How to construct a portable building?

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1. The portability and disassemblability of buildings – new trends of construction

In the early 1950s, U.S. companies began to market a cheap and simple form of portable housing which could, in addition to functioning as a holiday home, serve the needs of more long-term accommodation. Districts of portable buildings began to take shape around popular cities. In fact, portable houses have been in residential use for decades in the United States and Canada.

In Finland, prefabricated construction began to gain popularity as early as the 1960s, which led to a significant decrease in on-site construction. The elements can be easily built in the sheltered factory environment, eliminating the need for protecting them from the elements during construction. In modern building activities, modular construction has emerged alongside the use of prefabricated elements. The movable modules are used to build either permanent or portable buildings. Portable buildings can be used temporarily and transported to another location as needed. (Keisu, 2016)

Currently, the latest building-related innovations in Finland are related to the movability of buildings. The first modern portable building was brought to the Finnish market by Teijo-Talot Oy in 2007 with the introduction of a ready-for-use home that would be transported to the site on special delivery lorries. The buildings were lowered onto a bed of gravel and, according to the company, the installation only took a few hours (www.teijotalot.fi).

The future of portable buildings looks promising in Finland. The typical portable building is constructed from modular units and can be easily transported on a lorry bed without special transport arrangements. A complete portable building is usually one or two modules wide, with the option to add modules if necessary. (Puumies 10/2018; Keisu, 2016; www.teijotalot.fi)

A. Why are portable and disassemblable building solutions needed?

The rapid population increase coupled with the dwindling of residents in certain municipalities makes it more difficult to estimate construction needs. Suburban areas that are exploding in size require more day care centres, schools and health care and social welfare facilities, so portable buildings are used to combat the shortage in the fields of education and health care, for example.

In many towns, the population decline has impacted public building solutions. According to Vihola's study (2019), many municipalities have overestimated the need for school premises in their construction efforts. Yet a large number of municipalities have extensive school construction plans. A study on the use of space in education implies that large schools are already underutilised, which does not encourage the construction of large new schools. What we need to do now is look at the big picture, instead of individual buildings, and prepare comprehensive life cycle analyses. Movable school solutions and modular construction can also serve as solutions for declining pupil numbers since the schools can be moved or reduced in size if necessary.

In modern society, human behaviour and the logic of mobility are vastly different from before. People are far less static in their activities than earlier generations, which impacts the opportunities for applying modern architecture. As such, the design logic of modern buildings has only just begun to meet end user demands with regard to more flexible and adaptable architecture. (De Berardinis et al., 2017)

One new method for resolving space-related issues is to use prefabricated multipurpose modules that can meet a variety of needs. They are flexible and modular structures where the basic module can be connected to others, enabling increases in size depending on the users' spatial and functional requirements. Modularity is a flexible solution to meet the changing needs of businesses and public buildings. (www.teijocon.com, De Berardinis et al., 2017).

Figure 1. The Teijo-talot modules are transported with the foundation attached. Photo: www.teijotalot.fi

Thanks to the detachable components, modular construction is also a suitable solution for controlled disassembly. In addition to this, modular construction is flexible as spaces can be divided based on operations and user needs. The modules can also be used to build multiple storeys. The end result is a multifunctional, easily transportable, recoverable and modular product characterised by innovative design and advanced technological solutions. (De Berardinis et al., 2017)

The moisture and mould damage discovered in recent years has turned the spotlight on the risks of construction. Some risks related to building ownership have not been taken into account or valuated before now. Risks can be outsourced through a variety of agreements (e.g. life cycle construction) in which the builder assumes responsibility for the condition of the building for a specific period. A school building or parts of it can also be rented out, which assigns the risk to the building's owner. Many rental arrangements utilise solutions such as modular structures that can be moved, downsized and expanded as needed. (Vihola, 2019)

The portability of a building is affected by its weight. For this reason, the trend is to construct portable buildings especially from wood, which is lighter than other materials. Solid wood is also favoured thanks to its heat retention properties and capability to maintain a consistent and even temperature. Furthermore, wood is more efficient than other materials in controlling the humidity of indoor air. Moisture damage is one of the most critical causes for poor indoor air quality and related health problems, such as asthma and respiratory issues. (Niemeläinen, 2019)

The properties required of housing units depend on the life situations of the residents. Young people look for small and affordable studio flats. They often then move to a two-room flat and later need more space for children, work activities or hobbies, for example. Changing needs no longer automatically mean that new housing is needed, however (www.teijocon.com). With people less willing to take risks in purchasing a house, portable buildings increase the security and versatility of the investment. The house can be taken wherever it is needed. When the need no longer exists, it can be moved or sold to a new location or for a new purpose.

B. What kinds of buildings are considered to require portable and dismantlable solutions?

Temporary portable buildings

The need for temporary portable schools and classroom premises was born out of the need to replace schools with mould or other issues necessitating repairs with temporary portable buildings. The need for renovation has resulted in pressure to provide temporary premises, and the demand has been met with container schools, which are seen as cheap and easy solutions. The temporary nature of the arrangements is seen as a problem instead of an opportunity. A container school is a type of portable building built to provide temporary classroom space for schools lacking in that regard. They have been designed for immediate removal when the need for additional space dissipates due to the completion of a new extension, the opening of a new school or a reduction in the number of pupils. These buildings are often shipping container structures. (Cederlöf, 2016; Keisu, 2016)

A comparison of container schools and modular elements warrants the conclusion that container schools are usually not very well-suited to teaching. A building made from large prefabricated modules, on the other hand, works well as a new kind of modifiable learning environment. (Cederlöf, 2016)

Permanent buildings designed to be portable

Recent years have seen an increase in interest towards portable buildings, which is why we are now transitioning from temporary movable premises to facilities that correspond to permanent buildings but can still be moved if necessary. With developments in construction technology, we can now construct new energy-efficient and need-specific premises under building regulations for permanent buildings. (https://elementit.fi, 2019)

Teaching facilities in Finland will be subjected to substantial pressure for change in the near future. The teaching arrangements of schools are expected to become increasingly interactive and open. The desire is to make learning an active and practical process. The new teaching premises are expected to be adaptable and able to develop according to the users' needs. However, current school facilities support the development goals of the learning environment somewhat poorly, which is why entirely new and innovative premises are needed for schools of the future. (Cederlöf, 2016)

At present, the general consensus is that schools, day care centres and care homes need to be flexible and portable. There is a need for modifiable learning environments that can be customised according to pedagogic emphases, such as sports and art. Premises are now built to be modern and healthy, and support the new curriculum. Modular and flexible facilities consist of classroom and teamwork premises that can be opened and closed as necessary. Learning environments constructed based on pedagogic considerations enable flexibility in terms of time, place, learning content and implementation methods. (https://hoivatilat.fi, 2019) A portable building can feature one or two floors, and it can be moved from one place to another. With movable premises, it is also possible to increase or decrease the amount of existing space. A building can now be constructed in such a way that the portability is not immediately evident based on its operating properties, energy efficiency and appearance. (www.parmaco.fi, 2019) The elements of an ecological high-quality school are energy efficiency, intelligent heating and lighting, flexible and versatile spatial planning, ecological and emission-free materials and smart building automation.

Figure 2. A portable two-storey school building constructed by Parmaco Oy and located in Espoo. The school meets the requirements of new learning environments: the spaces are open, modifiable and contain learning areas of different sizes for varying needs. Photo: www.parmaco.fi

The needs regarding a residential building change with shifts in the residents' situation in life. Sometimes, the need to move to another town for work can emerge quite quickly, in which case it may be disagreeable to commit to a permanent residence. However, the changing needs no longer automatically lead to the necessity to change homes. Residential buildings can also be made portable, which means that they can be moved to a new location. With people less willing to take risks in purchasing a house, portable buildings increase the security and versatility of the investment. The house can be taken wherever it is needed.

