

CLT – material for the measure of the future

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Abstract: *CLT – material for the measure of the future.* CLT (cross laminated timber, X-Lam) is one type of engineered wood products. The first idea of CLT was presented in the seventies of the last century in Austria. Over the following years, the concept of cross-gluing wood was intensively developed in Europe, USA, Canada and China. Based on the literature data, this work presents history, structure, production process, selected mechanical and physical parameters and applications of CLT. CLT is a wood panel product made from gluing together layers of solid-sawn lumber. The number of wooden layers is unpaired, most often 3, 5 or 7. Each layer consists of closely spaced and parallel boards. Adjacent layers are perpendicular to each other. The physical and mechanical properties of this product depend on many factors, e.g. number of layers and their thickness, the width and thickness of the boards in the layer, class of lumber, species of wood. Despite the fact that CLT is rather new material often used, especially in construction industry (both single-storey and multi-storey buildings). The short time of project implementation and their ecological character indicate that CLT is the material of the future in construction industry.

Keywords: cross laminated timber, engineered wood, wooden construction

INTRODUCTION

Wood as a construction material has been used for thousands of years. The first primitive buildings were created by using grasses and tree branches (120000 – 40000 years BC). Today, wood is used in many areas of the construction (e.g. load-bearing elements, building facades, window and door frames). Due to the high price of good quality wood and intensive development of new technologies, wood - and wood-like materials are increasingly used (e.g. plywood, OSB – oriented strand board, LSL – laminated strand lumber, LVL – laminated veneer lumber, PSL – parallel strand lumber). These materials have got wood-like mechanical parameters and often similar visual impression. Recently, one of such versatile building materials is CLT (cross laminated timber). CLT (X-Lam) is a sub-category of engineered wood, also known as „man-made wood” or composite wood. Engineered wood is conducted from multiple layers of part of wood connected using heat, glue and pressure (e.g. glulam – glued laminated timber, finger jointed lamellas and of course CLT). Engineered wood products are used in a variety of applications, from home construction to commercial building and to industrial products. In fact CLT, thanks to its special laminar structure making it well suited for use in construction, provides new horizons in timber engineering, in areas which had until now been the realm of mineral building materials like concrete and masonry. This paper provides information about history, production, properties and application of CLT. CLT panels can be produced from many types of wood, especially softwood. The main species is Norway spruce (*Picea abies* L.) and less often White fir (*Abies alba* Mill.).

HISTORY OF CLT

The first idea of CLT was presented in the seventies of the last century (Cziesieski, 1974). Over the following years, the concept of cross-gluing wood was intensively developed. The development of CLT from concept till now is illustrated in Figure 1.

