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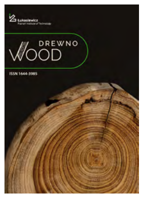

The Prefabrication of Glued Timber Houses for Residential Construction in Poland

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The building sector is under pressure to reduce its high amount of carbon dioxide emissions. In order to do so, whilst at the same time searching for solutions aimed at reducing the increasingly high costs of housing construction, various technologies are being tested that could speed up construction time and reduce the costs of production of multi-family residential buildings. Currently, in many countries the construction of such buildings from a prefabricated system made from massive, glued pine wood is being tested. This technology enables the reduction of labour requirements on the construction site and the use of basic building materials from renewable sources. This article analyses several examples of residential buildings constructed using glued timber systems in order to determine the real advantages of this technology as well as the difficulties and threats. The development of this technology is at a key point, with the possibility of its further development and dissemination, or its abandonment. It is also important to determine the boundary requirements for the location of this type of construction. Important boundary conditions include the legal system in force in each country, especially regarding the fire protection of buildings, as well as the availability of local wood resources, and the necessary transportation distance between the source of the raw wood material, the place of production of thick-walled plywood, the place of prefabrication of the elements, and the location of the final building site. Transportation logistics is one of the basic factors that can significantly contribute to reducing the costs of housing constructions built using this system. A separate problem to consider is the mental barrier in a society accustomed to the belief that true durability of a residential building is ensured by a concrete or masonry structure, and that wood is associated with impermanence. In the case of glued wood and the highly advanced technologies used to produce prefabricated elements such as CLT panels and to connect them using advanced technological joint solutions, the final product and technology meet all of the necessary technical requirements and ensure suitable climatic conditions within buildings.

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Introduction

Environmental analysis of the construction sector. In the face of intensifying climate change [Brussels Energy, European Commission 2019] and the high level of responsibility for carbon dioxide emissions being assumed within the construction sector [Zhao, Gao, Su, Wang 2023;Horowitz 2016], as well as society's growing environmental awareness, the search continues for effective methods of building housing architecture with a low level of ecological harm and high economic availability [Zhao, Zhou, Liu 2023; . Ekhaese, Ndimako 2023]. Most buildings currently being constructed are made of brick or reinforced concrete. These technologies, which are used on a massive scale, have contributed significantly to the degradation of the natural environment,

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Fig. 1. The construction site of a wooden detached house using the CLT system in Oświno (PL): (a) assembly of CLT panels, (b) interior finishing of CLT panels, (c) floor heating installations in the wooden interior, (d) construction of the house in its raw state. Photo by Natalia Paszkowska-Kaczmarek

climate change, and a significant increase in the costs of housing construction. According to latest research, activities related to the construction sector, consisting of the construction of buildings and their subsequent operation, generate approximately 40% of global carbon dioxide emissions, and thus contribute significantly to climate change [Horovitz 2016; Zhao, Zhou, Liu 2023]. Therefore, the building sector is seeking to decarbonize [de Oliveira, de Oliveira, Nascimento, Sampaio, Nascimento Filho, Saba 2023] and looking at ways of minimizing the negative impact of construction activities on the environment by using advanced technologies, while remaining aware that there is no technology that has zero impact on the natural environment [Liu, Wang, Wang, Liu, TangYang 2022].

Searching for new solutions to the housing problem. In the search for optimal solutions for residential architecture, the contemporary renaissance of wooden architecture deserves special attention. In the countries of Northern and Central Europe, wooden construction has a rich tradition, as is evidenced by the many historic wooden buildings featured on the international UNESCO Heritage List [Szwedzińska 2021] Modern wooden architecture is increasingly being implemented based on advanced glued timber technologies [Omer, Noguchi 2020]. These technologies can be used in particular in residential construction. They are expected to reduce the increasingly high costs of building homes using brick and reinforced concrete technologies, using various technologies that could speed up construction time and reduce the production costs of multi-family houses. The main subject of this article is a multifaced analysis of the cross-laminated timber (CLT) construction system[Albee 2019; Cherry, Manalo, Karunasena, Stringer, 2019;