When the need no longer exists, it can be moved or sold to a new location or for a new purpose. The purpose of use can also change, which is why the building automation must be designed to be flexible to increase the building's life span. (www.teijocon.com, 2019)

C. Future prospects

The development of portable buildings within the framework of Finnish construction culture has been significant in recent years. Building standards have created competition between companies, which means that construction is cheaper and faster for consumers. Portable buildings are the future and provide those with a busy lifestyle with a good option for purchasing a home.

Varying service needs, indoor air problems and functionally obsolete premises present challenges for the day-to-day providers of teaching and early education services. To address the issue, some businesses have begun to offer "day care centre as a service" models, for example, which involve the company in question fulfilling all construction-related obligations from permit acquisition to ownership (https://hoivatilat.fi; www.parmaco.fi). A municipality can then rent the premises, or the services can be provided by a private body. The relevant services can also be produced through various life cycle services.

The popularity of log is increasing in public construction due to the good construction properties of the raw material. Particularly due to the prevalence of moisture damage and the requirements of ecological and energy-efficient construction, solid wood construction is on the rise (https://hoivatilat.fi). As a naturally breathing material, log guarantees the high quality of indoor air, which is important to sensitive target groups, such as children. Log walls balance out changes in air humidity, maintaining the humidity of the indoor air at an optimal level in terms of health and comfort. Customers tend to like log construction specifically because of the aspects related to indoor air, but also because a log building is beautiful and atmospheric.

Ecology is emerging as an increasingly important factor in the selection of construction materials. In a log building, all load-bearing structures are made of wood. Buyers also expect environmental aspects to be considered from the carbon footprint of production to the energy solutions of the production facilities, for example. https://elementit.fi/toimintamalli/

D. Economic impacts of portability

Impacts on financing – bank's perspective

From the perspective of the bank, the decision to grant financing for the construction of a building is always primarily based on facility (income, expenses, assets, liabilities, etc.). As a general rule, however, loans must always have collateral. In the context of collateral, the true value of the collateral is considered as one of the key aspects affecting the financing decision. In proper banking terminology, this is referred

to as 'fair value.' In reality, the ultimate value is determined on the market in connection to the actual trade, which means that the valuation can be challenging. (Bank consultation 2019)

The collateral being situated in a sparsely populated area or outside an urban area makes it more difficult to determine fair value and affects the collateral value percentage. Depending on the bank, the collateral value percentage for a building or housing unit that is located in an urban area and is in a good condition is normally about 70–80 per cent of the fair value. To simplify, this means that for a flat valued at 100,000 euros, it is possible to receive a loan no higher than 70,000–80,000 euros, if no other collateral can be provided besides the housing unit itself. If the collateral is located in a sparsely populated area, the insurance valuation is about 50–60 per cent, depending on the bank, which means an increased requirement for the self-financing portion or other securities.

From the bank's perspective, the possibility to move an entire house and take it with you could have a positive impact on access to credit and favourable terms, since location is an important factor in determining a building's value. However, the process of transporting a building raises some questions. For example, can the bank be confident that the building remains in good condition during the transport and land prices do not increase excessively. There can also be other variables. The transport presents a big risk to the bank, as it is possible for something to break in the process. On the other hand, this could provide insurance companies with new opportunities to sell insurance policies to cover the transport arrangements. Other things to consider include the price of using the new site and whether or not it is even permissible to transport a movable building to the site. If moving entire buildings were to become more commonplace, would this affect the price of sites directly or indirectly?

This topic is extremely interesting and could spell dramatic changes in the field if sufficient reliability, affordability and overall convenience could be secured in all aspects of the process and relevant activities. The bank finds that there are some families who postpone construction because they live and would like to continue to live in an area with a dwindling population but estimate that the value of the completed house will not be in line with the construction costs. (Bank consultation 2019)

Impacts on financing – resident's perspective

Buying movable buildings involves less risk since people often need to move to new municipalities after work, in which case the house they have purchased in the former home town, often on loan, can become a burden. Portable buildings provide the possibility of transporting your entire home, and the property inside it, to a new municipality with relative ease. In the future, it may be possible to replace your home with a new and bigger one in the same way you would replace your old car.

Figure 3. Elementit-E Oy's buildings are 100% recyclable and portable. Photo: elementit.fi/toimintamalli/

It is often more affordable to move a building than to disassemble it, and the arrangement also means that the customer maintains access to good premises after the move. Modern modifiable buildings are 100% recyclable and portable. If necessary, their purpose of use can also be changed flexibly. This reduces the waste load caused by construction. https://elementit.fi/toimintamalli/

2. Technical solutions of a portable log module structure

A. Factors affecting module size

The module size is affected especially by the transport equipment and the allowed width and length of transport. For example, Skoha Ab's version of a movable building is assembled from two modules and roof elements. The modules are 9.7 metres long and 3.3 metres wide. The building can be loaded onto three lorries and moved to another municipality. The building consists of 49 square metres and is designed for seniors, singles and small families who have no need for unnecessary space. (www.skoha.fi/, 2019) The units can also be used to assemble "housing villages" for seniors. This means a cluster of 20–40 houses with a business-driven service centre in the middle.

Olokoto is a log housing module designed by Ilmari Mäenpää. It was introduced at the Seinäjoki Housing Fair in July 2016 and has since then been shipped to countries across Europe. According to Mäenpää, Olokoto buildings have been purchased for tourist destinations in Lapland, Northern Norway and Sweden. (www.maaseuduntulevaisuus.fi) Olokoto is a modular, expandable, portable and complete-on-delivery miniature home. The living area of an Olokoto module is 21 m2.

Figure 4. The Olokoto log module concept is perfect for constructing halls of residence, for example. www.kontio.com/fi-FI/olokoto 2019

The external dimensions of the basic unit are 3,500 mm x 7,000 mm, and the building can be expanded with additional modules. Olokoto weighs about 7,000 kg depending on the features and equipment. Energy self-sufficiency and minimal wastewater generation were considered in the design process. Olokoto consists of precisely dimensioned modules which can be combined freely according to the customer's wishes to construct larger buildings as needed. The popularity of reasonably-priced portable buildings will only increase going forward, and the Olokoto concept is perfect for setting up temporary operating premises or residential facilities, for example. (www.kontio.com/fi-FI/olokoto, 2019)

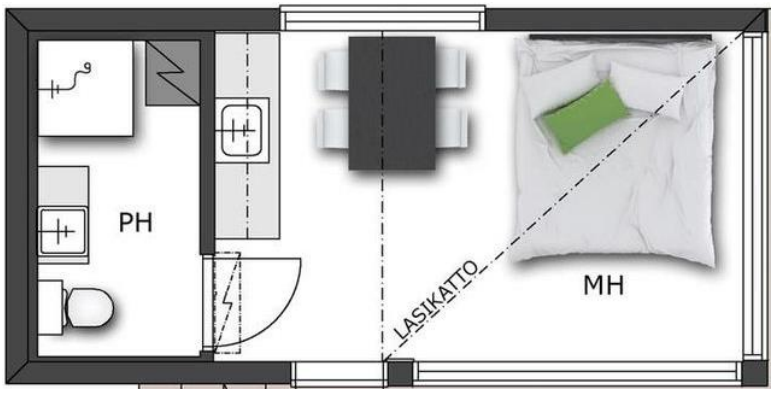


Figure 5. Olokoto floor plan (www.kaleva.fi)

