Wooden Public Buildings and Their Fire Safety Regulations

A direct comparison in execution of the German and European building code

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ABSTRACT

The construction sector is experiencing a revolution on the idea to switch to its ancient building material i.e. wood. With climate change being a major crisis, world leading countries, such as Germany and Finland, have introduced massive timber construction, due to the benefits of timber.

The aim of this thesis was, to evaluate the knowledge of the building code standards in Germany and to develop an educational course for wooden public buildings and their fire safety regulations. Furthermore, projects from Germany and Finland were compared on their fire safety design and regulations. Fire was seen as a big influence on the idea of building with wood, as many disasters occurred in the past. However, such tragedies happened due to poorly planned structures.

Concluding was the fact that regulations have been restricting certain creative architectural projects. However, since the 2000's more and more buildings, completed out of engineered wooden products, have been constructed and proved that the essential knowledge is there and applicable to any building, with irrelevant size. Companies, governments, educational institutions, and passionate builders must work together to create a general acceptance among the people of this world, to start the mass production of wooden buildings on a general basis.

Keywords construction, wood, public building, fire, regulations

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1 INTRODUCTION

The construction field is one of the biggest industries in the world. As apartment prices skyrocket and the demand for better and newer living standards is rising, the field is experiencing changes in the way things are being done.

Further appreciation for the planet and its nature, lead to conversions in all diverse ways. More and more people want to leave a better place, than they have lived in. Therefore, a vast majority able to build buildings, with no regards on money, is trying to invest in new possibilities to build more environmentally friendly, with the same amount of safety and living capacity.

Steel and concrete have been the major key components of a stable, safe and fire resistance building. Therefore, no one was implying to change these. But with global warming being a major crisis, affecting our planet largely, new technologies must come to use.

Timber structures have been around for centuries and with new technologies, the timber construction field is experiencing a revolution in constructing higher, wider and more complex buildings.
Several countries have wooden building histories, especially countries such as Germany, home to a large number of very old timber-framed buildings. Therefore, the handling with wood, and the knowledge on how to build with this natural material is very different from the way the northern countries, such as Finland build.

However, the needed essential knowledge is still insufficiently represented in the educational system. It is still lacking a major focus on the new building revolution. As for this, this bachelor’s thesis is written to provide essential know-how to establish a new course for wooden public buildings. Topics will be about the construction process of wooden buildings, their benefits to the environment, and the general wood-based movement. The general idea of a public building will be discussed. To evaluate the fire safety regulations, projects in Finland and Germany will be analyzed on their design and execution.

2 PAST, PRESENT, AND THE FUTURE

2.1 Environmental impact of traditional construction

As the environment begins to be more appreciated by more and more people, the fact that the humans and their technologies keep destroying it, is still very frustrating.

Four years ago, the UN gathered in Paris to discuss the further development of global warming. The 184 participating countries have agreed to limit the critical temperature to well under 2°C by the end of the century. (United Nations, 2018)

In the past century, people have searched for solutions to find options on how to reduce carbon dioxide emissions in any way possible. Car manufacturers have developed highly efficient electric cars; meeting the standards of most fossil-fueled cars, meat consumption has lowered among the population; the cattle-industry e.g. is with 2 % a huge contributor to global warming. Additionally, public transportation has become widely accepted and furthermore, energy management has become a key role in urban development.

Yet, for the construction sector, which makes up to 40 % as seen in Figure 1, of the global waste, technological development has not yet been drastically changed. (TheReUsePeople, 2010) However, buildings nowadays must meet the national standards, which are based on experience and research, based on the agreements set by the UN. The standards should reduce energy consumption or energy waste, by using highly insulated building components, hence decreasing the energy loss of the building.

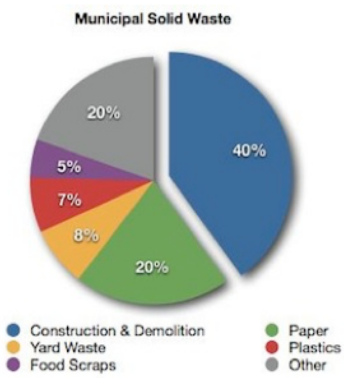

Figure 1. Solid waste, (THEREUSEPEOPLE, 2010)

However, the part of the construction field, which produces most of the waste and carbon emissions, has remained unchanged. Since the widespread use of reinforced concrete at the end of the 19th century, little to no change in the actual construction process has been made. Surely, new technologies such as concrete pumps, precast concrete, etc. have been given to the public; however, the idea of shifting back to the old but very effective material wood, has not yet fundamentally found widespread attention and acceptation. Steel and concrete, both very stable and durable materials, have been used to perform unthinkable engineering projects. The Burj Khalifa with 828m in height (Burj Khalifa, n.d), the Golden Gate Bridge with a range of almost 3 km (Wikipedia, 2019), or the Channel Tunnel in Britain, would not have been possible to construct, if not with these building materials. Most of the educational authorities build on the ideology of teaching mainly the traditional steel and concrete structure courses. As most developed countries in the world are participating partners of the UN climate peak, certain modifications in the construction sector have now entered. Carbon Concrete (carbon fiber reinforced concrete) (Sigmund, 2016), plastic bubble technology (less weight) (COBIAX, 2019) are technologies trying to use less steel or less concrete to balance out the carbon emissions for a building.

However, none of these new technologies have completely reformed the construction industry. In Figure 2 emissions of a cement fabric are displayed.

Figure 2. Cement production in China (GreenSpec, 2019)

2.2 Benefits of building with timber

Wooden structures have been around for more than 10,000 years, since the time people begun settling down, and farm the lands. (Price, 2017) In countries such as Germany, Switzerland, and Austria, timber houses still stand hundreds of years after being constructed. Timber products have always had the needed durability for tension and compression. Wood is used in many different ways, e.g. in furniture, bioplastics, energy resource, etc. However, since the race to the sky, the timber building construction has been moved on just small houses or barns, with no long-life expectancy.

2.2.1 Natural resource

Environmentally seen, the fabrication of concrete is one of the earth's biggest carbon dioxide pollutants, as cement is still its key component. The production is described as "a thermal energy-intensive process, which requires heating solid particles (…) and cooling it down." (Claisse, 2016) The production of cement is one of the world's leading industries, as e.g. 4 GT were annually produced in 2013. (Claisse, 2016) For each tonne, 750 kg of CO_2 is released, compatible with 400 m^3 of gas. Therefore, cement production is responsible for 7 % of the worldwide greenhouse gas emissions (Third after transportation and electricity contributors). Cement production releases carbon dioxide emissions directly and indirectly. Directly through heating its key component; limestone, and indirectly through burning fossil fuels for heat and transportation.

This is where timber gets the upper hand. As an ecological and biological product, its production has almost no effect on the global greenhouse crisis, like trees, plants and marine life (such as algae and corals), are the only producers of the sustainable essential to living on land: OXYGEN (O_2). As taken from the bio-economy Finnish website, timber construction slows down climate change, as trees trap carbon dioxide from the air during their growth. (Jensen, 2018) Wood is a natural product, meaning it can be easily regrown. In fact, the amount of wood needed to build 30000 one-family houses in Finland, is naturally growing just in one day (during the growing season – April to September). Furthermore, wood is storing carbon rather than releasing it, as seen in Figure 3. As Finland is just one of many possible mass producers of complex timber building materials, the future of the construction sector is very bright.

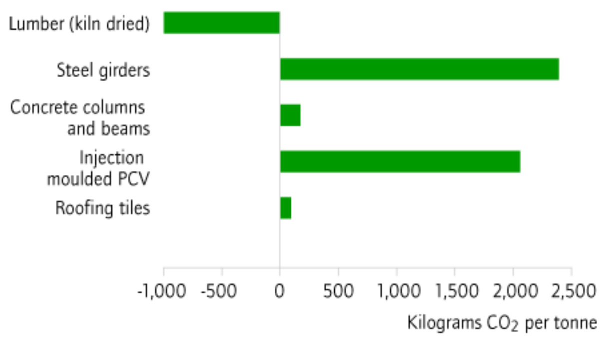

Figure 3. CO2 emissions construction materials (EuropeanWood, n.d)

2.2.2 Time management and construction logistics

As construction sites constantly undergo time and logistic issues, this is acting in favor of timber products, as they are incredibly time efficient. Traditional construction relies on the arrival of concrete, finishing frame works, and reinforcing steel on time. Following the need to achieve ultimate concrete strength properties, and to ensure the correct type and mixing, it takes up 28 days to cure. Time loss, such as framing or reinforcing, would disappear, thus the time for completion would drastically decrease to a minimum. As wood is still much lighter than steel, certain parts can be assembled by weaker cranes (seen in Figure 4), resulting in cheaper construction machine costs. This is different for any prefabricated material. In most cases prefabricate elements take only a short time to install. Producing engineered wooden products, e.g. a CLT panel, is taking up to one day at the factory. The element is ready for shipment on the next day. Taken from the interview of a student from Helsinki University, the general time saved to build with CLT is about 20%. (Scalet, 2015, p.17) Like precast concrete, wooden panels and beams are delivered to the site just-in-time to ensure the further flawless course of the agenda.

