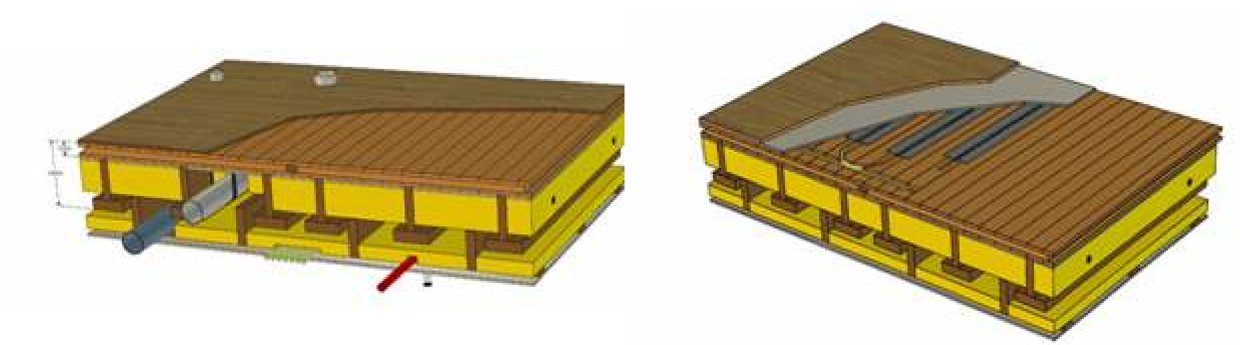
Figure 13 Connections wall-to-wall in elevator cage frame

To connect walls together, SFS screws were used. Next figure illustrates the concept.

Figure 14 SFS screw used for wall-to-wall connections

2.5.7 Services and utilities

Holes and grooves were made in cross-laminated elements into factory prior to shipping. Services and utilities in floor were inserted between joists and were installed into factory as well. The connection between pipes and wires were done on site.



Source: Växjö University

Figure 15 Services and utilities in floors

2.5.8 Vibration and acoustic performances

A Ph.D. research project has been conducted on the floors at progressive stages of the building construction to evaluate the vibration performance and to examine the effects of construction details on the performance including walls and ceilings. The following figures show the shake testing on the floor under construction to determine its natural frequencies, damping rations, and mode shapes.

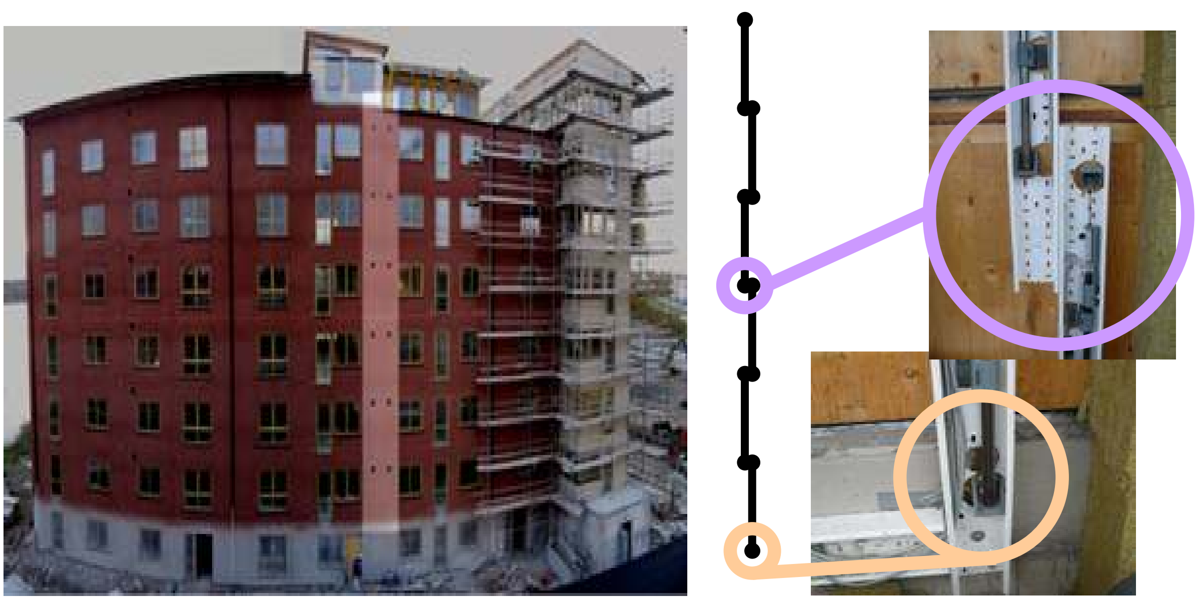
The constructions of the floors and walls shown in previous sections were designed for meeting Swedish code requirements for sound insulation. A Ph.D. research project has been conducted to measure the field acoustic performance of the buildings closely working with an acoustic expert of Lund University.

