Prediction Model of Shear Force Capacity and Stiffness of the Connections in Timber-to-Timber Composite structures

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SCHOOL OF CIVIL ENGINEERING
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By

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ABSTRAK

Kajian ini membentangkan penemuan kajian eksperimen yang meluas mengenai prestasi mekanikal jangka pendek sambungan skru kayu yang diperbuat daripada kedua-dua spesies kayu lembut dan kayu keras, menggunakan pelbagai jenis pengikat (dimasukkan pada 45 dan 90 darjah ira) dan jenis kayu yang berbeza. produk (kayu gergaji pepejal, kayu berlamina terpaku, kayu berlamina silang, dan kayu venir berlamina). Konfigurasi ujian direka bentuk untuk meniru sambungan yang terdapat dalam struktur komposit hibrid kayu-ke-kayu untuk kegunaan dalam kedua-dua projek baharu dan pengubahsuaian. Eurocode 5 menyediakan panduan untuk menentukan kapasiti daya ricih sambungan yang diperbuat daripada struktur komposit kayu-ke-kayu. Tambahan pula, analisis Regresi Linear Berbilang (MLR) digunakan untuk meramalkan kapasiti daya ricih dan model kekukuhan daripada set data daripada kerja sebelumnya. 39 spesimen daripada ujian tolak keluar telah diekstrak untuk menjalankan analisis. Telah diketahui bahawa ketumpatan kayu mempengaruhi kapasiti daya ricih dan sudut skru mempengaruhi kekukuhan dalam sambungan.

ABSTRACT

This paper presents the findings of an extensive experimental study on the short-term mechanical performance of timber screw connections made from both softwood and hardwood species, using different types of fasteners (inserted at 45 and 90 degrees to the grain) and different types of timber products (solid sawn timber, glued laminated timber, cross laminated timber, and laminated veneer lumber). The test configurations were designed to mimic the connections found in timber-to-timber hybrid composite structures for usage in both new and retrofit projects. Eurocode 5 provides guidance for determining the shear force capacity of connections made of timber-to-timber composite structure. Furthermore, Multiple Linear Regression (MLR) analysis was used to predict the shear force capacity and stiffness model from a set of data from previous work. 39 specimens from push-out test were extracted to conduct the analysis. It was known that the density of timber influenced the shear force capacity and angle of screw influence the stiffness in the connection.

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LIST OF ABBREVIATIONS

TTC	Timber-to-timber Composite
MLR	Multiple Linear Regression
ANOVA	Analysis of Variance
LVL	Laminated Veneer Lumber
CLT	Cross- Laminated Timber

LIST OF NOMENCLATURES

D	diameter of the fastener
F_v	shear force capacity in Eurocode 5
L_c	fastener length embedded within the concrete
L_t	embedded length of screw within timber
L_{span}	length of the beam
L_s	length of screw
l_c	distance of hinge from timber-concrete or timber-timber interface
l_t	effective length fastener in timber
P_{max}	maximum shear force capacity
σ_t	timber normal stress
σ_c	concrete normal stress
$\sigma_{y(s)}$	yield strength of the fastener
$\sigma_{y(B)}$	flexural strength of the beam member
σ_m	bending stress in fastener
f_{hc}	concrete bearing resistance
f_{hw}	wood bearing resistance
M_{y}	stud plastic moment
Lw	minimum stud total lengths embedded in wood
l_{w}	wood effective length

CHAPTER 1

INTRODUCTION

1.1 Introduction

A rising interest in using timber more extensively and effectively in the construction industry has emerged in recent decades. This is due to the efforts to reduce buildings' carbon and energy footprints. In addition, it is possible to manufacture large solid engineered wood product (EWP) panels, such as cross-laminated timber (CLT), glued laminated timber (GLT), with sufficient dimensional stability and durability, especially in indoor environments due to the improvements made in chemical treatments, adhesive, and fastener manufacturing, as well as wood processing technologies. In comparison to more traditional building materials like concrete, such as reinforced concrete and/or steel-concrete composite systems, solid EWPs' aesthetics, lightweight, high strength-to-weight ratio, and prefabricated qualities have made them more competitive and well-liked. As a result, the use of big CLT panels has become more common in mass wood and composite construction (Chiniforush et al., 2021).

Based on Chiniforush et al., (2021) timber and EWPs have relatively low elastic moduli when compared to steel and concrete as they have many benefits. As a result, long-span timber floors have very low stiffness, making them vulnerable to excessive short- and long-term deflections as well as vibrations brought on by people (Weckendorf et al., 2016a). Increasing the thickness of flat timber slabs is the simplest method to meet the requirements for deflection and vibration control in long-span floors but applying overly thick solid timber floors is neither structurally effective nor justifiable from an economic standpoint. Accordingly, efforts have been made to find a good balance between the price and improved structural performance (higher stiffness and strength) of the timber floors by developing timber composite systems that utilise lightweight panelised EWPs in conjunction with steel, reinforced concrete (RC), or timber (Jacquier and Girhammar, 2014), (Tomasi et al., 2010), (Hassanieh et al., 2016) .