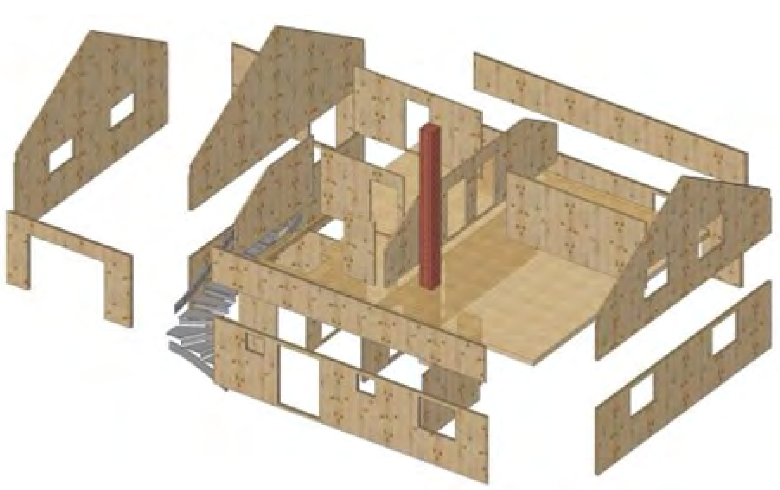

Fig. 2. Scheme of the prefabricated CLT panel structure of a detached house. By courtesy of Masterdom (PL)

Cherry, Manalo, Karunasena, Stringer 2019; Brandner, Flatscher, Ringhofer, Schickhofer, Thiel 2016; Kurzinski, Crovella, Kremer 2022].). Currently, many countries are testing the construction of multi-family residential buildings using a prefabrication system based on massive pine wood laminated panels or modules [Ilgın, Karjalainen, Mikkola 2023].Structures made from "mass timber" are becoming more and more popular in countries such as Austria, Sweden, Denmark, Switzerland, Germany, Australia, the USA, Canada, and China. The popularity of structures made of massive, glued timber has been boosted by the informal competition taking place around the world for the tallest building constructed using a prefabricated timber structure. In 2023, the 86.6-metre-tall mass-timber Ascent building in Wisconsin was certified as the world's tallest timber building. Last year, in the city of Perth in Australia, the tallest building project in a hybrid massive timber structure, designed by Fraser and Partners, was launched. This 189-metre-tall residential tower, named the C6 Tower, is setting the "new benchmark in height for mass timber". On completion, the C6 Tower will become the world's tallest hybrid timber housing building. Other planned timber towers include a 180-metre-tall hybrid timber tower in Sydney designed by SHoP Architects, and a 100-metre-tall housing block in Switzerland designed by Schmidt Hammer Lassen [Peacook 2023] .

In the Scandinavian countries, wooden structures have a historically established position as one of the leading technologies for residential construction. One of the best-preserved wooden towns in Sweden is Eksjö in Småland province, dating from the 17th century [Visit Smaland (2025]. The houses of Eksjö were built from massive beams, protected with characteristic red protective paint Falu Rödfärg. Modern mass timber technology has been displayed by the world-renowned Swedish enterprise [Stora Enso 2023]. The newest example of structural development in mass timber architecture is the "Wood City" quarter in Stockholm[Carlson 2023]. This investment has been planned by the developer Atrium Ljungberg, using contemporary CLT technology, and by the Danish architectural firm Henning Larsen Group [Henning Larsen 2025], in cooperation with White Arkitekter [White 2025] from Sweden, as a part of the postindustrial revitalization of the Sicla District.

A number of different, parallel technologies used in residential construction illustrate the current dynamic development of glued timber construction technology, generally called Glue Lam or "mass timber" [Lawrence 2019]. The reason for the widespread development of various technologies is the search for construction solutions which are most appropriate to the project and have the lowest possible negative impact on the environment.

