BACHELOR THESIS.

OVERVIEW OF SYSTEMS IN TIMBER ENGINEERING.
USE OF CROSS-LAMINATED TIMBER WITH TWO SPECIFIC EXAMPLES.

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ABSTRACT

“Systems in timber engineering. Use of Cross laminated timber with two concrete examples” is my Final Project of Grade.

This project summarizes the most common timber systems used over time. It studies thoroughly the wood product “Cross laminated timber”, which is a relatively new wood product that was first introduced in the 1990's in Austria and has gained popularity in residential and non-residential buildings in many European countries and around the world in the recent past. Two specific projects of two existing single-family houses are designed with CLT solid wood panels.

This paper is divided into three parts:

In the first part an overview of the construction systems in timber construction is given. The systems are introduced, their characteristics and loadbearing performance are explained in a superficial way.

The second part deals with Cross laminated timber. In this chapter, an extensive study of this wood system is carried out. X-LAM, its abbreviation, is introduced in many general aspects as a product. All the specific and technic information which is shown is, in particular, form the Austrian firm “KLH Massivholz GmbH”, which I had the pleasure and honour to visit.

And in the final third part, two projects of two single-family houses are shown. Starting from a basic plan of the house, which have been obtained from two architects with which I'm truly grateful for their help, X-LAM system is used to design the house. Floor plans, sections, details and concrete component connections are designed.
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CONCLUSION

In timber construction the novel and advantageous solutions have been defined in the technical field of the structure and the disposition of the layers of the building envelope. Likewise, the different load-bearing systems and therefore the proper timber constructing systems have had a recognizably re-orientation.

Experienced master builders have constructed during the history with traditional systems, just like log and timber-frame systems, or as balloon- and platform-frame construction. But this systems have lost the meaning long time ago and this traditional systems are used in only some remote regions. Although the building professionals must understand the architectural traditions in building, they have to build with timber in a new and modern way.

Cross-laminated timber is one of the most relatively newest timber constructing systems. Since it is a heavy construction product, the green building movement, the better efficiencies and product approvals, it has been gaining popularity in residential and non-residential buildings in many European countries.

Learning about this system in Austria and having the opportunity to visit the Austrian firm (KLH Massivholz GmbH) which constructs X-LAM panels has been one of the most worthwhile things that I have had the chance to do while writing the thesis.

The most exciting and remarkable part of this thesis has been to try to understand the X-LAM product by designing two existing houses with X-LAM panels.

In short, it has been interesting and gratifying to write this thesis and to learn about timber construction systems in general and Cross-laminated timber in particular.
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1 TIMBER CONSTRUCTION SYSTEMS.

INTRODUCTION.

Overview of the construction systems in timber construction.

In timber construction the novel and advantageous solutions have been defined in the technical field of the structure and the disposition of the layers of the building envelope. Likewise, the different load-bearing systems and therefore the proper timber constructing systems have had a recognizably re-orientation.

The most common systems are:
- Log construction.
- Timber-frame construction.
- Balloon-Frame, Platform-Frame.
- Panel construction.
- Frame (skeleton) construction.
- Solid timber construction.

These systems can be schematized also in terms of structure:
- Rib construction: Timber-frame, Balloon/Platform and Panel construction.
- Framework construction: Frame construction
- Massive construction: Log and Solid timber construction

The timber construction systems currently used are mainly dealt with:
- Panel construction.
- Frame (skeleton) construction.
- Solid timber construction.

Experienced master builders have constructed during the history with traditional systems, just like log and timber-frame systems, or as balloon- and platform-frame construction. But this systems have lost the meaning long time ago and this traditional systems are used in only some remote regions. Although the building professionals must understand the architectural traditions in building, they have to build with timber in a new and modern way.
Combination of systems:

All of the systems are built with three individual components: walls, suspended floors and roofs. Overall systems are constructed if the components are built with the same type of system. However, this elements can be combined and a structure which has different types of systems in his components can be erected. The only requirements are that the components assist the building structure all together and that any damage shows up from the building structure owing to the combination of different systems. The combination of systems can optimize building structure.

This next table shows the building component systems which in combination can form a complete system.

![Diagram of building components](image)

**Figure 1:** Overview of walls, suspended floors and roof which can be used in combination to form a complete system. Illustration from the book "Systems in Timber Engineering, Josef Kolb".
Fabrication process in terms of systems:

All of these timber construction systems are solved with prefabrication. Walls, suspended floors and roofs, formed by individual parts and layers, are assembled in factory units. There are three prefabricated systems which maximize the prefabricated work:

Figure 2-Panel construction and Solid timber construction: the loadbearing structure is combined with the enclosing elements.

Figure 3-Frame construction: the loadbearing structure and the enclosing elements are separated. Firstly the structure is erected, secondly the enclosing elements are added to the loadbearing structure. This prefabricated system is used for larger structures.

