Robotics in Timber Structures

Bachelor's thesis

Hämeenlinna University Centre, Degree Programme in Construction Engineering

Spring semester 2020

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ABSTRACT

Degree Programme in Construction Engineering
Hämeenlinna University Centre

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Subject Robotics in timber structures

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ABSTRACT

The purpose of this Bachelor’s thesis was to analyze the current uses and benefits of robotics in timber structures and their uses in the Finnish environment, opening a discussion on the subject.

This study was carried out by exploring the historical context and properties of each element, Timber and Robotics, separately before delving into their combined use.

With the information acquired it is possible to notice an already existing, although lacking, utilization of robotics in timber structures in Finland.
The impact of automation in this industry was briefly discussed including conclusions on the lasting effects on society and the environment.

Keywords Timber, Wood, Robotics, Automation, Carbon footprint.

Pages 33 pages

CONTENTS

1 INTRODUCTION

The introduction of timber as material or when associated with a building methodology separately is not a ground-breaking discovery. However, when combining both technologies that will be dealt in this thesis - timber and robotics - and how they have advanced over the years, combined with all factors that nowadays are essential during the project design, leads to believing that the next big step is a cross of optimized uses of natural resources and efficient workforce, that being human or not.

For generations, wood has been a common choice of material used in construction of shelters, storages, dwellings, and other significant buildings all around the world. From indigenous huts in South America to Etruscan temples and dwellings in Asia, the use of timber for the construction of shelter has followed us and has been used since humanity first began utilizing tools. Consequently, as humanity has evolved throughout the years, so have the materials used been studied and adapted to fit into standards. Timber, which started as a rustic material, has been used for its accessibility and easiness to handle - now it is part of many Engineered wood products available to the market.

With the necessity of working with new and improved materials, tools also had to evolve to accommodate to the working speed and quality that has come with time. Although the word tool can have many meanings, shapes and forms, in the field of civil engineering for commodities it will be referred to as any device or implement used to carry out a function. It is easy then to associate the word tools with robots, a machine designed to perform certain tasks or orders with the tools that are provided.

While the first impression of the word robot is of a highly advanced machine, in a historical context, robots are not a recent creation. A history that spans back even as far as Greek mythology, where one of the first records of a giant human-like mechanical being made of bronze made with the purpose of protecting the island of Crete. The story of Talos might have introduced the idea of mechanical beings performing tasks they were programmed to, in this case protecting Crete and patrolling the island in circles three times a day. However, the present popularity and origin of the word robot comes from 1920’s Czech play called Rossum’s Universal Robots, or R.U.R.

Differently to what we consider it today, robots in R.U.R were not a purely mechanical machines. In fact, they were synthetic organic matter made from artificial flesh and blood with an appearance so humanlike that they could not told apart from humans. Taking from the Czech word robota meaning “forced labour”, these robots were created with the only purpose

to follow tasks given with efficiency. It is easy then to connect the word and how it came to include what is now the norm of what is now considered a robot.

Taking a step towards the fusion both these technologies which have been adapted throughout the years at first seemed very far from each other, a natural resource with an artificial workforce might not be the most visible path. However, taking how both work separately and what the combination of these two technologies could achieve in complementing and improving one another has been seen to be efficient and necessary when dealing with current dilemmas affecting society.

These dilemmas affect society in a wide range of levels, ranging from singular individuals – involving health and sustainability concerns - to nations dealing with affordable housing and even worldwide, where global warming and other collateral affects that surged from population growth and demand for natural resources came hand in hand with the technological advancement of humankind. And while these issues were caused by humankind, the same technological advancements could be used to delay or solve these dilemmas keeping humanity ahead of the curve of the complication that it created.

1.1 Objectives

This thesis deals with the application of robotics in timber structures. Building up from how they separately function and came to be, to how they can be used together. Aiming to bring up discussion points, pros and cons, of how the material and work methodology are used in real scenarios while looking at what is impeding its growth, misconceptions, and doubts.

While the topic is present worldwide, however more predominant in technological developed areas, the scope for this study will be focused on the European region, more specifically Finland.

Throughout the development of the thesis a deeper understanding of the present conditions of utilization and availability of companies that utilizes of automated assemblies lines in Timber structures, possibly ranging from large scale elements to more specific cases, is the first most objective. Second to that the understanding of current environment, analyzing if there are further issues that could be untangled with the information previously acquired to later then finding what are the possible limitations to the wide spread use of robotics in timber structures.

Additionally briefly will be discussed the possible impacts of the implementation of these automated processes in a social-economical aspect that is concern with the quality of life for employees and what

possible changes the automation process could lead in the working life of these workers.

1.2 Methodology

For the development of this thesis a literature study will be the main method of gathering information. Since a practical approach would demand a further knowledge in robotics that are not in pair with the degree of Construction Engineering, any real-life scenario cited will be after reaching out to companies or professionals in the field.

Taking the questions set in the “Objectives” sub chapters together with a qualitative research approach with the intent to analyse what further information is gathered while transmitting it to the reader a concise interpretation of the data collected.

Additionally, since the topic of robotics in timber structures reaches a level of technology that is beyond the usual access by a single individual, information regarding which companies utilize it, if they advertise it’s uses and their process might be guarded by their discretion of the own companies to share it or not.

2 HISTORICAL CONTEXT

2.1 Wood construction

Being part of one of the first materials mankind ever used, it is difficult to pinpoint a specific time where timber became a norm in constructions. Traces of uses of wood in construction go at least as far back as 5000 years, with one example being the use of wood in the scaffolding process while building the pyramids. While this would not be any structural element after the construction is done, it is important to note this shows that the mastery of the use of wood was already present even in locations where a broad quantity of raw material was at disposal (Smith & Snow, 2008, p. 505).

Another example would be the construction of the so called Long Houses, also dating back to also 5000 years to the end of the Neolithic period. These houses had a wooden structure while the walls were usually made of wattle and daub. As the name might imply, Long houses were made for the purpose of dwelling, achieving lengths of over 20 meters and a width of 5 to 7 meters. These sort of construction are a good example of how a material together with vernacular architecture lead to most knowledge we have today.

Wood was shown to be a crucial material used for most vernacular architecture - its wide availability and properties were essential to the development of distinct construction methods while at the same time showing how alike the human mind can be even from thousands of kilometers away. Long houses, as mentioned before, could be found in North America and Scandinavia though with a couple differences in design, such as Scandinavian Longhouses had a more curved roof almost reminiscent of a boat. However, even earlier traditions in different continents also exemplified the partial use of timber in the construction of vernacular dwellings. Different tribes native to South America used timber and other wooden materials, such as Taquara a type of bamboo, to design huts usually projected to their own tribe. Examples of these can be seen below in Figure 1.

Oca – reaching diameters of 30 meters. This name came from the Tupi tribe, and was a communal space that took between 10 to 15 to be built and lasted for over 15 years.

Figure1. Traditional Oca building. (Casas na Terra, 2017).

Maloca – A communal space, for each tribe had their own style but always following their idea of divine archetype. Maloca is shown in Figure 2.

Figure2. Traditional Maloca building.(Carlos E Duarte, 2015).