Materials and methods

This article applies a descriptive method with regard to construction technologies using glued timber, with a discussion of their origins, and an assessment of their usefulness in contemporary residential architecture, having regard to different features and the possibilities of further development. Their positive and negative features are compared based on a binary comparison, with an attempt at a synthetic summary. Most of today's leading and most interesting construction systems using glued timber technologies include CLT (cross-laminated timber) technology[WoodWorks 2025]. This conclusion is based on an analysis of the contemporary situation in relation to the authors' own architectural projects carried out using CLT technology, as well as an analysis of the cases of other ongoing or completed projects, with a scope limited to Northern Europe. It should be noted, however, that CLT technology has also been widely developed in the North American and Australian markets, and in Canada. There have also been interesting attempts to introduce and develop this technology on the African and Asian continents [Horowitz 2013] There are, however, broad differences in the legal frameworks relating to the performance of CLT technology around the world. The differences in the functioning of building codes around the world are compared and analyzed in [Kurzinski, Crovella, Kremer (2022].

In Europe, the production and use of cross-laminated wood (CLT) developed only around 1990, leading to an industrialized technology for the large-format production of CLT. The production of CLT timber structural elements was begun by the Austrian company KLH Massivholz [KLH 2025]. That company launched its first production operation in Teufenbach-Katsch, Austria, after three years of research and development in cooperation with TU in Graz. CLT, as a new ecofriendly building material representing a new technology type, spread rapidly in both Europe and North America.

The CLT technique is one of the leading construction systems amongst the different glued and laminated timber technologies.[1] CLT panels are composed of odd layers of dimensional timber oriented at right angles to each other and then glued to create structures with exceptional strength, stability and stiffness. CLT panels are used to construct walls, floors and roofs – either as a stand-alone system or with other structural products (e.g. columns and beams). Thanks to cross-lamination, CLT offers large span possibilities in two directions. CLT laminated timber technology reduces necessary work on the construction site and shortens construction times, as well as providing a number of other benefits, described below. Several other types of glued timber structures, based on techniques similar to CLT, have been developed, such as:

- Glulam timber (glulam or, when used as panels, GLT)
- Nail-glued timber (NLT)
- Dowel laminated timber (DLT)
- Structural composite lumber (SCL)
- Parallel strand lumber (PSL).

There follows a more extensive description of the above-mentioned technologies.

1. Glulam (GLT) combines traditional mass techniques with precision and quality of engineering. The result is a stronger, lighter structural material that also offers a cleaner, more attractive aesthetic. GLT panels can be manufactured in a wide range of configurations, sizes and species for an infinite number of impressive and ecological design applications. The finish can be tailored to customer specifications. The technology can be used for framing in tall timber buildings or structures, particularly for floor and roof panels. Advantages include their aesthetic appearance, reliability, strength and light weight, making them a convenient alternative to concrete slabs [Naturally:Wood 2022].
2. Nail-glued timber (NLT) is produced by placing dimensional lumber on edge with individual laminations mechanically fastened together with nails or screws. The boards are of nominal 2x, 3x and 4x thickness. The width is typically 4–12 inches. NLT derives its strength and durability from the nails or screws that hold individual pieces of dimensional lumber together in a single structural member [Think Wood 2025]. NLT's resurgence is due in large part to its domestic availability. The mass timber product does not require a dedicated manufacturing facility – unlike other building materials such as CLT – and can be manufactured using readily available dimensional lumber. This allows project teams and contractors to use locally sourced materials. Applications for NLT include flooring, decking, roofing and walls, as well as elevator and stair shafts. Because it is made of wood, NLT offers a consistent and attractive appearance for decorative or other visible applications. The International Building Code (IBC) recognizes NLT as code-compliant for buildings of varying heights, areas and occupancies
3. Dowel laminated timber (DLT) is a mass-produced wood panel product made by stacking or cross-laminating dimensional lumber with hardwood dowels. DLT is made from graded lumber that is structurally finger-jointed, passed through a moulding machine to cut and shape the wood, and laminated into large panels. The product is prefabricated into panels using a high-powered hydraulic press, which presses the hardwood dowels into tight-fitting holes in the lamellas (layered panels pressed together) all within a factory setting. The product uses the different moisture content of the softwood and hardwood components to create a friction fit. This means that differences in the moisture content of the boards, which shrink, and the dowels, which swell, help to hold the panels together. Typically, the sheathing is pre-installed and the exposed faces are finished, making the product ready for delivery to the construction site. DLT is the only all-wood mass timber product, which means that it can be easily machined and cut using computerized numerical control (CNC) machines or modified on-site. Adhesives and glues are generally not used in the manufacture