The early research on timber composite systems have mostly concentrated on timber-concrete composite (TCC) floors in which RC slab is joined to the top of the wood joists/beams consisting of sawn timber, Laminated Veneer Lumber (LVL), or glued laminated timber (GLT) by mechanical shear connectors like screws or bolts. Recently, mechanical shear connectors and notches have been proposed for TCC flat floors built of RC slabs attached to the top of the CLT panels. These have been experimentally tested by push-out and bending tests (Chiniforush, et al., 2021).

There are variety of connections can be employed, including glued joints, mechanical fasteners (such as screws and steel dowels), as well as notches and plates that can be applied in timber composite system. Among the range of joint types considered by Dias (2005), the glued joint is the stiffest, although it also exhibits brittle behaviour. Dowel type fasteners are preferred by many researchers who are examining the connection behaviour for timber-concrete composite structures because, according to Dias (2005) review of the types of connectors, they enable more ductile failure behaviour and have higher plastic deformation than glued joints. Based on Ceccotti (2003), the use of mechanical fasteners is still essential as they are less expensive and easier to install than glue, even though glued joints offer sturdy and stable shear connections for timber composite systems. Currently, timber-to-timber composite structures are designed using the EC5, which is the primary guideline for timber-timber composite structures.

1.2 Problem statement

This study was carried out to determine the significant parameters that is needed to improve the existing predictive strength and slip modulus models of screw connection from the EC5 and published works. When such connections are used in combinations that are not expressly stated by product specifications, it is obvious that their performance must be tested experimentally. Extrapolating data from other "similar" fastener types is not recommended unless the extrapolations are tested first. In Eurocode 5, for example, the slip modulus of a timber-concrete connection is recommended to be double the value of the modulus derived using the formula for a parallel timber-to-timber connection.

1.3 Objectives

Aim to develop empirical model of shear force capacity and stiffness of the screw connection in TTC. To achieve this aim, several objectives are outlined below:

1. To establish a database of the parameters of the connections in timber-to-timber composite structures based on previous work data samples.

2. To analyse the database by using statistical analysis tool (MS. Excel).

3. To investigate the effect of material properties of screw connections, and timber on the shear force capacity and stiffness.

4. To propose prediction model of shear force capacity of the screw connection in TTC

1.4 Limitation of study

The short-term behaviour of screw connections in timber-to-timber composite constructions is the focus of this study's experimental programme. Under fire and changing moisture circumstances, dynamic, cyclic, and long-term consequences and behaviour have not been explored. This study does not consider timber-timber composite joints with screw configurations that cause the screws to behave exclusively in shear compression.

1.5 Outline of the research

There are 5 chapters in this dissertation. The first chapter introduces timber-to-timber structures and the many types of timber-timber composites. The importance of connection system stiffness, strength, and ductility in timber-to-timber composite constructions is explored.

The limits of existing design models for timber-to-timber composite structures are further clarified in this chapter. The study's goals are to develop a credible model for predicting the mechanical properties of connections in timber-to-timber composite structures.

The history timber is first described in the literature review in chapter 2. The several sorts of connecting systems that are employed in a timber composite system are discussed. A discussion of the design model for screw connection strength is also included, which is based on previously published work. The mechanical characteristics of the screw connections in the timber-to-concrete/timber composite interfaces are detailed in this chapter. It is also examined how the varieties of timber utilised and the screw's inclination angle affect the ductility of screws connections.

In chapter 3, the justification on the choice of extraction of data from previous published works were explained. From earlier journals, and study, around 39 samples of cross screw formations on timber-timber composite were acquired. In this chapter, how the data is tabulate using excel, ANOVA and statical analysis using MLR is explained. The prediction model for shear force capacity and stiffness of screw connections in timber-timber composite constructions may then be developed.

By using data from previously published work, chapter 4 covers the creation of new prediction models of shear force capacity of the connection and connection stiffness. The shear force capacity prediction models were compared with the Eurocode 5 model. In this chapter, the prediction stiffness model is also developed and compared the stiffness model in EC5.

Chapter 5 of this thesis includes a summary of the entire study as well as suggestions for further research to enhance the design process of timber-to-timber composite structures.

1.6 Summary

As a conclusion, In Eurocode 5, for example, the slip modulus of a timber-concrete connection is recommended to be double the value of the modulus derived using the formula for a parallel timber-to-timber connection. By considering the screw embedded in the concrete, the study aims to establish a shear force capacity and slip modulus model of screw connections in timber-to-timber composite constructions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Compared to more traditional building materials like steel and concrete, timber has a higher strength to density ratio, less embodied energy, and a reduced carbon footprint. Additionally, the development of engineered wood products, such as glued laminated wood (Glulam), cross laminated wood (CLT), and laminated veneer lumber (LVL), with improved mechanical properties and dimensional stability, has allowed for the construction of multi-story timber buildings with the reliability comparable to those of steel and reinforced concrete structures, but with significantly less negative environmental effects (Weckendorf et al., 2016b). Lightweight wooden floors can greatly lower the structure's self-weight in mid- to high-rise buildings, in addition to the obvious environmental benefits of wood. This characteristic also lowers the stresses caused by seismic inertia, which can lower footing costs, especially in construction sites with unstable soil. Additionally, timber floors with mechanical shear connectors (bolts or screws) can speed up construction, lower labor costs on job sites, and offer a great deal of flexibility in terms of deconstruction, recycling, and/or reuse of building materials and structural components (Chiniforush et al., 2021).