When constructing a structure from CLT wall elements, the height of the element is determined by the floor height, which is usually 3 m. The widths of the wall elements, in turn, are determined by the building's division into housing units, with the width of the element establishing the width of the housing unit (usually no more than 8 m). The floor panels are usually 1.8 m wide and of equal depth with the frame, however no more than 8.5 m or 12 m with an intermediate support. Modular units made of CLT

panels are usually slightly larger than a room in size. A small studio flat can consist of one modular unit, a two-room flat requires two elements, and so on. Portable buildings are often designed for lifting on one side so that they can be loaded onto and off of lorries with a crane. (Huuhka, 2018)

The Eco School concept differs from typical modular unit construction. The portable modules are large, and the length and width of normal transports have not been considered in their design. The basis of the Eco School concept is a school module of approximately 600 m2, which can house about 100–150 pupils or 5–8 classes. The module was designed in accordance with the modern Finnish curriculum, but it is also highly adaptable for a variety of educational needs. The size of the large school module enables simultaneous use by different age groups and classes with different learning needs. The open plan facilitates open activities, communications and group teaching. (Niemeläinen, 2019)

In the Eco School concept, the construction materials are CLT (cross laminated timber), LVL (laminated veneer lumber) and side panels and glued products, such as beams and pillars. The floor and room height are variable and are not necessarily limited by the height of a single wood wall element (2.95 m). The shape of the roof, the central halls and the room appearances are left open in the design process. They can be tailored specifically to meet the special needs of the customer or the users. (Niemeläinen, 2019)

Figure 6. The Eco School concept as presented in Aleksi Niemeläinen's presentation at the 'Ilmastoviisasta rakentamista' seminar in Seinäjoki on 24 October 2019.

The Eco School concept also includes "mini modules." In open-plan learning environments, they provide acoustically and visually separate closed spaces for silent study or listening to music, for example. The modules' acoustic capabilities, which vary according to use, must be taken into account. The modules can be insulated or uninsulated, for example. Structurally, the mini modules are designed to serve as non-load-bearing partition wall systems. (Niemeläinen, 2019)

The building can be fully completed at the factory, including the foundation. For example, Teijo-Talot buildings are constructed directly onto a concrete foundation, but they can be lifted onto a lorry with jacks for transport to the construction site. This means that they can also be easily moved to a new location at a later time.

Figure 7. A partially two-storey school built from Teijo-Talot modules. Picture by Teijo-Talot Oy as shown in Mika Leikkonen's seminar presentation on 9 May 2019.

As an example, the town of Järvenpää ordered a 2,100 m2 school for 288 pupils from Teijo-Talot. The school consists of 30 modular units. In addition to classrooms, the school features a spacious and high-ceilinged lobby and two storeys in some sections. (Puumies 10/2018; Leikkonen, 2019)

The Teijo-Talot solutions are transported as complete modular units including concrete foundations and fixtures. The foundation of the portable building can also be laid on screw piles, a traditional cast plinth or an even and unyielding surface on concrete blocks.

Portable buildings are usually manufactured indoors at a factory, which means that they are never exposed to moisture or changing weather conditions. This also helps minimise the time spent on the construction site, which boosts construction efficiency (Mantila, 2019).

B. Module connection solutions

The connections between the elements are normally nailed joints in the same way as in on-site construction. The most significant challenge is to implement the joints in a way that ensures their tightness and thermal insulation. In terms of reuse, element buildings can be divided into disassemblable and reusable components. However, the structure may feature nail joints at tight intervals, which can make the joints as difficult to disassemble as any structures built on site. (Huuhka, 2018)

The large and small panels used in the walls are usually the height of the wall. The width of both panels usually matches the 3M module dimensioning (dimensioning at 300 mm intervals). Small panels are

typically no more than 1,200 mm wide, but wider elements are possible. Large panels, on the other hand, are the size of the entire building or wall and require a crane to handle due to their weight. As such, the advantages of small panels over large ones are the flexibility of layout options and the fact that they can be easily handled by two people. One of the disadvantages is the number of joints. These benefits and drawbacks remain the same in reuse. The larger number of joints in the small panels can also result in a higher risk of structural damage during use, if the sufficient tightness of the joints is not ensured at the outset. (Huuhka, 2018)

With solid wood panels, the "load-bearing walls" structural system is used, in which the floors and horizontal structures are supported by the load-bearing wall lines in the same way as in concrete element buildings. The solid wood panels serve as load-bearing and stiffening components in the building frame. The stiffening structures usually include the floors and some of the walls. The span lengths for wooden floor structures are usually about 7–8 m. For this reason, the load-bearing lines usually include the building's exterior walls and some of the partition walls (normally walls between housing units). Openings can be made in solid wood panels fairly freely, which enables the construction of diverse facades. The panels can also be used to construct modular units. Practically all wooden CLT buildings in Finland have been constructed from modular units. (www.puuinfo.fi: teollinen-hirsi-uudistaa-monisatavuotisen-hirsirakentamisen-perinnettä)

Solid wood building components are joined together mechanically. The joints in LVL panels are usually screw joints. In CLT structures, the joints between panels are made with steel components. In addition to this, sealing tape and sealing strip are used to ensure the airtightness of the structure. (Stora Enso 2012).

The joint can be either a tongue-and-groove joint or it can be covered with a panel. In addition to this, hidden joint components can be used.

Figure 8. Example of fastening solid wood panels from Pauli Paintola's presentation at the Puurakentaminen – kiinnikkeet ja liittimet event held on 29 October 2019 in Ähtäri. The figure features Rothoblaas fasteners.

Design Company Toni Kekki talked about joint types in modular construction at the Puurakentaminen – kiinnikkeet ja liittimet event in Ähtäri on 29 October 2019. Among his other projects, Kekki was involved with designing the award-winning Puukuokka wooden blocks of flats built in Jyväskylä. The buildings are made of modules which, according to Kekki, ensures more consistent quality than on-site construction. According to him, modular construction is an industrial process instead of a construction process. It is easier to control quality (e.g. joints, airtightness and material quality) since the industrial process involves a high degree of prefabrication.

Figure 9. Example of wood structure fastening from the presentation of Konepuristin Oy's Antero Kujala at the Puurakentaminen – kiinnikkeet ja liittimet event in Ähtäri on 29 October 2019. The figure features hidden joint components.

The modules are usually attached to each other with horizontal and vertical connection plates, which can be either metal or wood. In buildings with multiple floors, the modules must be fastened with both horizontal and vertical plates since it is necessary to transfer the forces affecting the building to the foundation from all modules. A dowel solution can also be used for the joints. The joints must be "loose" to ensure appropriate soundproofing. Rubber insulation is used for this purpose. Rubber anti-vibration strips or friction insulation solutions are used in the module joints to prevent vibration.

Jianmei et al. (2017) compared the disassemblability of various wooden structures and the time required for dismantling. A beam and column structure was found to be the fastest to take apart. It features fewer structural components, and the joints are often made with bolts, for example, which are quick and easy to remove. Buildings with frame structures are the most difficult to disassemble as they include plenty of smaller components and screws, which are slow and difficult to remove. Panel-type structures, on the other hand, are easy to dismantle. Based on the study, some guidelines are provided for designing structures that are planned to be dismantled. 1. Select the right structural solution. 2. Minimise the number of small components. 3. Design the joints for easy dismantling and repair. 4. Use standardised and reusable joints to reduce the dismantling time.

About dismantlable structures and joints

In dismantling buildings made from small elements, large elements and modular units, it can be easier to detach complete elements from the frame for reuse, instead of disassembling them into parts. In theory, it is possible to attempt to disassemble frame walls constructed on site in sections resembling elements, which requires them to be initially supported for transport. In newer buildings, the nail panel trusses of roof structures should not be disassembled into parts. Instead, they can be lifted out as full elements after detachment. The challenge with detaching and transporting nail plate trusses is the highly optimised nature of the truss components, which makes them susceptible to breakage and more demanding to handle. (Huuhka, 2018)

The glulam beam and column structures and frameworks of hall-type buildings are simple to take apart. The connections are often bolt joints that are fairly easy to detach. The foundation joint of the pillar is likely to be the most difficult of these structures to dismantle. The foundation joint almost always includes steel connecting components embedded in concrete, which means that recovering the original connectors would require the concrete foundation to be shattered for disassembly. The joints can also be disassembled by cutting, in which case the joint must be redesigned for the new application.