Fabrication process in terms of building principles:

- Small units based on a modular dimension: walls are made of small timber units that are piled up together being this way at the same time loadbearing and enclosing elements.

- Elements based on a modular dimension: elements are one-storey-high on a modular dimension.

- Elements with room dimensions: elements are one-storey-high on a room dimension.

- Room modules: completely in a prefabricated way on a room dimension. All elements included (walls, suspended floors and roofs). Then the room is placed where it is supposed to be located.
1.1 LOG CONSTRUCTION

Traditional log construction belongs to a particular environment such as mountainous regions, and it requires specialists who are in the position of being able to design and construct such buildings properly. Log construction was the most common building technique in large regions of Russia and Scandinavia, where houses, palaces, towers and churches are constructed with log construction. In the mountainous regions of Central Europe, mainly in the Alps, log construction has played an important role in housing for the local residents.

Characteristics:

In earlier times the building envelope was a single layer. It gave the clad, enclose and loadbearing function to the element. Old but well preserved buildings, even multi-storey buildings, can prove the possibilities of this system. Nowadays a higher level of insulation and comfort is demanded, and other layers are disposed in the inside part of the wall, just like in masonry or concrete buildings. As mentioned right above, log constructions can be constructed nowadays with the insulation and comfort that it is demanded. But because of the extremely hard work, meticulous selection of the wood, high timber consumption, but above all, the constructional and economic reasons, log construction, when multi-storey log construction buildings even more, is practically a system of the past.

Types of milled logs:

Milled log buildings tool different profiles. The following pictures show the composition of a wall from exterior (left) to the interior (right):

1.-Swedish Cope logs: round inside and out, with a half-moon-shape groove on the bottom.
2.-Full-round logs: fully round insight and out.
- 3.- Higher level of insulation and comfort is demanded, and other layers are disposed in the inside part of the wall. It is a traditional log wall with internal thermal insulation. The proper log wall (loadbearing structure), thermal insulation and a vapour barrier are disposed in the wall.

-4/5.- Square logs: flat inside and out.

-6.- Walls can be prefabricated also with log construction.

Corner styles:
- 1.- It is the popular corner style used in the Scandinavian countries. Large diameter round logs are laid one over another. If the corner is well executed, it is totally protected against water and any air infiltration.

- 2.- The Dovetail corner makes a tight and interlocking corner. It is most suited to traditional slab side log or timber style homes. There are a lot of variants.

- 3.- There are many other corner solutions. The following examples are some of them.
1.2 TIMBER-FRAME CONSTRUCTION

The traditional way of timber-frame with the visible external load-bearing structure is rarely used any more. The traditional arrangements with diagonal braces have been replaced for new wood-based products, board materials and methods of fabrication much more economic and effective when constructing.

In whatever manner, carpenters still now know how to build with struts and angle braces like former times. Timber-frame structures can turn out to be still a good solution when constructing simple buildings of one or two storeys for agricultural purposes for example. Timber-frame construction can be naturally an economic building system for previously mentioned uses, if computer-controlled factory units, accurate modern machines and novel manners of drying wood are used.

**Characteristics:**

Timber-frame construction is erected storey-by-storey. The assembly and erection are simple to execute. The framework that has been designed to withstand the weight of the building can be clad from the inside part and the outside usually stays visible, although both sides can be clad. Wooden joints are used, such as mortise and tenon, slots for inserting one piece of wood into another (dado) and half divided joints.

Old but well preserved buildings, even multi-storey buildings, can prove the possibilities of this system.
Loadbearing behaviour:

Tiber-frame walls begin with a sole plate, which joins the wall to the slab in the found floor made out of concrete.
The vertical posts direct forces vertically to the ground. Posts form the jambs to doors and windows. The separation between the posts depends on the placement of the doors and windows. Structural calculations have to be carried out, naturally to prevent posts to bend and collapse.
Inclined posts are called braces. They give stiffness and transfer horizontal forces to the supports.
Horizontal rails are not there for structural purposes. They give stiffness, withstand the cladding and work as lintels and sills for windows and doors.
Head plates closes the wall. They hold the posts and braces in position, giving stability and stiffness to the wall. It gives also support for floor joists and roof beams. They carry the loads and forces from the upper floors direct to the posts.