(Hassanieh et al., 2016) and (Loss and Davison, 2017) have thoroughly studied the structural performance of timber-to-steel composite joints and beams, but research on timber-to-timber connections primarily focuses on the behavior, analysis, and modelling of dowel type connectors and the structural performance of lap and/or edge joints (Uibel & Blaß et al., 2007), with less attention being paid to the structural behavior of timber (Chiniforush et al., 2021).

2.2 History of the Timber

As it may have guessed, the history of wood is somewhat complicated. Timber is one of the oldest building materials known to man, the use of timber is over 10,000 years, and it is used to construct everything from humble homes to imposing towers. Timber has affected our way of life since the Roman era, and it is used to build anything from awe-inspiring high rises to the most exquisite Chinese temples. Both Roman and Egyptian civilizations employed timber for roof construction. During the Saxon period, timber cladding was also extremely common. When you look back at pre-civilization times, you'll notice that the utilization of wood was crucial. When artisans needed great expertise to construct something out of that material in the 9th century, builders invented timber frame. Since then, timber framing techniques have become more widely available, with most of this occurring in Africa and Asia. The Neolithic longhouse in Europe, a wooden residence erected approximately 6000 B.C., is an amazing example of how people used wood to build incredible structures. It was one of the most important structures of the time, and it is both sturdy and magnificent. It was big enough to house thirty people, this shows how big it was. Wood has not been superseded by the discovery of bronze and, eventually, steel. They've made a positive impact on how it used. Oak was previously the preferred material for such constructions, but as time goes on, softwood is becoming increasingly popular. Softwood is now more widely available, easier to work with, and stronger in a variety of ways. Timber had a profound cultural impact on the Vikings. They constructed a different type of longhouse, which was normally inhabited by the highest-ranking members of that culture. They were load-bearing constructions with inverted boat-like steeply pitched roofs.

According to Snin et al., (2021), TCC systems were introduced in Europe after World War II due to a lack of steel for concrete reinforcement. To link concrete slabs and timber joists, Muller (1922) created a system of nails and steel braces. Meanwhile, Schaub (1939) introduced the timber layer under the concrete layer floor system, which uses steel I and Z-sections as shear connectors. TCCs were first installed on existing ceilings in Bratislava, Slovakia, in 1960, utilizing nails as shear connectors (Postulka et al., 1983). Between 1975 and 1988, the project was reviewed during its use, with the result that no significant deflection was discovered (Postulka et al., 1997). In addition to the development of various fastening, analysis, and design approaches for the use of TCC systems, extensive research began in Germany in the mid-1980s

(Steinberg & Faust et al., 2003). Steel connections between lumber and concrete were first introduced in the United States circa 1930 at the University of Oregon (Benitez et al., 2008).

Timber has been utilised extensively for construction throughout history. Timber is a functional and expensive material because of its strength, light weight, workability, aesthetics, and ease of finding. The most significant instances of Turkish architectural history's vernacular culture are traditional timber-framed homes, or "Turkish houses." Early Ottoman and mediaeval architecture saw the emergence of timber-framed buildings, which were later developed and made fashionable throughout the 18th century. The first examples included not only homes but also governmental structures like mosques. According to the literature, the traditional structures that the term "Turkish house" describes date back to the 18th century. Timber framed houses typically consist of a masonry foundation, masonry first floor, timber-framed storeys, and a timber roof (Amadio et al., 2009). These structures are often two or three stories high as shown in Figure 2.1.

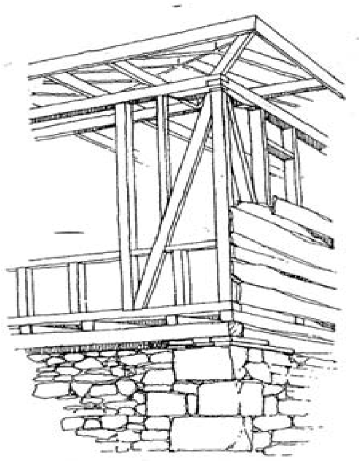

Figure 2.1: Structural order of timber framed buildings (Amadio et al., 2009)

Masonry materials like clay bricks, adobe, or stones are often used to fill a timber frame. There are several instances of this kind of structure worldwide. Even while each of these structures, collectively referred to as classic timber framed infilled buildings, has a different typology, their structural behaviour is essentially the same. The ground floor and foundations of conventional timber-framed homes are often built using stone or mud brick and stone for the masonry basis. Rubble stone is used to construct the foundations in a continuous or discontinuous pattern, all the way up to the first story. The ground floor's wall, which is typically 60 to 80 cm thick, is made of stone or mud brick and combined with timber tie beams (lintel), which are consistently spaced apart at intervals of 70 to 100 cm. The lintels protect the walls from lateral loads and seismic activity (Amadio et al., 2009).