As time management is linked to the positive income of any business, the certainty in evaluating the profit is easier predictable and, in more cases, predefined, resulting in thinking about using prefabricate timber. The saying "Time is money" describes this advantage perfectly.

Figure 4. Massive timber element installation (Riley, n.d)

2.2.3 Safety for the workers

As production is moved to the factories, firstly material properties achieve highly precise values, and mistakes are easier to avoid. A CLT production factory is shown in Figure 5. Most of the heavy lifting and dangerous cutting is done by highly developed robots and machines. However, more important is the fact that through this shift from site to factory, the workers' health and safety is secured. Many of the work accidents mainly happen on site. In Austria, in the year 2017, 17070 accidents occurred. Of those, about 5000 were in traditional high-building construction. Compared to this, carpenter accidents only happened 732 times. (AUVA Abteilung Statistik, 2018) As this number will only decrease with time, the change from working on-site to producing the structural components mainly in factories, will prove that prefabricating, and in general working with massive timber is going to provide much better and safer working opportunities. Additionally, it is said that wood is a much more pleasant working material than concrete. It is not dirty, smells good, and while working with a natural product, positive energy is generated among the people.

Figure 5. CLT prefabrication (Massivholzsystem, 2019)

2.2.4 Thermal and sound insulation

“Wood is an important raw material, a socioeconomic treasure.” (Oreholm, 2016) As wood brings not only a very classical and beautiful look, it also provides huge amount of technical properties. As mentioned earlier, timber structures are able to withstand a large amount of forces. With the technology developing different wood-based products, the variety of usage is enormous. Wood can not only be used as the load bearing structure, but also as the technical insulant to provide the necessary heat and moisture regulations of a newly build standardized building of the 21th century.

Wood-fiber made out of cellulose has excellent absorption and releasing properties, without getting damaged. Furthermore, wooden insulation provides twice the storage capacity of mineral wool, because of its high density, delivering good damping properties. Wood-fiber might also be used as “semi-rigid boards or rigid boards”, optimal for the use of windbreak layer. The stiffest available board can also be used for sound- or underfloor heating insulation. Because cellulose is a much more pleasant insulation material to work with, it has gained plenty of popularity among the people working with it. As it causes no itching while or after working with it, it saves time to install compared with other insulations, and is still a natural based material, wood-fiber (cellulose) might be the future of building new homes and working places, completely out of wood. (Oreholm, 2016)

2.2.5 Disadvantages

No matter which material, whether it is concrete, steel, or wood, all of them have their disadvantages, which might exclude them from construction. In the case of timber, certain drawbacks must be noticed, while choosing it as the load bearing structural material.

As wood is a biological and natural product, decay is one of its drawbacks. Wooden decay is seen in structures which are either not properly designed, or buildings exposed to very harsh environments, such as wind, ocean water, and snow. (Heritage Insurance, n.d) However, as technology has perfected the design process, even in the hardest locations, timber housings can be erected. It is important to store wood according to its behavior to water. Wood is able to maintain its strength properties, if getting wet and drying again. However, in the case of timber elements being wet for a long period of time, the rotting process is going to move on quicker, if the wood is not getting back to its dry state. The reason for this biological process is that at the moisture value of 19% fungi are starting to colonize its host, the wood (Fachwerkhaus, n.d). Besides wet rotting, there is also dry rotting. This scenario is found seldom. A rotten wood log is seen in Figure 6.

Fire might be a vulnerability to some extent; however, this is only the case for poorly planned buildings, and small timber framed houses.
The idea of fire safety in a modern 21th century building will be discussed later in this thesis.

Figure 6. Rotten wood (rosebud10, 2006)

2.3 **A brief history on timber construction in Germany**

Timber framed houses or *Fachwerkhäuser* as they would be named in Germany, have their roots dating back to the 5^{th} to 6^{th} century A.D. The name derives from the open intervals, named *Gefach*. Starting just as small ground floor buildings, *Fachwerkhäuser* soon became much higher and stronger structures. (Fachwerkhaus, n.d)

Since the medieval ages, timber framed buildings have begun to emerge, as guilds, such as the carpenters, have gathered generations of knowledge to build longer lasting and stronger houses.

As wood was able to be obtained in large amounts, cheap, and easier to transport, than e.g. stones, it was a preferable building material for all people. Since mathematical or mechanical structuring was not yet being used, the carpenters were relying on their experience with the basic natural triangle phenomena, nowadays known as truss systems. As adopted through failures and mistakes, the builders have understood that a system, made out of only three parts, is able to withstand much more weight, then a more logical but weaker square system. Using this constructional idea, huge storage houses were able to be built. To fill the empty space in between the triangle structure, either bricks or a wood-clay mix was used. This had the advantage, as the clay could be directly taken from the excavation pits. With this technique, timber framed buildings were able to live over hundreds of years. The oldest to date still standing *Fachwerkhaus* is located in Esslingen am Neckar, with its construction dating back to the year 1261. (Großmann, 2015)

Timber-framed houses were built in masses until the beginning of the 18th century as wood, its most valuable building component, was barely findable, as the European powerhouses (Britain, Netherlands, France, Spain, and Portugal) started colonializing the world. For the construction of the ships, wood from central Europe was used, as it was the strongest and most reliable of its kind. This has led to a central European wood shortage (seen in Figure 7), causing a rising in wood prices. (Holznot, 2019) Apart from that, the owners and builders were no longer satisfied with the thin walls and, above all, the repair-prone wood, which led to other materials being used for solid construction.

Figure 7. 17th century deforestation (Freitag, 2012)

The tradition of carpeting is still performed until this day. However, the fact that timber has been, pushed out of the rising construction game has left the tradition to just a minimum of its capabilities. With the growing popularity of wood and its properties, this tradition might see its resurrection. For many years the wood construction company *AMANN*, from the south black forest, has been one of the leading companies for enormous wooden structures in Germany, and Europe. Lately, the swim hall of the Europapark has been finished. (SWR, 2018)

The history of fire protection and fire safety has its routes dating back to the great Roman Empire, being the developer of the first “fire-department”. (Zimmermann, Radanovic, Hartwig, Polat, 2009) Certain rules were established on regulating the use of fire in buildings and in public spaces. Night watchmen were introduced to secure the location and warn the people in case of an emergency. In the 14th century, *Dekrete*, the early building codes, very formed. (Zimmermann et. al., 2009) With the beginning of the 20th century the first *Landesbauordnung*, or national building code, was written down, explaining which materials and regulations buildings must be considered. The first authentic fire code, DIN 4102, was submitted in the year 1940. (Brandschutznormen, 2017) It was the first paper, reviewing test results, providing information about materials, and giving the current state of the art on fire and its prevention. Technological advances such as smoke detector and sprinklers, have been introduced to the public since the beginning of last century. (IBS, 2017) (Rauchmeldertest, 2019) However, certain fire prevention ideas have already been around for 500 years. Nowadays, no building, certainly no public building is designed without the necessary fire detection systems.

3 MANUFACTURING OF HIGHLY ENGINEERED WOOD PRODUCTS (EWP)

3.1 General

Wood has been criticized for its susceptibility to fire and decay. This might be true to traditionally sawn material. However, since the rise of highly engineered wood products such as cross-laminated timber (CLT), laminated strand lumber (LSL), and glue-laminated timber (glulam), wood has reached a new potential in civil engineering.