Figure 19: Detached house with all the structure visible in construction phase. (www.stlouishousepaintingcontractor.com)

Figure 20: Detached house erected with the traditional way of timber-frame with the visible external load-bearing structure. (www.blackandwhitehouses.co.uk)
1.3 BALLOON-FRAME, PLATFORM-FRAME

In the medium of the nineteenth century, when United States was in complete developing and quickly erections of buildings were demanded, Balloon Frame system appeared in scene. With its rapid and large-scale manufacturing, this system could supply this huge demand. Although the production was fast, the erection phase was long, and still it is due to the short extent of prefabrication. Some decades later it arrived to Europe but it wasn’t successful. Not until a few decades ago, a further development of this system was spread out in Europe, in ways of condition and quality requirements. The name is timber Stud Construction. Because of the short production dimension but hard and long work when settling and erecting the building, consideration of protection against the weather when erecting the building, and the nowadays condition and quality requirements, panel construction has superseded in Europe balloon- and platform-frame construction.

Characteristics:

Balloon frame system is based in a structure of timber ribs. The timber posts spacing is small. The stiffness of the structure is given by planks or boards, which are nailed to the timber posts. Balloon-frame and Platform-frame constructions are erected in a slightly different way.

When Balloon-frame system, the ribs or posts don’t stop in between floors and continue for two or more floors. Soul and head plates are uncharged to close the structure. And suspended floors are made out of timber joists. When Platform-frame, a platform is laid in between storeys.
1.4 PANEL CONSTRUCTION

Panel construction structure that withstands the weight of the building is essentially loadbearing girders or ribs of squared section and a roof that makes stable the supports. The use of compound solid sections will give the right dimension stability. The elemental concept of panel construction is connected with prefabrication in the factory. Every wall, floor and roof is planned and produced as elements to adapt different building uses. Thermal insulation will be given by boards made out of mineral-fibre, cellulose fibres and wood fibreboards.

Characteristics:

As usual, the structure is planned, designed, produced and erected storey by storey. When manufacturing the elements, a factory unit in good conditions with computer-controlled materials-holding, certainly can offer a precise and correct fabrication. Nowadays physical size and weight of the building elements would be no more a problem when designing with panel construction, thanks to appropriate machines and powerful lifting equipment that helps when lifting, transporting and erecting this building elements. But the conditions when transporting this elements by road make engineers optimize the prefabricated elements dimensions. In terms of time, erection of the building can be carried out in two days when talking about a second-storey detached house.
**Loadbearing behaviour:**

In a simple way, walls made out of vertical ribs give stiffness to the structure when carrying the vertical loads from the roof and suspended floors to the foundation.

So, starting from below, soul plates are normally fixed to concrete foundations and externals walls are attached to the concrete slabs. If a soul plate is not laid on top of the concrete slab, not normal neither recommended, elements are fixed directly to the concrete ground slab with steel angles. The anchorage will be achieved with perforated sheet metal strap and fasteners (expanding, heavy-duty or bolt anchors). The protection against moisture will be given with a damp-proof course placed between the concrete and timber.

Prefabricated external and internal walls can be erected storey by storey after the soul plate is been positioned.

Because of the reasonable size of the walls, the transport and lifting of the elements into place must be achieved with appropriate machines and powerful lifting equipment. Suspended floors and roofs also require them.

To connect a storey to the storey below, they will be anchored with perforated sheet metal and some type of fasteners.
1.5 FRAME (SKELETON) CONSTRUCTION

Frame construction is one of the oldest structural systems. It’s a construction system composed by columns, beams and bracing elements. It offers quite large distance between columns and separates clearly the loadbearing frame and the enclosing walls. The timber frame, without any problem, can be unprotected on the inside or on the outside, or clad on both sides.

Before designing and building a frame structure, knowing the type of building which it is planned to erect is basic. For example: the size of the building and rooms, façade design, usual formats of elements and of sheathing and cladding materials, standard dimension of doors and windows, etc., among other considerations. When knowing the conditions, then horizontal and vertical grid will be found out as the best option for frame structures.
Loadbearing behaviour:

There are two types of structure in a frame construction building. The first one, and principal, is made of big loadbearing columns (vertical) and beams (horizontal). Columns or beams can be in solid glued laminated timber or in combination with steel or reinforced concrete. The second structure is made of prefabricated walls, timber joist suspended floors and roofs. This second structure resists the horizontal forces created by wind loads. As a result, the second structure sends his loads to the first and main structure, which sends them together with his proper loads directly to the foundations.

In both structures, diagonal steel bracing is a good option to transfer the horizontal and vertical loads.

Walls don’t support any loads from suspended floors or roof. They are basically designed as panel construction wall elements are designed, but as mentioned, they differ from them in not being loadbearing elements. This permits to place large windows or glass facades.

Junctions:

There are different ways of joining columns and beams and different types of connection, which will be mainly steel components. The election of the initial grid and principal structure dimensions will help choose the correct frame construction form.

Figure 31.

Columns and compound beams.
The columns are in one part, the beams in two.

Figure 32.

Beams and continuous columns.
The columns are in two parts, the beams in one.
Columns and oversailing beams.
The one-part beam bears on top of the column.