With continuous advances in technology, Timber became an even more predominant material in construction of dwellings. As post and beam constructions became more common, together with the advancements in milling, it led to an increase of productivity and decrease in the overall cost, allowing for a faster and cheaper process. Furthermore, it was pushing the development of techniques in use, such as timber framing.

While examples of Timber framing can be found in many different countries and aesthetics, further reassuring the properties of wood in vernacular architecture, it all followed the concept of sawn timber, fitted and joined together in a post and beam form, which would provide the whole load bearing support for the building. Walls were only partitions to divide and enclose the space, usually infilled with different materials depending on the region. Assembling these structures was also one of the interest points for using this method; after all components of one frame of the structure were ready to be assembled, the frame was completed firstly on the ground and later raised and connected with horizontal beams to remaining parts of the frame. (Beemer, Buckwalter, Lewandoski, Mullen, Oatman, 2003, p.4; see also Dangel, 2017, p,85)

This type of structure was prominent until the beginning of the 20th century. With the coming of the industrial revolution, the demand for affordable, quick housing grew exponentially. It was then necessary to be able to improve on the format and push for new possibilities. With the use of the new sawmills that were available at the time, timber was milled in smaller scales making it possible to have a light, easily accessible and available material at demand, creating a variation called Light Timber Frames. Unlike older timber frames, the new Light frames made use of mechanical fasteners, reducing the need for master carpenters and jointers, and reducing even further the necessary time and cost of the

construction, which were highly desired during war times. (Dangel, 2017, p.85)

Below in Figure 3 an example of timber frame house can be seen.

Figure 3. Wooden frame house. (Jaksmata, 2008).

2.2 **Industrial Revolution**

With the coming of the Industrial Revolution not only the demand for new technologies increased but also how people started to treat natural resources changed significantly. The changes caused by the Industrial Revolution were so extensive that when compared to the daily life in a family household 100 years prior it would be completely different. Before the Industrial Revolution, people had a closer proximity to the nature; needing to take everything from it; meals were cooked over a fire, crops planted and harvested in their own fields, game was hunted, people lived in rural areas, etc. After the revolution the mentality and habits of people drastically changed. With the advent of Industrialization people were coming to the cities to work, replacing the necessity of harvesting their own crops and opening the opportunity to work to pay for the amenities that before came from their own soil. (Green, 2012; see also KhanAcademy, n.d)

Another consequence of the Industrial Revolution was of the improvement of efficiency by mechanical ways. While the demand of a particular raw material or the processing of a material was necessary, the productivity would only benefit as the slowest link of the chain could provide. Machines powered by the burning of coal became a staple in many factories, aiding the workers in the more specialized jobs and creating the possibility of unskilled labour to be implemented quickly. (Green, 2012; see also Rafferty, n.d)

Having the possibility then of hiring unskilled workers to perform simple single tasks in a factory while machines performed the more difficult tasks

made path to the idea of an assembly line. Although the full concept of an assembly line did not come until much later with Henry Ford, considered to be the one of the pioneers of the use of the assembly lines and automaton.

Using the knowledge that the whole production is only as fast as the slowest link, Ford was able to improve the task cycle from 514 minutes in 1908 to mere 2 minutes in only five years. This substantial improvement all came down to the Ford's investment in new technologies and machines. He first started with a couple of simple machines in the spam of a decade, which then became one of the most sophisticated production lines in the world, designing specialized machines for unique tasks (Rubenstein, 2008, p.126).

However, there were still disadvantages that came with the growth of production. Whereas before cars were an object of craftmanship requiring many different individuals specialized in different fields to assemble a one-of-a-kind car, now with the use of the assembly lines there was no space for customization - every new car came out the factory as the one before. That can be summarized by Ford's quote: "Any customer can have a car painted any colour that he wants, as long as it is black." (Crowther & Ford, 1922, p. 72)

This was the model to the beginning of the story of assembly lines and automation of industries leading to what would be considered the new standard not long after Ford. Figure 4 below shows an example of Ford's assembly line.

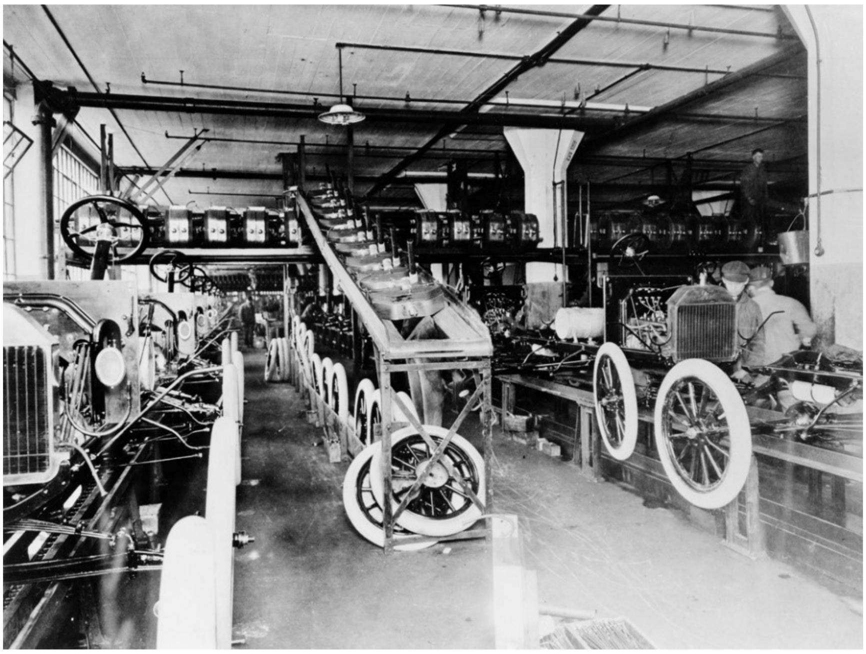

Figure 4. Ford's assembly line. (Ford Industries, n.d.).

2.3 **Robotics industry**

With continuous technological advancement that came in the years after Ford started the assembly line, it was just a matter of time before other new technologies were going to be applied to improving the efficiency in the assembly lines even further. One of these advancements that also led way to improvements in many other sectors was the Numerically Controlled machines - together with the rising of computers created the possibility to implement simple tasks to the machine program, which would be performed without the help of humans.

The simple definition of a machine programmed to complete a task according to its program without any human interaction is a loose description of what we nowadays call a Robot. While their use in assembly lines was a desired outcome, it was still a costly investment with very limited applications.

However, the advancements of technologies continued to grow, bringing a boom to the robotics market. From the mid 1950's when the first industrial robot, Unimate as shown in Figure 5, had the maxing carrying capacity of 200kg and weighing over 1800kgs, while nowadays companies can have a wide range of different robots varying in price, range, carrying capacity, and performing tasks. These advancements allowed the use of robotics in many new sectors that before were mainly only able to be performed by humans, providing the opportunity of new and better paying jobs with less manual labor, creating growth cycles and demand. (Qureshi & Syed, 2014)

Figure 5. Unimate robot. (Kawasaki, n.d.).

3 PROPERTIES

Given the brief introduction of the two components and how they merge, it is necessary to further elaborate their properties separately before further explaining their combined use.