Generally speaking, structures assembled from solid wood panels are simple to disassemble. The connections are typically screw joints, but the number of fasteners is normally high. The screws used to join solid wood panels are long, which can increase the risk of screw breakage during disassembly. Even with solid wood structures, the simplest disassembly method is to cut the structure next to the joint area, despite the fact that this shortens the structural component recovered for reuse. (Huuhka, 2018)

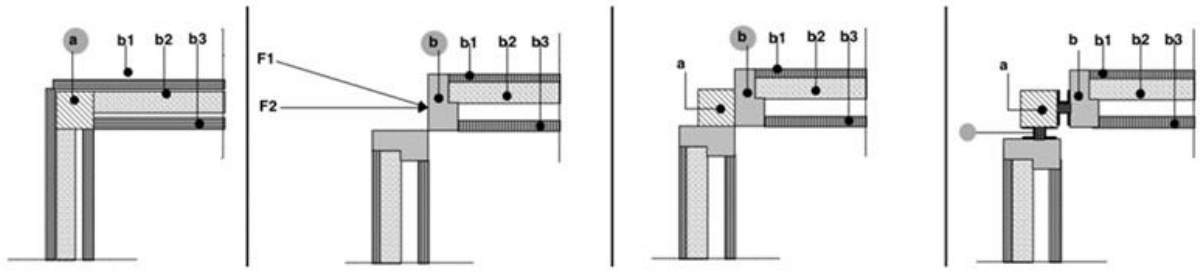


Figure 10. Disassemblable joint structures in the presentation by Satu Huuhka at the 'Purettavuus, siirrettävyys ja kierrätys – tulevaisuuden rakentamista' seminar in Seinäjoki on 9 May 2019.

C. Cost efficiency of modular construction

Compared to conventional construction, modular wood construction can ideally reduce construction time, general worksite costs and financial administration expenses. The shortened construction time in the project's production phase is one of the main reasons for favouring wood in construction. The method can result in up to 30% faster construction compared to more site-intensive options. Modern CNC processing technology enables the production of customised panels, which in turn enables flexible and cost-efficient design and construction. (Niemeläinen, 2019)

Lakea Oy has developed its own Sydänpuu concept for modular wood construction and applied for a patent. The concept involves assembling wooden modular units around concrete wet room modules. The concept yields savings in construction costs and enables later modification of the housing units. The wet rooms are constructed from modular units that are separate from the dry room elements and can be installed on top of each other without a separate frame. (Mantila, 2019)

According to Mantila (2019), future climate policy will push developers towards more energy-efficient and carbon-neutral construction. Carbon footprint calculations are being incorporated into building codes, and responsibility has become a focus in customer purchases. Mantila particularly emphasised the necessity to develop industrial construction to ensure competitiveness. According to him, developing industrial construction is the only way to improve cost efficiency in building activities. In factory conditions, efficiency can be increased by adopting operating models used by the car industry, i.e. 'conveyor belt type' operations where modules move from one installation phase to the next. At construction sites, activities cannot be streamlined any further.

Kekki (2019) states that industrial production accelerates schedules since construction can commence before the actual site is even opened. However, it should be noted that the plans must be completed before beginning production. Changes can no longer be made on site. According to Kekki, the industrialisation provides efficiency and further benefits with increased volume.

Compared to concrete structures, using wood significantly reduces the weight of the building, which results in reduced basic demands. The lighter wood elements can be installed with lighter cranes instead of heavy and expensive tower cranes. The wood elements are transported to the construction site fully finished or assembled. Lighter loads reduce the total number of heavy transport vehicles required, which leads to lower costs (Niemeläinen, 2019).

3. Modern vertical log construction

A. Vertical log construction method

Log buildings constructed with the traditional method have not been suitable for factory construction. However, log elements can be used to construct a vertical log building. The method is to stack logs horizontally as normal and then tip the structure on its side. This forms a modular element with two walls, a floor and a ceiling. The floor and ceiling joints of the element are strong, since they correspond to the corners of traditional log walls. This ensures an unyielding and very stable vertical log module. The end walls are added to the module as complete elements. Using this manufacturing method, buildings can be constructed as modular elements at the factory. The modules, which are manufactured to be almost immediately usable, can be transported to the site on lorries for connection to each other. (Puumies 10/2018; www.pystyhirsi.fi)

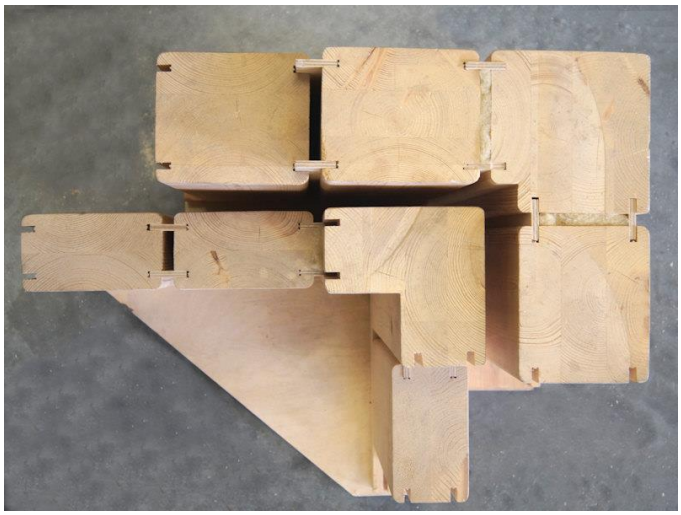


Figure 11. Insulation of a vertical log structure and profile shape. Photo: www.pystyhirsi.fi

The issues with a horizontal log structure are the settling of the wood and poor tightness especially in corners. Log settles horizontally by 0.5–2 cm for each metre of wall height, depending on log quality. Round logs settle the most and laminated logs the least. Wood does not settle vertically, which means that a vertical log building is a non-settling structure. Vertical log structures made from laminated log eliminate tightness problems due to the moisture expansion of the wood. The walls remain straight and tight, maintaining the excellent properties of a log wall, such as superior moisture response and indoor air quality. In vertical log construction, the logs featuring dovetailed joints are stacked, doweled and tied together by the corners with steel rods to form a supporting structure. (Puumies 10/2018; www.pystyhirsi.fi)

The vertical orientation of the logs also enables the implementation of complex floor plans. The structure is simple, which means that it effectively prevents construction errors. The method provides the opportunity for many types of floor plans. The building forms a durable structure which can also be transported. (Puumies 10/2018)

B. Profile shape and cladding possibilities

A vertical log building is constructed from laminated log, which eliminates tightness problems due to moisture behaviour. These buildings are suitable for a variety of applications from housing to office activities. They are also accepted for planning areas that require painted wood board as the facade.

Figure 12. Bottom edge structure of the wall. Photo: www.pystyhirsi.fi

The thickness of the module or wall element log can be selected based on the insulation need. Another log wall inside the exterior wall is sufficient for insulation. You can either leave an air gap between the walls or fill the space with an ecological insulant, for example.

C. Technical solutions for building a vertical log module

Currently, vertical log modules are usually 3.5 metres wide, 3 metres high and up to 12 metres long, as necessary. A module weighs 10–20 tonnes, which means that a mounted crane is needed for lifting the elements onto the foundation. The buildings are assembled at the factory. On-site work phases are limited to lifting the elements onto the foundation and connecting them.