The secondary beams bear on the primary structure.

The secondary beams are connected with their upper surfaces aligned with the primary structure.

Beams and compound columns.
The beams are connected to the continuous columns.

Forked columns.
The main beam passes through the column. The secondary beams bear on the primary structure.
1.6 SOLID TIMBER CONSTRUCTION

Solid timber constructions is made nowadays thanks to factory-produced components. These components are usually made of glued-, dowelled- or nailed timber.

The loadbearing layer of the complete component, which is a solid timber plate, is in the same plane of the plate of the other layers.

Solid timber components absorb and save moisture from the interior air and liberates it when the dry period arrives.

The assembly is simple. It is erected storey by storey.

There is a requirement which dictate that a solid timber component will be named as such, when at least 50% of the total component works for the loadbearing structure.

**Solid cross-sections and compound cross sections:**

The main difference between these sections is the dimension they are manufactured in. In solid cross-sections, the manufacturing is in large format planar elements, with plan or room dimensions. In compound cross-sections, the manufacturing is small format planar elements, with modular dimension, that when joined together, they create a plan or room dimension.
1.6.1 Solid cross-sections

The planar solid timber wall, suspended floor or roof works as a loadbearing and enclosing element.

In terms of thermal insulation, the thickness of the element depends on the thermal needs. The thermal insulation will be disposed in a continue layer on the outside of the element, eliminating the most existing thermal bridges.

The importance of the performance in terms of shrinkage and swelling in timber is high. Cross-banded glued or dowelled systems offer a limited shrinkage and swelling due to the cross-wise disposition of the layers. Therefore the stability is very good.

Loadbearing behaviour:

The stability of the building is ensured by structural actions of solid plates which are in the same structural plane. The vertical and horizontal loads are carried by way of solid-timber-plate elements from up the roof until down to the foundations.

Most common systems, large-format planar elements:

-Cross-laminated timber (CLT): Is a type of structural timber product comprising a number of layers of dimensioned timber bonded together with durable, moisture-resistant structural adhesives.

-Edge-fixed timber: large wooden boards fixed to each other. The laminations are interconnected to each other with nails or hardwood dowels.

-Cross banded and dowelled: Large wooden boards disposed in several layers, cross-wide, and attached by means of hardwood dowels.

-Wood-based product: Pressed particleboards or OSB plies used in large, storey-high wall elements.
1.6.2 Compound cross-sections

Elements joined by gluing ensure very good dimensional stability. In terms of thermal insulation, the thickness of the element depends on the thermal needs. The thermal insulation will be disposed in a continue layer on the outside of the element, eliminating the most existing thermal bridges. As in the solid cross-sections, cross-banded glued or dowelled elements offer a limited shrinkage and swelling due to the cross-wise disposition of the layers. Therefore the stability is very good.

Loadbearing behaviour:

When the individual elements are joined, they act as an independent planar section wall. The loads are transferred via these plates (the elements joined together) direct to the foundations.

Most common systems:
-Cross-banded spaced plies: Elements which are made from cross-banded glued boards. They can work, when joined together, as walls, suspended floors and roofs. The dimension stability is very good.

-Modular building block system: Just as masonry, prefabricated small handy-sized modules, but made out of solid timber. Made for walls, external and internal ones.

-Tongue and groove timber pranks.
INTRODUCTION

In this chapter, cross-laminated timber is introduced in many general aspects as a product. The CLT specific information which is shown in this chapter is, in particular, from the Austrian firm “KLH Massivholz GmbH”, which I had the pleasure and honour to visit.

The chapter is divided in several parts:

The first part introduces and defines the CLT in a very general form.
The second part is about the fabrication of the CLT product (KLH).
Third part talks about the connections in CLT buildings and shows some details with the proper explanation (KLH).
Fourth, building enclosure for CLT assemblies is explained. Airtightness, heat insulation, protection against moisture matters are briefly introduced.
In part five, the sound insulation of CLT assemblies. The terms airborne and impact sound are introduced.
Sixth, the fire performance in CLT assemblies. Just a very brief introduction.
And seventh, ways and systems of lifting and handling of CLT elements.

Figure 48: View of a CLT staircase coming to the wall. (www.tilling.com.au/node/267)
2.1 INTRODUCTION TO CROSS-LAMINATED TIMBER (KLH).

Cross-laminated timber (CLT) is a wood system of solid timber construction. It was first introduced in the 1990’s in Austria. Since it is a heavy construction system, the green building movement, the better efficiencies and product approvals, it has been gaining popularity in residential and non-residential buildings in many European countries. Striking buildings and other structures are built all around the world using CLT (Canada, USA, Australia, New Zealand, Japan, Taiwan, etc.).

In Europe it has been proved that CLT construction can be competitive in single-family buildings and multi-storey residential and non-residential constructions.