Source: Växjö University

Figure 16 In-situ tests for vibration performance

2.5.9 Relative displacements due to wind loads

In-situ tests for evaluating the relative displacements of each storey due to wind loads will be done.



Source: Växjö University

Figure 17 In-situ tests for measuring relative displacements of storey

2.5.10 Fire issues

Until mid-90s, timber buildings above 2 storeys had been forbidden in Sweden for over a century. The introduction of a new national building code based on a performance-based format paved the way to build multi-storey buildings using wood. With the main objective to promote the use of wood in Scandinavian countries, especially in multi-storey buildings, a Nordic project related to fire issues and design was launched. One of the objectives was to provide fire-safety design solutions. A new guide called "Timber Building Fire Safety" was then published. A new version of the guide is planned and should include recent developments such as wooden massive structures.

For buildings up to 4-storeys, the minimum fire-resistance rating is 60 minutes. For buildings with more than 4-storeys, the minimum fire-resistance rating is 90 minutes. The new 8-storey buildings in Växjö are sprinklered throughout.

2.5.11 Logistics and construction schedule

In this project, almost all floor and wall elements were different. The general contractor was Martinsons and the builder, NCC, was the sub-contractor of Martinsons. Both coordinated the delivery of elements. Wall and floor elements for one storey were delivered to the site progressively every two weeks. Five (5) trucks are needed for one storey. It takes about five (5) days to erect one storey. They move the tent up during the week-end. There are about six (6) workers for the building erection.

2.6 Two First 5-Storey Buildings Built in Vaxjo in 1980's

There are few examples of light-frame timber buildings with 5 storeys built in Vaxjö in 1980's. Due to lack of experience, these buildings experienced vibration, noise, and moisture problems. After remedying the situation, the buildings are still in a good shape and passed the test of time.

Figure 18 Light-frame 5-storey building

3 Norway

3.1 Moelven Massivtre

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3.3 Visit of the Moelven Massivtre Plant

Moelven Massivtre produces about 4500 m^3 of cross-laminated panels per year. The products were technically approved by SINTEF Byggforsk, the national research institute for building and construction in Norway (similar to CCMC). As said by the manager of Moelven, the actual market for wooden massive buildings is approximately 5000 m^3. At the moment, they work only on one shift of 8 hours. Maximum width of the panel is 1.2 m while the maximum length is 14.5 m. They can supply elements with a thickness varying from 63 mm to 240 mm. Figure on the next page gives the thickness of panels including the number of ply and thickness of lamellae for each case.

Tabell 1
Moelven Massivtreelement.
Oppbygning av standardelementer.

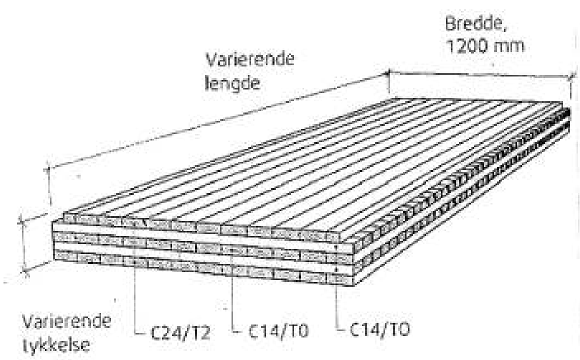
Element-tykkelse [mm]	Tykkelse til hvert sjikt [mm] *						
	L	T	L	T	L	T	L
63	21	21	21				
75	21	33	21				
100	33	34	33				
120	19,5	30	21	30	19,5		
140	32	21	34	21	32		
160	30,5	33	33	33	30,5		
180	32	41	34	41	32		
200	33	22	34	22	34	22	33
220	30	32	32	32	32	32	30
240	29,5	39	32	39	32	39	29,5

