Usage and Consumption of the Plywood and Sawn Timber in Construction Industry of China

a Case Study and an Analysis for Historical Demand

Weiyi Li

Supervisor: Dr David Evison

University of Canterbury

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ABSTRACT

New Zealand logs exported to China are mainly made into plywood and sawn timber which are used in construction industry in China. This dissertation had two parts. First part of it analyses the public available data to reveal historical total floor space under construction in China and found what the historical trend of construction industry is. The second part of the study models how plywood and sawn timber are consumed and what the average consumption rates are based on model prediction and actual reported information. The average consumption rates of plywood and sawn timber were found to be 0.00762 m^3/m^2 construction area and 0.00203 m^3/m^2 based on actual report and 0.01153 m^3/m^2 and 0.00141 m^3/m^2 from model. The total plywood and sawn timber demand for China 1998-2013 are found to be feasible but the results may be overestimated. The accuracy of data is found to be not reliable.

Content

1. BACKGROUND

In 2014, New Zealand exported 16.585 million m^3 logs and 2.593 million m3 of sawn timber (Ministry of Primary Industries, 2015). China, New Zealand's largest market for forestry products, is consuming about 70% (11.498 million m3) of logs and poles (a 1.97% increase over 2013). China's total import of logs was 51.19 million m3. New Zealand logs exporters are almost exclusively relying on China, but New Zealand logs only had about 20% market share in Chinese market. It is important to understand how New Zealand logs are used and the volume of logs demanded in China. New Zealand logs are mainly made into plywood and sawn timber in China and 68.75% of 1.6m^3 New Zealand logs exported to China were consumed by plywood and temporary construction market in 2003 Katz and Silva (2004).

Over 80% of buildings constructed in China which have over 10-20 storeys use on-site concrete casting techniques to build the structural components (Cai & Zhang, 1998). Most concrete is cast on-site using construction formwork as temporary structure to hold the fresh poured concrete in the position and will be removed when the strength of concrete satisfied the GB50010-2010 Code for design of Concrete Structure, which usually takes about 24 hours (Li, Liu, & Wang, 2005). The majority of removed construction formwork would be re-used until failure. However, the reuse number for the wood construction formwork material is 3-5 due to poor quality (Liu, 2013; Wu, 2002). The tremendous size of construction industry in China and low reuse time of timber formwork together determines the high demand of New Zealand logs in China.

1.1 Construction procedure in China

In order to construct a new building in China, usually three parties will be involved. A real estate development company (the first party) will purchase the right to use of a piece of land from the local government or the collective, and then the first party will make the building and landscape design for the land. One to three years ahead of the actual construction procedures, the first party will contract out the construction rights to a construction companies (the second party, also known as the contractor) through a project procurement process. At construction stage, a supervision company (the third party) will ensure the quality and speed of the whole project.

1.1.1 Management structure of a construction company

For a construction project, the management structure usually has three hierarchies and at least eight teams. The projector manager is the head of the project and several construction supervisors report to him or her. Usually each construction supervisor monitors the construction activities of one building. The third party would also send several quality control supervisors to the site. Under the construction supervisor are at least eight teams. They includes carpenter team, scaffold team, rebar team, concrete team, lift and crane team, utility installation team, health & safety team and at least one team to provide services such as catering, landing cleaning, public relationship etc.

The carpenter team is responsible for the formwork designing, fabricating, installing, removing and relocating. Usually this team is the largest for the project because of the current construction technique. The carpenter team, according to the chief engineer for the project constructed by Nantong 2nd Construction Company in Shanghai, is usually the critical component to determine the total construction time for a project.

1.1.2 Current and historical formwork engineering techniques and materials used for Chinese construction industry

There were two major developments for the construction techniques and materials in China according to the project manager, Wang and Jiang (2007) and Mi (2011). Since the Reform and Open Up in 1978, the construction industry around China was using the technique called “Sanzhi-sanchai (散支散拆)” which means the formwork material components were scattered when brought in and they would be assembled on site based on demand to form the formwork. After the strength of the poured concrete was sufficient the formwork would be deconstructed into scattered components and these components would be relocated and reassembled at next section.

In 1980s, the construction industry was mainly using combined steel formwork. This type of formwork board and rib had very high stiffness while the size was very small because formwork were all installed and relocated by manpower. At that time, steel pipe or U-steel were mainly used as formwork rib.

Bamboo plywood formwork was firstly introduced into China in 1987 but it was not commercially applied in formwork industry until mid-1990s. The combined steel formwork was replaced by bamboo plywood formwork because of the small average size and the quality problem. Although bamboo formwork had higher commercial benefit to construction industry, there were still many problems for this type of material. Firstly the bamboo was easy to deform or tackles after using a few times therefore typically each board could only be re-used by about 20 times. Secondly the dimensions of a standard board were usually 1220*2440*15 mm^3 which was too big and it was hard to cut a standard board into smaller pieces because of the stiffness of bamboo fibre. Thirdly, after a few years, some small bamboo formwork manufacturers started rat race and started to lower product quality to cut the cost and price. Sawn timber was used for formwork rib since that time.