The key to reach wood’s full potential is to balance its grain-orientation and its moisture content. Controlling this, wood will provide precise, strong, and ultimately more durable properties. (TALL WOOD BUILDINGS, 2016, p.27)

Different species of wood have different characteristics of strength. This leads ultimately to the importance of making the right choice. In Europe the Norway spruce and Scots pine are the most common for structural applications. The ability to withstand a given load is measured by failure. It might be exposed to compression, tension, bending, shear and torsion. According to these test results the durability of the materials is evaluated, leading to its classification according to the Eurocodes or national Codes. Wood is strongest in tension or compression, parallel to its grain. However, the inconsistency of natural wood makes the predictability rather difficult. Therefore, EWPs have been researched and engineered to their maximum. Engineered wooden products, e.g. glulam, are fabricated by connecting strands, veneers or other sorts of wood fibers to make a much bigger unit, which is stronger. One advantage in comparison to traditional sawn wood products is that for EWPs, e.g. parallel strand lumber, smaller trees give the essential nature product. This is resulting in a much wider use of forestry. As the fibers are kiln dried, the manufacturing process is much more precise and can provide further essential data for construction safety. (TALL WOOD BUILDINGS, 2016, p.27)

3.1.1 Cross-laminated Timber (CLT)

The idea behind this engineered wooden product is that wood itself is greatly substantial to forces applied parallel to its grain direction. However, in case of most structural building components, this is only theoretically applicable. Therefore, forces must also be absorbed perpendicular. CLT is several layers of wood boards stacked together, where each layer is orientated orthogonal to the previous. By doing this, structural rigidity for the building component is obtained in both, parallel and perpendicular directions of the grain. The panels are mostly fabricated with odd numbers, to prevent the grains not having the same orientation of the outermost layers. A setup of a CLT panel is shown in Figure 8. Common panel sizes are (Stora Enso, 2017):

Width/Length/Thickness: 0.6m - 2.95m/ 0.6m – 16.0m/ 60mm - 320 mm

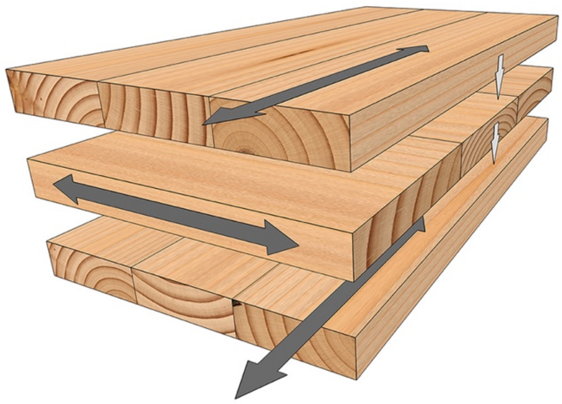

Figure 8. CLT cross section (Ebnesajjad, 2016)

3.1.2 Laminated Veneer Lumber (LVL)

LVL panels are produced by bonding thin wood *veneers* to a larger and thicker altogether panel. The grain direction of all veneers is parallel to the long direction. The layers are held together by a water proof glue. As the layers are so thin, irregularities, such as knots or splits, have been eliminated (Universal, 2019). This leads LVL to be virtually free from warping and splitting.

LVL comes in also a special form with 20% of its veneers directing perpendicular to orientation. This concept is used in situations where much more crushing endurance is needed.

Sizes are similar to Parallel Strand Lumber panels. However, LVL panels are much cheaper to produce, making them more attractable to be used as beams. To add, a further benefit of using LVL is that it can be fabricated in narrower widths and multiple plies can be nail-laminated together to from a larger beam. This is profitable for situations, where the montage is rather cumbersome (Hoesly, n.d). The setup is given in Figure 9.

Figure 9. LVL panel (Ultralam, 2019)

3.1.3 Laminated Strand Lumber (LSL)

LSL is made from flaked wood strands. These strands are typically arranged parallel to the longitudinal axis of the panel. To fabricate an LSL panel, the wood strands then are combined with glue and then compressed. Due to its high allowable shear strength, LSL beams have a capacity for larger penetrations than other engineered wood products. However, laminated strand lumber beams, do not cover the endurance of LVL or PSL panels, LSL beams are often used in situation of short distances, as the panels are generally cheaper. A setup can be seen in Figure 10. Alongside, LSL can also be used as floor, wall, and floor components. As all EWPs, LSL provides predictable strength, moisture resistance and stability. The maximum width is 2.4 meters. (TALL WOOD BUILDINGS, 2016, p.29)

Figure 10. LSL (Weyerhaeuser, 2019)

3.1.4 Glue-laminated Timber (glulam)

Glulam products can be used as columns, beams or even vertically and horizontal trusses. The production process of glulam has not fundamentally changed since the early 20th century, when it was first introduced in Germany. However, the lumber grade is now precisely evaluated and selected. In Europe, Red Pine is commonly used for its the fabrication. The given lumber comes in three different grades: L1, L2, and L3. The lumber is kiln-dried, providing a moisture content of 10 – 14%, and then glued together by the ends to fit the necessary length. This results it in the fact that glulam can be manufactured to any given length, making them especially attractable for long span construction components (there are, however, also common fabricated lengths and widths).

Glulam beams are usually laid up so that the load is perpendicular to its vertical long face orientation, as seen in Figure 11. The upper and lower laminations are exposed to higher compression and tension forces, resulting in higher lamstock grades, as the middle ones. On the other hand, Glulam panels are designed to withstand loads applied parallel to the long face of the laminations. (TALLWOOD BUILDINGS, 2016, p.27-29)

As these properties have shown its quality over the past 100 years, glulam is definitely one of the most used EWPs.

Figure 11. Glulam beams (Weekesforest, n.d)

3.1.5 Parallel Strand Lumber (PSL)

One of the newer EWPs are the parallel strand lumber products. This technology was developed in the year 1980. Its production is based on the idea to cut wooden veneers into long parallel strands and gluing them together under compression. PSL beams can be seen in Figure 12.

As the other engineered wood products, PSL also provides highly consistent properties. Most common use of PSL are beams, which are high bending stresses, and for header and lintels in load-bearing panel systems. PSL beam are generally more expansive then glulam or LVL beam. However, if the intention is to have a ready and clean look, PSL is an attractive opportunity. (TALL WOOD BUILDINGS, 2016, p.29)

Figure 12. PSL (Standard Building Supplies, 2019)

3.1.6 Adhesives / Glues

For engineered wood production, mostly formaldehyde-based glues are used. Going further in depth for cross laminated timber elements, three main different adhesives are being utilized: PRF (phenol-resorcinol-formaldehyde), EPI (emulsion polymer isocyanate), and PUR (one-component polyurethane) (Scalet, 2015, p.20). Which glue is used, depends on the location of the product, i.e. if it's an interior or exterior part, on the temperature, and whether it is necessary for the product to look good afterwards or not. Once the components are pressed together, the time needed to achieve ultimate stability is about 10 min in the compressing machine. Most of the glues contain the hazardous chemical, formaldehyde. (TALL WOOD BUILDINGS, 2016, p.31) It is a naturally occurring organic compound, found in wood and its products. For general wellbeing, this chemical is listed in WHO list of the bigger indoor air pollutants, as high exposure to this substance might have impacts on the occupant's health. For now, research is focusing on finding low to non-formaldehyde adhesives. However, some EWP's have the possibility to be fabricated with no glue needed. This is the case for the CLT panels of the *WOODCUBE* in Hamburg, which will be analyzed later on. The system is held together by mechanical dowels, leading to the building being completely adhesive free.

4 WHAT IS A PUBLIC BUILDING?

As countries of the European Union, Finland and Germany, both have their national building codes, based on the Eurocodes. However, the individual annexes, must meet the essential qualifications for each country. Northern countries such as Finland, must consider much higher snow loads, higher relative humidity differences etc. Compared to this, northern parts of Germany, builders must rely on data on wind loads, given them by the German national building code. However, all the calculation processes are somewhat similar. A hospital consisting of wooden columns is mentioned in Figure 13. Furthermore, a LVL beam church is shown in Figure 14.