* L=langsgående sjikt
T=tverrgående sjikt

Source: Moelven

Figure 19 Panel thickness and dimensions of lamellae for Moelven products

The lamellae used for manufacturing the panels have two grades: C14 and C24. Lamellae with the better grade, i.e., C24, are put longitudinally at the outer faces of the panels. Only plies located at the outer faces of the panels are edge-glued. The plies inside the panels are not edge-glued. Melamine adhesive is used. Next Figure illustrates lamellae properties and locations into the panels.



Egenskap		C14 / T0 [N/mm²]	C24 / T2 [N/mm²]
Fastheter			
Bøyefasthet	$f_{m,k,0}$	14	24
Strekkfasthet, - lengderetning	f_{t0k}	8	14
- tverretning	f_{t90k}	0,3	0,4
Trykkfasthet, - lengderetning	f_{c0k}	16	21
- tverretning	f_{c90k}	4,3	5,3
Skjærfasthet	f_{vk}	1,7	2,5
Rulleskjærfasthet	f_{Rk}	0,7	
Stivheter for stabilitetsberegninger			
Elastisitetsmodul	E_{0k}	4700	7400
Stivheter for deformasjonsberegninger			
Elastisitetsmodul	E_0	7000	11000
	E_{90}	230	370
Skjærmodul	G_0	440	690
	G_{90}	50	
Midlere densitet	ρ	~500 kg/m³	

Source: Moelven

Figure 20 Properties of lamellae used in the cross-laminated panels

After gluing, the panel is sent to a radio-frequency press for a certain time, to assure the curing of the adhesive. Pressure is applied laterally and vertically. For example, for a panel having 5 plies, the minimum pressure time is 3 minutes. The panel is pressed by section of 3 m. Maximum vertical capacity of the press is 10 kg/cm^2.

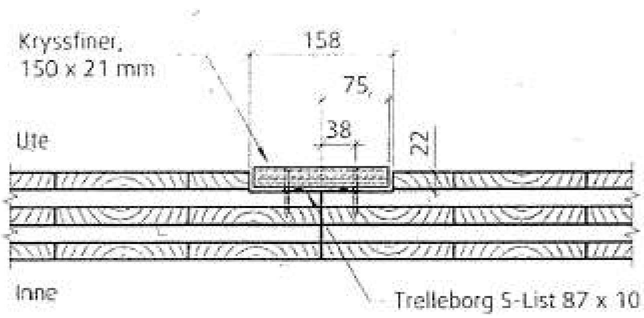
Figure 21 Manufacturing process of cross-laminated panel

Figure 22 Radio-frequency press for cross-laminated panel

After the press, panels passes through a planer. If necessary, panels are sent to a CNC machine. Moelven uses the PBA 5 axis developed by Hundegger.

Figure 23 CNC Machine – PBA from Hundegger

To connect the panels together, a Plywood or Kerto-Q strips of about 150 mm x 12 mm is used. Next figure illustrates the concept.



Source: Moelven

Figure 24 Connection between panels

For the quality control of their cross-laminated timber products, they do three flatwise bending tests (3rd point loading), three shear tests (small specimens) and three delamination tests (one-cycle) per shift of 8 hours.

3.4 Single Family Houses Made of Cross-laminated Wood Panels

During the trip to Norway, we visited two single-family houses made of cross-laminated wood panels. The two house visited are built using concrete and cross-laminated timber panel elements. For example, the first house (Figure 25a), is built with wall elements of 100 mm thick and roof is built using elements of 140 mm and 240 mm thick. At the request of the client of the first house, all apparent sides of walls and roofs were made of oak. This means that the visible layer of panels (i.e., about 20 mm thick) is made of oak and the rest of spruce. Photo shown in Figure 25b was taken in the second house. As shown on the figure, the entire roof and floor of the house used cross-laminated wood panels. Different from the floor construction of the 8-storey building in Växjö, Sweden, the floor was built using only massive wood panels, without joists, which is very similar to the construction of concrete slab floors. This type of construction solution demonstrates the potential of massive wood slab to replace concrete slab. The house design has received several best design awards.