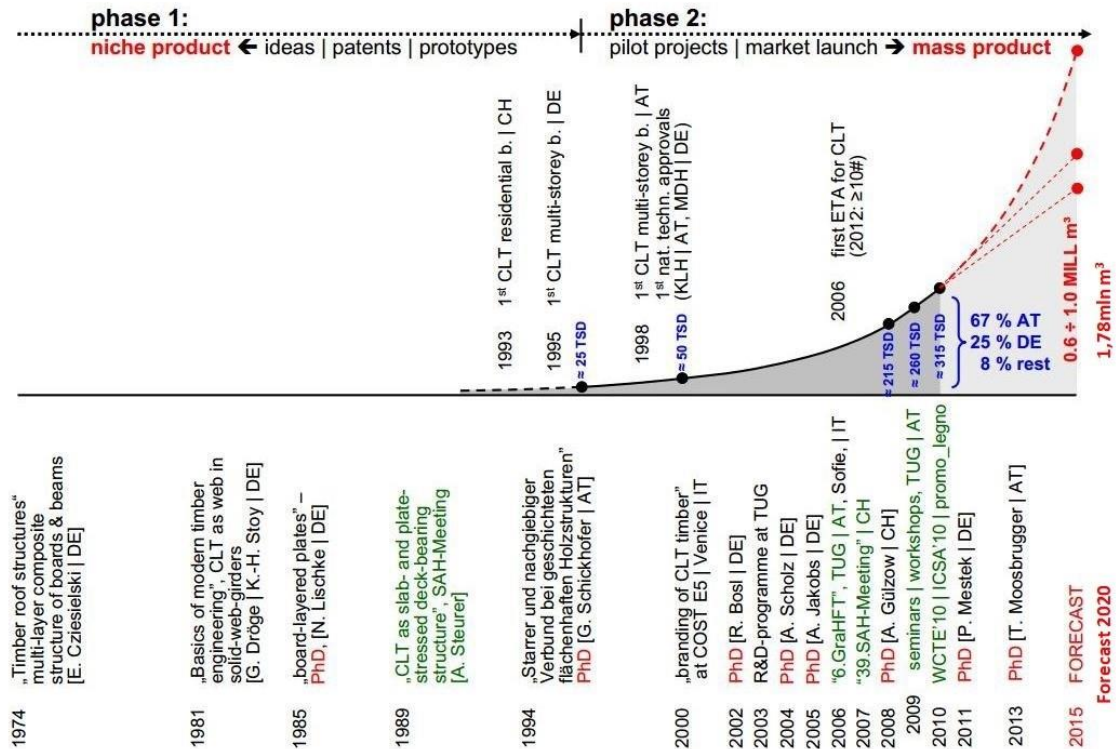


Figure 1. Development of CLT- timeline (Brandner, 2013); modified

The first CLT patent was obtained in France in the mid- eighties of the last century. Development of CLT technology have been realised primarily in Austria and Germany, where in the early 90's the CLT as an innovative material was presented. Over next years, the CLT production technology was constantly improved and the application possibilities expanded. The first residential building with CLT was built in Switzerland in 1993. Two years later, the first multi-story building from this material was built in Germany. In 1998, two European companies received approvals for the production and sale of CLT. Two years later, the term "Cross laminated timber" as an international nomenclature was approved (COST 5 Conference in Venice). In 2005-2010 CLT boards became widely used in the construction industry (Schickhofer, 2010). Currently, there is a very high demand for CLT panels, even exceeding their supply. In 2016, Europe produced about 680tys m³ CLT and forecast production for 2020 was 1.78 million m³ (an increase of about 1 million m³). Nowadays, around 65 % of the globally produced CLT comes from Italy, Czech Republic and the DACH region (Germany, Austria and Switzerland) (Ebner, 2017). Currently, CLT production is carried out in many places around the world, in North America, among others. The CLT industry in North America is growing slowly, but steadily (e.g. at the end of 2018, International Beams in Alabama launched the first CLT line with Southern Yellow Pine (*Pinus palustris* Mill. & *Pinus elliottii* Engelm), Vaagen

Timbers launched a CLT-glulam combination line in the state of Washington) (Günther, 2019). Antarctica was the only continent without CLT plants in 2020.

STRUCTURE AND PRODUCTION OF CLT

CLT is usually composed of boards with thickness 12 to 45mm e.g. in Austria is widely accepted standard for CLT layer thicknesses is 20, 30 and 40mm. According to the commonly used standard (EN 16351), panels with a thickness of 4 to 80 mm are allowed (i.e. also veneers and logs). Recently, there was no limit to the width lumber on CLT. Currently, according to EN 16351 the board width is regulated from 40 to 300mm. According to norm for structural timber (EN 338 and EN 384), the most suitable lumber width for CLT is 150mm. In general, only boards of prismatic cross section are used for CLT. In some cases, longitudinal edge of lumber is profiling (e.g. by tongue-and groove or special types of clearance profiles). The number of wooden layers is most often unpaired, 3, 5 or 7. Each layer consists of closely spaced and parallel boards. Adjacent layers are perpendicular to each other (Fig. 2). As a result, the desirable effect of a cross arrangement of fibers is created. Sometimes, adjacent layers (especially the outer layers) are arranged parallel to each other. This type of solution is especially used for floor and wall elements (Grasser, 2015). CLT panels can be produced from many types of wood, especially softwood. The main species is Norway spruce (*Picea abies* L.) and less often White fir (*Abies alba* Mill.). Furthermore, softwood such as European larch (*Larix decidua* Mill.), Scots pine (*Pinus sylvestris* L.), Swiss stone pine (*Pinus cembra* L.), Douglas fir (*Pseudotsuga menziesii* Mirb.), Maritime pine (*Pinus pinaster* Alton) are used. Hardwood is also used more and more for the production of CLT, Most often, the wood of silver birch (*Betula pendula*), Ash (*Fraxinus excelsior*), poplars (*Populus spp.*), locust tree (*Robinia pseudoacacia* L.). Thanks to use of hard wood (e.g. ash wood, locust wood), the CLT panel can retain certain mechanical parameters with a reduced thickness. Often, hard hardwood is used only for the outer layers CLT; inner CLT layers are made of cheaper and less durable birch or poplar wood. This significantly reduces the cost of CLT production while maintaining aesthetic values and mechanical parameters (Stauder, 2013).