3.1 Timber

Timber, which is lumber that has been sawed and shaped to fit different purposes varying in dimensions, is one of the most sustainable resources available and when compared to other typical materials - steel, concrete, masonry - has a smaller carbon footprint. As previously mentioned, timber was one of the first materials used for building construction due to its availability and flexibility. However, just like not all trees are the same, not all timber has the same properties.

3.1.1 Kinds of timber

Timber can be classified into softwood and hardwood, and even in this classification it can be further sub classified again into soft and hard, having the possibility to have soft hardwood and soft softwood. However, the distinction of softwood to hardwood does not come from their hardiness but rather of their botanical origin from which the timber was sawed from.

3.1.1.1. Softwood

Softwoods come from coniferous or evergreen trees; these trees usually present needle-like leaves, naked seeds and bear cones. Usually found in temperate weathers in the Northern hemisphere forming taigas or boreal forests, these trees can be found mostly in North America, Europe and Asia with some exceptions in the Southern hemisphere such as Chile and New Zealand. In Finland, the best examples of Softwood are Spruce and Pine.

Although all timber from these trees can be considered softwood, material properties might vary from species to species, location from where it was removed, area of the tree where timber was extracted and age.

Timber used in construction usually comes from softwood due to its quick growth rate. Having a quick growth rate, softwoods can be felled faster, making it readily available and comparably cheap when compared to most hardwoods. An early fell also provides softwood with a low density and low strength but still consistent with a good weight to strength ratio. On the other hand, softwoods need to be properly treated or can be affected by weathering and other defects.

3.1.1.2. Hardwood

Hardwood typically comes from deciduous trees, which are broad-leaved trees that usually lose their leaves at the end of growing season. These are generally angiosperms that have a seed protected by a shell or fruit and can be found in mostly all latitudes, although most come from subtropical regions.

Unlike softwood, Hardwood trees have a slower growth rate, taking up to three times more time to mature when compared to softwood and having a better durability to weathering. This slow growth rate provides a higher density but at the same time increases the price of the wood. Nowadays, hardwood is typically used in furniture, flooring and finishing.

3.1.2 Properties of timber

When talking about properties of timber many variants need to be considered. Besides the usual occurring imperfections that any natural resource is vulnerable to such as knots, wanes and shakes, timber is also very dependent on its moisture content which directly affects its strength and susceptibility to organic attacks.

Being an organic material timber has an inherent property of retaining moisture in its cells. While this is desired and necessary during the life span of the tree for transporting nutrients and growth, however, when applied to a building material the inconsistencies in properties usually represent possible grave errors. Timber can hold even above its own weight in water content, meaning that the moisture content (MC) in a specific piece can surpass the 100%. (Timber Queensland, 2014)

To reduce the wide range of moisture content, timber can be treated and dried in many ways in order to achieve the desired moisture content that is required for the job , ranging from 15% to 20% MC in external joinery, framing and structural use to 8% to 10% in internal joinery and furniture. Taking that into consideration, an average of 8 to 15% is usually agreed to be standard when dealing with treated timber, providing the best strength to stiffness ratio at around 12% where the material is still elastic enough to use while providing high strength. (Woodproducts, n.d; Swedish Wood , n.d)

Naturally, it is possible to use materials where the moisture content is above or below the standard although it comes to their own risks. A low moisture content, below 8%, can cause timber to become more brittle and increase the possibilities of damages, such as honeycombing. Meanwhile, high moisture, above 20%, reduces the strength of the material and at the

same time leaves it open to organic damages, such as fungal decay. (Kermani & Porteous, 2013, p. 9-11)

In order to prevent future failures due to natural defects present in timber materials, these pass by either a visual or machine inspection. Since visual inspections are always in risk of human error and machine testing cannot detect certain parameter that are outside mechanical properties or only have visual cues, there is usually a mix of both methods for the grading of timber materials providing a more accurate result. It is important to note that different countries might have different requirements for the qualifications of materials. (De Nicolo, Fragiacomo, Nicoletta & Valdes, 2017, p. 4)

Grading of any products can only be done by certified laboratories that will provide the CE qualification, their strength class and quality class. While different countries can provide different requirements and classification of their materials, this thesis will focus on their uses in the Finnish environment.

While there is a European Standard that deals with the strength grading of timber (EN 338) Finland also uses the pan-Nordic standard (DS/INSTA 142) that have interchangeable nomenclature which also present the parameters for quality classes that involve from dimensioning to tolerances and treatment. Furthermore, it also provides guidelines to which quality class should be used in different situations. Following Figures 6 and 7 shows their classification and grading respectively.

All strenght classes	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Common strenght classes in Finland			X			X		X	X	X		

Strength classes in accordance with INSTA 142

All strenght classes	T0	T1	T2	T3
Correspondance with EN 338	C14	C18	C24	C30

Figure 6. Strength Classes acceptable in Finland. (Wood Products, 2018).

USE	US I	US II	US III	US IV	V	VI	VII
Carpentry products Products with high requirements in terms of appearance							
Window- and door frames that require painting							
Furniture, glue boards							
Frame structures, roof trusses, load-bearing structures							
Exterior cladding							
Interior panels							
Batten strips							
Slating							
Floors							
Underfloor structures							
Rough-tongue-and-groove boards (surface boards)							
Fences, wind fairings and snow covers							
Concrete moulds							
Euro- and Finnpallets							
Disposable packaging pallets							
Packaging							
Boat building							
Handicraft, ornaments							
Sauna panels							

Figure 7. Quality classes and their uses. (Wood Products, 2018).

Many factors will lead to the determination of the strength in the timber that a tree trunk might yield, even inside a single tree the variations of the same properties might greatly vary from which part of the trunk the timber was extracted from. Density is one of those factors that can be connected to other important qualities of the material.

Averaging at 20% of possible change in density throughout a tree trunk and even varying between climates inside the same country, density correlates to the moisture content, strength, thermal conductivity, elasticity, and durability.

Density not only goes hand-in-hand with other important properties in timber, boosting their qualities, but also provides one of the most desired qualities when timber is used as a material, its weight to strength ratio. When compared to other construction materials such as concrete and steel, timber shows a relatively low weight while keeping strengths that are paired with the materials previously mentioned.

Other factors that make timber a desirable material for its overall versatility - unlike steel or concrete that usually exceeds only when under specific forces, tension and compression respectively - timber has a high strength in both loading conditions. However, with wood being an anisotropic material, meaning that its strength varies depending on in which direction the force is applied, the positioning of the material and understanding of how the internal loads affects the structure is crucial.

Compression strength in timber can reduce up to 1/6 to its normal value when applied across the grain; the same happens when under tensile strength, reducing upwards to 1/30 of the normal strength under the same circumstances. Meanwhile, shear strength is at its highest across the grain, proving that it is essential to know how the whole structure would be working in the case of a timber frame structure. (Swedish Wood, n.d)

When considering all the necessary possibilities while dealing with timber and the change in people’s opinion overtime on utilization of new technologies in their daily lives, this resulted in the branding of timber as an outdated material. Influencing the decline of its use as a construction material outside the traditional dwellings towards the use of new and thought to be improved materials such as concrete or steel. (Concu, 2019, p. 2)

3.1.3 Engineering Wood products

In response to the increasing number of manmade materials combined with new industrial advancements starting as early as the beginning of the 19th century, timber also went through a modernization process. Where it was only was possible to use quality saw timber due to the restricting properties of the material, once processed the new product was as strong, or even stronger than the best quality timber cut in a trunk while utilizing the less precious wood and minimalizing waste.