Since 21 century, the construction industry for the whole country started to use timber plywood to replace the bamboo plywood. Although timber plywood was introduced in China at 1981, the shortage of timber made the price of timber plywood unacceptable to the construction companies and in 1990s the coated plywood production techniques were immature. Uncoated timber plywood's quality was also very low and reuse time was only 3-5 times. After 2000, the techniques of both coated and uncoated plywood were more and more mature and dropping timber price made the timber plywood more and more acceptable for the construction companies. However, uncoated plywood could still only be re-used by 3-5 times and coated plywood could be re-used by about 20-25 times. The uncoated plywood usually had a layer of red painting so it was also usually called as *red plywood*. The coating material of plywood board was usually black so coated plywood was also known as *black plywood*. Sawn timber had much higher reuse times and usually one piece of sawn timber can be used for two construction sites or even three if there storey number is not very big. Sample of both types of plywood and sawn timber were showed in Figure 1.

*Figure 1 Three types of timber formwork materials. From left to right is uncoated plywood, coated plywood and sawn timber. All of them were used formwork collected from an active construction site in Shanghai. Both plywood are 15mm thick and sawntimber has a 43*68 mm^2 cross section.*

The timber plywood had two standard sizes: 915*1830*(15-30) mm^3 and 1220*2440*(15-30) mm^3. Standard sawn timber has many different cross section dimensions from 38*88 to 60*100 mm^2 and the length varied from 2.2m to 6 m. Because the prices of one piece of 915*1830 mm^2 and one piece of 1220*2440 mm^2 black pine plywood are about ¥45-60 (NZ$11-15)and ¥80-110(NZ$20-28), all the sites that I visited were using the 915*1830 mm^2 plywood. Equivalently, the price of 915*1830*15 mm^3 and 1220*2440*15 mm^3 are ¥1792-2389/m^3 (NZ$442-588/m^3) and ¥1792-2463/m^3 (NZ$442-607/m^3). The price of sawn timber is about ¥1350-2150/m^3 (NZ$333-530/m^3) depending on the species and cross-section area[1]. Price of sawn timber made of radiata pine is about 1350-1650/m^3 (NZ$333-406/m^3).

[1] http://www.wood168.net/b2b/pricefind.asp (in Chinese) accessed at 30 Sep 2015.

2. RESEARCH QUESTION

The construction industry is very big in China and construction material is one of the major cost components of this industry. Radiata pine sawn log and plywood plays an important role in construction formwork and timber exporting is one of the biggest business for New Zealand. It is important to understand the performance, consumption rate and potential demand of Radiata pine timber from the construction industry in China giving, especially as the real estate market in China is not as good as a few years before.

The goal of this paper is to provide answers for several important questions.

1. What factors / metrics can be used as indicators to represent construction industry in China?
2. What portion of all construction activity is residential-related building and what are the major building components?
3. How many cubic meters of sawn timber and plywood would be consumed to construct one square meter of concrete building on average in China?

These tasks will be achieved by analysing the statistical data of Chinese construction industry and visiting construction companies and contractors and their sites in China.

3. LITERATURE REVIEW

3.1 Use of timber in high rise construction industry in China

In China, construction industry has been developing at a high speed over sixteen years, and 70% of actual investment to this industry ended up in residential building segment (Figure 2). 80% of residential buildings are using reinforced concrete as the structure part and the current construction techniques used for companies and contractors in China require the concrete casted on-site. Construction formwork is a temporary structure into which concrete is poured. The formwork is removed manually after the concrete has cured which usually took about 24 hours (Li et al., 2005).

According to the Song and Wang (2007), the unit cost of timber construction formwork for a residential building in Beijing was ¥23 /m^2 (NZ$5.6/m^2) [2]. Given the cost of construction for Beijing in 2008 was ¥1089/m^2 (NZ$268/m^2) (China Engineering Cost Network, 2015), the construction formwork cost was only about 2.1% of the total cost of construction. But the Table 14-9 in National Bureau of Statistics (2014) suggested that the output value of construction industry is 14.11 trillion Yuan ($3.5 trillion NZD) in 2013. Assuming the formwork cost was the same ratio to the total cost, the actual market value of timber formwork in China would be 298 billion Yuan, or about 75 billion New Zealand Dollars. At the same time, the total floor under construction of China had also increased by seven times between 1998 and 2013 (Figure 3). Accordingly, construction formwork is an important component for the construction industry and also important for New Zealand explorers.