2.3 Engineered Timber in Constructions

Based on Snin et al., (2021) construction materials that are stiffer and stronger are being developed because of advancements in timber technology. In the construction business, the development of TCC structures has been rising (Yeoh et al., 2011). The technique for creating engineered wood has improved as it has become more commonly employed in several nations (Beskitt et al., 2016).

2.3.1 Engineered timbers

According to Snin et al., (2021) glulam was the first engineered timber to be introduced in Europe in the early 1890s (APA--the Engineered Wood Association., 2007). This style of engineered is made up of a series of parallel layers with a thickness ranging from 40mm to 45mm and is often constructed of spruce and larch wood species (STA, 2014). According to (Sebastian et al., 2016), is states that the flaws (such as knots) are commonly observed on glulam, which can decrease its strength. The layers are glued together under pressure in the manufacturing of Glulam, with the grain in the laminates running parallel to the section's longitudinal axis. This is shown in Figure 2.2 (Moody & Hernandez et al., 1997).

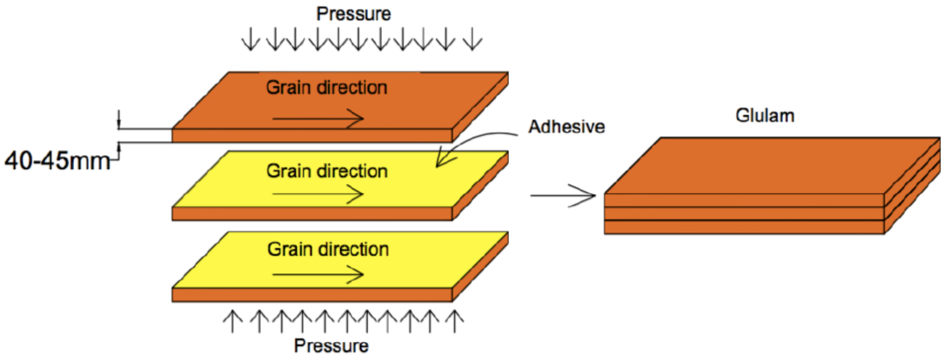

Figure 2.2: Glulam process making (Snin et al., 2021)

Cross laminated timber (CLT) is another type of engineered wood that is now widely used around the world (APA--the Engineered Wood Association., 2007). Since it has the aim improved efficiency, product approvals, and marketing and distribution channels, the usage of CLT in building has expanded dramatically since 2000 based on (Mohammad et al., 2012). The European experience with CLT has been positive, as seen by its use in mid-rise and high-rise structures, as well as the ease with which it can be handled during construction (Gagnon et al., 2013). CLT panels are created by stacking a few layers of lumber boards (usually spruce) as shown in Figure 2.3 and Figure 2.4 At least three layers of board should be bonded together to produce CLT panels (Mohammad et al., 2012). CLT is made up of perpendicularly connected layers of wood that provide structural strength in two dimensions while also increasing structural integrity and dimensional stability (Sutton et al., 2011). Here is a little process on how the CLT panel is made, First, triangular joints are cut using a machine into wooden boards which are slathered in glue and then are heated for 180 ̊c and it is pressed together into a panel. Then, the next layer goes on to a 90-degree angle and process is repeated over again until the panel reaches its desirable thickness. The board are then glued and stacked on each other to be airtight as possible. To ensure the glue does not stick onto the compressor machine, it must be coated with plastic. Thew boards are compressed at a minimum 100 pounds per square inch, and it is set to dry. It could take 2 to 8 hours depending on the season (APA--the Engineered Wood Association., 2007).

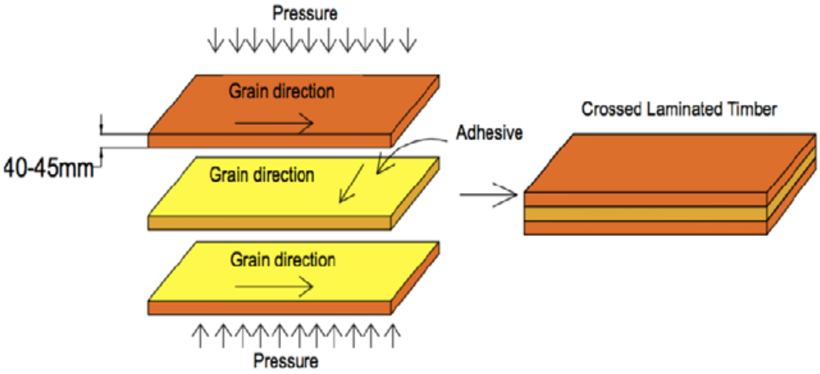

Figure 2.3: CLT making process (Snin et al., 2021)

Figure 2.4: Ready CLT (APA--the Engineered Wood Association., 2007)

Based on (Sebastian et al., 2016), most engineered timber is made up of a few thicker layers of wood, thinner laminations can improve the consistency and performance of the material. According to (Pollmeier et al., 2007), modern rotary cutting machinery has developed to make exceedingly thin laminations by peeling layers off the original round hardwoods like beech. The machine creates a 4mm thick lamination as in Figure 2.5, which results in a different type of engineered wood known as laminated veneer lumber (LVL), that has more consistent material qualities and fewer flaws. Moreover, LVL was first employed as a structural application in the United States in 1978 (Youngquist et al., 1985). However, the softwood species Douglas-fi and Pine were used in the manufacturing of LVL based on (Vosky et al., 1994). There has not been much research and studies done on the usage of hardwood LVL joists in structural applications. The majority of LVL hardwood is used in furniture making. Boccadoro & Frangi et al., (2015) and Sebastian et al., (2016) conducted investigations on the usage of LVL hardwood in structural applications for simply supported and indeterminate beams, respectively.