This was the beginning of production and use of Engineered Wood Products (EWP) or Wood-based composite products. Although it started with the use and production of plywood, which still to this date is one of the most popular products, EWP improved utilizing the same concept while applying in different orders according to the need. (Kermani & Porteous, 2013, p.21; see also Dangel, 2017, p. 99)

The basis of an EWP is utilizing strands, veneers, plies from timber while arranging them according to the type of product. Usually they are adhered together in a mesh array or in perpendicular layers, covering weak links that may come from the anisotropic property of the material. Additionally, it is often composed of an odd number of layers.

These EWP have a higher resistance to defects, having the possibility to eliminate for completely natural occurring damages such as knots, while also having a higher strength, yield and length when compared to sawn timber. All these lead EWP to become close to the new standard for high strength timber materials.

The downsides to the use of EWP come in the way of logistics. While it is true that these products can achieve great spans, the transport and assembly may be affected by the fact that these products come prefabricated to the site in one piece. (Stora Enso, 2016, p. 87)

While having a great variety of assembly and material, the most common EWP are Laminated Veneer Lumber, Cross-Laminated Timber, plywood and Glue-Laminated Timber which will be discussed in the following.

3.1.3.1. Laminated Veneer Lumber, LVL

A combination of several veneers pressured and heated to form a large billet which then is cut to size depending on their use or request. This allows LVL to form shapes different than lumber, including dimension and shapes.

These veneers are approximately 1.5mm to 6mm assembled together lengthwise with the direction of the grains making them suitable for structures under bending forces such as beams, trusses, planks, and rafters. Figure 8 below shows a picture of a LVL beam.

Figure 8. LVL beam. (PuuInfo, 2020)

3.1.3.2. Cross-Laminated Timber

Cross-Laminated Timber, as seen in Figure 9, consists of several odd layers of timber boards stacked perpendicular to each other while glued face-to-face forming large structural panels. Due to the multi direction of the grains in the structure, the grains of both outer layers must run parallel with the loading. CLT elements are normally used for walls, floors, and roofs due to its considerable dimensions.

Figure 9. CLT Panels. (Storaenso, n.d.).

3.1.3.3. Plywood

One of the most commonly used EWP, plywood consists of several plies, stacked in an odd number of layers, glued together with resin where the direction of every ply veneer is perpendicular to its adjacent layer (Figure 10). Taking the same principle as CLT, in the outer layers grain direction must be lengthwise to the intended use. Plywood panels have a wide range of uses from wall sheeting, to their use in furniture, or fencing. Figure 10 below shows a picture of a plywood board.

Figure 10. Plywood Panel. (Sydenhams, n.d.).

3.1.3.4. Glue-Laminated Timber, Glulam

Produced by face-laminating three or more, in odd numbers, of individual boards together glue-laminated timber boards were kiln-dried, sorted, stress-tested and finger-jointed to form a continuous lamination before adhered together.

Coming in various sizes of beams and columns, Glulam provides a variety of standard shapes and sizes while allowing certain customization if requested by the customer. Figure 11 shows a variety of Glulam elements.

Figure 11. GLULAM elements. (VersoWood, n.d.).

3.1.4 Fire Safety

Throughout history there have been many cases of fires that leveled major cities like Rome, London, Turku, etc. These fires caused not only devastating effects on the cities and life of their habitants but implanted the idea that buildings made of wood are destined to burn.

This idea is not without foundation - wood is one of the main sources of fuel domestically. However, in the many years that have passed, the material properties and treatment for timber material have evolved beyond their natural properties. Discoveries such as how wood can be impregnated with fire retardant, how its natural properties like density and moisture content interfere with the spreading of fire and how wood products naturally defend themselves using the charred carbon layers as insulation to the untouched center, creating a natural fire barrier, initiated the debate on the regulations necessary for timber structures. (Arup, 2019, p. 38; Arup, 2019, p.66)

One of the biggest hurdles on the prospect of building a multi-story building made fully, or mostly, of timber materials has always been the strict regulations that are imposed. Now with the new discoveries and trials, possibilities and exceptions have been granted making for buildings such as the Mjøstårnet, an 18 storey building made mostly out of cross-laminated timber (CLT) and laminated veneer timber (LVL), both EWP, have been made possible. (Hunt & Thinkwood, n.d, p.2; see also Metsä Wood, n.d)

3.2 **Robotics**

While there are a variety of uses and types of robots available in the market today, this thesis focuses on the industrial sector of autonomous or semi-autonomous robots due to their capacity to function in an assembly line performing malleable repetitive tasks, as seen in Figure 12.
.
In the construction field the presence of robots is at the lowest level, mostly since the best quality of a robot, the capacity of performing repetitive tasks, does not translate well to a construction site. The presence of many variables needed to reprogram combined with an environment prone to damage, the machinery restricts their use on site. However, some activities were able to be translated, such as brick laying robots and mobile robots that resemble a 3D printing machine capable of molding an entire shelter out of a mortar compound.

Most of the uses of robots in the construction field comes from their uses in assembly lines for prefabricated elements or materials. These workshops present an array of different types of service robots, some that were even made only for those specific tasks, ranging from very simple machinery to complex tasks.

Figure 12. Automated assembly lines. (Oxford Mail, 2018).

3.2.1 Robot types

Nowadays the idea of an industrial robot comes mostly from images of assembly lines, where robots that almost resemble a human arm are set in a chain and each performing a single task before carrying out to the next. Robots like that are the called articulated robots, possibly being one of the most useful types. This sort of robot is characterized by the sort of task that it can perform and the freedom of moment in their axis. (Hägele, Nilsson & Pires, 2007, p. 967; see also Technavio,2018)

Robots can be roughly classified into six different categories which will be discussed in the following.

3.2.1.1. Polar coordinate robots, or spherical robots

Considered to be the first industrial robot, spherical robots are fixed to their base capable of pivoting around their shaft while a twisting motor makes it possible for the arm to move vertically to a certain degree. Although the nomenclate joints allow them a direct comparison to human joints, robot joints are capable of extension, and that capability gives polar robots their last degree of freedom (DoF). The combination of the joints and different motors gives the workability area of this robot to come close to a sphere; hence where its name came from. As previously mentioned, Unimate the first industrial robot, can be classified as a Spherical robot type (Hägele et al., 2007, p. 964). Figure 13 is an example of a polar coordinate robot.

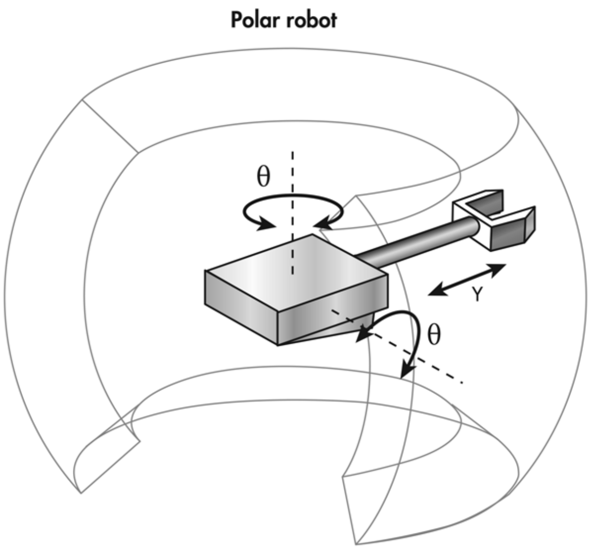

Figure 13. Polar coordinate robot. (Machine Design, 2016).