1 In Poland, CLT technlogy is subject to the rules and norms laid down in the following Polish standards:
– PN-EN 16351:2015 Wooden constructions – Cross-laminated timber – Requirements.
– PN-EN 1995-1-1:2010 Design of wooden constructions – Part 1-1: General provisions – General rules and rules concerning buildings.

of DLT, unlike other products, and there are no metal fasteners or nails. DLT, like other mass timber products, is used in a wide range of building types, from offices and schools to commercial and public buildings. It can be used for walls, floors and roofs. DLT panels can be used as stairs and lift shafts and can be bent and assembled to create curved roof structures [Naturally:Wood DLT 2025] .

4. Structural composite lumber (SCL), which includes laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL) and oriented strand lumber (OSL), is a family of engineered wood products manufactured by layering dried and sorted wood veneers, strands or flakes with a moisture-resistant adhesive into blocks of material known as billets, which are then resawn to specified sizes. In SCL billets, the grain of each layer of veneer or flake is predominantly in the same direction. The resulting products outperform conventional lumber when either face- or edge-loaded. SCL is a solid, highly predictable and uniform engineered wood product that is sawn to consistent sizes and is virtually free of warping and splitting. Typical applications for SCL include rafters, headers, beams, joists, studs, columns, and I-joist flange material. Two or three sections of SCL can be joined to form 3-1/2" or 5-1/4" members. These thicker sections fit easily into 2x4 or 2x6 framed walls as headers or columns.
5. Parallel strand lumber (PSL) is a part of the SCL family described above, and consists of dried and graded wood veneers, strands or flakes that are layered and bonded together with a moisture-resistant adhesive into large blocks called billets or columns. PSL columns are strong and uniform. The manufacturing process uses veneer strands, allowing a significant percentage of each log to become a high-quality structural member. The advantages of PSL columns include consistent performance; availability in large lengths, excellent joint performance, visual appeal in exposed applications, and efficient use of natural resources. Due to its flexural strength, PSL is used for long span beams, heavy duty columns and large headers, and is well suited to applications where high flexural or compressive loads are required. It can be used in both internal and external applications. PSL is manufactured from strands bonded together in a continuous press using water-resistant phenol formaldehyde-based adhesives. It can be manufactured from plywood and LVL production waste, pine and western hemlock. It has a rich texture and retains numerous dark glue lines. PSL can be stained to enhance the warmth and texture of the wood. It is sanded at the end of the production process to ensure accurate dimensions and a high-quality finish. Specific technical properties of PSL are unique to each manufacturer and are not subject to any common production standard or design values [Naturally:Wood PSL 2025].
6. The following comparative table, showing the main characteristics of different wood technologies, has been prepared on the basis of technological descriptions and the authors' field experience. It shows that CLT and glued laminated timber (GLT) are preferred over the other technologies for housing construction in Poland.

APA – The Engineered Wood Association, a not-for-profit trade association in the United States, founded in 1933, that works with its members to create engineered wood products with exceptional strength, versatility and reliability, provides the following definition of CLT technology: "Cross-laminated timber (CLT) is a large-scale, prefabricated, solid engineered wood panel. (…) A CLT panel consists of several layers of kiln-dried lumber boards laid in alternating directions, held together with structural adhesives and compressed to form a solid, straight, rectangular panel. CLT panels consist of an odd number of layers (usually three to seven) and may be sanded or pre-finished before shipping. At the factory, CLT panels are cut to size, including door and window openings, using state-of-the-art CNC (numerically controlled) plotters capable of making complex cuts with high precision. Ready-made CLT panels are extremely stiff, strong and stable, transferring loads from all sides" [APA Wood 2024].