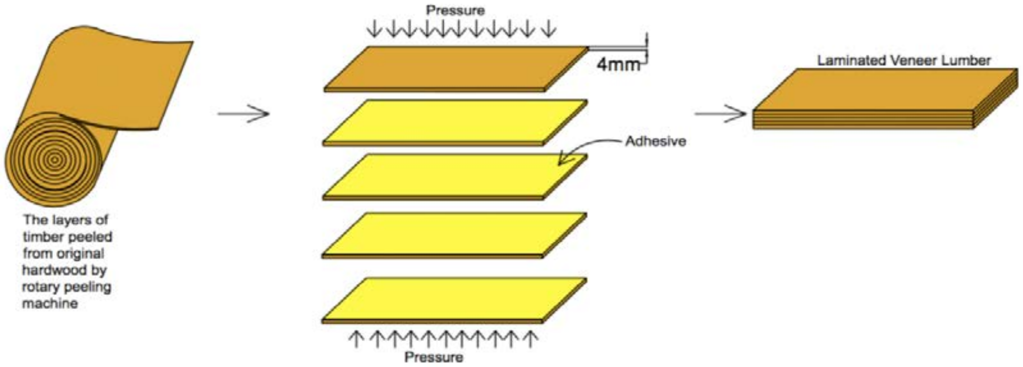

Figure 2.5: LVL process making (Snin et al., 2021)

Figure 2.6: ready LVL (Ultralam, 2016)

2.3.2 Application of Engineered Timber

There are various of application in engineered timber in TCC structures. One of the uses of engineered timber in a structure was Tte Stadthaus apartment building in Murray Grove. The building was constructed using KLH UK Ltd's special technique, with solid wood walls and flooring. Techniker Ltd. is the engineering firm and Waugh Thistleton is the architect. A panel of solid spruce made of perpendicularly stacked strips is the typical product, which is then bonded with pressure of 60 tonnes/m2. Compared to untreated timbers, these units as building materials have less moisture movement and more strength. The layout of the manufacturing facility allows for the provision of panels with a maximum transportable dimension of 2.95 m x 16.5 m and a maximum thickness of 32 cm. Therefore, the largest panels weigh 15 tonnes, which is well within the capabilities of a normal mobile crane. The panels are typically stacked in folded plate assemblies or in mutually supportive configurations (like a card house). By using light metal fasteners to distribute forces, the joints are kept as simple as feasible. Figure 2.7 shows the External photograph of Stadthaus (Wells et al., 2011).

Figure 2.7: External photograph of Stadthaus (Wells et al., 2011)

Another application of engineered timber is the Pioneer of TCC bridges in Germany (Rautenstrauch et al., 2010). This is the oldest TCC bridge in Germany for heavy load traffic. It is 16.4 metres long and 4.5 metres wide and was constructed in 2008. This project serves as an illustration of both the functional and structural benefits of this bridge type. For forestry objectives, lorry traffic was the primary driver behind the construction of this bridge. As shown in Figure 2.8, the concrete slab and glulam beams are combined to create this bridge. Bolts and screws are used to assemble the composite (Snin et al., 2021).

Figure 2.8: Pioneer of TCC bridges in Germany (Rautenstrauch et al., 2010)

Engineered timber also applies in the Agger TCC bridges in Germany (Holzindustrie, 2018). The old bridge, which required periodic repairs owing to flood damage, was replaced by this TCC bridge in 2014 shown in Figure 2.9. The new bridge has just two columns on the riverbanks, and the timber construction is raised sufficiently to protect it from flooding-related damage. The wave-shaped glulam beams were created to create a scenic picture and adapt to the load. The span length and breadth of the spruce glulam bridge are 40 metres and 4.75 metres, respectively. The primary carrier of the bridge has a stepped cross-section. Additionally, the bridge has a concrete slab covered in mastic asphalt and steel railing. The safety rope is also included with the accoyed handrail that is utilised on the bridge.

Figure 2.9: Agger TCC bridges in Germany (Holzindustrie, 2018)

Next is the Renovation and extension work in St Joseph's Primary School (Wood Solutions, 2016). St. Joseph's Primary School in Hawthorn underwent reconstruction and expansion, which was finished in 2016 as shown in Figure 2.10. A big span structural timber floor system measuring 17 metres across had to be manufactured and installed as part of the project. The primary and secondary beams of the first-floor design were made of 1 m LVL hardwood, and the entire structure was covered in 25 mm plywood before the concrete was poured on site. Being a far more lightweight and cost-effective alternative to a solid concrete floor, the choice of a TCC floor system in this project was beneficial. The use of engineered wood also made it simple to coordinate with the safety rope and the surrounding steel framework (Snin et al., 2021).