Modules of this size can be transported on lorries without escorts or special permits. They can also be delivered as oversized loads, in which case the modules can be up to 6 metres wide and 5 metres high. This increases the transport costs, but it is sometimes necessary to transport large modules.

Depending on the construction site and size of the building, the foundation can be constructed from screw piles, concrete beams or a movable concrete slab. The idea is to ensure that the buildings can be moved later. (Puumies 10/2018)

Vertical log buildings are faster to build than horizontal log buildings or wood-cladded buildings. When erected on site, it can be assembled by a single person since the logs are light and easy to handle thanks to their dimensions. Vertical log buildings can be erected without cranes, which makes them well-suited to difficult locations. They can also be assembled from complete wall elements. (www.pystyhirsi.fi)

Figure 13. When erected on site, it can be assembled by a single person since the logs are light and easy to handle thanks to their dimensions. Photo: www.pystyhirsi.fi

4. Technical solutions for portable elements

A. Comparison of portable elements constructed at the factory and on site

Buildings can be constructed in a variety of ways. If necessary, you can order bulk materials to the construction site for handling and assembly. Through cooperation with the architect, this ensures that the building meets all the specified needs and the end result can be something entirely unique. This method of construction is slow and susceptible to weather conditions at the site. The necessary tools must be transported between construction sites. Buildings made from bulk materials are constructed to be permanent – they are very difficult to make portable.

The pre-cut method involves very little prefabrication. Only the timber is cut and notched in advance. The components of the load-bearing and non-load-bearing frame are cut to size and delivered to the worksite, along with primed cladding boards. This method facilitates the efforts at the construction site but resembles construction from bulk materials in terms of the amount of work conducted on site.

The alternative to constructing buildings from bulk materials is to use elements. The elements are manufactured at the factory and assembled to form the building at the construction site. The benefits of element construction are clear as the elements are built inside a factory on a production line, which means that the developer company can reach significant scale benefits with regard to material acquisitions and work fluency. The work costs are also less than with bulk materials. In factory conditions, there is no need to move the necessary tools around and some construction tasks can also be automated. The construction quality of elements has improved significantly in recent decades. Element construction is an extremely sensible option if the floor plan of the building is not required to be entirely unique. However, developments in element construction now enable more unique buildings, too, to be assembled from elements. A comprehensive range of options is usually available to ensure that all needs are met in element construction. The elements can be designed to be disassemblable and portable.

The elements can be either small elements, large elements or modular units. Small elements can be erected without any lifting equipment. These elements are standardised and range from 300 to 1,200 mm in width. Large elements are the width of an entire wall. In the case of large projects, the width is limited to 10 metres to ensure safe handling and transport. Modular elements are complete structures including a ceiling, walls and floor as well as amenities. A crane is required to lift and install large elements and modular units.

Figure 14. Erecting small elements. Photo: Harri Lyytinen, 2012.

Log construction has a long history in Finland, rooted in good raw materials, crafting skills and the suitability of log buildings to the demanding Finnish climate. New industrial log materials, production technologies and indoor air requirements have rekindled public interest in log construction.

Thanks to its wide range of applications, industrial log has established a market share in private home construction and the construction of public buildings, such as schools and day care centres. Designers and architects, too, are increasingly interested in industrial log as it is a material that provides new opportunities. Where before log was mainly used to build holiday homes, for example, it is now being used more and more for buildings intended for continuous use.

Log buildings are most commonly constructed one log at a time, but log walls can also be assembled at the factory to form complete wall elements. Log walls are constructed in the conventional way of adding dowels, pressing the logs tightly together with a hydraulic press and finally connecting them with threaded rods. Log wall elements are connected to the building's corner pillars with Sherpa fasteners. This also automatically creates the "city corner" joint suitable for urban construction.

A wall element resembling a log wall can also be constructed from CLT panels into which a log pattern has been etched. These elements are erected in the same way as normal CLT buildings.

Figure 15. HOISKO log. Photo: www.hoisko.fi

Figure 16. Modern log building with non-settling log and zero corners. Photo: www.honkatalot.fi

B. Partition wall solutions and connections that enable transport

Partition walls are separating walls inside or between housing units. The fire resistance and sound insulation demands for walls between housing units are usually stricter than those for partition walls within individual dwellings. A partition wall can feature a single, double or separate frame (zig-zag frame). A successful end result requires an easily implementable frame structure, suitable and mutually compatible structures, and affordable and appropriate structural materials. At present, builders are spoiled for choice in this regard. New options are entering the market constantly.

The majority of small houses (especially detached homes), regardless of whether they are built fully on site or from prefabricated elements, are still constructed with a wooden frame where the exterior and partition walls are frame structures. In the increasingly common CLT buildings, partition walls can also be built with a frame structure instead of CLT. Furthermore, the partition walls of log buildings can be constructed with a frame structure instead of solid log. In the construction of partition walls in log buildings, the settling of the log walls must be taken into account, if non-settling log is not used for the exterior walls.

Light partition walls are easy to build and disassemble, but for portability they should be constructed from elements. The complete partition wall elements are attached to the other structures with appropriate and easily disassemblable fasteners. In the simplest arrangement, the partition wall elements are fastened to designated points in the floor, ceiling and walls by screwing them into the fastening holes in the elements.

A variety of fasteners have been developed for fastening partition walls. The most common ones are multi-shear fasteners made from steel plate. The multi-shear fasteners are attached to walls and floors in advance. Partition walls with ready-made holes for fasteners are lifted into place and fastened with self-tapping dowels. A more advanced solution is to use Sherpa fasteners by fastening the female side of the fastener to the wall and the male side to the end of the partition wall. When installing a partition wall, the nesting parts of the fastener attach the wall to the correct position. Both of these fastening solutions can be dismantled, and they are well-suited to portable buildings. (Kujala, 2019)

A partition wall can be connected to a log wall with a dovetail joint, which results in a tight and functional interior corner solution that does not require separate fasteners. The partition wall can feature a frame or log structure. In the context of a partition wall with a frame structure, the possible settling of the exterior log wall must be considered. (www.pellonpuu.fi)

C. Roof element solutions

The traditional process of installing a roof at the construction site involves many phases. Limitations are imposed by the season, size of the building and schedule.

The walls of buildings that are constructed from elements can be erected quickly. In order to retain the benefits of the elements constructed in dry factory conditions, the elements must be quickly protected from weather. It is sensible to construct the roof, too, from elements to ensure that the buildings can be sheltered from weather as swiftly as possible. Many element solutions that enable rapid construction and are suitable for a variety of construction locations are available on the market.

VETOKATTO® is a truss set that is manufactured at the factory in a cost-efficient manner. The solution comes with preinstalled end elements, eaves, roof sheeting, ventilation battens and support members that determine the truss interval. The VETOKATTO® solution is transported to the worksite, lifted on the walls, and opened quickly and safely with a winch motor and special friction carriages. When open, the roof provides immediate protection from weather conditions. The VETOKATTO®, which can be used for roofs of various shapes, stays on as a permanent part of the roof structure. VETOKATTO® is perfect for detached homes and terraced houses.

Figure 17. Installing a VETOKATTO® roof. Photo: www.rakennuslehti.fi

Roof elements with a truss structure can be assembled in advance to form large roof blocks that are lifted in place with a crane. The benefit of assembling roof blocks at the factory is the ability to build and store them in a dry indoor environment instead of the construction site.