CLT advantages in general:
- Sustainable, environmentally friendly building material.
- Light-weight construction.
- Short erection time due to prefabrication.
- Buildings are ready for occupancy in a short time
- Extremely accurate shapes and openings.
- Combinable with many different materials (steel, glass, etc.).
- Allows for maximum architectural freedom.
- Excellent static properties.

Areas of application:
- Detached houses and apartment buildings.
- Multi-storey residential buildings.
- Public buildings.
- Hotels and restaurants.
- Old people’s homes.
- Schools and kindergartens.
- Office and administrative buildings.
- Event halls.
- Industrial and commercial buildings.
- Reconstructions and extensions.
- Bridges.
2.1.1 KLH Massivholz GmbH.

There are lots of firms around Europe and the world that produce CLT panels. As it has been explained in the abstract, the CLT specific information which is shown in this project is in particular from the Austrian firm "KLH Massivholz GmbH", which I had the pleasure and honour to visit.

KLH Massivholz GmbH is a manufacturer of large-format glued laminated timber walls, ceilings and roofing elements. KLH solid wood panels are used both as load-bearing, reinforcing elements and non-load-bearing elements.

It is an international market-leading manufacturer, which has his markets in:

- Prime market in Europe: France, Austria, United Kingdom, Germany, Italy, Norway, Sweden and Switzerland.
- Other European markets: Belgium, Netherlands, Poland, Czech Republic, Slovakia, Slovenia, Spain and Portugal.
- International markets in development: Canada, USA, Australia, New Zealand, Japan, and Taiwan.

Overview of the corporate history:

- 1996 Product development.
- 1997 Establishment of the company.
- 1999 Opening of the current production plant in Katsch/Mur.
- 2005 Establishment of the subsidiary company „KLH UK Ltd.”.
- 2011 Beginning of internationalization.
- 2012/2013 Offner Group assumes sole ownership of KLH Massivholz GmbH.
- 2014 Investment CNC machine (1,5 Mio.) – increase of production capacity to 1 Mio. m² resp. 125.000 m³.

Figure 49: Photograph from the main office building of KLH facilities in Frojach-Katsch (Murau), Austria.
2.1.2 CLT solid wood panels (KLH).

KLH is the abbreviation for Kreuzlagenholz in German, which means Cross-laminated timber (CLT). CLT is produced from layers of spruce wood which are arranged crosswise (normally at 90 degrees) on top of each other and glued to each other with a pressing power of 0.6 N/mm$^2$ to form large-sized solid wood elements.

As it is explained previous chapter (1.6.1 Solid cross-sections), the cross-wise arrangement of the longitudinal and transverse layers reduces the swelling and shrinkage of the wood in the plane of the panel. This gives an excellent dimensional stability. Wood is dried down to a wood moisture of 12% (+/-2%) so as to eliminate any damage (pests, fungi or insects).

KLH Product:
- Crosswise glued lamellas mainly in spruce.
- Large sized structural elements for walls, ceilings and roofs.
- Maximum dimensions 16.50 m by 2.95 m up to 0.50 m thick.
- Non-visible, industrial visible and domestic visible quality.
- 3, 5, 7 or even more layers, according to structural requirements.
- Production made to order.

KLH plates maximum size:
- Maximum length - 16.50 m
- Maximum width - 2.95 m
- Maximum thickness - 0.50 m
- Minimum production lengths - 8.25 m, respectively in 10 cm increments up to the maximum length.
- Produced widths - 2.40 / 2.50 / 2.73 / 2.95 m
  / On request 2.25 m

Gluing:
The adhesive has to be in accordance with the EN 15425. It has to be approved for load-bearing and non-load-bearing, and indoors and outdoors engineered wood components. With KLH solid wood panels, solvent-free and formaldehyde-free PUR adhesive are used. The glue is applied over the entire surface with an optimized amount of adhesive. A high-quality level of adhesion is achieved with a high pressing power.
Surfaces:
KLH solid wood panels are offered as standard in non-visible quality, industrial visible quality and domestic visible quality.

- Non-visible quality in spruce: appropriate for load-bearing components.
- Industrial visible quality in spruce, single-sided: appropriate for industrial buildings with low requirements on surfaces.
- Domestic visible quality in spruce, single-sided: appropriate for permanently visible surfaces in residential buildings.

2.2 FABRICATION OF CLT PRODUCT (KLH).

In this section, the process of the manufacturing the CLT product is explained step by step. The process is in particular the KLH one.

1-Primary lumber selection.
As explained in the last section, KLH solid wood panels are offered as standard in non-visible quality, industrial visible quality and domestic visible quality. So lumber stock is selected conforming to grade of CLT solid wood panels.
In the production of KLH solid cross-laminated timber boards, wood will have a humidity of 12% (+/- 2%). Therefore, the lumber packages are wrapped and stored in a warehouse where the moisture content and temperature of the lumbers are controlled thoroughly.