Figure 2.10: Renovation and extension work in St Joseph's Primary School (Wood Solutions, 2016)

The Four storeys ETH house of Natural Resources (Frangi et al., 2014) was finished constructing in 2015. It was Switzerland's first structure that constructed by applying LVL hardwood as its primary materials. TCC floors that was, made from LVL hardwood, for instance, were used in the building of the new laboratory of Hydraulics, Hydrology and Glaciology (VAW) in the structure. A 6.48 m of LVL hardwood, boards and concrete make up the timber-concrete composite (TTC) slab. Thickness of the LVL boards is about 40 mm, and the concrete is 160 mm in thickness and also the rectangular notches that has a depth of 5 mm are applied in connecting the concrete and timber. Figure 2.11 shows the slab during the construction stage and the result of the building (Snin et al., 2021).

Figure 2.11: Four storeys ETH house of Natural Resources (Frangi et al., 2014)

From the article (Gellef et al., n.d), the 2016 construction of T3 Minneapolis, a LEED Gold-certified structure designed by Michael Green Architecture and DLR Group, made it the largest timber skyscraper in the US. T3, which stands for "Timber, Technology, Transit," is a seven-story, 220-square-foot building that uses timber construction to produce a warm, welcoming workplace that stands out from steel and concrete alternatives. The architects aimed to design an interior environment where people would genuinely enjoy working by utilising the warmth of natural materials.

T3 is simple, despite its boxy form. Its structure is made of spruce, pine, and fir NTL panels, spruce glulam post-and-beam framing, weathering steel siding, and a concrete topping slab. The structural bays of the structure are 20 feet by 25 feet, with NLT panels spanning 20 feet and timber beams extending 25 feet. Furthermore, the NLT's relative affordability in comparison to alternative structural timber systems was a factor in the architects' decision to utilise it.The Minneapolis T3 team took extra effort to include efficiency and environmental awareness into the project's choice of materials and sourcing. All of the timber used in the project was certified under the Sustainable Forestry Initiative, and the majority of the lumber came from trees in the Pacific Northwest that were decimated by the mountain pine beetle (Gellef et al., n.d). Figure 2.12 shows the structure of T3 Minneapolis.

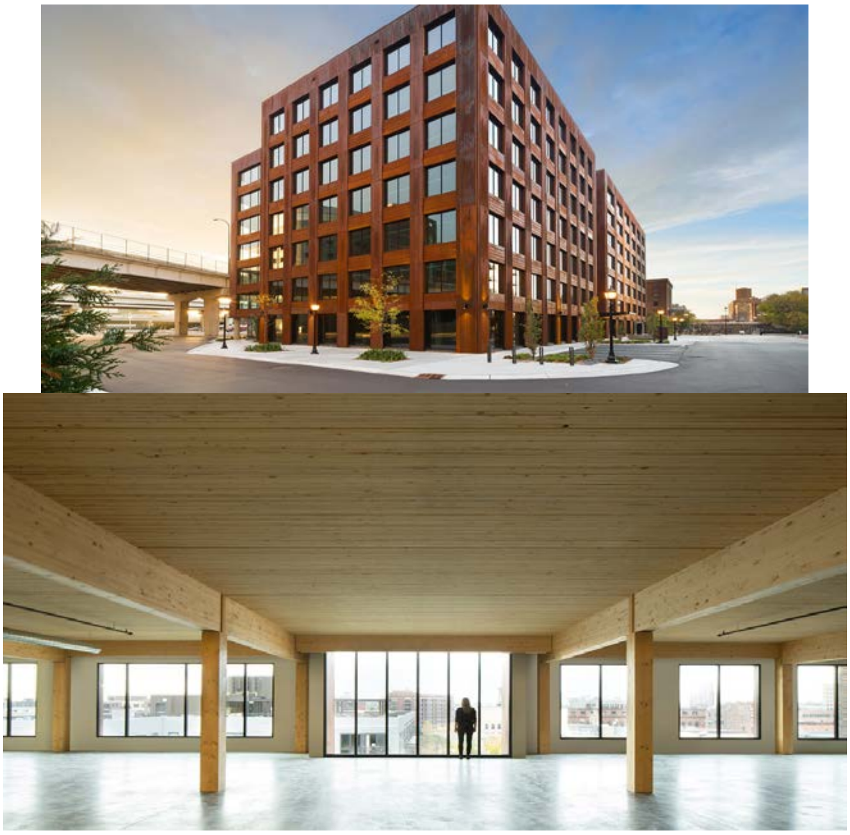

Figure 2.12: Four storeys ETH house of Natural Resources (Gellef et al., n.d)

Based on the article from (Gellef et al., n.d), the tallest mass-timber building in the world, Brock Commons, which is eighteen floors high, is situated on the Vancouver campus of The University of British Columbia. When it was initially constructed, the architects believed that this structure would serve as a prototype for later timber buildings that are easy to construct, affordable, and effective in capturing greenhouse gas emissions in large cities. For instance, Brock Commons was constructed in just 66 days and uses timber to store a remarkable 1,753 metric tons of carbon dioxide. The prefabricated façade has windows that are already installed and is organised in a pattern of repeating vertical striations. Finally, the structure's inside and exterior are covered with cladding that is made of 70% wood fibres (Gellef et al., n.d). Figure 2.13 shows the Brockwood Commons Tallwood House.