Figure 18. Lifting a roof element onto a detached house. Photo: www.abc-service.fi

In the case of larger structures, such as production halls, retail outlets, sports venues, farm buildings and residential buildings, the roof can be built from wooden roof elements that are lifted onto the load-bearing structures. These roof elements are normally 8–21 metres long and about 2.5 metres wide. They come with heat insulation, vapour barrier, HVAC and electrical penetrations, and roofing materials, depending on the bottom surface and material. Sheet metal and tile roofing materials are installed at the construction site. The elements are constructed in a dry factory environment, packaged in weatherproof bundles and transported to the site for installation. The roof elements are quick to install – more than 100 square metres of roof elements can be installed in a day. This minimises the amount of demanding and hazardous roof work that is also susceptible to weather detriments, and there is no need to store large quantities of roof construction materials on site. (www.seikat.fi)

Figure 19. Roof elements can be installed quickly. Photo: www.termater.fi

Roofs with ceiling insulation can also be constructed from elements. The roof faces are built into complete elements at the factory and lifted into place onto the load-bearing structures. The installation process is fast and ensures that the building can be quickly protected against weather.

Figure 20. Installing a roof face element. Photo: www.simons.fi

D. The differences and benefits of various foundation solutions

Foundation structures are usually hidden underground, which is why their significance is often neglected in planning the construction of a detached house. However, the foundation supports all upper structures, so its functionality and reliability are essential for ensuring the durability and long service life of the building. Construction in areas with soft, fine-grained and organic soil layers, in particular, requires special expertise. Based on sufficient soil surveys, a proficient foundation engineer can choose the foundation method that suits the requirements imposed by the structure and soil.

The foundation usually consists of the base that conveys loads from the structure to the ground, the foundation wall (sometimes the pillars) and any layers that control moisture penetration and heat insulation. Building foundations must be designed with care, as errors in their implementation usually damage other structures as well in ways that are difficult and costly to repair. Foundations are divided into two main categories based on the elevation of their bottom surface: shallow foundations and deep foundations.

Shallow foundation

A shallow foundation means that the foundation is left fully above the frost line. The freezing of the soil under the foundation is prevented with sufficient frost insulation.

Ground-supported foundation

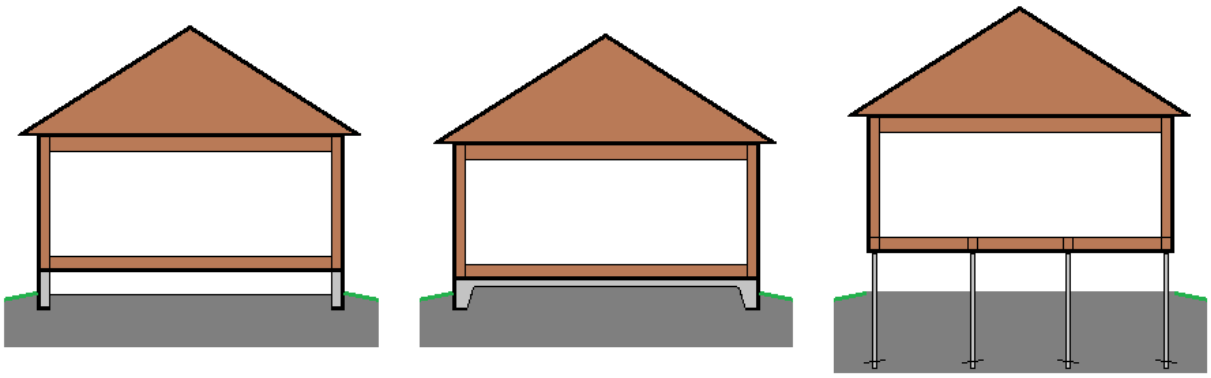
A ground-supported foundation is the most common option for small buildings. Constructing a ground-supported foundation is cheapest when the differences in elevation at the construction site are small.

In a ground-supported foundation, a foundation wall (plinth) is built on the base. The foundation wall can be cast from concrete using moulds or laid with blocks. The interior of the foundation wall is filled entirely with rock material, after which the insulants are installed and the concrete floor is cast on them. Another method of laying the foundation on the ground is the use of a slab with reinforced edges. This involves casting a concrete slab on the ground but making its outer edges thicker. This foundation method does not involve a separate base or plinth. Both of these solutions are referred to as ground-supported base floors. The term ‘base floor’ usually refers to the assembly formed by the floor and any connected structures.

Ventilated base floor

A ventilated base floor is a base floor structure in which a clearance of no less than 80 cm is left between the ground and the floor structure. A base floor structure of this type can be constructed by building a load-bearing floor structure onto a continuous plinth. This can be done with load-bearing beams, for

example. A base floor of this kind features a crawl space. You must always remember to ensure the ventilation of the crawl space between the floor and ground by means of ventilation openings in the plinth. A ventilated base floor can also be implemented with pillars. This method involves erecting pillars at suitable intervals under the building and then constructing the load-bearing floor structure on them.



Foundation wall with a ventilated base floor

Ground-supported slab

Screw pile foundation

Figure 21. Various foundation solutions. Photo: https://rkntkn.blogspot.com

Integrated ground-supported concrete foundation

Teijo-Talot has developed a unique production and transport method that can be used in all kinds of construction. All of the buildings come with a fixed ground-supported reinforced concrete foundation. This ensures that the buildings can be constructed quickly and transported to multiple locations over the course of their life spans. The buildings are manufactured from start to finish in dry and highly controlled factory conditions to keep them dry during the construction process regardless of the season.

The Teijo-Talot solutions are constructed at the factory on a robust reinforced concrete foundation. The ground-supported foundation concept then travels with the building as a fixed component from the factory to the site. At the site, the building modules are lowered onto a gravel bed with their concrete foundations and then connected to each other and the utility services. If necessary, the buildings can be moved to another location, leaving behind nothing more than a levelled and compacted gravel field and the utility connections. (www.teijotalot.fi)

Figure 22. Installing Teijo-Talot modules on a gravel bed. (Teijo-Talot presentation in Seinäjoki on 9 May 2019)

Deep foundation

A deep foundation means transferring loads arising from the building's mass below the frost line by means of pillars or foundation walls.

Piling

Sites are increasingly zoned in areas with soft soil that is not sufficiently firm to bear ground-supported foundation. In these cases, a pile foundation must be used. There are many piling methods and pile types available. Selecting the correct pile type and piling method depends on the soil composition and the surrounding structures. In addition to traditional driven piles made of reinforced concrete, driven or drilled steel piles can be used. The range of steel pile sizes is particularly suited to constructing foundations for small buildings. The equipment needed for installing steel piles is light, which enables low costs, work in cramped locations and minimal environmental impacts.

A building with a pile foundation will not sink even if the surrounding ground does. A load-bearing base floor is used with pile foundations. In conjunction with load-bearing ground-supported base floors, an unventilated space can easily be formed between the sinking ground and the base floor resting firmly on the piles. The warm and moist space under the building is highly susceptible to the formation of mould,

which presents a risk to both the structures and the residents' health. This is why the base floor should be constructed as a well-ventilated structure with a crawl space.

The settling of the surrounding soil must be given special consideration when designing connecting structures, such as sewers and water lines, and any structures in the yard area. The settling may cause aesthetic issues and break pipes if it is not considered in the design of the structures.