[2] Current exchange rate is 1NZD = 4.06 CNY at 28 Sep 2015, http://www.xe.com/currencycharts/?from=NZD&to=CNY&view=1D

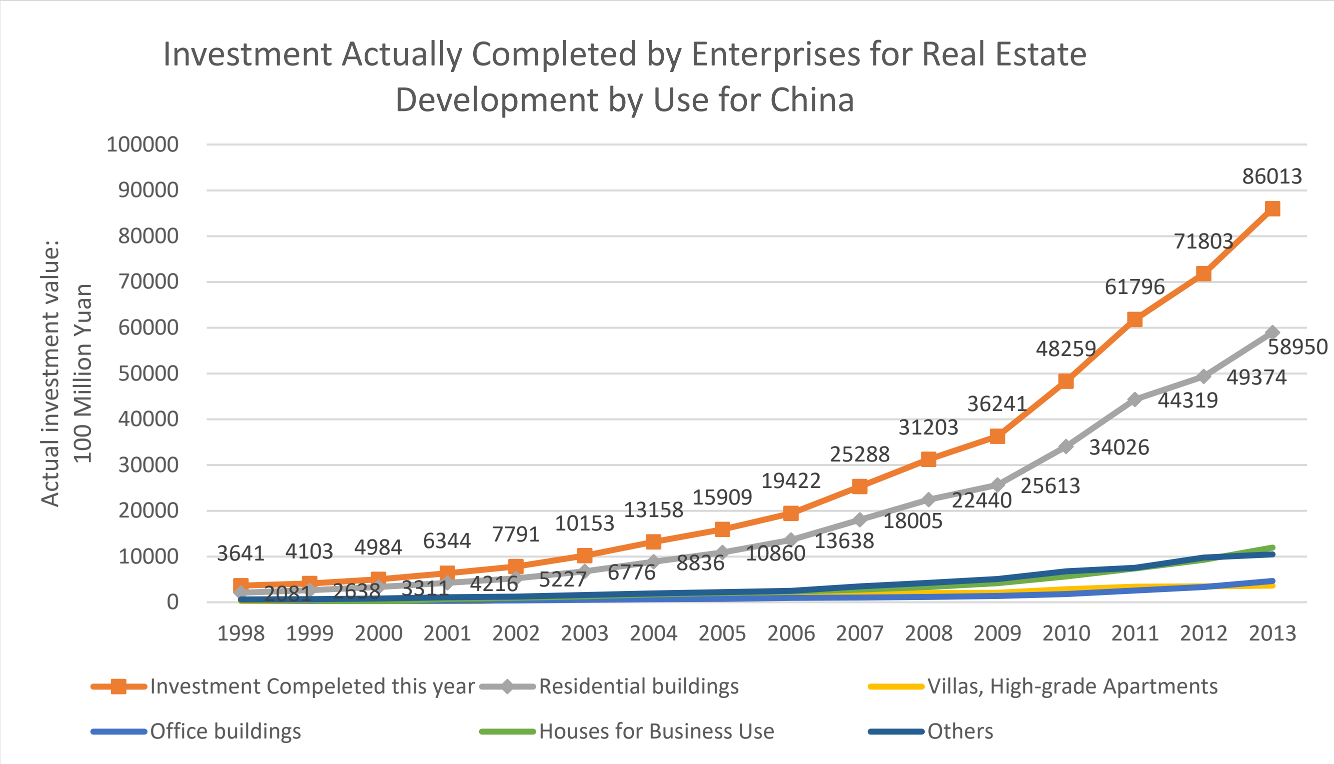

Figure 2 Actual Completed Investment to Real Estate industry in China between 1998 and 2013. Data from Table 15-5 National Bureau of Statistics (2014)

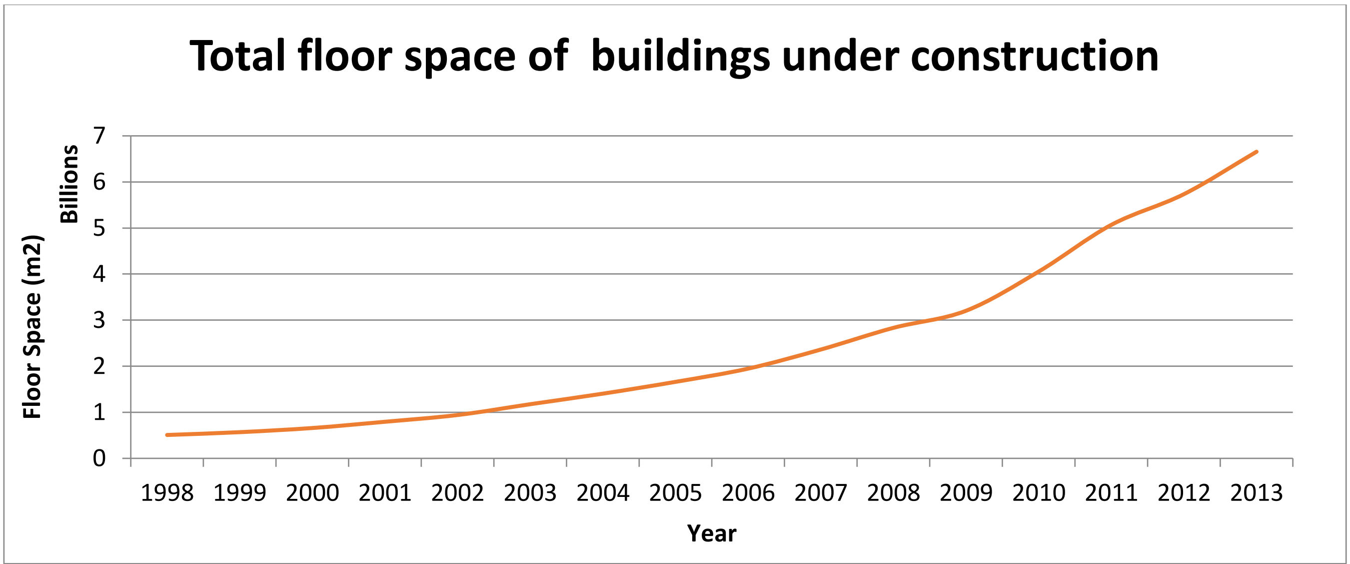

Figure 3 Total floor space under construction for China, Data from Table 15-7 National Bureau of Statistics (2014)