Figure 13. Hospital in Salt Lake City (Big-D, n.d)

Figure 14. Church in Germany (Homify, n.d)

4.1 **Public building and public authorities**

Countries around Europe differ on how a public building is defined. The Czech Republic e.g. defines a PB as, “all buildings that are not apartments or non-residential”. The UK characterizes it as, “a building that’s occupied by a public authority and frequently visited by the public.” For the Finnish government it is “a building which provides public services.” (DesigningBuildings, 2018) As in the case of Germany, the officials abstractly define a Public Building as, “in particular cultural and educational institutions, sports and recreational facilities, health care facilities, office, administrative and court buildings, shops and restaurants, parking lots, garages and toilets.” (DIN 18040-1,2017). Furthermore, found in paragraph 2 of the *EEWärmeG*; the Renewable Energies Heat Act, public buildings are specified as “non-residential public-sector buildings used for legislative, executive, judicial or public-sector tasks. This excludes public-sector buildings when providing services in free competition with private companies, in particular public companies for the supply of food and beverages, the production, storage and distribution of goods, agricultural, forestry or horticultural enterprises and businesses for the supply of energy or water. *Bundeswehr* buildings used to store military or civilian goods are also excluded. Mixed-use buildings are public buildings if they are used predominantly for tasks or facilities to that extent." In general, there is a variety of public buildings in Germany. They can be divided into six different categories (DIN 14676,2019):

1.) Social Life (e.g. schools, kindergartens, town halls)
2.) Healthcare (e.g. hospitals, nursing homes, prisons)
3.) Culture (e.g. libraries, museums, theaters)
4.) Infrastructure and traffic (e.g. train stations, airports, public garages)
5.) Economy and leisure (e.g. playgrounds, parks, fair halls)
6.) Religion (e.g. churches, cemeteries, temples)

Now the question must be clarified what a public authority is and what it represents. As for the German government, a public authority is the part of the executive, which takes up public tasks. As public tasks, the German legislative defines responsibilities, fulfilled by a public sector in needs of the general well-being of the society. The public authority is the administrate sector of the executive power. This could be a school council, governor or sport and activity department etc. As the topic of this thesis is based on the idea on developing a course for constructing a public wooden building, this clarification is somehow needed, as public buildings and their requirements, differ from residential and private ones. This is especially the case, for safety in case of an emergency, such as fire. Most of the public buildings are being built for the state. Therefore, in many cases money is a smaller problem. However, as most governmental institutions are already built and in use the demand for new and architecturally, engineered wooden buildings in such areas is rather small. Schools, churches, and smaller public buildings such as sun shades etc. are the buildings constructed in most of the cases.

4.2 German national building code (DIN) and the Eurocode (EN)

The Eurocodes are a set of European Standards for the design of buildings and other civil engineering works and construction products. However, they do recognize the responsibility of reach authorities in each Member State. The member states have the choice to use the given sets; however, they can also rely on their Nationally Determined Parameters (NDPs). They come from differences in geographical or climatic conditions, or in ways of life, as well as different levels of protection that may prevail at the national, regional or local level. (EuropeanWood, n.d)

The National Standard transposing the Eurocode Part will be published in the Eurocode by the National Annex. The National Annex may contain information on the NDP's to be used in the country concerned, on the application of informative annexes and reference to non-contradictory complementary information. Eurocode 5 covers the design of timber buildings and civil engineering works. (EuropeanWood, n.d)

The Eurocodes are to apply basic European standards as unified design rules in construction and in structural design. They have been legally binding in Germany since 1 July 2012 (with the exception of EC 6 and 8) and must be complied with by the building authorities, planning bureaus, and building owners. The individual federal states may, if appropriate, make transitional arrangements for their possible area of responsibility for the possible further application of the previous DIN standards.
The Eurocodes are subdivided into 10 main groups. In total, they consist of 58 parts of the series DIN EN 1990 to DIN EN 1999 with corresponding national annexes. (DIN 14676, 2019)

The introduction of the Eurocodes also requires a corresponding consideration in the General Technical Terms of Contract for Construction Work (ATV) for the individual trades in the VOB, Part C. The purpose of the Eurocodes is to achieve and apply more uniform criteria throughout Europe for the planning, exchange of products and services of the construction industry, and the tendering of works contracts and works.
However, if the state or country chooses to apply further research or regulations, they have the chance to do so. In the end, the basis of all calculations are the Eurocodes. (Baunetzwissen, n.d)

5 FIRE SAFETY

As many might think, wood is highly flammable. This is the case, when small wood chips are exposed to fire. Fire is not as big of a danger to a wooden structure. It is quite the opposite. Certainly, wood burns easier than concrete. However, the fact that when wood burns, the time of a woodblock to be fully burned, is very controllable. While being exposed to fire, wood develops a layer of coal. This layer is preventing further and faster burning. It must firstly be breached by the fire to cause further damage. Additionally, most of the modern buildings will not have open timber surfaces but will be covered as most of the traditionally built ones e.g. by gypsum boards. The different design ideas will be discussed later.

Steel, on the other hand, is in most cases protected by concrete. However, in a fire emergency, the steel is still very easily affected by the increasing heat. With the temperature rising, the steel loses its durability and can easily collapse or buckle, causing instability of the structure. In factories or wide hall structures, where steel is unprotected, this is a very big problem. Massive wood structures hold their durability much longer in cases like this.

The greatest risk and the most important designing aspect in massive wood structures, is fire safety. As mentioned earlier, a great misconception among the idea of building with timber, is that when exposed to fire, a wooden structure might not stay structurally stable. Therefore, many might still fear the consequences of living and working in a wooden structure, based on historical events as the Chicago or Boston fire.

For the evaluation of fire risk, it is important to differentiate between fire coming from the outside, and the more troubling fire from the inside, better known as compartment fire. (TALL WOOD BUILDINGS, 2017, p.39)

5.1 Fire safety for public buildings in general

Structural fire protection for timber buildings is subject to specific regulations. Therefore, fire protection depends mainly on the building materials and their fire resistance.

Generally, every *Bundesland* of Germany has their own law on how to execute a construction. To a great extent they are all similar, however certain parts might differ from location and experience in these states. The executive way of the country Rhineland-Palatinate will be taken.

As taken from the *LandesBauOrdnung Rheinland-Pfalz (LBauO)*, fire safety is applied to all buildings similarly. Further regulations must be met, by certain special building (such as public building e.g. hospitals). However, the base of all fire safety regulation is the same. Buildings must be placed and constructed in a way that fire and the spread of fire and smoke is prevented, the rescue of humans and animals, and effective fire extinguishing is possible. (section15 paragraph 1). Continuing in this section of the building code, certain topics, such as flammability (section15, paragraph2), resistance to fire (section15, paragraph3), accessibility to escape routes (section15, paragraph4), and lightning protection (section15, paragraph6) are discussed. (Krumb, 2016)

Section 27 determines that load bearing structure must be constructed in a way to stay stable until the fire department has arrived and started with the extinguishing works. Buildings are classified in five sections. Building-class 5 is resistant to fire, BC 2 should be mostly built out of inflammable materials. (Krumb, 2016) Furthermore, section 28 is applying this to the outer walls and section29 for dividing non-load bearing walls.

Apartment or building complex separating walls, called fire walls, are introduced in section 30. They must be enclosing and be constructed from non-combustible materials, e.g. gypsum. The idea being building a *BRANDWAND* is to ensure that in case of a fire outbreak, the risk stays to one apartment or building complex. It should not affect the other parts of the building. (Krumb, 2016)

On the topic of rescue possibilities, section 33 defines the need of stair cases. Stair cases are needed for every floor which is not ground-level. In case of further rescue, additional stair cases can be designed. They must be easily accessible and easy to find. Doors must be opened to the side of evacuation, securing a safe passage. Stairwells must ensure safety, if the only safe place is the stairwell. Safety must be guaranteed until rescue. This is achieved with non-combustible doors, walls, and ceilings

To achieve a uniform test evaluation on an international base, a uniform curve (ETK) was developed, describing the course of the fire. (Figure 15)