Pile foundation systems

In addition to soft soil areas, pile foundations can also be used on firm ground in solutions where the piles are connected directly to the building's load-bearing frame without separate base or plinth structures. This ensures that the foundations can be completed quickly, which shortens the completion time of the entire building. The piles can extend above ground, and the requisite beams and a traditional ventilated base floor, for example, are installed on them. This means that there is no need for base structure moulds, reinforcements and waiting around for the concrete to dry or spending time on dismantling the moulds. Frost protection may not be needed at all if the piles are driven deep enough below the frost line and injected if necessary. Major excavation work is not required. This keeps the environment intact, which is especially suitable on sites where one of the aims is to preserve the existing nature.Subsurface drains are not required for the base structures if the inclinations are sufficient to keep the crawl space dry. The foundation work can be conducted during any seasons, including winter. Drilled steel piles can also be disassembled without leaving significant marks in the environment and reused. (www.rakennaoikein.fi)

Figure 23. Log frame erected on a screw pile foundation. Photo: www.paalupiste.com

E. The impact of element size on cost-efficient transport solutions

The transport costs are affected by the length of the trip, amount of equipment involved and any possible special arrangements required. The most sensible approach is to manufacture the elements required for the building in such a way that minimises the requirements for transport equipment. In other words, including as many elements as possible into a single shipment reduces the transport costs. If the amount of transport equipment can be reduced, the number of transport kilometres per building is also reduced. If the elements are large enough to require special transport equipment, this will naturally drive up the transport costs. Large elements require more robust lifting equipment. For this reason, the length of large elements is limited to 10 metres to facilitate transport and handling. (www.puuinfo.fi: Woodfocus Oy - avoin puurakennusjärjestelmä – elementtirakenteet)

F. Element/module support solutions during transport

The transport of elements must adhere to effective acts, decrees and official regulations. There are many pieces of legislation that apply to road transport. Load handling and vehicles are governed by the following acts and decrees:

- Road Traffic Act
- Decree on the Use of Vehicles on the Road (1257/1992)
- Road Carriage Act (345/1979)
- Decree of the Ministry of Transport and Communications on the Construction and Equipment of Motor Vehicles and Trailers (1248/2002)
- Ministry of Transport and Communications Decision on Special Transportation and Special Transport Vehicles (1715/1992)
- Ministry of Transport Decision Governing the Load Compartments of Vehicles, Loading and Securing of Loads (940/1982)
- Occupational Safety and Health Act (738/2002)

A load on a vehicle may not move, tip over or fall in such a way that hampers the safe operation of the vehicle in traffic. The cargo may not move significantly when impacted by a forward force equal to 10 m/s2 of acceleration or sideways or backward force equal to 5 m/s2 of acceleration.

The elements must be tied forward with a strength equal to the weight of the load and at the sides and rear with a strength equal to 50% of the weight.

Tall wall elements must be transported secured with transport supports. In the longitudinal direction, the supports must be chained to the bed, or the bed must be equipped with stops that secure the support in place. The elements must be tied together through the lifting loops at the top. The longitudinal angle is not recommended to exceed 60°. In order to enable the cargo to be unloaded from one side only, the transport supports must always be attached to the bed in a lateral direction.

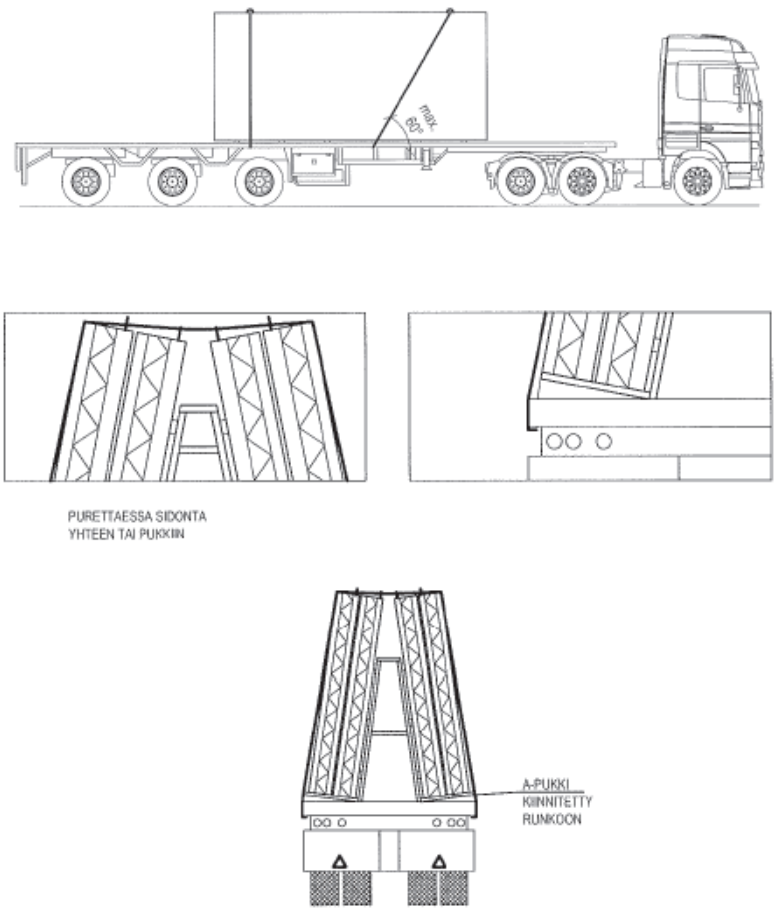


Figure 24. Supporting the elements with A-shaped supports during transport. Photo: www.elementtisuunnittelu.fi

The elements are industrially cut to size for specific buildings. For transport, frame elements must be supported in a crosswise arrangement to maintain the dimensions and quality. Perforated steel bands can be used to stiffen the frame elements. Faced elements must be supported by the window and door openings with disassemblable cross supports. Thanks to their crosswise lamination, CLT elements support themselves, which means that they do not require disassemblable cross supports. CLT elements can be transported either vertically or stacked on their side.