3.2 Use of wood in construction formwork

Construction formwork is a board and diverse concept. According to Li et al. (2005), formwork is made up of two main components: the formwork panel and the rib. The panel can be made of wood-based panel, bamboo panel, stainless steel, aluminium, plastics, concrete, paper-based material or a combination of some of these materials, such as bamboo panel with steel frame. Rib is usually made of steel, plastic or sawn timber. Wood-based panel has become the most commonly used formwork all around the country (Wang & Jiang, 2007).

Radiata pine has also become an important species used for wood-based panel production. China is also the second biggest plywood producing country. Food and Agriculture Organization of the United Nations (2015) pointed out that the total production volume of plywood for China was about 100 million m^3 in 2013. Mao and Wu (2015) also suggested that about 45% of plywood produced in China was used for construction. Therefore about 45 million m^3 of plywood were used in Chinese construction industry in 2013.

3.2.1 Plywood and sawn timber used in construction site

When the structure part of a project commenced, the first thing to be done is the formwork design and installation by the carpenter group. Standard formwork materials will be cut or jointed to match the surfacing area and shape of different structure parts including floor, column, purlin, joist, shear wall and other vertical and horizontal parts. Usually one storey of formwork will be prepared and installed on place at once (Figure 4). A few days after fresh concrete is poured the formwork for ground storey will be relocated without removing the scarfed and installed on the top of the this floor to serve for concrete pouring for the first floor (Figure 5). If the project is urgent, two storeys of formwork will be prepared at once therefore the first two floors can be poured at once.

Figure 4 Installed floor formwork system. Rebar are laid on top of plywood

Figure 5 Carpenters are removing the formwork for second floor while keeping steel scaffold in position

When the single storey or two-storey formwork is reused for a few times, some parts will be damaged. If the level of damage is unacceptable these will be replaced by new parts. In order to have spare formwork materials available when some parts of formwork is damaged, usually more materials which is sufficient to prepare for half to one more floor's formwork will be brought at the beginning. For a building using red plywood, if the building is 7-10 storeys, formwork material which can build half set of formwork for a floor will be prepared as separate parts. If the storey number is between 10 and 15, one set of formwork of material will be prepared. After the roof is finished, all formwork would be removed and some of them, usually sawn timber, which have acceptable level of damage would typically be collected and sent to the next construction site if any. Other used formwork materials would be sold to a dealer called Middle Man who will then resell them to some sawmill or other types of manufacturers for recycling or re-using for other purposes.

3.3 Reuse of sawn timber and plywood formwork

The reuse time of plywood would be significantly influenced by two factors: building design and urgency of the construction project. Typically each floor of a building would be called either 'Standard Floor' or 'Non-standard Floor'. Use a 32-storey residential and commercial building as an example, the first three floors might be used for retail and other commercial purposes. If so the structure design for first three floors is completely different for the floors 4 to 32. These three floors are called 'Non-standard Storeys' because their design is different from the major part of the building although the design of the ground floor is very similar to the first and second floor. Floors 4 to 32 are called "Standard Storeys" as their structure designs are very similar with each other and they are the major part of the building. Typically a single storey formwork would be made for the first three floors. But when the third floor is finished, less than half of the formwork components removed from the formwork could be re-used for next 29 storeys' formwork. The actual portion of plywood re-used to standard storey after non-standard floors are finished varies a lot from site to site and no one has the record, according to most project managers that I interviewed. They are assumed not to be re-used in the model. Therefore the reuse time for the Non-standard Floor formwork is 3. Reuse time means the times a piece of timber formwork material will be used as part of formwork before being disposed. For the Standard Storeys, a single storey formwork would be built and re-used with damaged part replaced. If two storeys of formwork materials are consumed when the roof is finished, the reuse time for each piece of formwork material would be 14.5. However, if this 32-storey building were only used for residential purpose and the structure designs from ground floor to the 32 floor are similar, and the reuse time for these formwork materials would be 16.

The urgency of the project was another major factor to influence plywood reuse time. Here use the same building as example. Because typically formwork can be removed when fresh concrete was poured for seven days. If the structure part of the project should be finished by 40 weeks, the above mentioned construction procure could be applied and total time consumed for structure construction is about 32 weeks. But if the structure part must be finished within 30 weeks, the formwork for three Non-standard Storeys may be assembled at once and the formwork for Standard Storeys has to be assembled two-storey at once. Now the total time consumption is 15.5 weeks. Reuse time is one to two times for Non-standard Storey formwork and less than 14.5 times for Standard Floor formwork. When a project is finished, usually no plywood will be delivered to next site.