According to a description of CLT technology by the Modus company of Warsaw, Poland: "the elements consist of several boards, most often spruce or larch boards, laid crosswise in layers at an angle of 90 degrees, then glued and cold-pressed". The thickness of the panel depends on the number of layers used. CLT panels can be produced in non-standard dimensions, tailored specifically to customer needs. The material used to build a house made of CLT wood is subjected to a drying process. In this way, a humidity of approximately 8% is achieved. This degree of humidity ensures the high stability of the element and prevents the formation of gaps. Moreover, the wood becomes resistant to all kinds of pests, fungi and mould. The boards are connected using micro-joints and structural glue. The slats are glued together in all directions.

Adhesives for bonding structural wood elements are an important part of the construction of CLT panels. The adhesives used to join the structural wood elements are completely odourless and transparent when cured, and do not contain harmful substances such as formaldehyde or solvents. The adhesives used in production must comply with European standards and be approved for use in load-bearing construction.

Table 1. Comparative characteristics of different types of wood technologies for housing purposes in Poland. Evaluation prepared by the authors

	The features of timber technologies	**CLT**	**GLT**	**NLT**	**DLT**	**SCL**	**PSL**
1	Application:						
2	• frame structure	high	high	no	high	high	high
3	• long span beams	low	high	low	high	low	low
4	• curved beams	low	high	high	high	high	high
5	• walls	high	high	low	high	med	high
6	• floors	high	high	no	high	med	high
7	• columns	high	high	low	high	high	high
8	• intermediate ceilings	high	high	med	low	high	high
9	• roof's structures	high	high	med	low	high	high
10	Interior finish:						
11	• aestetic appearance	high	high	med	high	low	low
12	• design trendy	high	high	low	high	low	low
13	• wooden not chemical smell	high	high	high	low	low	low
14	Production:						
15	• individual production on-site	no	no	high	no	no	no
16	• labor intesity	high	high	low	high	high	high
17	• manufacturing	high	high	low	high	high	high
18	• standard panels production	high	high	low	high	high	high
19	• CNC customised production	high	high	low	high	high	high
20	Standarisation grade:	high	high	low	high	high	high
21	Wood type used:						
22	• wood beams	low	low	low	high	no	no
23	• wood lumbers	high	high	high	high	no	no
24	• wood veneers strands and flakes	no	no	no	no	high	high
25	• plywood waste	no	no	no	no	high	high
26	Other components used:						
27	• Steel nails	no	no	high	no	no	no
28	• phenol-formaldehyde	no	no	no	no	high	high
29	Construction:						
30	• customised prefab assembly	high	high	low	high	high	high
31	• standard element cut on-site	no	no	high	no	no	no
32	• structures elaborated on-site	no	no	high	no	no	no
33	Availability of products in Poland:	high	high	low	low	low	low

The main research questions addressed in this article are: How can the experience with CLT technology in Northern European countries be transferred to Poland? How can Poland benefit from this technology and the already rich spectrum of knowledge related to it?

In Poland, a number of organizations promote architecture using wooden structures. One of them is [Polskie Domy Drewniane SA 2025]. This company intends to build residential buildings of up to 9 storeys from pine trees growing in the northern and central parts of Poland. This industrialized mass production is planned to be supported by CLT technology. In 2023, the Polish National Center for Research and Development granted a sum of PLN 12.45 million to a project for developing the technology of construction panels made from Polish cross-laminated pine wood. These new panels should have an increased fire resistance class in order to be used in the construction of multi-storey wooden housing structures. Timber-structure buildings built in Poland at present are permitted to have only four storeys. The planned new CLT technology, thanks to its fire-resistant features, will allow the construction of buildings up to nine storeys high. Relevant research has already been performed in various countries and the results reported [American Wood Council 2023]. Other research is also being carried out on the safety of CLT boards, with regard to their impact on human health and the environment [Evans 2013].

More and more construction companies are focusing on the production of wooden houses using new technologies, such as CLT. These include the Multicomfort family company from Wieliczka near Krakow (Poland), which has been operating in the construction market for 15 years. Currently, it specializes in the construction of single-family and multi-family residential buildings, as well as CLT office buildings, with up to 5 storeys. The company provides a full range of services, from the production of glued CLT sandwich panels, and the prefabrication of wall, ceiling and roof elements in its own production plant, to the on-site construction of complete residential buildings. The company's portfolio already includes 500 completed CLT structures [Multicomfort 2024] . The second example of such a company is Modus House Sp. z o.o. of Warsaw [Modus House 2024]. Modus is a group of architects who not only design interesting structures using the CLT system, but also closely cooperate in the construction process, achieving notable results. This ability to integrate design and construction, thanks to their ability to guarantee a high standard of work and compliance with the design vision, gives them an advantage in the construction market. They also popularize CLT technology by advising other architects on how to design structures using this system. The growing demand for CLT products has also led to the establishment of several new companies offering design and construction using the CLT system.