3.2.1.2. Cylindrical Robot

Having mostly the same properties of a polar coordinate robot, cylindrical robots can be considered a slight improvement on the previous model. While polar coordinate robots depend on a twisting motor to be able to perform any vertical movement, Cylindrical robots can move vertically along the base improving its reach to a more cylindrical shape. Figure 14 shows a representation of a Cylindrical robot.

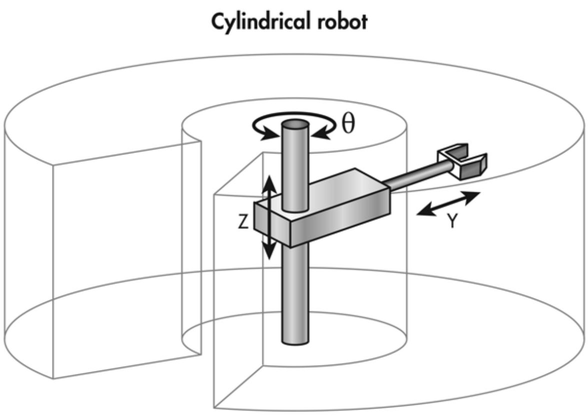

Figure 14. Cylindrical robot. (Machine Design, 2016).

3.2.1.3. Cartesian robot

When compared to the previous models that were in a fixed unmovable base, Cartesian robots added another dimension in the axis movement. With the possibility to move objects laterally these robots serve mostly to the transportation of heavy materials or usually accompanied by scanning accessory for inspection of pieces. Its name comes from the similarity of

moment as of the cartesian plane. Figure 15 below shows an example of a Cartesian robot.

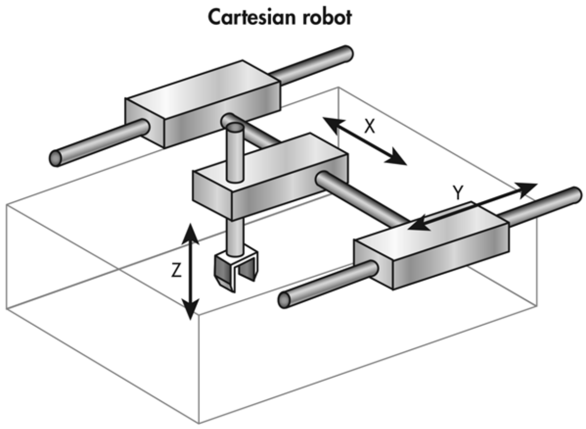

Figure 15. Cartesian robot. (Machine Design, 2016).

3.2.1.4. Articulated robots

The most common robot used in assembly lines is that which resembles a human arm. Improvements came from the addition of articulated joints, making it possible to achieve a full 360° degrees working area in two different planes. Having the widest range of tasks that it can perform; these robots are mostly used for precise welding and high dexterity works. Figure 16 exemplify and pictures a representation of an articulated robot.

Due to the high demand of this kind of model, it is one of the most advanced models that has been brought to environments other than factories or assembly lines. Companies such as Universal Robots™ provide smaller scale products that are easily accessible without the need for previous robotics knowledge. (Yamaha, n.d; see also Universal Robots, n.d)

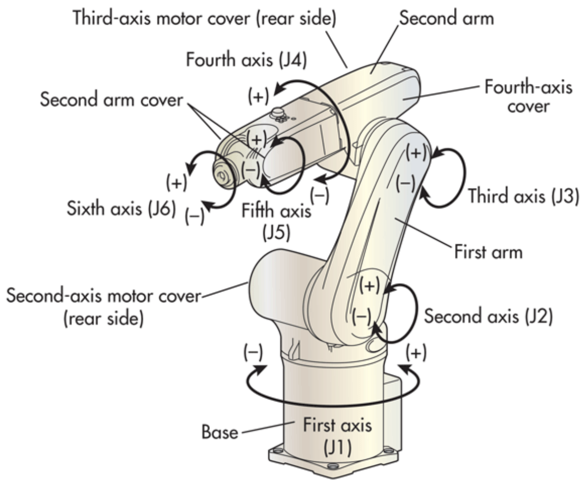

Figure 16. Articulated robot. (Machine Design, 2016).

3.2.1.5. SCARA

SCARA, or Selective Compliance Articulated Robot Arm, was directly designed to improve work in lateral movements and in two parallel planes. Unlike the previous model it is not much of an overall improvement but a focused design on the tasks they would perform, an example of how restricting in one area might lead to improvement in another. (Fanuc, n.d)

Figure 17 below shows an illustration of a SCARA type robot.

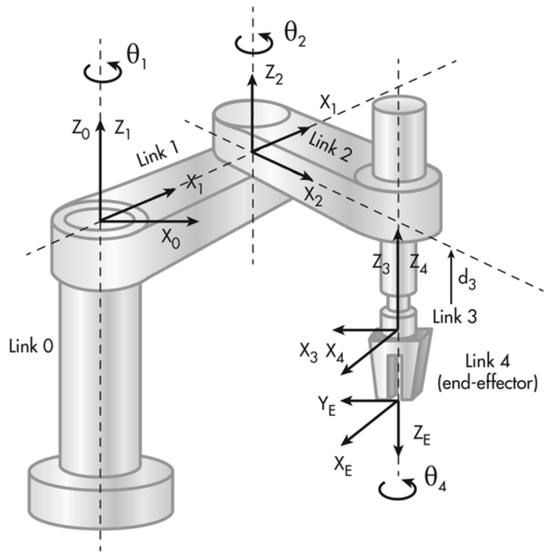

Figure 17. SCARA robot. (Machine Design, 2016).

3.2.1.6. Delta robots

Often referred to as Spider robots, these are also specialized robots for specific tasks. In exchange of its short range its speed is improved, capable of carrying high loads in high velocities. Figure 18 below shows an example of a Delta robot.

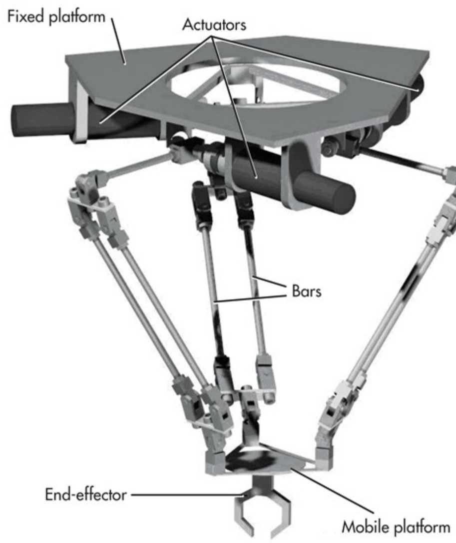

Figure 18. Delta Robot. (Machine Design, 2016).