Sawn timber reuse time was estimated in a different way. Project managers and quantity surveyors don't know the exact reuse time of a piece of sawn timber because used sawn timber with fine condition were get transported to next site and maybe to the third site and the same construction team may not work for next site. Instead, everyone confirmed one piece of sawn timber can be reused for two or three sites. Given the average storey number of all projects in Appendices 3 is 15.05 the model used 30 as the reuse time of sawn timber for all projects.

The current techniques used in the construction industry require the most part of the horizontal formwork which is for floor concrete pouring and some parts of the vertical formwork which is for columns, walls and joist installed, removed and relocated by manpower. These may use over 40% of the total manpower of the whole site; the time to lay out and take off formwork would also consume over half of the total construction period (Cai & Zhang, 1998; Yao, Zhao, Wang, & Fei, 2013). These requires the weight and size of the formwork are capable to be handled and carried by workers (Wu, 2002).

In order to understand the amount of sawn timber and plywood used in the construction stage of a reinforced concrete building it is necessary to know how many times the formwork would be re-used and how much timber is required to cast the whole building. The reuse times of both products are highly variable. Previous research on timber plywood suggested that plywood used for floor concrete casting could range from less than three times (for example Liu (2013), Song and Wang (2007)) to eight times (for example Li et al. (2005); Poon, Yu, and Jaillon (2004) and Wu (2002)). Secondly, the products would have some depletion after transportation but before put into use, and the ratio can be 15% (Song & Wang, 2007). Thirdly, quality problem is a big issue. Production techniques and skills from most plywood manufacturing facilities in China are far behind the overseas peer factories (Chen & Gao, 2011; Liu, 2013) because some facilities may use timber that doesn’t satisfy the National Standard GB/T 17656-2008 Plywood for Concrete Form. And quality variance is high due to the non-mechanized plywood production techniques (Yao et al., 2013). Fourthly, Yao et al. (2013) stated that there was not many specialized plywood products which would be specially used for construction formwork. All these influenced the quality of the formwork and thereafter the reuse times.

Factors that influenced the reuse of timber formwork are different, in which manpower was the core factor for the on-site working process while the design and contract played important role for the design management aspect(Ling & Leo, 2000; Poon et al., 2004). If the design was not prepared taking the material availability, the formwork design would be complex and modification were often required(Cai & Zhang, 1998; Poon et al., 2004). Since the two most important constrains to govern the construction process were the cost and time, the construction contractor would prefer the formwork without coating which has significant less reuse time than coated plywood (Wu, 2002). On the construction site, a high-skilled, positive-attitude carpenter would install and remove the formwork efficiently while carefully(Ling & Leo, 2000). These would make the damage to the formwork during stripping which could maximize the reuse number for formwork.

A carpenter who has been working in a carpenter group for 7 years confirmed that altitude of manpower and management skills/criteria are the key factors to determine the reuse time of plywood and sawn timber. For example if the manager will fine the whole crew if one found a piece of sawn timber longer than 1 meter was disposed, the reuse time of sawn timber will be higher than if he/she did not make such a requirement. A friendly manager will have the reuse time of plywood and sawn timber in the project higher compared to a rude or captious manager's site.

3.4 How plywood and sawn timber are used and re-used

When the structure construction is actually commenced, engineer of the carpenter group will calculate the actual plywood and sawn timber demand for each floor and requires the plywood manufacturer and sawmill to deliver formwork materials two to five days ahead. At the middle of the construction process, carpenter group only needs a small amount of sawn timber and plywood to replenish damaged materials. If a set of formwork must be replaced during constructing process, new plywood and some more sawn timber will be ordered in advance.

At the end of structure construction process, all the sawn timber which is shorter than one meter and plywood removed from the formwork would be sold to the middle man or thrown away as construction rubbish. If there is another on-going or immediately commencing construction project, sawn timber which is longer one metre would be delivered to the next site.

At every site that I have visited, basically no timber is wasted. The residual materials cut from plywood would be connected (Figure 6) or used for other purposes (Figure 7, 8, 9 and 10). For sawn timber, the new sawn timber will be cut into desired length to be used as formwork rib. After a few times of re-using, both edge of sawn timber will tear and/or wear therefore both ends will be cut for a small section or this sawn timber will be used for other places.

Figure 6 Two piece of cut plywood connected together to make a piece of 915*1830 plywood board

Figure 7 and 8 Cut plywood used for other purposes. Left side showed the residual plywood used to isolate sewage pipe well. Right side showed two piece of plywood connect by a residual sawn timber used as temporary wall.

Figure 9 and 10 Cut plywood used for other purposes. Left side was notice boards made of residual plywood and sawn timber. Right side was the cut plywood used as deck of a steel pipe walking bridge.

Typically after the structure part is finished, on the one hand, 10% total plywood removed from formwork is still in good condition. They will then be used for the installation and finishing processes. At the end of the whole project, no plywood would be delivered to next site. Sawn timber, on the other hand, will be continuously be reused until either the length is less than one meter which means connecting a lot of them is not commercial or it cracked or buckled.