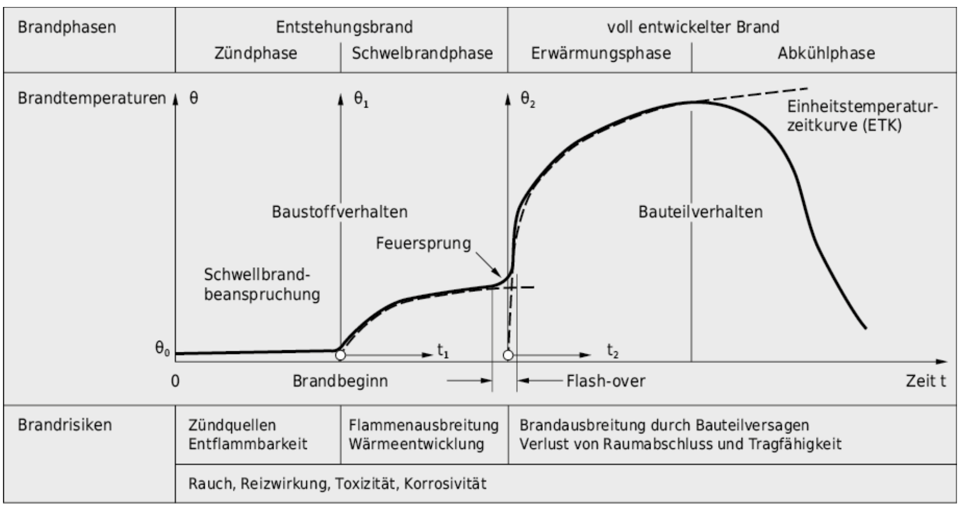

Figure 15. Fire course diagram (Zürcher, 2018)

On the Y-axis, the temperature difference ΔT is given in Kelvin. On the X-Axis the combustion time is lain down. The fire cycle starts with the ignition, developing into the "flash-point" where the temperature rapidly increases. After reaching its turning point, where the material does not feed the flames enough to produce more energy, the cooling phase starts. The diagram is divided into four sections: ignition phase, smoldering phase, heating phase, cooling phase. Every flammable material has this course. Burning temperature and combustion time is, however, material dependent. (Albert, 2014, p.10.90)

The German building code defines its fire regulations under the DIN 4102. This standard is based on researching materials and their behavior, under exposure to fire. While designing and planning a timber house, it is of importance to regulate certain aspects, such as accessibility to extinguishing water, withstanding stability under fire, and dividing the building into segments, to prevent uncontrollable fire expansion.
To narrow it down (Rauchmelder-Shop, 2015):

- Fire should not be able to expand quickly or in the best case not at all
- Escape route possibilities should be easily accessible
- The fire department should have easy admittance to the building and its surroundings.

Building code *DIN 4102* defines the behavior of building materials such as timber. They are classified, under their behavior on flammability and resistance to fire. In summary there are two classes: A and B. Class A represents inflammable material and B the opposite. These two classes, however, are separated into five subsections from A1 to B3, with lastly mentioned being very flammable, e.g. wood chips. (Albert, 2014, p.10.91)
The course of a fire accident is mainly certified by the amount of the combustible material, its concertation, and its storage density, the geometry of the room, the thermal properties of the rooms surrounding materials, the type and amount of oxygen supply, and the type and amount of extinguishing power. (Albert, 2014, p.10.91)

For wooden buildings, the most important feature is for the load bearing structure to be able to withstand fire exposure until all occupants are safe. Although the solid individual elements are made of combustible material, this plays a minor role in the assessment of the fire resistance duration of the entire building construction. It is more important how long the structure resists the fire. Being exposed to fire, 1 m^3 of wood releases about 45 liters of evaporated water, preventing the massive timber element to go up in flames. (TALL WOOD BUILDINGS, 2017, p.41)

The European classification system *EN 13501* is more complex than the German national annex Din 4102-1. The materials are separated into sections A1, A2, B, C, D, E, and F. Additionally, it is differentiated between construction materials and flooring materials, and a new category of smoke development of each material is introduced. Each member of the European Union has then the option to add their own safety issue if need. (Albert, 2014, p.10.91)

As most of the known public buildings are regarded as extraordinary buildings after table 10.88c in the construction table book *Schneider*, public buildings must undergo higher regulations, especially in the case of fire safety. One reason for further regulating the risk, is that visitors e.g., do not know the building, and might therefore not find the quickest exit in time. This is why the planning of very simple escape routes is crucial for public buildings. (Albert, 2014, p.10.87)

The design is divided into three sections: material and constructional fire security, device fire safety, and organizational fire safety. Material and constructional fire safety concerns as already earlier mentioned, the flammability and endurance of building material under exposure to fire. (Rauchmelder-Shop, 2015)

Device fire safety regulates the usability of certain fire prevention devices, e.g. smoke detectors and sprinklers, and how they should be positioned inside a building.

Lastly, the organizational fire safety defines how a building is designed properly against fire, by evaluating and classifying the building into its key components, such as height, volume, and occupants. Knowing this data, fire engineers are deported to educational meetings and talks about fire prevention, and how to act while being in a fire alarm. (Rauchmelder-Shop, 2015)

To further evaluate the necessary precaution on developing a fire secure building, further input will be taken on escape route design. Escape routes are routes which need special attention. They must lead the occupants to safety in any case. Therefore, they must lead into a secure space or outside. Section 15 paragraph 4 of the *LBauO* defines that any housing construction, whether residential or public, must provide two from each other independent escape routes on each floor. Both routes, however, are allowed to follow one of the building's common hallway. The main escape option is formally named "escape exit". The second is representing the less commonly used but available emergency exit. The escape routes higher than ground level, must be accessible by stairs. However, this is only the case for bigger buildings, with no possibility to evacuate the occupants by mechanical help of the fire department. Elevators are excluded from any form of the escape route system. The validity of the evacuation design is tested with fire drills. It is measured how long it takes to get the people outside. The escape routes must always be free of any obstacles, which prevent a smooth evacuation. The paths must be visible at any given point and must be easy to understand. In areas such as shops, or other public spaces, obstacles must be possible to remove with a maximum force of

150 N, in the opening direction. In general, all escape routes must deliver the quickest possible way out. However, the route lengths depend on the building size and usage. (Krumb, 2016)
For rooms without or limited fire possibility, they must not be longer then 35 m. On the other hand, for rooms with increased chance of fire, the route must not be longer then 25 m. This is the case for rooms without a fire extinguisher. However, the actual walking distance is not allowed to be more the 1.5 of the designed paths. For the width of the escape route, the number of occupants is crucial, linking it to the building's usage. The width is divided into five groups. The group number, the number of occupants, and the resulting width is given in Table 1. (Baua, 2007)

Table 1. Width of the escape routes (Baua, 2007)

Nr.	Anzahl der Personen (Einzugsgebiet)	Lichte Breite (in m)
1	bis 5	0,875
2	bis 20	1,00
3	bis 200	1,20
4	bis 300	1,80
5	bis 400	2,40

Resulting from this, comes furthermore the size proportions of the room dividing doors, and the "to the open" leading stairs. For five people in the hallway, the width, however, is not allowed to surpass 0.80 m. The other groups have a limited play value of 0.15 m. (Baua, 2007)

As earlier mentioned already, doors must always be open in direction of the escape. They must open easily and be able to be opened without any mechanical help. The knobs or handles must be visible, so that the opening direction is quickly understood. Revolving or gliding doors are in all of the design options, excluded as they might lead to interferences. Escape doors closed from the outside, must always be able to be opened from the inside. On the outside, the area must be designed so that no blocking of the escape route is possible. On the outside of an opening escape door, signs must be placed, forcing no obstacles to be placed in front of them. All paths must be endowed with lightning symbols, which in case of a power blackout, the occupants still find the exit. Every room must have a certified floor plan, providing essential information on what the quickest way to safety is. They must be up to date and free from any object covering them. Furthermore, they must contain information on where the exits are, but also where the extinguishing possibilities, and the first aid kits are located. Additionally, the rules on behavior while in a fire, must be short and precise, in their information. Firms and employers must give annual instructions on updates and general information. (Baua, 2007). Such escape route plan is defined in Figure 16.