3.2.2 Functions in assembly lines

As previously mentioned, robots can be implemented in a wide array of tasks. In the case of their application in production lines, their use can sometimes be interchangeable, having different types of robots to execute the same tasks even if with a slight difference. For a better optimization, this decision is usually carried by either an Automation engineer or a Production engineer after analyzing what are the necessary demands, how they chain with each other while at the same time considering cost and benefits. (White, 2018)

While the possibility of using only articulated robots that can perform most tasks is plausible, it might not be the most optimized. In that case, utilizing the strengths of each separate robot as it seems fitting is the best option. This comes from the fact that each robot will have a different operation speed, area requirements and how they are connected to the main line.

Another factor that must be taken into consideration are End Effectors - these are how a robot is able to interact with the environment. Just as it is not possible to humans to perform all possible tasks without tools, a robot will utilize these attachments to perform the task in hand. While they can be further separated into categories such as Grippers, Welding torches, Sensors, tools, etc. It is important to elect the right end effector to the model that will be in use. (Hägele et al., 2007, p.980)

3.2.3 Automated assembly lines

As in many other fields, the final product is the aim of the process. However, when considering how many variables are needed to be taken into account just for the production of a single product - which doesn't even use an automated assembly - when the question of how the same

procedure would operate raises plenty of question rather than just what type of robots would be necessary.

The outline design of the assembly line might look flawless; however, when this design is done completed defects might come unexpectedly. An air draft caused by gaps in the building envelope might create deviations in the working temperature, weakening a weld or turning plastic unworkable, limiting, or completely shutting down the production until that flaw is located and corrected.

Although flaws as mentioned previously might be rare, many smaller but more frequent issues might show up starting from the design phase. When planning to utilize an automated assembly line first it is necessary to consider the already existing production line, if there is one, and how its integration with the current space and processes would be. Furthermore, if it is an already existing production line, how much of the process would be automated. Usually processes which are mundane or hazardous to workers are the most often automated due to how straightforward they are to be replaced, normally not being necessary highly advanced machinery.

When considering the floor plan for a new, or existing, automated system the question of how this would fit in that space and what methodology will be used becomes an essential question. While the concept of a single straight assembly line might be the most usual, and often, most implemented method used in the market, it does not represent the only option. Simply changing the shape of the assembly from a straight line to a U-shape can already show improvements, providing a reduction in the overall length necessary and at the same time allowing a closer communication and transport of workers between stations. (Guan, Jahanzaib, Saif, 2014, p.100)

However, approaching an assembly line as only possible in a line, or a U shape in that matter, would be a mistake. Assemblies can be comprised of different smaller functional lines, each working in a different subpart of a product merging together in a different line, which is the case in many automotive industries. Likewise, the assembly doesn't need to be in a line at all; it is possible to have different cells formulated of a combination of workers and robots, in a variable amount, that would perform tasks while connecting them via manual workers or conveyor belts. (Guan et al., 2014, p.95)

The introduction and integration of the machinery to the human workforce is also a factor that needs to be taken into account. If there is the need for additional training, workers' safety, training for new workers, and how intuitive the change from one station to another will be.

3.2.4 Human factor

When dealing with workers, another concern that comes with automation is the question of how this will affect the employment of human work force, how many workers it is necessary to keep, the moral dilemma of how the laying offs might affect society and what types of tasks should be automated. An array of predictions has been made of the possible displacement that workers will suffer from implementation of robots in assembly lines, ranging from promising numbers of raise in employment and wages, to upwards to 50 percent of workers displacement by 2030 (Freeman & Rodgers III, 2019)

It can be said that robots are excellent at completing simple tasks that require no or few decisions; consequently, it is clear that they would be a great fit to industries that thrive in such activities. However, since these tasks were before performed by humans after their substitution would cause the worker not to be necessary anymore. While sometimes that can be a positive change, in the case of workers that deal with hazardous materials or situations, which was the case of the so called “Radium Girls” (CNN, 2017).

However, the substitution comes in with other side effects. Once the technology is applied, automatically a need for technicians and other professionals related to the market generated by the demand for automation is created, enabling new better paid job opportunities (Graetz & Michael, 2018). Even in the factories where workers coexist with robots, there is a chance of improvement that comes from the possibility of transferring tasks (IFR, 2017, p.7).

Whereas before a worker would be required to perform the tasks manually, once the automation system is in place that worker’s tasks might transform to a supervision job. This generates an upscaling flow to the jobs created, allowing a better environment for industry workers.

It is important to notice that the implementation of this sort of technology is not yet available in a broad spectrum. Most of possible candidates for automation are restricted to developed countries where labor wages are regulated and to industries that benefit from repetitive use of simple tasks(Atkison, 2019).At the same time, it is relevant to distinguish that in these environments an accessibility to opportunities to training and learning of new technological knowledge, allowing the possibility of creating higher skill workers.

Whereas, in communities where the access to this sort of opportunities is scarce, especially when dealing with minorities and people at young age and/or without a college degree, the introduction of automatic assemblies can lead to a reduce in employment rates (Freeman & Rodgers III, 2019).

That being said, in places where automation is already a reality a transition has been seen in the sector where the majority of employment has shifted towards the service industry, an industry that seeks hospitality and human touch. Another area which has seen an improvement is in specialized craftmanship products. As the cyclical tendency that humans have the appreciation of handmade products that contradicts modern developments has also grown, giving appreciation to traditional ways and techniques coming from times before many technologies common to nowadays existed (Berlingieri, 2014).

4 ROBOTICS IN TIMBER STRUCTURES

Having presented the basic idea of both previous topics extending from their uses, capabilities, and advantages, it is possible to speculate that once combined these technologies might create sometimes greater than the sums of its parts

As was mentioned before, in the construction industry hardly any use of robots is present on constructions sites. Most often than not their uses are restricted to workshops specialized in creating prefabricated elements that then can be taken to assembly on site. However, wooden products still take the smallest share when compared to their counterpart materials such as concrete and steel.

At the same time, prefabricated elements possibly get discredited as inferior, having traditional building methodologies being favored instead. Further decreasing its accessibility to the common public, the market which would benefit the most from such technologies. Approximately over 80% of single-family dwellings in Finland are made of timber framing processes - meanwhile the share of wooden multistory buildings as of 2017 was 4.3%, adding to a total of less than 80 buildings. (Konttinen, 2019, p.10)

While it is widely used in low stories, when applied to multi story buildings wood is one of the least used materials. This may be due skepticisms of material properties under high stress, lack of information on wooden multistory construction, the inexperience of contractors and designers when dealing with wooden structures, inherited risk of new technologies, and governmental interference.

Legislation on wooden multistory constructions has been developing since the early 1990’s, with the change in legislation that then allowed wooden buildings to rise up to four stories high. Nowadays, legislation allows up to 5 to 8 stories with the possibility to go beyond that provided that the building provides necessary safety requirements approved by a rigorous check. That was the case for Joensuu’s Lighthouse, regarded to date as the

highest timber structure in Finland standing at 48 meters tall, or 14 stories, it utilizes a combination of different Engineered wooden products together with a concrete first floor and steel bracings.