3.5 Methodology for estimating formwork material use and reuse in Chinese building construction industry

When the carpenter group needs to estimate the total formwork board demand, they will use a factor of total concrete surfacing area including horizontal and vertical structures of one floor (or the whole project) to its floor space (or to the construction area of the whole project) to make the estimation. The factor is usually between 2.5 to 3.5 based on the rule of thumb. For example, if the total construction area of a 32 storey building is 20000 m^2, the total surfacing area of all concrete structure parts is between 50000 to 75000 m^2. Commercial buildings and office buildings will have lower values because they has few walls, while residential building and high-grade apartments' factors are higher because the internal structure design contains more walls per square metre of floor area in term of surfacing area. The formwork required for foundation, roof and other structure parts has been taken into account for this factor. The wastage of plywood due to cutting and modifying are also taken into consideration. All the engineers, managers and carpenter group leaders suggested that no one would further subdivide the factor for vertical and horizontal structure components in practices.

However, quantity surveyors would not estimate the actual number of plywood and sawn timber required. Instead, they use the surfacing area of all horizontal and vertical structure components to multiply the empirical unit construction costs per square meter to get the total construction cost for the project. The cost of sawn timber is not reported as a separate cost term but included in the unit construction cost.

3.5.1 Estimation of formwork materials in reality and its rationality

At the stage of project procurement, the first party and each of the second parties will estimate the total costs and margins for the project. Estimating the formwork costs and time consumption is minor task for quantity surveyors because the formwork material cost usually only makes up 2-9% of the total cost (Appendices 3). The estimations are made relying on their empirical numbers based on rule of thumb. In Huangshi, contractor will enclose the formwork budget into the concrete unit cost in their tender. In Shanghai, however, construction companies will make separate budget if the real estate development company has such a requirement.

Appendices 1 and 2 are the Table 37-27 and 37-28 from China Architecture & Building Press (2003). They provided the main structure indexes of 37 commercial and office buildings and 34 residential buildings around the country. These two appendices suggested that the volume and surfacing area of structure components had a lot of variations for these two types of building. This makes the engineers and quantity surveyors from the second party unlikely to forecast the formwork board and sawn timber demand based on technical drawings accurately. The manager of projects 6 and 7 commented that the total construction cost of residential buildings and commercial buildings in Shanghai are about ¥1300/m^2 (NZ$321/m^2) and ¥2600/m^2 (NZ$642/m^2). National Bureau of Statistics (2014) reported the average cost of building completed for Shanghai in 2013 was ¥ 4670/m^2 (NZ$1150/m^2). Although these two prices were very different, it was still rational to estimate formwork material only based on empirical factors given the retail price of project 6 is about ¥ 60000/m^2 (NZ$14778/m^2).

At procurement stage, the cost of formwork material and labour would either be included into the concrete cost by increase the unit concrete cost by an empirical ratio or be prepared by multiplying the concrete cost with a factor. Inaccurate estimation of formwork material costs would not have impact to actual construction cost because this rough estimation would not be used during actual construction process. When the project is going to commence, used sawn timber from other sites will arrives and new sawn timber will be ordered if necessary based on carpenter group's estimation. This made controlling the actual formwork material budget harder.

Two construction engineering books also provided some indexes about the timber consumption rate. Table 1 suggested the average total timber consumption rate was about 0.0313 m^3 per meter square of construction area but the associated content in the book did not mention what kind of timber materials were included in this rate. Table 2-11 from China Mechanie Press (2005) mentioned that the total timber consumption rate for a 12 storeys office building was 0.029 m^3/m^2. China Architecture & Building Press (2003) also suggested that between 1991and 1995, total timber consumption index of different building and structure types in Beijing was between 0.025-0.045 m^3/m^2, among which residential building has slightly higher timber consumption rate than commercial buildings. I

Timber consumption index for 100 m2 construction area		
Building type	Formowrk board (m3)	Sawn timber (m3)
Civil use	1.5	1.48
Industrial use	1.82	1.43
Average	1.69	1.44

Table 1 Timber consumption index per 100 m2 construction area. Data from Table 2-9, China Mechanie Press (2005)

4. METHODOLOGY

4.1 Analysis of public-domain data

Statistical data about Chinese real estate and construction industry are obtained from the Chinese Statistical Yearbook and Chinese Real Estate Statistical Yearbook. These statistical yearbooks would be able to provide historical data about total floor area and value for both residential and non-residential construction projects of the whole country and of every province. These data were found to be able to indicate the construction industry for China.

From the public data collected from two yearbooks, information about building construction for residential and non-residential use were also reported and the proportion of building floor area and value for residential building, commercial building, office building and buildings for other purposes were all summarised. Data trends will be analysed primarily using graphical methods to reveal the size and trend of the construction industry in China.

4.2 Survey method

The aim of the survey is to determine the amount of wood used for formwork on the structure building stage for different buildings. It aims to determine how much wood is used on a specific site by estimating the plywood and sawn timber consumption rate and total consumption volume.