Figure 2.13: Brockwood Commons Tallwood House by Acton Ostry Architects Inc., Vancouver, Canada (Gellef et al., n.d)

British Columbia has taken the lead in recent years in the adoption of construction codes that allow for an increase in the use of timber in big, tall structures. The six-story Wood Innovation and Design Center, built by Michael Green Architecture as in Figure 2.14 is an important illustration of British Columbia's expanding proficiency in this field (Gellef et al., n. d). A new combination of glulam post-and-beam frame construction, a specially created CLT floor system, and CLT elevator, stair, and mechanical shafts makes up the main structure. Only the ground floor slab and the mechanical room floor of the penthouse were constructed with concrete. Finally, the design makes use of timber types that may be found naturally in the province, including hemlock, pine, spruce, Western red cedar, Douglas-fir, and pine.

Figure 2.14: Wood Innovation and Design Center by Michael Green Architecture, Prince George, Canada (Gellef et al., n.d)

2.4 Advantage and disadvantage of timber

Timber has many advantages in construction that is why it use widely in various country in construction buildings. One of the advantages is that timber can be shaped easily and modify. It also eco-friendly as it produces less pollutants compared to other building products. It is easy and quick to join the timber together by using dowels, bolts, connectors, screws, and nails. Adhesives may also be used to join the timber element when the temperature and humidity are under control. One of the reason timbers is applied in construction is its light in weight characteristic. This will make the timber easy to handle in manufacture, transport, and construction.

However, the use timber in construction also has disadvantages such as requires careful regular maintenance. If it is not adequately seasoned and is not given the preservatives, it is prone to crack, wrap, bend, and decay. It also runs the risk of catching fire. It is not recommended to utilise timber in applications where fire safety is a concern since it can burn.

2.5 Connection systems in TTC structures

Any composite beam structure must have a strong connection system. There are numerous connecting system configurations that have already been researched. The connection systems utilized in TTC are discussed in this section. Over the past 20 years, a number of self-tapping screw typologies have been developed, encompassing a wide range of structural applications and currently being sold on the market. Referring to the fastener threaded part might help to categories them. There are three primary types of screws: completely threaded screws, double threaded screws (FT, also referred to as all-threaded screws), and partially threaded screws (also known as single-threaded screws, ST). There are other screws that are made for specific tasks like joining timber with other materials like concrete or steel that do not fit into either of these three categories. The specifications for structural screws are not currently governed by an unified standard, unlike other connector types (such as lag screws). As a result, fasteners in each of the three classes (ST, DT, and FT) have different thread, head, and tip geometries.

Based on Loss et al., (2016) and Sebastian et al., (2016) it is shown that their performance needs to be empirically assessed when such connectors are utilized in combinations that are not clearly stated by the product specifications (Schiro et al., 2018). The results from other "similar" fastener types should not be extrapolated without first being tested for accuracy. For instance, as stated in the previous chapter, it is suggested in Eurocode 5 that the slip modulus of a timber-concrete connection be considered as being twice as large as the modulus determined using the formula provided for a parallel timber-timber connection. This is due to the lack of a method designed specifically for connections between timber and concrete. Previous research on testing of timber-to-timber screw-connections in hybrid configurations focuses on connection configurations for use in the field of timber-to- timber composite structures where the fasteners may be inserted at an angle other than 90˚ to the grain and may connect various types of wood (for example, solid sawn timber with cross laminated timber) and/or elements from various species of wood (for example, softwood elements with hardwood elements) (Schiro et al., 2018).

More and more typically, structural solutions use DT and FT screws that are loaded in both shear and tension. The literature Bejttka & Blaß et el., (2002) and Tomasi et al., (2010) contains interesting investigations on the mechanical performance of these connections (softwood), as well as formulae for assessing connection strength and stiffness. To the best of the authors' collective knowledge, ST screws have never been loaded in a shear tension configuration, despite the existence of applications that demonstrate the benefits of doing so (Schiro et al., 2018). Timber as a building material is also a part of the optimization/specialization process that results in the expansion of the range of timber fasteners. Solid sawn timber, glued-laminated timber, laminated veneer lumber, and cross-laminated timber are now all included in the category of timber structural products. Construction companies are currently considering "new" wood species (such poplar, oak, birch, and beech) for structural uses, which may soon compete with the traditional (for construction) softwood species (e.g., pine, spruce, larch).

Only after a comprehensive investigation of the performance of mechanical connections achieved with these new products characterized by very high-density values—and the development of good analytical formulations to forecast their behavior—will this become truly feasible. As a result, tests on the timber-concrete connections under consideration provide support for these enlarged forecasts for timber-to-timber connections. First insights from previous studies, have helped bridge the gap between the availability of innovative engineered components made of renewable materials with good mechanical performance and their widespread use in actual construction projects (Schiro et al., 2018). The findings of a thorough experimental campaign on the short-term testing of timber screw-connections, which included specimens made with various combinations of timber products, screw types, and screw configurations, will be reported in the following sections of this study. Following a description of the samples and testing, an analysis of the findings to deduce the connection's strength, stiffness, and ductility properties will be presented. Conclusions are at last reached (Schiro et al., 2018).