Results

A search of the available information showed the existence of many examples of designs and implementations of these types of structures and significant progress in the development of the system. A review of the projects indicates the high standard of these buildings, in terms of both architectural form and innovative design ideas, and in the technology used. CLT boards have the advantage that they can be left as the final interior finish of the surface of the supporting structural material. The visible wood structure of ceilings, load-bearing walls and partitions offers additional aesthetic value. Wooden walls and ceilings provide completely new possibilities for the shaping of interior architecture, giving it a modern character. It is also important that this technology significantly simplifies the finishing stage of buildings, eliminating the need to perform additional finishing works on walls and ceilings, using standard materials such as plaster and emulsion or plaster and paint.

Examples illustrating the principles of this construction system, and the final effects of the completed buildings, are presented at the end of this paper. The literature survey and the authors' own experience in designing and building glued-laminated timber structures, as well as visits to the construction sites of residential buildings in Poland and abroad built using this technology, have

Fig. 3. Houses in Krakow constructed by Multicomfort using CLT, covered on the outside with thermal insulation panels and steel or plaster final finishes, protecting the timber structure from adverse weather conditions. This also reflects the social prejudice that it is better to live in a brick building than in a wooden house. Photo by the authors

led us to the opinion that this system has an excellent future and a huge potential sales market. Important technical aspects are those related to the production costs of this type of construction. All forms of prefabrication, typification and repeatability may, in the long run, significantly reduce the unit costs of construction, similarly to the possibility of constructing tall objects from wood. The regional diversity of buildings is also indicated, arising from such factors as the availability of materials, formal characteristics of the architecture, the size of the development, and the availability and unit costs of building land.

Discussion

Manufacturers and contractors involved in wooden construction and using the CLT construction system agree that it has numerous undeniable advantages and brings benefits to all parties. The most important advantages of this system include:

1. **Environmental advantages.** Use of CLT decreases the impact of the building sector on the environment, lowers its carbon impact, promotes recycling, and reduces the amount of waste. Living in wooden houses is also healthier.
2. **Strength of wooden construction materials.** All panels are have a high strength-to-weight ratio, good stability and unprecedented static load-bearing capacity, creating a safe and fully wooden structure. The drying and gluing technologies used guarantee the durability of the panels' shape, even with changes in humidity levels.
3. **Installation of CLT wood panels.** One of the advantages of building with CLT wood is the simple technology for assembling the prefabricated walls, simple construction details, and the small number of assembly connections needed. The finished panels are delivered direct to the construction site, where, in a short period of time, the fully assembled structure can be created using a crane. Shortening the construction time translates into lower investment costs.
4. **Customization of CLT panels to individual needs.** All panels are produced in precise formats with selected processing of connections, with openings for windows and doors and individual adaptation for the connection of internal installations in the building, such as water supply, sewage, electricity and gas. If necessary, additional hydrophobic and/or thermal insulation can be provided.
5. **Energy saving.** CLT boards minimize energy losses due to prior processing in the factory and the large format of the boards. This makes them an impermeable material, with few butt joints. For this reason, buildings constructed using this technology achieve high air-tightness.
6. **Possibility of additional thermal insulation.** The CLT construction system provides the possibility of insulating walls made of CLT panels with an external thermal insulation layer, ensuring high comfort of use of the building in winter. External thermal insulation can be achieved using insulation systems made of wood wool or rock wool panels and external finishing with plaster or external cladding.
7. **Precision.** The list of advantages of the CLT system also includes precision of workmanship. Because CLT panels are made using advanced technologies, including the production and cutting of boards and connections using CNC numerical machines, the technology and the final product meet all necessary technical requirements for a precise finish. This allows the walls of residential interiors to be left as wooden surfaces without finishing, and ensures a pleasant, homely atmosphere inside.