2-Lumber grouping:
Basically in this step, all lumber with same engineered properties will be placed in the same place. The ones with major strength direction will be placed as longitudinal planks, and the ones with minor strength direction as transverse planks.

3-Lumber/layers cutting and surfacing:
A machine equipped with the most advanced CNC technology (Computer Numerical Control) will remove a thin layer from all four sides of the lumbers, which will help to ensure an optimal gluing, and will cut the lumbers with accuracy.
4-Adhesive application:
Lumbers are put together correctly forming a continuous layer. Then a machine with some extruders push out some threads of solvent-free and formaldehyde-free PUR adhesive. The threads of adhesive are thrown on top of the lumber, which are already placed together, in a weaving side-to-side movement.

5-CLT Panel lay-up:
After being sprayed with the adhesive, another group of lumbers put together forming a continuous layer, but this time in the opposite orthogonal direction is placed on top of the previous layer. The process will be repeated until there is 3, 5, 7 or more layers depending on static requirements.

6-Assembly pressing:
The time between when the adhesive is applied and when the pressure to the layers is done, the proper pressing time should be essentially monitored in terms of ambient temperature and air humidity, in order to not affect the CLT performance. After the process a test is carried out as part of the product qualification.

7-Machining and cutting:
After testing the performance of the CLT panels, they are transported to a section in the industrial bay where a machine controlled with a computer program cuts the openings for doors and windows, slots and holes for connections and lifting causes.

8-Packaging and transportation:
After cutting the last openings, the CLT solid wood panels are ready to check over, pack and deliver the product via truck transporting to the private client.
In order to ensure an optimal assembly sequence of CLT, a setup sequence has to be determined. A loading sequence is defined for the means of transport.
2.3 CONNECTIONS IN CLT BUILDINGS (KLH).

There are two common structural systems to design and construct CLT buildings with. Platform construction and Balloon construction.

- **Platform construction**: walls lay between floors. The floor panels rest on top of the wall panels. This simplifies the erection of upper storeys and imply simple connection systems. It's probably the most used structural system in Europe for CLT assemblies.
- **Balloon construction**: walls continue some storeys up with intermediate floor assemblies attached to the walls. High buildings with several storeys cannot use this system due to the limitations in the length of the CLT panels for example.

2.3.1 Details of the connections in CLT assemblies.

The simple axonometric drawing shows a common multi-storey CLT building, with its ordinary connections, just as CLT wall panel’s connection, connection between walls and foundations and walls, floors and roofs. All of the details shown in this subsection are extracted from the official documents of KLH (www.klh.at).

There are many solutions for the marked encounters in the drawing. For example in the way of sealing. Sealing in the panels can be given by:

a) A heat trap fitting, in a permeable material (air tight layer), adjusted to the wall structure.
b) Sealing strips if no vapour retarder or heat trap fitting is installed.

Only most common and used solutions for executing these encounters are shown in the following pages in specific details.
Detail number 1: Exterior/interior wall - concrete connection:

Figure 60: Axonometric view of a wall-concrete encounter. Extract from www.klh.at.

1. KLH wall panel according to static requirements
2. E.g. BMF angle bracket for shear and tensile forces – special solutions are required for high tensile forces
3. Oak or larch sill laid in mortar bed – with the entire surface resting on the base
4. Caution: At least 2 dowels must be installed for each BMF angle bracket; otherwise the effect of the angle bracket is highly reduced (preferably use the two holes directly next to the wall or the sill plate)
5. Concrete component (wall, ceiling, concrete slab)
6. Protection against rising moisture
7. Install joint tape, if necessary

Detail number 2: Exterior wall – interior wall – ceiling connection:

Figure 61: Axonometric view of an exterior wall-interior wall-ceiling encounter. Extract from www.klh.at.

1. Cross wall connection – screw connection from the outside
2. Cross wall connection – screw connection from the inside
3. Shear force transmission along the joint and tension anchorage of walls – e.g. BMF angle bracket – type, distance according to static requirements
4. Screw connection of ceiling with walls according to static requirements
Detail number 3: Exterior walls - ceiling connection:

Figure 62: Axonometric view of an exterior wall-exterior wall-ceiling encounter. Extract from www.klh.at.

Detail number 4: Exterior walls - roof connection:

Figure 63: Axonometric view of an exterior wall-roof encounter. Extract from www.klh.at.
Detail number 5: Roof – roof connection:

Figure 64: Axonometric view of an exterior roof-roof encounter. Extract from www.klh.at.