2.5.1 Timber fasteners in TTC

Schiro et al., (2018) reported on using timber connectors in timber-to-timber composite. Two macro categories, single (or partially) threaded screws (STA and STB) and double threaded screws (DTA and DTB), make up the fasteners used in the investigation. The screws can be seen in Figure 2.16. The ST screws all had a countersunk head and a milling cutter between the thread and the shank, and their geometries were relatively similar to one another. The shape of the tip, with a noticeable cutter on the tip of STB, is the primary distinction between STA and STB fasteners (Schiro et al., 2018).

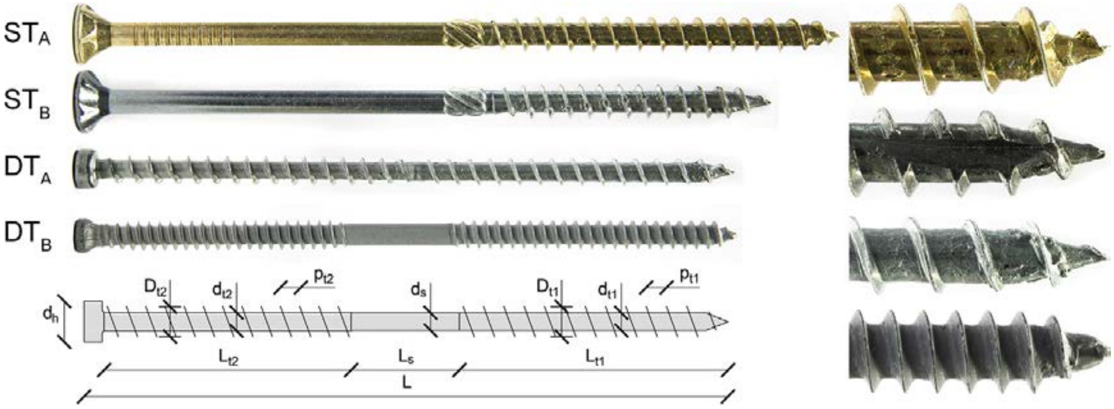

Figure 2.15: Screw types (Schiro et al., 2018)

From Schiro et al., (2018) research, washers with various shapes that the manufacturers provided were used and it is shown in Figure 2.17. Specifically, STB screws were coupled with the washers reported in Figure 2.4.2C and STA screws were linked with the washers displayed in Figure 2.17C (top) (bottom). The first type of washers has a narrow section and a bottom surface that is countersunk, whereas the second type has a squarish, more compact construction with a bottom that is completely flat. To have a larger contact area between the wood and the washer in the configurations where the single threaded screws were inserted at an angle other than 90, groove cuts (GC, Figure 2.17D) were prepared before the samples were assembled (Figure 2.17E) (Schiro et al., 2018).

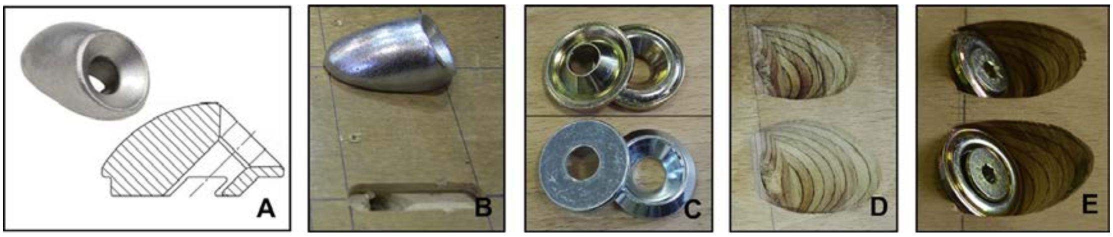

Figure 2.16 : Washers and groove cuts (Schiro et al., 2018)

Samples without washers were also evaluated for timber-to-timber hybrid retrofit solutions (where softwood joists are linked with hardwood reinforcing parts) to confirm the necessity of applying washers. This extra solution was taken into consideration while keeping in mind that failure is determined by thread withdrawal from the softwood portion due to the high density of wood under the screw heads (Schiro et al., 2018).

The washers for single threaded screws that are currently on the market are typically made for a 90 configuration. The usage of washers with a changed geometry could simplify the assembly processes as an alternative to the groove cuts. However, because washers made specifically for steel-to-timber connections (Special washer, Figure 2.17A and B) were not available, they were used in timber-to-timber joints with inclined screws. Nevertheless, a groove cut was required due to the SW's bottom surface's design, as seen in Fig. 2.17B. As will be detailed further on, the design of a washer that has been improved may completely do away with groove cuts. The following observations can be made about the double threaded screws used in the tests: DT_A screws differ from DT_B screws in that they have a larger head diameter, a shorter smooth part of the shank, and a broader pitch for each thread (see Figure 2.16) (Schiro et al., 2018).

Bejttka & Blaß et al., (2002) proposed a theoretical model for the assessment of the connection capacity for fasteners put at an angle an about the shear plane (0 ≤a≤ 90). In this