Figure 16. Emergency exit plan of a hospital (Firesafe, 2011)

Fire preventing and Device fire safety regulations are based on the current technical stand of the art. The operating equipment must be designed in a way that even in changing acoustic levels, warnings are able to be heard, by anyone, being deaf or profoundly deaf. In private rooms such as the bathrooms, deaf people must have the possibility to be warned by visual alarm signals. Smoke detectors are mainly represented once per room. If the room area surpasses 60 m^2, the number of detectors must be adapted. If the height surpasses 6 m, they must be placed on levels. In Germany and Finland, smoke detectors are a forced precaution. In case of death or any fire accident, where no smoke detector is installed, insurance companies deny any expense on their behalf. In Germany each year 500 people die in from carbon monoxide poisoning. Smoke detectors are proposed to be positioned in the middle of the room, or not less than 0.5 m from the walls. Generally, it should be somewhere where the danger is detectable. Most of the public buildings have their fire preventing system connected to the nearest fire department. Therefore, help is on the way, even though nobody might have noticed. (Rauchmelder-Shop, 2015)

In bigger and more used buildings such as factory halls, hospitals, and schools, sprinklers can be used to act as an active fire prevention system. Sprinklers automatically deliver a constant water flow, after detecting fire or smoke. Therefore, wide spread extension of the fire and further damage is prevented. However, in cases of huge fires, the system does not provide full fire prevention. In Germany, sprinkler systems are usually designed in accordance with the *VdS CEA 4001* (VdS Schadenverhütung, CEA Comité Européen des Assurances). The design is carried out depending on the risk of fire in the area to be protected by determining the water exposure of the fire between 2.25 mm / min and 30 mm / min (1 mm / min corresponds to 1 l / m^2 / min), the action time between 30 and 90 min and the distance between the sprinkler heads (GAMA-TRONIK,2019). In Figure 17 a combination of smoke detector, sprinkler and escape exit sign is shown.

Figure 17. Smoke detector (right), sprinkler (middle) (CBC, 2014)

5.2 **Fire safety calculation and design for wooden structures**

To evaluate the load bearing capacity of a building structure, under exposure to fire, in general, three different validation methods are being done (Albert, 2014, p.10.106):

- table method (Verification 1)
- simplified calculation method (Verification 2)
- general calculation method (Verification 3)

Verification 1 is evaluating the fire safety dimensioning, after using table content, after similar tested structural components.

Verification 2 and 3, both use calculations to evaluate that after enduring fire exposure for a regulated time, the substantial mechanical impact on the load bearing component, will not surpass its strength capacities.
In the case of wood and structures built from wood, certain differences to reinforced concrete and steel must be adapted.

The German annex uses the European standard procedure after *DIN EN 1995-1-2:2010-12*. The design process however does not accept the use of tabular verification in the case of wooden structures. The simplified or exact calculation is therefore applied.
Fire loads are calculated as follow:

$$E_{d,fi} = \sum G_{k,j} + \psi * Q_{k,1} + \sum \psi_{2,i} * Q_{k,j} \quad (1)$$

The load bearing strength of an ideal burned cross section is calculated, by considering the burning depth d_{ef}.

$$d_{ef} = d_{char,n} + k_0 * d_0 \quad (2)$$

$$d_{char, n} = \beta_n * t \quad (3)$$

β_n equals the burning rate after table 10.106a; t equals the fire resistance time. d_0 equals 7mm, being a higher burn. k_0 = t/20 for t more than 20 minutes, resulting in k_0 in 1.0. (Albert, 2014, p.10.106)

According to the table in the building code, different materials have different values for the above-named variables, as wood is not only used as structural loadbearing element, but moreover mostly as construction wood.

In table 10.1106b a k_{fi} value is introduced. This value defines the 20% fractile value, if the burning time is more than 20 min. For massive wood elements this value is 1.25, resulting a k_{mod} value of 0.8 (1/1.25).

This calculating process shows on how to plan the structural element on its strength properties. (Albert, 2014, p.10.106)
For the design of the building it is to understand the difference between prescriptive and performance-based codes. Prescriptive based codes define how a building must be built to show certain safety regulations. “For decades clients, architects, engineers, insurance companies and authorities having jurisdiction found it expedient for reasons of economy, familiarity or liability, to simply build in accordance with the methods prescribed in the code”. (TALL WOOD BUILDINGS, 2016, p.39). The problem with this is that they are based on research based on performance. As the architect or designing engineer, wanting to use wood as the key structural component, the preposition of the project as an “alternative solution”, is the way to undergo the prescriptive based jurisdiction. (TALL WOOD BUILDINGS, 2016, p.40)

As Building Information Modelling and computer aided designing is also applicable to fire simulation, buildings of the 21st century can be designed and evaluated on their fire behavior. “A virtual three dimensional model can be constructed to evaluate the effects of multiple variables, including the size and starting point of a fire, the degree of compartmentation, design details and materials used for fire separations and, in the case of tall wood buildings, the area and location of exposed wood surfaces.” (TALL WOOD BUILDINGS, 2016, p.41).

Coming now to the fire design options of a wooden building, it can first be said that the design depends on the decision of the building’s authority. In most cases this is the client.

Full-Encapsulation is the first option a client of wooden building can have. In this case the load bearing structure is fully secured against fire, because of protection of non-combustible materials, such as gypsum. It is the most conservative and traditional way to construct. (TALL WOOD BUILDINGS, 2016, p.41)

Semi-Encapsulation is a newer approach to design a building more naturally and relying more on the actual design. In his method, certain parts of the structure wood are exposed. However, not all of it. As ceilings are the part which are most likely to be exposed continuously to fire, ceilings are primary concealed by a non-combustible material. On the other hand, columns or wall elements, are in the most cases unlikely to be getting much of the fire exposure. Consequently, those elements must not be encapsulated by any securing material. (TALL WOOD BUILDINGS, 2016, p.42)

Non-Encapsulation is the last design option. It is by far the most liberal method to construct a wooden building. Its intention is to leave as much wood exposed as possible. Its idea is based fully on the design with fire simulation and calculating the risk. This approach was used in the *WOODCUBE* in Hamburg, one of the projects in this thesis. In most cases, however, fire will burn the load bearing wooden structure. The non-encapsulating design approach is using “over-designing”, meaning using more than necessary as strength properties. The extra thickness of the wooden element is therefore acting as a sacrificial-layer. The thickness is calculated by using researched based information on the flammability of the building material. As a matter of fact, the most liable part of the wooden structure is the steel connectors, as in some cases they might be exposed to the surface. Thus, most of the connecting parts, must be fully encapsulated by the timber elements. (TALL WOOD BUILDINGS, 2016, p.42)

6 PROJECTS

Wooden projects have gained a lot of attention all around the globe. Especially in Europe and North America, as the essential technology and resources are given. Moreover, most of these countries are part of the first world culture, having the possibility to invest in further development and environmental thinking.

As educational systems still lack the knowledge and the idea on how to lecture the future generations on how to build with timber efficiently, recent projects will be analyzed and discussed, based on their design, location, and effect on their surroundings.

6.1 WOODCUBE, Hamburg/Germany (Timber-Panel System)

As one of the exhibiting projects of the IBA in the year 2013, the *WOODCUBE* was a pioneering project in the new timber building era. It was constructed as the first five-story massive timber building, which was completely pollutant free and carbon neutral. As governmental regulations tighten the building technologies, the intention of its developer, *DeepGreen Development,* was to "be as climate-neutral, sustainable and healthy as possible. Because sooner or later that will be the requirement in construction." (DeepGreen, 2013) This was achieved due to its structure being entirely built from non-glued solid wood. I.e. without biologically harmful construction chemicals, without PVC, glues or other toxins. Consequently, health and environmental impacts of building pollutants can be completely excluded. This is a huge advantage to its traditionally constructed rivals, the passive houses, which are built on the standard, to tightly seal the building, ensuring almost no energy loss. However, for insulation and vapor resistance, harmful material is used, releasing contaminants into the air. As a consequence, the indoor air pollution is affected, certainly not matching with the idea of the "environmentally friendly" living and working space.

The *WOODCUBE* is still, however, built with some support of reinforced concrete, as it needs a stable and humidity resistance base for its foundation, as wood is easily attacked by the permanently wet surroundings. The concrete core is used to ensure lateral resistance and as the wood panels are the same material, for slabs and the balcony cantilevers. These connections produce no heat bridges, ensuring its carbon neutrality.

In 2010 *DeepGreen Development GmbH* started a partnership with the construction company *P&P AG*. The construction began at the beginning of 2012 and ended in May 2013. As far this goes, the time management is incredible in comparison with traditionally reinforced concrete or masonry buildings. The construction started in the summer with the concrete foundation and continued with the elevator and staircase core. This stage was finished by the end of October. The construction process of the *WOODCUBE* is based on the modular building method. It represents the time reduction due to prefabrication and just-in-time delivery. In this case, the outside walls, floor, ceiling, and roof panels were delivered. However, the untreated wooden cladding of the building was attached on-site by the contractor.