Furthermore, the inexperience in use of such material and technologies could be assigned as the main reason for the low number of wooden multistory buildings. This inexperience leads to a series of factors that affect the overall cost and quality of the final product, alienating possible investors. While building with timber, specifically prefabricated timber products, can utilize its faster construction, the lack of experience in both design and execution phase hinder the full capacity of the material delaying the construction, contracting to the purpose of the material.

Altogether added with the cost barrier for the use of novelty materials, inconsistent uniformity between European countries delays the advancements in wooden multistory constructions and the integration of automated assembly lines connected to timber structures.

4.1 The causes of the holdback

Given the information on the factors why WMC and the overall idea of how timber structures are present in Finland, it is possible to start drawing a conclusion as to what has influenced the low adoption of automated assembly lines in the country.

Most often than not the capital is the main reason. The high entrance price usually scares small to medium potential clients, combined with reduced market created by the majority of clientele focused on single dwelling houses creates a great risk for investors that could take years to amortize the cost of automation or not even break even. Investing in automation is a risk that should be seen as an investment for future profits. However, in Finland this burden can be slightly lifted by possible grants given by the Ministry of the Environment which provides up to 2.5 million euros to companies in the Wooden Building Program.

Another factor responsible for the scarcity of automation in timber construction field in Finland is the availability, both of machinery itself and knowledge. At the time of writing this thesis, only one company based in Finland provided specialized services towards full automation of timber products, resulting in a lack of specialized professionals.

4.2 Benefits

Promoting a new material or methodologies often starts by displaying the possible changes offered and benefits that come with it. In the case of

applying automated solutions to the construction of timber structures, it takes benefits from both areas - ranging from mechanical and valuable qualities of wood to the efficiency and quality singular to automated industries.

Aside from all mechanical properties previously mentioned in timber structures, the coming renaissance of wooden structures incentivized on the research of different aspect of woods that go outside mechanical. To its core wood is a living material allowing it to adapt and accommodate to its surrounding environment. When that is applied to timber structures it grants it the ability to “breathe”; however, being different from breathing that humans do.

Due to its hygroscopic property, wood is capable of regulating moisture in an effort to achieve moisture balance within the environment. During that process, the release of moisture creates a phenomenon that boosts the relatively low thermal conductivity creating a more pleasurable environment. Another factor that connects timber to better living is its septic characteristics - its possible antibacterial properties allow for an unintentional improvement in air quality.

Some studies also connected the benefits of psychological and physiological conditions in humans to the use of exposed wood in timber structures (PuuInfo, 2020). Capable of regulating stress and physical manifestation on the body, wood was shown to have constructive reinforcement behavior to positive personality traits such as responsibility, reliability, honesty, and success.

While the timber element presents sensorial and environmental benefits, together with the utilization of an automated assembly line further pushes to a possible necessary quality assurance and replacement of manual labor - an area that has been on the decline in Finland due to silver market phenomenon and the decrease of birth rates in the country since 2010.

Reinforced by the governmental estimate given by then Prime Minister Antti Rinne that wooden construction would double from the period of 2019 to 2023, the necessity to create rightly available, fast production lines capable of delivering continuous quality products while not hindering with the workers’ health may prove essential.

Additionally, taking into consideration that the majority of population density in Finland is concentrated in the Helsinki metropolitan area, integrating an automated assembly system of timber structures allows for fast production and erection on site while minimizing the load that the transportation of elements to construction site would take. It is estimated that for a building in the same dimensions while only changing materials from a prefabricated timber structure to prefabricated concrete structure could reduce transportation time by at least 25% (Sun, 2016 p. 42).

When on site the utilization of these prefabricated products firstly apply a lower load than compared to its concrete counterpart, relieving some pressure from underground work and foundations. Additionally, while on site this allows for faster framing cycle days, reduces the use and waste of material on site while providing a better and safer environment for the workers.

Inside the assembly lines, the possibility to use machinery CAD accessible together with cross training workers between sectors further improves the efficiency and quality while still allowing for customization following the demand.

4.3 **Companies**

For the subject of fully automated assembly lines two companies will serve as examples: Finnish based Trussmatic Oy and Swedish based Randek.

4.3.1 Trussmatic Oy

Trussmatic Oy was founded in 2015. It is the developer of the first fully automatic and IP- connected wood truss production line, providing a complete product with possibilities for smart care support, remote maintenance, and training.

The development started in 2006 by Trussmatic’s predecessor company Autoprod Ltd, until then in 2015 made their first sale to the company Kosken Puunjalostus Oy. Further sales came in for two American companies and one Nordic country.

Their production line comes with 2 industrial scale KUKA robots, capable of producing trusses up to 28,5 meters long and 4 meters tall. These robots are fully automated and capable of operating in three shifts, while allowing online monitoring and remote access.

This production line aims to reduce the workforce by 75% while providing consistent quality, customization and occupying less space. Figure 19 below is a visual representation of an assembly line provided by Trussmatic Oy.

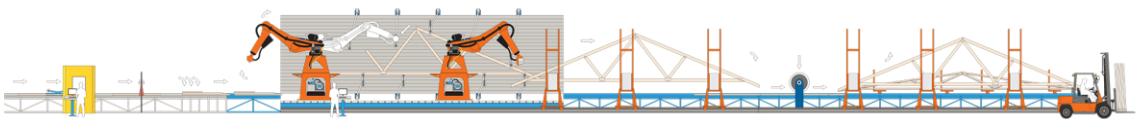

Figure 19. Trussmatic assembly line. (Trussmatic, n.d.).

4.3.2 Randek

Randek was founded at the beginning of the 1940's. It is a Swedish company that offers an array of solutions to the manufacturing of pre-fabricated products, ranging from cut saws to entire framing elements such as floors, walls and roofs. These products have the possibility to vary from manual, to semi-automated until a fully automated assembly line named ZeroLabor.

Randek's ZeroLabor is a fully automatic robot cell unit, capable of performing various working processes independently, having the flexibility to be configured according to customer needs. This cell can be integrated into already existing lines or as a standalone unit capable of production of walls, floors, and roofs, a visual representation can be seen in Figure 20.

The system is compatible with CAD-files and performs all tasks necessary to building the frame. Even capable of leaving cavities for service connections, it delivers a finished product without the need of human interaction.

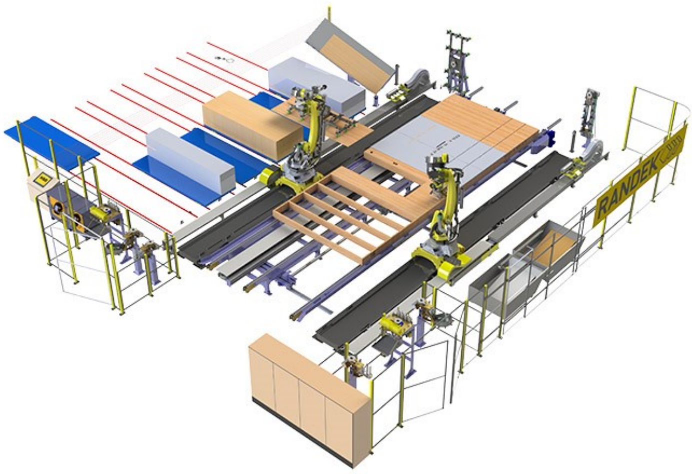

Figure 20. Randek ZeroLabor assembly cell. (Randek, n.d.).