(a)

(b)

Figure 25 Single-family houses made of concrete and cross-laminated wood panels

3.5 2-Storey Multi-family Building Made of Cross-laminated Wood Panels

Figure 26 shows the concept of the 2-storey multi-family building using massive wood panels for ceiling, walls and floors. The idea of using massive wood panels was to provide cheap and affordable living solutions. As we can see, the floor system is the non-joisted wood slab floors are similar to concrete slab floors, which proved that : what concrete can do, wood can do.

source: Moelven

Figure 26 Concept of the 2-Storey multi-family building using wood slabs for roofs, walls and floors

(a)

(b)

Source: Moelven

Figure 27 (a): Massive wood walls of the multi-family building; (b): Massive wood panels for ceiling and floor with topping for sound insulation

Figure 27a shows the walls made of Moelven massive wood cross-laminated panels of 100 mm thick. The massive wood walls that separate two unites are not covered by anything such as gypsum board, thus providing fire protection and exposing the beauty of the wood of the walls. The fire resistance meeting the code requirement was ensured by the volume of wood in the walls and the insulation materials filling the gap between two wood walls.

Installation of the building was quite simple. We were told that it was the first time the carpenter built a system using massive wood panels. After he completed this project, he loved this building solution so much, that he built his own massive wood panel house. Besides being environmental friendly, this construction technique is also simple, easy and efficient.

3.6 4-Storey Office Building Made of Cross-laminated Wood Panels and Glulam

The new building owned by "Viken Skog", a forestry research center, uses about 500 m^3 of cross-laminated timber and glulam elements. The system of construction consists in circular glulam columns and cross-laminated timber panels for non-joisted wood slab floors, walls and roof. Interior and exterior siding is made of cross-laminated timber panels (3-ply).

The building architecture is complicated. The core of the building is a pine-cone structure as shown in Figure 29 for meeting rooms. As we known, a pine-cone manifests a pine-tree, therefore designing the pine-cone shape structure for meeting rooms symbolized that any ideas or decisions(represented as a pine corn) born at the meeting and may bloom and become one day into a tree. Note the small thickness of the floors, similar to a concrete flat-slab system.

The entire building is triangle. Construction of such complicated floor system is challenging. However, the massive wood slabs made the construction simple and efficient. Hundreds pieces of different shape and size of massive wood slabs were calculated, designed, and made in Moelven's mill, then shipped to the construction site to assemble the non-joisted floor system having the complicated floor plan. It was very efficient without need of in-site trimming and wasting materials.

Figure 28 Viken Skog building – 4-Storey building made of cross-laminated timber panels

Source: Moelven

Figure 29 Viken Skog building under construction

3.7 SINTEF – BYGGFORSK

The SINTEF Group is the largest independent research organisation in Scandinavia. SINTEF works on many topics: health, information and communications technology, marine activities, materials science and applied chemistry, petroleum and energy, technology management and building/construction. The building and construction department employs about 270 peoples and is recognized by the European Union for giving CE evaluation/certification (CE Marking).

4 Establish Collaborations with Sweden and Norway on Massive Wood Constructions

During discussion with Sweden and Norway scientists and with massive wood panel producer, we saw the great potential of collaborations on various topics. Collaborations are expected to be providing Forintek the massive wood panels for laboratory test specimens, sharing test data and results, and working together on technical solutions on the issues of interests.

5 Closing Mark

This report only demonstrates a small portion of the great potential of wood used as building materials for a broad range of constructions. This report also convinces that with the innovative wood products and building technology, wood can do more than what we have used to see in the conventional wood-framed construction in Canada. For example, the massive cross-laminated wood panel shows the great potential to replace concrete slab. Similarly, glulam has a great potential to replace steel. But, our mind should not be restrained to cross-laminated wood panels and glulam as the only candidates to replace concrete and steel as building materials. In Canada, Structural Composite Lumber such as LVL and Glulam Panels could be used for floors and walls. Finnforest from Finland developed a massive wooden panel system made of LVL and Lumber.