Figure 2. CLT structure (*Global Warming, Carbon Dioxide, Buildings and CLT! - New Materials & Applications / New Materials & Applications (elsevier.com)*).

The base material for CLT has a moisture content of 8 to 12%. Moreover, the material must be visually suitable and mechanically strength according to norms (e.g. EN 14081-1 or DIN 4074-1). Within a single layer, all boards have to be of the same grade, otherwise the grade

of the single layer has to be assigned according to the lowest grade of the boards used. The most common strength class of lumber for CLT is C24, for a homogeneous layup, and, if combined, with C16/C18 for the transverse layers (Brandner, 2013). The simplified CLT production process is shown in Figure 3.

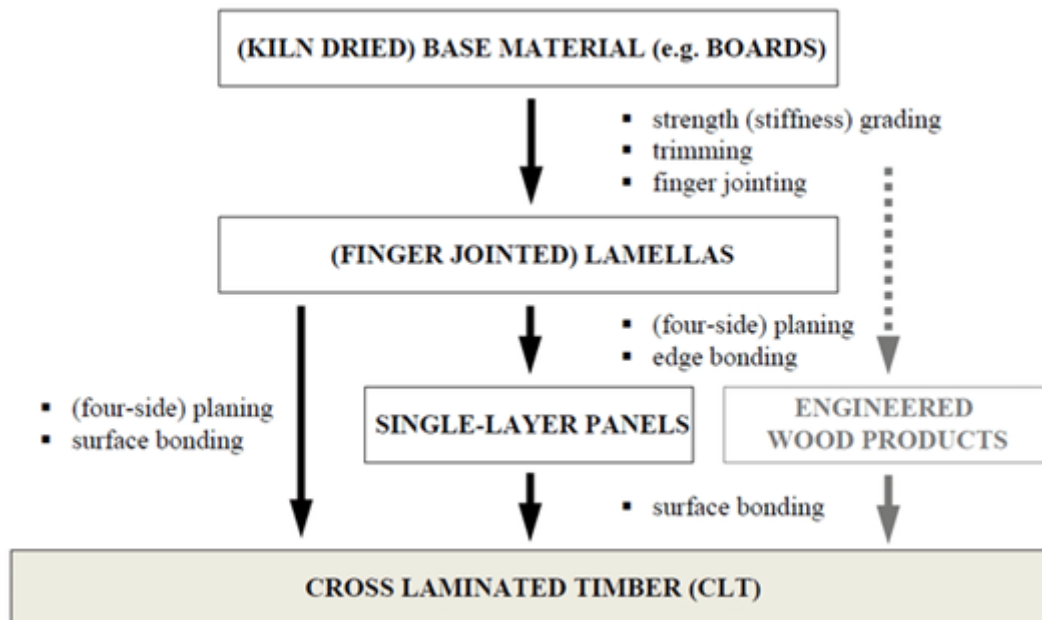


Figure 3. CLT production process (Brandner, 2013)

Structural timber can be classified, according to EN 338: 2016, into strength classes taking into account two decisive criteria: static bending strength and tensile strength along the fibres. Strength classes C are based on the bending strength. Timber in class, for example C24, has a guaranteed static bending strength of 24 MPa. The T grades are based on the tensile strength of the lumber along the grain. Timber classified as class T14 has a guaranteed tensile strength along the fibers of 14 MPa. T-classes are intended for use in the production of glued-laminated construction timber, where tensile stress is the dominant load. Class C is recommended in applications where the predominant load is static bending. For sawn timber in the C24 class, the characteristic value of the bending strength is 24 MPa, and for sawn timber in the T14 class, the characteristic value of the bending strength is only 20.5 MPa.