Detail number 6: Ceiling – ceiling connection:

Figure 65: Axonometric view of a ceiling - ceiling encounter. Extract from www.klh.at.
2.4 BUILDING ENCLOSURE FOR CLT ASSEMBLIES.

Building enclosure has the most important role in terms of the energy performance, durability of the structure, air quality and comfort. To accomplish these requirements, the prevention of water intrusion, the control of the heat flow, air flow and moisture flow is basic. Panels situated between the exterior and interior such as exterior walls and roofs, separate two environments. These panels must deal with rough weather, sudden change in temperature, solar radiation, humidity, etc. As any other system or material, these solid wood panels and their assembly areas have to be prepared for water and air infiltration and vapor movements. These can cause moisture problems, which no building wants.

2.4.1 Air tightness.

Building envelopes must be made permanently airtight and windproof. The tightness of the CLT construction depends more on the connection joints to other construction components and panel joints, rather than panel themselves. The air tightness of a construction component or an entire building is a measurable unit (air change rate). It indicates the quantity of air per hour [m3/h] flowing between the inside and outside of a construction component or building at a particular defined pressure difference. A bad design or execution of an envelope which permits the air flow through the joints of the panels will make the building envelope excessively permeable and will unprotect the noise protection and lose excessive heat as well.

There are offered two flow-tight connection options for giving airtightness:
• Wrapping and sealing the whole building with a membrane, usually a textile fabric (air tight layer) by way of a convection barrier. The membrane is adjusted to the wall structure. This way of giving airtightness needs no sealing tapes.

Figure 66: Airtightness given to an encounter through wrapping and sealing with a convection barrier. Extract from www.klh.at.
• Using pre-compressed sealing tapes. When no vapour retarder or convection barrier is positioned outside, sealing tapes will seal the building connections.

2.4.2 Protection against moisture.
Any construction material should not transport moisture. Wood is no exception. CLT panels must prevent the vapour diffusion, the absorption of humidity and capillarity in surfaces. Wood is an anisotropic material with hygroscopic properties. This factor and the crosswise arrangement of the layers and the high-quality gluing during the production of the solid wood panels, makes the swelling and shrinkage of the wood in relation to moisture limited.

In wet rooms, joints are the critical elements. This problem can only be solved by means of elastic, permanently flexible connections. Elastic sealing joints are also necessary for impact sound insulation with side walls.
2.4.3 Heat insulation.

When cold temperatures attack the building, the objective of the building is to fight back somehow and create comfort temperatures which levels of comfort demand. Three ways can be used to create temperatures that ensure a high level of comfort:
• Decrease the transmission losses. No heat transfer through components.
• Add thermal energy from outside. Using the solar energy from the rays of sunshine which enter through windows.
• Add thermal energy from inside. Using heating energy or energy consumption from home.

2.5 SOUND INSULATION IN CLT ASSEMBLIES.

This chapter explains several general matters related to sound in CLT buildings, e.g., the definition of the sound, its sources, acceptable levels of sound, sound vs. noise, etc.

Definition:
Sound is a physical disturbance in an elastic medium (gas, liquid or solid) which is capable of being detected by the human ear. Human introduces inside buildings constant sound, such as talking, playing instruments, music, TV/radio, walking, playing, etc.

Airborne and impact sound:
Sound insulation in buildings distinguish between airborne and impact sound. These two ways which a sound can be transmitted from room to room, are shown very clearly in the following pictures. In ‘Fig. 70’, sound is transmitted via airborne sound. In ‘Fig. 71’, sound is transmitted via impact sound.
To measure the airborne sound the Octahedron speaker is used. A structure of two rooms is construct to test the airborne sound in the facilities of KLH. There is a structure which has one room on top of the other (to test the ceilings), and one room beside another (to test the walls).

Regardless, Octahedron speaker transmits sound vertically, horizontally and also diagonally in one room. In the room on the other side of the KLH solid wood panel, some receptor machine tests the intensity of the airborne sound.

![Image](image1.png)

**Figure 72 and Figure 73:** An Octahedron speaker is positioned inside the room and transmits sound in all directions.

To measure the impact sound, an impact machine is used. The intensity of the impact sound levels can be adjusted. The same structure of two rooms which is construct to test the airborne sound in the facilities of KLH, is also used for the impact sound test.

![Image](image2.png)

**Figure 74 and Figure 75:** An impact machine is positioned inside the room and transmits impact sound which will be measured in the room on the other side.

When measuring airborne sound transmission and impact sound levels, there are important factors which will influence the capacity of insulation of the panels:

- Weight of the construction component per m2.
- Internal damping of the component.
- Leaf distance in case of multi-leaf structures.
- Dynamic rigidity of the separation layer in case of multi-leaf structures (e.g. impact sound insulation between screed and KLH solid wood panel).
- Flexibility as defined in building acoustics.
- Minimization of sound transmission through contact surfaces and fixing elements.
2.6 FIRE PERFORMANCE IN CLT ASSEMBLIES.