6.1.1 Outer Wall Panels

The building's outer walls are based on a panel system, consisting of solid glue-less cross-laminated timber. The elements are held together by wooden dowels, with a specific system by the developer at *DeepGreen* and *Holz100*. The dowels are in the right angle to the layers, spacing distances of 30cm lengthways. The dowels are kiln-dried, performing approximately 15% of humidity (±3 %), so that they adjust to the pressure inside the element. The total thickness of the outer wall is 32.4cm with a heat transfer coefficient of 0.19 W/m^2*K. Layers start with 25.1cm of fir wood, 4.4cm soft wood fiberboard, and 2.9cm of fir wood board. Ninety-five percent of the element is fir and five percent is spruce wood, while the load bearing solid timber is class S10 (C24) after regulation of the *DIN 4074-1*. The outside wall element consists of 12 layers (Figure 18), with its façade component being a 29mm, inlaid and dowelled with the two, soft wood fiberboards (Gutex Multiplex-top), each 22mm thick (Petersen, Rödel, (2014). p.12). As cladding, a 26mm thick slotted, ventilated board was chosen.

Figure 18. Outer wall cross section (Petersen, Rödel, (2014). p.11)

6.1.2 Floor and ceiling Panels

As well as the wall panels, the roof, floor, and ceiling elements consist of non-adhesive cross-laminated timber. They are fixed by wooden dowels, in the same way as the outer-wall elements are. The floor element is 42.5cm thick. The layer setup is given in Figure 19.

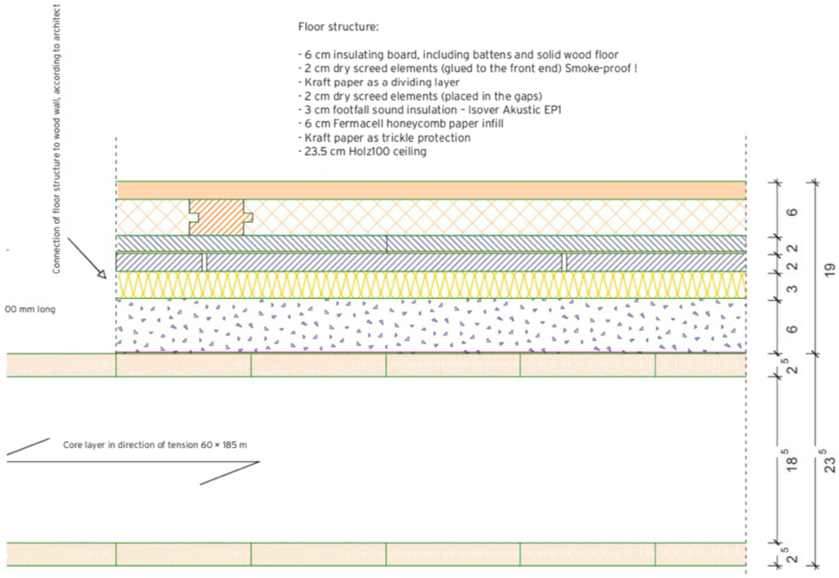

Figure 19. Floor cross section of the WOODCUBE (Petersen, Rödel, (2014). p.13)

As mentioned earlier, the elements cover the distance from the elevator core to the outside wall, or further, in the case of e.g. a balcony cantilever extension. The ceiling elements are connected via floating T-Square. In areas of higher loads due to the building components on top of them (in particular, underneath the cantilevered balcony slabs), solid timber supports are integrated into the outer wall structure (Petersen, Rödel, (2014). p.13). The top of the elements is covered by 60 mm of dry screed and 30 mm of mineral fiber insulation, to certify noise decrease.

6.1.3 Fire safety

In Germany, buildings are divided into building classes according to the state building regulations of the individual federal states. The classification of a building into a building class depends on the height and the area of the building. The division of the buildings into different building classes entails different demands on building material and component requirements. In general, the higher the building class, the stricter the requirements for the fire resistance of the components. It must not be deviated from in the course of the creation of a fire protection concept. (Albert, 2014, p.10.88)

After section 2, paragraph2 subsection 4 of the *LBauO* the building is with its 12m of height categorized into group 4. This is necessary to meet the fire regulations, due to rescue options in the building. The WOODCUBE meets all of the requirements of a multi-story building. Approval went over areas of burn rates, fire protection, and flue gas risk analysis (Petersen, Rödel, (2014). p.15). However, a specific test had to be carried out, as e.g. the façade is not ventilated. The test consisted of checking the air tightness, fire safety of the massive wood, and condensation of water in the outside wall elements.

After evaluating the test results from the University of Darmstadt, the conclusion was that “wood is three to five times more resistant to fire then concrete or bricks.” (Petersen, Rödel, (2014). p.15). The outer wall elements are resistant to fire for more than 90 min, due to 84 mm thick sacrificial layers of solid wood. The load bearing element, with its 80mm is also allowed to burn 15mm. Combining both leads to a fire resistance capacity of 120 min. This puts the wooden building in the category of F120, as taken from Figure 20. This means that the fire resistance is very high, because of almost non-combustible materials.

Feuerwiderstandsklasse	Widerstandsdauer (in Minuten)	Bauamtliche Benennung
F30	30	feuerhemmend
F60	60	hochfeuerhemmend
F90	90	feuerbeständig
F120	120	hochfeuerbeständig
F180	180	höchstfeuerbeständig

Figure 20. Fire resistance classification (Baua, 2007)

The floor and ceiling elements are covered by ta “burn-up” layer as well, giving 28 min of rescue time.
Fire tests were conducted on elements which were exposed to a flame with 900 C. In Figure 21 below, the damage after 60 min is displayed.

Figure 21. Damage after 60 min, on a solid wood OWE (Petersen, Rödel, (2014). p.16)

The F 90 fire resistance duration (= 90 minutes) required in building class IV at 1000 degrees continuous flame was easily achieved, the special construction of the solid wood prototype achieved even record-breaking F 180. (Petersen, Rödel, (2014). p.16)

6.2 PUUKUOKKA, Jyväskylä/Finland (Timber-Panel System)

The next proposed project is located in Jyväskylä in Finland. It is built as a panel element system, just as the WOODCUBE. Puukuokka is Finland's first eight story timber building. This is rather strange for a country consisting of roughly 75% of forest. (Finish Forest Association, 2019) Reasons for this late approach to massive timber buildings are building code restrictions, lack of skilled carpenters, and a functioning development industry producing engineered wooden products such as CLT. However, with the construction of this residential building further development in this new industry has been made. The first of three buildings were completed in 2015. Building 2 was finished in 2017 and building 3 in 2018. Its developer *Lakea* provided an option for buyers to get a 7% down payment on the purchase price of an apartment to secure a state-guaranteed loan and, after a rental period of 20 years, assume freehold ownership of the unit. (TALL WOOD BUILDINGS, 2016, p.96). As Finland values justice and sociality, this concept gives more people the chance of buying and living in a modern timber house.

The building has been extremely well received by the residents who praise it for creating a comfortable living space with an excellent framework for a friendly and safe neighborhood (ArchDaily, 2018). It has been given several prices and awards, among them the Finlandia Prize for Architecture in 2015, the Wood Award in 2015, the Resident Act of the Year Award in 2016, the Canadian Wood Design and Building Honor Award in 2015, and the German Design Award in 2017, and it was shortlisted for the Mies van der Rohe European Contemporary Architecture Award in 2017. (OOPEAA, 2019)

Figure 22. Puukuokka on the private side (OOPEAA, 2019)

6.2.1 Construction process

Puukuokka was built using the modular prefabricated assembly method. All the essential elements such as wall, roof, and ceiling panels were prefabricated in a local company less than two hours away (Stora Enso). This led to the building's very small carbon footprint.