Apart from the classic CLT (glued), there are different varieties of this product on the European market. For example these are boards joined with aluminum nails. This type of CLT production technology is used, for example, by the German company Hundegger. HOLZ 100 is another variation of the CLT. In this version of CLT, the boards are connected with wooden pegs (panels consist only of solid wood, no glue, no metal). HOLZ 100 is produced by Thoma Holz Company, for example. The Holz 100 technology was developed in the 90s of the last century in Austria by Erwin Thoma.

SELECTED MECHANICAL AND PHYSICAL PROPERTIES OF CLT

Example of physical and mechanical parameters for the selected types CLT, according Unterwieser and Schickhofer (2013), are presented on Table 1 (strength class CL 24h and 28h with the T14 as basic material, number of CLT layers - 5).

Table 1. Mechanical and physical parameters of the example CLT (*strength class CL 24h and 28h with the T14 as basic material*); strength and stiffness – N/mm², densities – kg/m³. Basic material (board): height depth – $h_{CLT,ref} = 150\text{mm}$, thickness – $t_{1,CLT,ref} = 30\text{mm}$, width - $b_{CLT,ref} = 600\text{mm}$, $b_{1,CLT,ref} = 150\text{mm}$, number of CLT layers - 5 (Unterwieser and Schickhofer, 2013 – modified).

| | Base material | T14 | |
|---|------------------------------|-------------------|----------|
| | $CV[f_{t,0,l}]$ | 25% ± 5% | 35% ± 5% |
| | | CLT strengthclass | |
| property | symbol | CL 24h | CL 28h |
| Bendingstrength | f_m, CLT,k | 24 | 28 |
| Tensilestrength | $f_{t,0,CLT,net,k}$ | 16 | 18 |
| | $f_{t,90,CLT,k}$ | 0,5 | |
| Compressionstrength | $f_{c,0,CLT,net,k}$ | 24 | 28 |
| | $f_{c,90,CLT,k}$ | 2,85 | |
| Shear strength (shear and torison) – in plane | f_v,CLT,IP,k | 5,0 | |
| | $f_{T,node,k}$ | 2,5 | |
| Shearstrength – out of plane | f_v,CLT,OP,k | 3,0 | |
| | $f_{r,CLT,k} - b/t \geq 4:1$ | 1,25 | |
| | $f_{r,CLT,k} - b/t < 4:1$ | 0,70 | |
| Modulus of elasticity | $E_{0,CLT,mean}$ | 11,000 | |
| | $E_{0,CLT,05}$ | 9,167 | |
| | $E_{90,CLT,mean}$ | 300 | |
| | $E_{90,CLT,05}$ | 250 | |
| | $E_{c90,CLT,mean}$ | 450 | |
| | $E_{c90,CLT,05}$ | 375 | |
| Shearmoduls | $G_{CLT,mean}$ | 650 | |
| | $G_{CLT,05}$ | 540 | |
| Rolling shearmoduls | $G_{r,CLT,mean}$ | 65 | |
| | $G_{r,CLT,05}$ | 54 | |
| Density | $\rho_{CLT,k}$ | 385 | |
| | $\rho_{CLT,mean}$ | 420 | |