The survey is divided into two parts. The first part is a pilot survey to senior engineers in Christchurch. This will help:

- Understanding of the parameters of the building design
- Determining how formwork design is established and how formwork is built
- Understanding the building process – for a given design and floor area, how much area is prepared for pouring concrete at one time?
- Understanding the reuse cycles – how much material from one pour can be re-used for the next and how the material is re-used.
- Finding the resource where the actual timber consumption information could be collected.

From the above information it would be possible to estimate the plywood and sawn timber consumption rate in a building of known footprint and number of storeys.

The construction sites in New Zealand and in Britain are not commonly using reinforced concrete as structure part. The formwork used locally is mainly made from metal and plastic. In order to estimate the amount and value of formwork used for a building construction site, there are two methods. The first is using technical drawings to calculate the actual concrete surfacing area and calculate the amount of pieces of plywood and sawn timber demanded. The actual plywood consumption rate is then worked out by dividing total demand a product of reuse factor and total floor area. Sawn timber consumption rate would be manipulated in a similar way. The second method is collecting actual plywood and sawn timber consumption volumes from quantity surveyor and dividing them with total finished floor area. The engineer suggested me to find the quantity surveyor and project manager when taking survey in China and familiarize the procedures of building construction at first.

The second part is surveying building construction companies and contractors in China. Based on the pilot survey results, I will adjust the survey to fit it into the real construction project in China. The survey for Chinese construction companies and sites aims to collect:

1. General information about a project, including total floor space, storey number, building type.
2. At what proportion of the total formwork is made of sawn timber and plywood?
3. Whether and how would the formwork be reused?
4. Average reuse times for plywood and sawn timber.
5. Whether an estimate of wood usage for formwork can be calculated from quantity surveyors' information and from technical drawings.

The information collected from pilot survey need to be confirmed and different information, if any, would be used to complete the methodology for estimating plywood and sawn timber consumption rate.

Between 21st Aug and 4Th Sep, I travelled to Shanghai, Hubei and Liaoning provinces and visited 14 building construction sites and the data from all projects is attached in Appendices 3. During this time I talked to project managers, carpenter engineers, site engineers and a carpenter group leader from several contractor companies and a manager from a third party. Information about these projects including total floor area, building number, storey number, design, formwork design criteria and actual plywood and sawn timber consumption were all collected. Conversations with these people also brought me the knowledge about typical procedures of a building construction project, formwork design and using processes, using and re-using of plywood and sawn timber and how the demand of these two materials were estimated.

4.3 Plywood and sawn timber consumption prediction model

4.3.1 Inputs and variables for the model

This model requires the design information of a building construction project and properties of plywood and sawn timber used in the project. It can predict the timber consumption in meter cube and average consumption per square meter of construction floor area in cubic meter per square meter for plywood, sawn timber and the sum of both materials.

The inputs of this model include:

- Total floor areas and storey number for standard storey and non-standard storey
- Concrete surfacing factor
- Reuse time of plywood and sawn timber materials
- Dimensions of plywood and sawn timber materials used
- Spacing between two piece of sawn timber rib
- Plywood residual proportion

4.3.2 Mechanisms of the model

The consumption of plywood and sawn timber materials of standard storeys and non-standard storeys will be calculated separately and total volume and rate will be summed up at the end. No previous model using similar methodology was found and all equations mentioned below were summarised from report of project managers and engineers during surveying trip in China.

For plywood, all projects are only plywood as formwork board. If a project has non-standard storeys, the average floor area of a storey would be calculated:

$$\text{Average floor area } A_{ave,non} = \frac{Total\ non\text{-}standard\ storey\ floor\ area\ A_{non}}{Non\text{-}standard\ storey\ number\ n_{non} \times building\ number\ b} \quad (1)$$

Volume of a piece of plywood is calculated:

$$\text{Volume } V_{single}^{ply} = thickness \times width \times length \quad (2)$$

Then average volume of plywood used for a non-standard storey is calculated:

$$\text{Average volume of plywood } V_{ave,non}^{ply} = \left(Floor\ surfacing\ factor\ F_{floor} + Other\ structures'\ facing\ factor\ F_{other}\right) \times V_{single}^{ply} \quad (3)$$

Although the surfacing factor is reported to be a single value from the people surveyed in China, they also pointed out that the spacing between two piece of sawn timber rib for floor formwork and other vertical parts are sometimes different. Therefore this factor has to be separated for sawn timber. Because the average floor reported in Appendices 1 and 2 are 0.85 and 0.88 m^2/m^2 of total construction area, I assumed the floor surfacing factor is 1.2 for all projects because the two averages are similar and the thickness of floor concrete should be taken into account.

Total volume of plywood used for all non-standard storeys is calculated:

$$\text{Total volume of plywood } V_{sum,non}^{ply} = \frac{V_{ave,non}^{ply} \times non\text{-}standard\ storey\ number\ n_{non} \times building\ number\ b}{non\text{-}standard\ storey\ plywood\ reuse\ time\ Reuse_{non}^{ply}} \quad (4)$$

The reuse time of plywood for non-standard storey usually equals to storey number because the plywood taken off from non-standard storeys could hardly be re-used for standard storey construction, reported by several managers and engineers. This part of plywood are assumed to be all consumed as no used plywood can be used for next project.