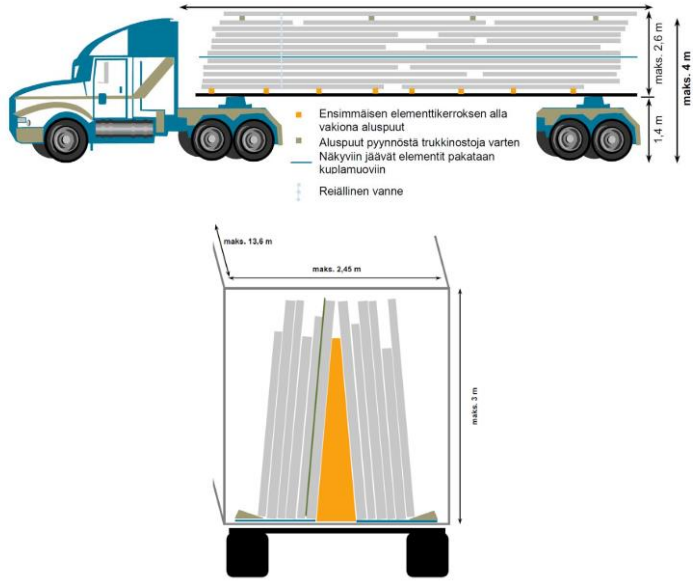


Figure 25. CLT elements in transport. Photo: www.puuinfo.fi

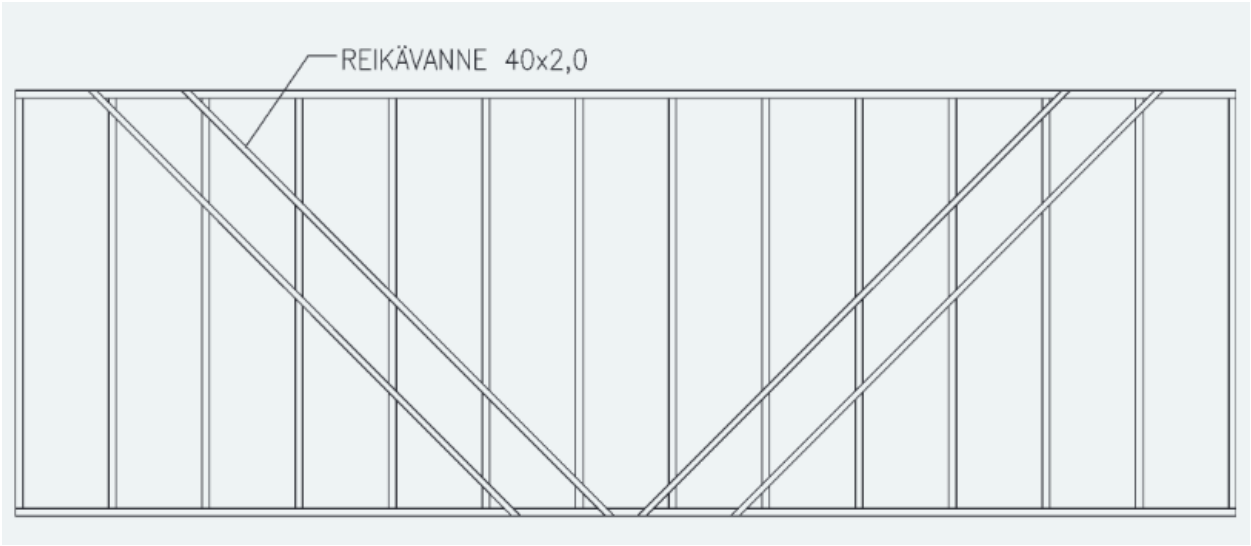


Figure 26. Perforated steel stiffeners for a wall element. Photo: www.puuinfo.fi (Woodfocus Oy - avoin puurakennusjärjestelmä – elementtirakenteet)

5. Comparison of module and element construction

Designers and professionals in the construction field emphasise the speed, ease of quality control and cost efficiency of modular construction. Module construction is an industrial process which can be streamlined to increase cost efficiency. Construction site processes, on the other hand, cannot be made any more efficient than they already are. Experts say that improving the profitability of wood construction requires the development of industrial processes. It also is easier to control quality (e.g. joints, airtightness and material quality) since the industrial process involves a high degree of prefabrication.

All new wooden blocks of flats completed in Finland are modular in structure. Apparently the speed and ease of the construction process rise to the fore especially in the context of modular construction. At the moment, there is a shortage of modular builders in Finland, which slows down and limits the number of projects for constructing wooden blocks of flats.

Element construction can be regarded as a hybrid of on-site construction and modular construction. The elements are manufactured at the factory but assembled at the construction site. A good example of this type of hybrid solution are the large modules used in the Eco School concept. While the concept refers to the components as modules, they are too large (approx. 600 m2) to be transported to the site in complete form and instead require on-site assembly.

Architecturally impressive wooden buildings can be constructed by combining the methods of modular and element construction. This is why we should not pit the methods against each other and instead use the best aspects of both approaches. Both of these methods are industrial approaches to construction that shorten the on-site construction time, reduce costs and ensure easier control compared to on-site building activities.

6. Summary and conclusions

Portability and flexibility

At present, there is a general desire to make schools, day care centres and care homes, in particular, more flexible and portable. Movable solutions and modular construction are modern solutions for both increasing and decreasing pupil numbers, as they enable the school to be moved or the premises to be downsized or expanded as needed. Moving schools or parts of them is already commonplace in today's Finland. Renting portable school premises has also emerged as an option to constructing separate buildings.

The teaching activities of schools are becoming increasingly interactive and open. The desire is to make learning an active and practical process, and customise learning environments according to pedagogic emphases. This is why new teaching premises are expected to be adaptable and able to develop according

the users' needs. Modular and flexible facilities consist of classroom and teamwork premises that can be opened and closed as necessary. Learning environments constructed based on pedagogic considerations enable flexibility in terms of time, place, learning content and implementation methods.

Portable buildings are also gaining popularity in the housing and travel sectors. Movability increases the safety and versatility of the investment, since the building can be taken wherever it may be needed. Moving residential buildings is a fairly new concept in Finland, which is why we currently lack extensive experience in the requisite practical solutions and successful transport arrangements.

Modular construction

In their seminar presentations in 2019, all experts in construction and building design emphasised the speed, easy quality control and cost efficiency of modular construction.

1. The modules are built indoors, which impacts quality. The quality is more consistent and the humidity conditions are fully controlled. It is easier to control quality (e.g. joints, airtightness and material quality).
2. Module construction is an industrial process which can be streamlined to increase cost efficiency. Construction site processes, on the other hand, cannot be made any more efficient than they already are. Improving the profitability of wood construction requires the development of industrial processes.
3. Modular construction is fast. Compared to conventional construction, modular construction reduces construction time, general worksite costs and financial administration expenses. The shortened construction time in the project's production phase is one of the main reasons for favouring wood in construction. In addition to this, industrial production accelerates schedules since construction can commence before the actual site is even opened.

Vertical log construction

Vertical log construction is an old method, which is currently being reinvented and incorporated as part of indoor modular construction. In modern vertical log construction, almost the entire construction process can be conducted inside a factory hall. The idea is to start by stacking logs horizontally and then tipping the structure on its side to create a modular element. The floor and ceiling joints of the element are strong as they match those of traditional log walls. This ensures that the module is non-settling and stable. The end walls are added to the module as complete elements.

A log module can be transported on a lorry without special permits if it does not exceed 3.5 metres in width. When erected on site, a vertical log building can be assembled by a single person since the logs are light and easy to handle thanks to their dimensions. Vertical log construction is relatively new as a form of business, which is why its profitability or wider market appeal cannot be accurately estimated at this time.

Element construction

The strengths of element construction, too, include construction speed, ease of quality control and cost efficiency.

1. The elements are built indoors, which impacts quality. The quality is more consistent and the humidity conditions are fully controlled. It is easier to control quality (e.g. joints, airtightness and material quality).
2. Element construction is an industrial process which can be streamlined to increase cost efficiency.
3. Elements can be built quickly. Compared to traditional building activities, element construction reduces on-site construction time and the overall worksite costs.

Log construction

The competitiveness of log construction is based on prefabrication, long building life spans and value retention. Log construction is a climate act that should be promoted through official measures, public construction and tax incentives. Funding the burgeoning green construction efforts is another good way to further wood construction as an aspect of the efforts to mitigate climate change. (Puuinfo 2018)

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Appendix 1. Catarina Thormark (2001): Design for disassembly and recycling.

Recycling Potential and Design for Disassembly in Buildings

Table 7.1 Guidelines for design for disassembly and reuse/recycling in building design.

Guideline	Reasons for the guideline
Choice of materials	
Choose recycled materials.	Stimulates the recycling market.
Choose recyclable materials.	Reduces waste to landfill.
	Increases the value of the product when it will be replaced.
Parts containing hazardous materials should be easy to remove.	Facilitates elimination of hazardous parts.
Minimise the number of different materials if they constrain the recycling process.	Simplifies dismantling and sorting.
Make inseparable parts from the same material or a material that does not constrain the recycling process.	Reduces the need for dismantling and sorting.
Code and mark all materials.	Simplifies the sorting and recycling process.
Design of construction	
Reduce number of parts.	Simplifies dismantling.
Modular designs will be easier to reuse.	Facilitates service and exchange.
Pay attention to stability during dismantling.	Dismantling is a reversed building process.
Design for serviceability.	Decreases disposal of non-functioning products.
Choice of Joints & Connections	
If two parts cannot be recycled together, make them easy to separate.	Simplifies the recycling process.
Design to enable use of common hand tools for disassembly.	Special tools may not be identified or available.
Avoid adhesives unless compatible with both the parts joined together.	Adhesives often cause contamination of materials.
Minimise the number of fasteners and joints.	Simplifies dismantling.
Fasteners and joints should be easy to locate, access and remove.	Facilitates the planning of dismantling and the dismantling process.
Try to use joints and fasteners of material compatible with the parts connected.	Enables disassembly operations to be avoided
Pay extra attention to the consequences of joints and fasteners if the goal is design for reuse.	Increases the amount suitable for reuse.
Modular designs will be easier to reuse.	Facilitates service and exchange.
Pay attention to stability during dismantling.	Dismantling is a reversed building process.