All of the CLT panels and further CLT constructions are proofed to be prepared to stand a fire. Proof has to be provided for the load-bearing capacity of each component in case of a fire in the form of a static calculation.

Multi-layer KLH solid wood panels also allow the construction of components with high fire-resistance ratings, and proof can be provided for R90 or R120.

5-layer ceiling panels already reach R60 without any additional measures or even R90 if the panel thickness is sufficient, making visible-grain constructions with high fire resistance easy to realize.

For wall components, the required fire resistance is usually achieved with panel layers, since, for example, with 3-layer KLH wall panels you can merely reach a maximum fire resistance rating of R30.

2.7 LIFTING AND HANDLING.

There are several techniques for handling and lifting CLT panels. The difference on the nature of the building or location normally in many cases impose the system that's going to be used. As it is easy to imagine, a 5 o 10 storey building in a city will not use the same system and will have much more preparation and precaution than a detached house in a village.

In some systems holes are normally used to fix the plates or bands. It is always better to seal the holes to ensure airtightness and to stop the relative expansion of sound, smoke or fire.

Contact lifting systems:
These are some lifting systems which use steel plates which provide compressive resistance on the lower face of the panels. It’s a very safe system although there has to be tactful when removing the steel plates from the panels.
Screw hoist systems:
These are some lifting systems which depend only on fasteners. It’s a very simple and effective system although there has to control when designing the placing them over the panel.

![Figure 79.](image1)
![Figure 80.](image2)
![Figure 81.](image3)

Integrated lifting systems:
These are some lifting systems which depend only on fasteners. It’s a very simple and effective system although there has to control when designing the placing them over the panel.

![Figure 82.](image4)

Unloading and storage:
KLH panels are usually lifted with the soft lifting slings system without support for horizontal and vertical elements. The lifting sling is inserted into a hole and pull put from a second hole. A maximum distance between the slings is 6 meters and the angle of the lifting mechanism between 45º and 60º.

![Figure 83 and figure 84.](image5)

Vertical and horizontal elements installation:
KLH panels (horizontal and vertical) are correctly positioned and a temporary support helps the wall or roof or ceiling to stabilize before the lifting slings are undone and moved away. Screw fixings are also fixed to stabilize more the process of assembly.

![Figure 85.](image6)
3 DOCUMENTATION OF CLT BUILDINGS.

INTRODUCTION

In this chapter, two projects of two single-family houses are shown. The basic plans of the house are designed by two different architects, which designed these houses with CLT panels. The work that’s shown in the next pages is the design of the proper houses designed from a particular point of view, using KLH solid wood panels. The final decision is conditioned by this specific panels.

Next two pages introduce the houses with some explanation about them, the purpose of the construction, some characteristics which are worth to comment, etc.

Then all the floor plans, sections, details and component connections, blueprints in general, are shown after the brief explanations of the house.
3.1 HOUSE C: “CERNY”.

This existent single-family house is designed by “SBA Architekt DI Oliver Seindl”. The clear separation between living and working areas of this house is reflected in the refined combination of two architecturally sophisticated building complexes.

![Figure 86: Exterior view of the living and work house.](image)

This construction is composed of a single-storey flat-roofed residential building with a rectangular plan and a two storey “office tower”.

![Figure 87: Exterior view of the terrace in the south façade.](image)

There are generous glass surfaces in all south façades which gives clear light during all the day. There is also facing to the south a wooden terrace upstairs in the second floor of the office building and a four doors open façade in the south façade in the residential building which connects the inside with the garden.
3.2 HOUSE P: “PYRAMIDES IN ALMERE”.

The pyramids are designed by the architect group “ArchitecteCentrale” in the Netherlands. The pyramids are designed with the same size ratio as the Great Pyramids of Cheops at Gizeh. The small one is ¾th of the big one. The distance between the pyramids in the floorplan is chosen as a numeric sequence 12-7-9, which gives a difference of 2-3-5, all primary numbers.

The large pyramid has a recess which is used as a bedroom. The small pyramid is a silence and meditation pyramid. The pyramids are privately owned and for private use.

The choice for massive wood was made because of the big and complicated windows. In a previous design the pyramid was constructed as a traditional roof: beams and planks. This however, although beautiful, would entail a lot of beams with sawed off ends under different angles.

Both pyramids wear two symbols as windows. The origin of the symbol is in India. The circular symbol has symbolizes the four forces of Wisdom, Creation, Love and Perfection.

The "star" symbol represents the upward triangle human aspiration and the descending triangle the answer to that aspiration. The square that make two triangles symbolizing the new man with the lotus on the water are proposing new consciousness.