4.4 **Case studies**

The application of the final product is also an element to be examined. In its current iterations, the automation of timber structures is applied to light timber structures, excluding then their use for WMC.

Even if restricted to light timber frame structures, the possibilities of their uses are still vast when considering how malleable designs can be with timber structures, and customizable dimensioning possible in the automated production lines while delivering products with quality and proper fitting.

With the addition of public buildings to the permitted list of wooden structures in the National Building Act of 2017, this included the new possibility of commercial buildings, hotels, nurseries, and schools to be further developed using timber solutions. These structures could take full advantage of modular building systems that an automated production line can create.

In the following will be discussed two cases where the utilization of an automated production line would be possible without any inconvenience.

4.4.1 Aarnivalkea School

Aarnivalkea School which is located in Espoo has a total floor area of 3 058m^2, having room to up to 350 students. The building consists of 50 large modules preassembled at a factory having each an area of approximately 70m^2. The ground floor is also wooden having the necessary ventilated space.

Built in the spring of 2019, this building is a prime example how the application of a production line could be implemented without any modification or hassle to original design. Figure 21 below shows the finished School project.

Figure 21. Aarnivalkea School. (Mikael Linden, n.d.).

4.4.2 Student Flats Virkakatu 8.

Located in Oulu, the building of Student Flats was a renovation project aiming to achieve a better energy consumption and improved appearance. Originally it was built in the early 1980’s with the proposition of using Timber-based Element System (TES System) to convert it to a passive house.

For that, one of the walls was removed to later be replaced by TES system. Being a retrofit renovation, exact measurements were taken and sent to prefabricated manufacturing. Precision was necessary to avoid mistakes in the assembly, an area where machinery accuracy is advantageous. Figure 22 below shows the picture of Student Flats.

Figure 22. Student Flats Virkakatu 8. (Jaako Kallio-Koski, n.d.).

5 ENVIROMENTAL IMPACT

Although the two components dealt with in the operation of automating processes for timber structures seem very distant to each other, a common point between them is how both sides aim for a sustainable clean use.

Part of the renaissance of wood as a construction material started due to current concerns over global warming and how it would be possible to prevent it or slow it down - harmful gases present as a side effect of many daily activities in societies’ life. Recently it has been discovered that the emissions of CO^2 and Greenhouse gases added to the carbon footprint

imbued in the lifespan of construction material present in our lives had a major contribution to global warming, reaching upwards to 30% in highly populated areas (World Green Building Council, 2019).

However, at the same it was discovered that wood was the material that had the smallest carbon footprint. Combined with the fact that wood is the only sustainable, restorable material in the list of construction materials and during its growth, due to photosynthesis, trees absorb CO^2 and releases O^2. This absorption in proportion of every $1m^3$ of wood can store up to 1 ton of CO^2, acting like a sponge entrapping the gases preventing them from returning to the atmosphere. When combined with a high forestry percentage, such as in Finland which has 78% of its territory covered by forest, creates a cycle that prevents the spreading of further pollution agents while utilizing sustainable materials with a small contribution to global warming.

Arriving at the end of its lifespan timber can also be reused and recycled in a variety of ways, ranging from decorative pieces, reutilization in other fields (e.g. structural logs can be charred and used as foundation piles), or used for fuel.

After the manufacturing of robots and consideration of its initial carbon footprint, once in motion mostly of all necessary environmental concerns comes from energy sources. The use of renewable energy sources together with the application of a passive building for shelter where heating - which is one of the most power demanding function in a building - is minimal creates the prospect of an energy neutral environment.

6 DISCUSSION

Considering the historical context of the uses of timber throughout times, from a simple, natural, accessible material to becoming a standard in use for centuries while humanity evolved. Later being forgotten and left aside, believing that it was not a reliable material compared to the discovery of new man-made materials before having now its renaissance slowly approaching due to new developments caused by humans themselves.

Humanity then took this very uncomplicated material that already was present in their daily lives and molded it to their use. With all the progress society has achieved until now it is possible to say that wood was not a simple material, its studies show more and more characteristics and properties that were unknown to society until now. As humanity evolved it learned to mold and be molded by its surroundings, taking what was before considered “simple” and accumulating all advancements throughout time to extract its core aspects while applying it to today’s standards and ideas.

The same idea can be applied to the introduction of robots and automation - taking mundane or simple tasks that were necessary to be repeated constantly, brought by as a side effect of societies' own needs. Together with the necessity of improvement carried by new discoveries lead to the conclusion that just as the same as humans could use tools, due to the evolution of new technologies it would be possible to create tools or mechanisms that could work by themselves, achieving a higher productivity while keeping quality, precision and efficiency.

Nowadays, the development of both mentioned technologies has come to a level that the possibility to connect them is plausible and already existent. While still not well integrated to society yet due to the constrains connected to cost barriers and accessibility, it provides with solutions to possible challenges brought by society itself that might be coming in future years. Questions of how to deal with the increasing aging of population, lack of skilled workers, increasing demand for constructions in metropolitan areas, and the impact on the environment are all complications caused by human development.

Anticipating these phenomena while aiming for the normalization of possible solutions, such as the automation of timber structures, is the next necessary step for human development. Eliminating the hurdles that affect the application of such technologies could possibly push to faster normalization, being the dissemination of information generally as one of the first hurdles that need to be overcome. This thesis aimed to bring the discussing on adopting automated solutions to the construction of timber structures to further incentivize its debate and development

7 CONCLUSION

While set with an objective to identify the current situation in the utilization of robotics applications in the building of timber structures - with a focus on the Finnish environment - it was possible to conclude that it still consists of a relatively small market with possible future expansion if properly stimulated by capital investments in research and development of products and marketing, while at the same time pushing for a reform in the current legislations that restricts or discourages the uses of timber structures outside the usual dwellings and low rise buildings.

Additionally, the lack of expertise and knowledge by both construction companies and the general public regarding the practices and benefits that timber structures have to offer, combined with old common misconceptions from outdated information on timber properties, products and processes, contributes to disinterest in the expansion on the use of

timber as a structural element due to related risk and higher cost that inherently comes from the paradoxical cycle that is possible due to oversight or errors that come from the lack of accessible knowledge.

Furthermore, with the current concerns regarding emission of noxious gasses, sustainability and unhealthy product consumption, timber offers a partial solution to the ones commonly used nowadays. Not only dealing with the reduction of carbon emission and carbon footprint, but also indirectly benefiting user's health and well-being.

This thesis had an aim to take on those misconceptions and doubts, while tackling the question of how the application of the relatively new process that is the use of robotics, combined with the progressively ever changing methodology that is building with timber. It was possible to attain from the previous statements that public availability and discussion of the topic was one of the main hindrances to the further progress and utilization of this technology. Setting the information and discussion, bringing it both to a broader light while giving it access in a condensed manner is the first step to improve the current dilemmas that are currently at hand, and what was hoped to achieve with the writing of this thesis.

The research also clearly illustrates that Finland as a country has access to the ways of automation, having the available technology and professionals while granting the opportunity to access to new technological knowledge - such is the example of Ammattikorkeakoulus, or Universities of Applied Sciences – however, it also raises the question of further social-economic impacts that the displacement of workers in favour of the automation of processes in the Finnish environment may result.

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