The discussion raises a number of problems that require further research and the finding of appropriate solutions. Among the most essential problems requiring further research are the following:

1. **Fire resistance.** Construction law in each country specifies different boundary conditions for the use of wood as a construction material, limiting its use according to the building's function, the size of the fire zone, or the number of floors in the building [Frangi, Fontana, Hugi, Jübstl 2009]. Proponents of the CLT system note that solid CLT wood has high fire resistance and is therefore suitable for use not only in single- and multi-family houses, but also in public buildings – offices, kindergartens, schools and hospitals. Comparing CLT boards with steel and reinforced concrete, it can be concluded that they are more resistant to higher temperatures due to their structure. During a fire, CLT boards, due to their massive size and wood processing, burn only on the surface, retaining their ability to carry static loads. As a result, CLT boards offer high fire resistance, and fire spreads much more slowly in the building [Wood Council 2023; Aloisio, Pasca, De antis, Hillberger, Giordano, Rosso, Bedon 2023; Ussher E., Aloisio A., Rathy S. 2023] Degrees of fire resistance are not obvious. Fire resistance is measured not on the basis of theoretical calculations, but on the basis of empirical tests, i.e. by fire testing. For example, prior to the construction of an 18-storey CLT building in Vancouver, Canada, a project supported by a 2021 U.S. Forest Service (USFS) Wood Innovation Grant demonstrated that a CLT-based exterior wall assembly could pass fire

testing according to the NFPA 285 standard. The IBC[2] initiated a burning test study of a solid wood external wall model. The fire test carried out according to the NFPA 285 standard for "assessing the fire spread characteristics of external wall units containing flammable components" was successfully completed[Izzi, Casagrande, Bezzi, Pasca, Follesa, Tomasi 2018; Mohd, Tahir, Lee et al. 2019]. This enabled the granting of permission to construct buildings having an external wall structure built using CLT with a height of 18 storeys. Without the successful results of such a test, any designer seeking approval for a design involving external CLT walls over 12 m high could be required to perform individual fire tests to obtain a building permit.

2. **Acoustics.** In terms of acoustics, the CLT system is a comparable alternative to heavier structures. The acoustic properties in multi-family buildings are a much more important design criterion than in buildings with other functions. Acoustic insulation issues within a CLT building, constructed either from a mass timber or a lightweight partition wall system, must be considered in conjunction with other requirements such as fire protection features and structural stability. The optimal design solution should determine the relationship between the interior finishing and the supporting structural system, and should also take into account the requirements and expectations of the constructor and future users. Despite the existence of IBC[3] standards regarding acoustics and system solutions used in wooden architecture, some investors expect a higher level of acoustic insulation performance than the minimum standards indicate. The final levels of acoustic insulation can be checked only empirically, using acoustic tests in the completed building. The transmission of sounds across walls between residential premises, such as conversation or music, is examined, as well as the sound of traffic or the impact of dropping a book between floors.
3. **Mental barrier to acceptance of wooden homes.** A separate problem worthy of consideration is the mental barrier, in a society accustomed to the belief that real durability of a residential building is ensured by a concrete or brick structure. For many years, wooden architecture was associated with impermanence and backwardness. The instability of wood is related to its decay due to moisture, flammability, the nesting of insects and arachnids in wooden beams, noise transmission, and lack of air-tightness. There is also the possibility of a reduced sense of security in the event of a terrorist attack, war, etc. Breaking this barrier is difficult because these fears are largely not justified in fact, but result from the previous experiences of European society, and the inherited trauma of danger, which has not subsided in the current geopolitical situation. The saying "my home is my castle" is becoming as relevant today as it was in the Middle Ages. Overcoming the mental barriers related to the rejection of wood as a construction and finishing material in residential architecture is extremely difficult. It requires awareness, perceptions and willingness [Mallo, Espinoza 2015] - education, advanced forms of marketing, good and attractive architectural designs, and above all, a sense of external security
4. **The renewable nature of wood as a building material.** The principles of sustainable development operational in Western countries indicate the need to have a comprehensive understanding of the protection of the natural environment and use it only to the extent necessary, and to ensure the use of renewable natural resources. This also applies to forest management. Structural wood can be used in construction, but excessive use may result in local deforestation or the lack of an appropriate forestry resources restoration system. Wood is undoubtedly a renewable resource, but the scale of production of wooden construction should be adjusted to the attainable pace of renewal.
5. **Transport.** The first element of the transport chain is the transport of harvested wood in the forest area to the sawmill, and then – in the form of formatted square timbers – to the place of prefabrication of the layer-glued structural elements. The next element of the chain is the transport of the prefabricated structural elements from the place of their production to the construction site, which is a factor that increases the cost of the process of constructing buildings using the CLT massive wood construction system. The ideal solution is to shorten transport delivery routes as much as possible, and thus to build local sawmills and CLT construction plants within a small transport service radius. Transportation logistics is one of the basic factors that can significantly contribute to reducing the costs of building homes using the CLT system.
6. **Hybridization of the CLT system**. The CLT construction system can be integrated very well with other systems or their elements. This is evidenced by numerous examples of the implementation of such "hybrid" structures around the world, especially integration of the CLT system with GLT and a commonly used frame system, as well as the combination of a wooden structure with a reinforced concrete foundation, plinth, podium or emergency staircase. The key is to find the most appropriate structural system to perform the functions of the elements of that system within the