CLT is a multi-dimensional material with many advantages, e.g. high dimensional stability, high load capacity in two planes. Compared to other wood-like materials, CLT also has a high resistance to fire. Due to the little free space inside CLT, this material slowly char and fire does not spread. (Crespell and Sylvian, 2010, Stauder, 2013). The disadvantage of CLT as a building material is unfortunately low soundproofing (especially for low frequency sounds). Covering the CLT with an additional material, e.g. drywall, eliminates this disadvantage (Ferk, 2013). One of the most important parameters of building materials is thermal conductivity coefficient. In the case of CLT, this parameter is practically the same as in the case of solid wood; it is therefore depends on the base material. Many studies have show, that there is a linear relation between wood density and thermal conductivity – increase of wood density = increase thermal conductivity coefficient = decrease isolation properties (Mac Lean, 1941, Mason et al., 2016, Cavus et al., 2019). CLT has, like other wood products, relatively good thermal insulating characteristics. Heat conductivity or so-called lambda value, expressed in W/m°C, comparable with, for example lightweight concrete and there is substantially lower than for concrete and steel. CLT has a comparatively high specific heat capacity (thermal inertia). Usually it is around 1300 J/kg°C and compared to concrete which has

about 880J/kg°C (<https://www.crosstimbersystems.com/wpcontent/uploads/2016/05/Thermal-protection-.pdf>).

APPLICATION OF CLT

Despite the fact that CLT is a rather new material is often used. The beginnings of CLT application were usually ceiling systems or single- and multi-family houses. At this time, large-size CLT panels more and more often in the construction of multi-storey houses are used (Ringhofer and Schickhofer, 2014; Kotwica and Krzosek 2018; Przepiórka and Kotarski, 2019). This type of multi-storey residential buildings has already been built e. g. StadtHous Muray Grove in London (9 storeys, 30m high rekord 2009), Treet in Bergen, Norway (14 storeys, 49m high, record 2015) (Abrahamsen and Malo, 2014), Brock Commons in Canada (18 storeys, 53m high, record in 2017) (Fast, 2016; Haden, 2017)), Mjostarnet in Norway (18 storeys, 85,3m high, rekord 2019) (. Currently, the world's tallest timber building is HoHo Tower in Viena, Austria (24 storeys) (Woschitz, 2015; Woschitz and Holzhochhaus, 2017). The multi-storey building created by CLT technology is shown in Figure 4



Figure 4. The multi-storey building in Montreal (*Fot. S. Krzosek*)

Guided by the motto "everything is possible", the engineers even plan to build 300 m towers used CLT technology (Danzing, 2013). In plans or at the design stage are among others: Trattopen in Stockholm (40 storeys, 133m high), River Beach Tower in Chicago (80 storeys, 228m high), Oakwood Tower in London (80 storeys, 305m high), W350 Project in Tokyo (70 storeys, 350m high) (Przepiórka and Kotarski, 2019; Przepiórka and Kotarski, 2020). Currently, the CLT technology allows for the construction of floors, ceilings, full-storey walls, balcony construction and various interior finishing elements (Fig 5).



Figure 5. Corner joint of the walls (Fot. S. Krzosek)

By creating entire facades in the factory, houses made of CLT are built in a very short time. An example of this type of facade shown in the Figure 6 (Ringhofer and Schickhofer, 2014).

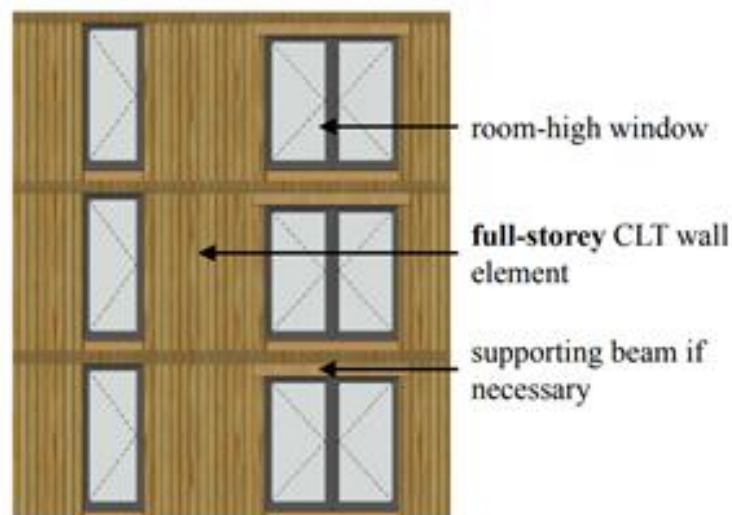


Figure 6. Proposed arrangement of wall elements in elevation ((Ringhofer and Schickhofer. 2014)