The project is built on a concrete foundation with a parking garage below the building. "To preserve the naturally hilly landscape of the site, as much of the bedrock has been left untouched as possible. The building follows the contours of the site to minimize disturbance to the underlying bedrock and existing vegetation." (OOPEA, 2019)

This construction process has many benefits for buildings in such areas. As the winters are long and cold, prefabrication is first of all quicker in assembly, and second of all, also possible to do in winter. If it is too cold e.g. while firming up, the concrete has to be heated or chemicals such as ammonium have to be mixed in the concrete. This falls out of the process, as prefabrication of massive wooden elements such as CLT is taking place in a warm and humidity regulated space. This project has two CLT elements which were produced: a wet one, and a dry one. Wet as wall and ceiling panels for the bathroom and kitchen, and dry, for living room and bedroom. (OOPEA, 2019)

While constructing Puukuokka was covered by a temporary roof, as the open CLT elements are highly vulnerable to weather changes. The finished product, however, is covered by a cladding, protecting everything precious. The temporary roof was removed when a new set of panels arrived to be stacked on top. This would go on for every story of the building. With its location, Puukuokka had advantages, as space was given in a high matter. Construction went smoothly like "stacking up Lego's" (OOPEA, 2019). The floor connecting stairs were CLT panels, too. Once all the parts of a floor were assembled, the building achieve rigidity, with the need of a concrete core. This is different from the previous project the WOODCUBE, as its structural rigidity was achieved due to the connection of the ceiling panels to the concrete core. In Puukuokka, the interior walls work as the structural safety against shear and lateral movement, as they act like bracings components. Most of the elements were prefabricated to the point, having all of the essential installations, such as electric cable, toilets, and kitchen parts, connected to the panels. The wall thickness decreases with height, ensuring the lightness of the building. The building is designed to be very colorful with lighting. Windows in the Atria and the hallways make Puukuokka a bright and joyful building. It is built on the idea of having a street and the private side, which is displayed in Figure 22. On its private side, the building is covered the untouched CLT panel elements. On the other side, the building presents its black paint covering. (OOPEA, 2019). In Figure 23 different cross sections can be seen, describing the connections to the different panel systems.

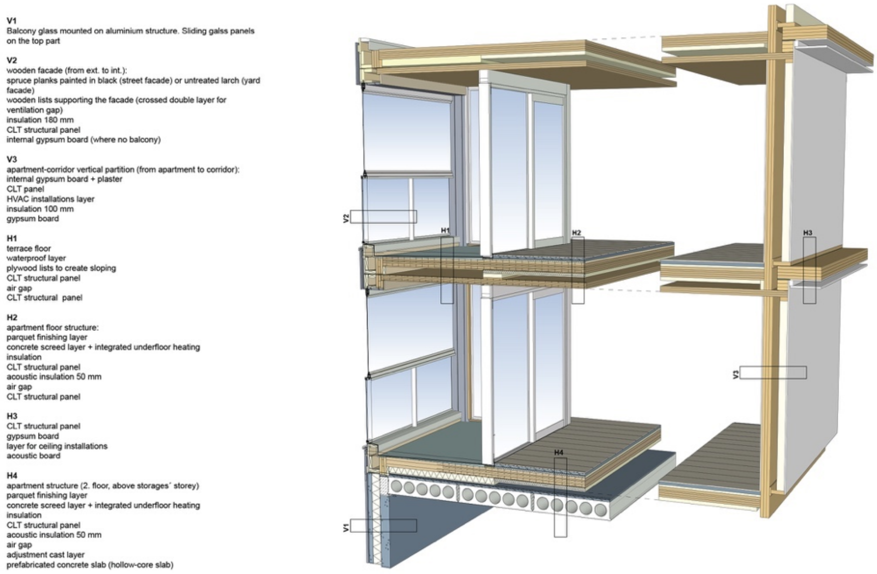

Figure 23. Cross sections of the Puukuokka (van der Rohe, 2019)

6.2.2 Fire safety

Based on fire restrictions in recent years, the timber industry had a major problem to face with. The regulations prohibited to build high multi story buildings from massive timber elements, as fire safety was not yet proven to be as effective as in traditionally built houses. Furthermore, another reason for restricting the construction of modern wooden buildings was the fear that in a case of fire, the fire department would have enough time to enter and rescue and extinguish the fire. However, based on research in different countries and universities, it was proven that massive wooden structures are much durable to fire than concrete or brick. This was mentioned earlier in the project of the WOODCUBE. But a change in Finland's building code in 2010 has now made it possible to build, as long as this load-bearing structure is coated, and an automated sprinkler system is fitted. (OOPEA, 2019). With the change in the building code a rise of construction has begun in Finland. With its land area covered by 75% of forest (Finish Forest Association, 2019), and the essential know-how for production, and as Stora Enso is one of the leading timber construction companies in the world, Finland now must show the rest of the leading first world countries how to grow resourceful and build efficiently with the re-growing material of wood.

The PUUKUOKKA owes its fire design to the untouched CLT panels. This alternative method, however, required the involvement of a fire protection engineer. (TALL WOOD BUILDINGS p.99, 2019). To prevent the load bearing structures to be exposed to fire, the panels are covered by a gypsum board layer, as gypsum is a non-combustible material. Fire simulation modelling was done by the company KK-PALOKONSULTTI.

The building is secure against fire by sprinkling the areas. No fire separating doors or walls are needed, as the extinguishing water from the sprinklers is enough to prevent further spreading of the fire, until the fire department has arrived. As a lake is nearby, water in the case of an emergency, is not in shortage.

7 CONCLUSION

As education is the key role in sustaining a profitable society, the construction industry and their educational institutions must think futuristically about the topic of wooden public buildings. For now, the technology is given to produce high quality, fire resistance, and relatively cheap wooden buildings. However, in comparison with the always growing construction industry of the 21th century, the wooden “boom” is rather small.

To conclude this thesis, it can be said, that with the astonishing pioneering thoughts, *DeepGreen* and *OOPEAA* have had great influence on the solid wood construction industry. They have proved the world that a building consisting mainly of natural and ecological products, is comparable to any other modern building. For the *WOODCUBE* with its idea of creating a house without any toxins, DeepGreen have further proved the other wooden building ideas wrong, and showed that a modern, and creative design is possible to use as a structural component, without affecting anybody’s health. As health is a huge role of everybody’s life nowadays, this is giving the industry a kick, to start thinking of building with the same amount of creativity and intelligence, so that other people might also live in healthy buildings such as the WOODCUBE. As mentioned, this building was built six years ago. With the technological advance of the coming next decade, further massive glue-less CLT buildings must be built. If the production is increasing higher demand, the value of such buildings might decrease to an amount, individuals of all wealth classes, can get a chance to live in this kind of environmentally friendly surroundings, if a financing system is proposed like for Puukuokka in Finland. Hopefully, this is going to happen, as climate change is still rising, and as mentioned in the beginning of the thesis, the construction sector is still one of the biggest pollutants. The fire safety of the WOODCUBE provides the uneducated majority of the people, that burning wooden buildings are from the past. Newly constructed, modern, and beautiful houses are the new standards of massive timber structures. Wood has shown that exposure to fire, it won't burn as many estimated. It rather starts to coal. Therefore, many of the next generation of engineers and architects, must understand the capabilities of the ancient construction material, as they have the key roles in developing a world in peace with the climate change.

With both buildings built, they act as role models for other architects and engineers. They prove that we have the necessary knowledge of the material. However, the knowledge around the topic is missing. As the educational institution concentrates on the statical properties of wood, benefits such as time management and further proof of fire resistance higher than concrete.

As all humanity is in the same boat, when it comes to the climate change, all industries must work together to achieve a certain change in the amounts of carbon dioxide we emit.

Therefore, wooden buildings and moreover, wooden pubic buildings, must be regulated to be the first construction option as they have in Sweden for example. If this is achieved, the construction sector has the change to prevent further extreme pollution, and the global solid waste and climate change can be prevented in such a short time.

Further generations of builders should be able to understand the benefits of working with wood. They have to understand how sustainable forestry works, how to design a massive wooden structure, and how to plan the fire safety of these buildings. Fire regulations used to prevent architects and engineers to build high wooden structures. As those regulations have been leased in the last 10 years, wood has gained a lot of attention in the industry.

The European Union is a group of world-leading countries, defining the standards of 21st century building. They must work together to create an educational system to teach about the benefits and disadvantages of timber. With timber being one of the oldest building materials, this ancient jewel has found its way back to mainstream attention. With the idea to preserve our planet from further destruction and the essential knowledge build ecological and stable, the time for wooden public buildings has come. The more people know that this option exists, the more people think about choosing this natural product as their load bearing building component. A revolution has started, and time for change is now.

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