2 IBC – International Building Code – an international organization regulating the principles of construction law.

3 These standards are specified in the International Building Code (IBC), as well as in international standards and construction laws applicable separately in each country.

Fig. 4. An example of multistorey housing using CLT hybrid construction. Steel construction elements strengthen the structural skeleton of the building, while the CLT panels fill the wall and ceiling structure. Photo courtesy of Multicomfort

building being designed and constructed. Multi-aspect optimization suggests various types of structural hybridization. The selection of solutions may depend on the availability of materials, construction location, technology, or specific functions to be performed by the individual elements of the system. Hybridization of the system requires the development of intricate details of interconnections, seals, expansion joints and insulation. These are the so-called "weak points in buildings" where construction failures may occur.

Conclusions

The following conclusions can be drawn from the study:

1. The CLT construction system, like any system, has specific advantages and disadvantages that are local and regional in nature and will stimulate the developmental possibilities of this system to specific extents in specific regions and urbanized areas.
2. Determining the actual advantages and disadvantages of wooden construction technology using the CLT system, documented in implementation processes and cost estimate analyses, is a key factor in the further development and popularization of the CLT construction system.
3. It is important to determine the boundary requirements for this type of structure: functional use, optimal and preferred forms of architecture, height of buildings, etc.
4. The single- and multi-family residential function is the preferred function for buildings designed using CLT wooden structures.
5. An important boundary condition potentially limiting the development of this system is the legal system in force in each country, especially regarding the fire protection of buildings and the protection of the environment and forest resources.
6. To enable the international supply and application of CLT constructions worldwide, the coordination and synchronization of regulations and norms between different countries should be a goal. This could help achieve a better understanding of environmental issues in different countries and coordinate forest harvesting, shortening transportation routes and reducing production costs.
7. When promoting the development of multi-family architecture implemented in wooden structures using CLT prefabrication systems, it is necessary to take into account the social mentality that does not always uncritically accept wooden architecture in places of permanent residence.
8. For the successful development of the CLT construction system, the availability of local, quality wood resources is a key precondition, in addition to short transportation distances between the place of logging, the place of production of CLT panels, the place of prefabrication of elements, and the location of the final construction site. These preconditions can lead to the identification of preferred localities for economically justifiable mass production of timber housing.
9. Education for CLT production and construction staff should be introduced, and knowledge of the CLT system should be disseminated amongst students of architecture, design and craftsmanship, as well as the general public, in order to make them more familiar with the application of timber in house-building.
10. Poland has great potential for the application of timber technologies in the housing sector. The obstacles to their development are the excessive prices of imported panels, the low level of CLT production in Poland, and mental barriers against accepting wooden structures as long-term stable and safe housing. However, it seems possible to overcome all of these barriers.

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