CLT technology is also increasingly used in the construction of buildings intended for offices, schools and kindergartens. CLT as a building material has many advantages (e.g. durable material, good thermal insulation and with the use of additional covers also good acoustic parameters, aesthetic form, fire resistance, short project implementation time). First of all, wood is an ecological material that is easy to recycle. Buildings made using CLT technology are not perfect of course. Their disadvantage is, e.g. sound transmission between floors, higher than in brick house (can be prevented by filling the ceilings with loose material). In recent years, the CLT board industry has been developing very intensively in Europe but also in the USA, Canada and China. Although many new CLT lines were recently deployed outside of the Alpine region from where the industry evolved, Alpine countries still account for over 70% the output volume and nearly 62% of the annual production increase (Muszyński et al., 2020). The CLT market has also grown rapidly in Poland. There are already many companies on the Polish construction market that offer houses built using CLT technology, e.g. Multicomfort Company in Wieliczka, MODUS-house „Centrum Kreatywności Targowa” in Warsaw, Przedsiębiorstwo

Budownictwa Drewnianego „Sowa” near Łańcut, BEST TIMBER POLSKA in Toruń, Markos Domy z Drewna in Istebna, CLT HOUSE in Kraków.

The short time of project implementation and their ecological character indicate that CLT is the material of the future in construction industry. After 25 years of development, the CLT industry still feels very young and as exciting as ever. However, that upbeat picture is clouded by the pandemic slowing down many sectors of the economy.

SUMMARY

CLT appears to be a solid wood substitute for many applications. Most often, this type of engineered wood for construction elements is used. CLT boards have got wood-like mechanical parameters and similar visual impression. CLT is a multi-dimensional material with many advantages, e.g. high dimensional stability, high load capacity in two planes. Compared to other wood-like materials, CLT also has a high resistance to fire. One of the greatest advantages of CLT is creating entire facades in the factory. Thanks to that and on the CLT structure, houses made of CLT are built in a very short time. The CLT technology was developed for soft wood and so far CLT boards from this wood mainly are produced. The main species is Norway spruce and less often White fir. Currently, hardwood (e.g. Silver birch, Ash, Poplars, Locust tree) more and more often for the production of CLT boards is used, especially for the outer layers CLT. In recent years, the CLT board industry has been developing very intensively in Europe but also in the USA, Canada and China. Unfortunately, there is no factory producing CLT boards in Poland yet. This may change in the future. Despite this, many Polish companies offer houses built using CLT technology, importing CLT panels from abroad.

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Streszczenie: *CLT – materiał na miarę przyszłości.* CLT (drewno klejone krzyżowo, X-Lam) jest jednym z rodzajów tzw. inżynierskich produktów drzewnych. Pierwszy projekt CLT powstał w latach siedemdziesiątych ubiegłego wieku w Austrii. Od tego czasu koncepcja krzyżowo klejonego drewna rozwijana jest intensywnie zarówno w Europie jak i w USA, Kanadzie i Chinach. W prezentowanej pracy, na podstawie danych literaturowych dokonano zestawienia informacji dotyczących historii, budowy, technologii produkcji, właściwości fizycznych oraz mechanicznych a także zastosowania CLT. Materiał ten jest coraz powszechniej stosowany w budownictwie zarówno do budowy domów jednopiętrowych jak i wielokondygnacyjnych. Ze względu na krótki czas realizacji projektów budowlanych oraz ekologiczny charakter materiału jakim jest drewno, płyty CLT mają przyszłość w budownictwie.

Słowa kluczowe: drewno klejone krzyżowo, drewno inżynierskie, przemysł drzewny

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