The total volume of plywood used for standard storeys is calculated in the same way. However the reuse time for plywood used for standard storeys equals to either the reported number if a project uses red plywood or half of the average standard storey number if a project uses black plywood and the total storey is higher than 20.

Then the total plywood consumption volume of both types of storeys will be summed and average plywood consumption rate of plywood is calculated as:

$$\text{Total plywood consumption volume } V_{sum}^{ply} = \left(V_{sum,non}^{ply} + V_{sum,standard}^{ply} \right) * 110\% \text{ (5)}$$

$$\text{Total plywood consumption rate } Rate_{sum}^{ply} = \frac{V_{sum}^{ply}}{A_{non}+A_{standard}} \text{ (6)}$$

Mentioned in section 3.4, when structure part finished, on average 10% of total plywood were still under fine condition when removed from formwork. This part of plywood would be then used in other construction activities on site until complete depleted. The 110% in formula (5) simulated this as the total volume consumed in both types of storeys did not include the formwork consumed in other construction activities.

For sawn timber, the consumption volume and rate for standard storey and non-standard storey are calculated separately. The volume of one piece of sawn timber is calculated as:

$$\text{Volume } V_{single}^{sawn} = thickness \times width \times length \text{ (7)}$$

The length of a piece of sawn timber is assumed to be equal to the length of plywood, because the total demand of sawn timber is calculated based on number of sawn timber per sheet of plywood and number of plywood. The average volume of sawn timber required per floor of non-standard storey is:

$$\text{Average volume of sawn timber } V_{ave,non}^{sawn} = V_{single}^{sawn} \times \left(\frac{F_{floor} \times A_{non} \times Number\ of\ rib\ per\ plywood\ sheet\ on\ floor\ N_{floor}}{length \times width\ of\ a\ plywood\ sheet} + \frac{F_{other} \times A_{non} \times Number\ of\ rib\ per\ plywood\ sheet\ on\ other\ parts\ N_{others}}{length \times width\ of\ a\ plywood\ sheet} \right) \times proportionof\ sawn\ timber\ rib\ P \text{ (8)}$$

Projects 1-10 only used sawn timber as formwork rib but projects 11-15 had the formwork rib mainly made of steel (Appendices 3). The surfacing factor for other structure parts rather than floor would be calculated by subtracting the total surfacing factor by 1.2.

Next step is calculating the total sawn timber consumption volume for non-standard storeys. As mentioned in the section 3.3, 30 is assumed to be the average sawn timber reuse time for all projects although the storey number of different types of construction are different .

$$\text{Total volume of sawn timber } V_{sum,non}^{sawn} = \frac{V_{ave,non}^{sawn} \times b \times n_{non}}{sawn\ timber\ reuse\ time\ 30} \quad (9)$$

Total volume of sawn timber consumed by standard storeys is calculated under similar way. The total volume and consumption rate of sawn timber for a project is calculated as:

$$\text{Total sawn timber consumption volume } V_{sum}^{sawn} = V_{sum,non}^{sawn} + V_{sum,standard}^{sawn} \quad (10)$$

$$\text{Total sawn timber consumption rate } Rate_{sum}^{sawn} = \frac{V_{sum}^{sawn}}{A_{non} + A_{standard}} \quad (11)$$

For the actual consumption rates for plywood and sawn timber, they are calculated by dividing the total consumed volume by the total finished floor area. This model also checked the actual average plywood re-used time by:

$$Actual\ plywood\ re-used\ time\ Reuse_{actual}^{Ply} = \frac{Total\ acutal\ plywood\ sheet\ number \times plywood\ length \times plywood\ width}{(A_{non} + A_{standard}) \times (F_{floor} + F_{other})} \quad (12)$$

4.4 Analysis of survey data

4.4.1 Statistical analysis and historical timber demand prediction

During the survey procedure in China, on-going analysis, modification and improvement of the survey would be carried out. This would ensure the survey could collect all the important information required to develop the model to estimate the total timber consumption rate for a building construction site. At this step, the analysis would be mainly focusing on the completeness of collected data.

After surveying, the average, minimum and maximum plywood, sawn timber and total timber consumption rate of all projects would be reported. Predictions of the total plywood and sawn timber formwork materials consumption of the building construction in China based on the minimum, maximum and average consumption rates would be made.

4.4.2 Standard model and sensitivity analysis

Two base models using the average values of these inputs would be firstly developed and a sensitivity analysis was also implemented. The base models were simulating the plywood and sawn timber consumption volumes and rates of one residential-related building. The single-storey-type model estimated plywood and sawn timber demand in order to build a 16-storey building as residential usage only and the two-storey-type model estimated the demand of plywood and sawn timber of the same building but the first two storeys of the building were for commercial usage. Inputs and assumption used for two models were listed in Table 2. Impact of ten percent variation for each input on plywood and sawn timber consumption volume and rate were reported. For the concrete surfacing area factor, the maximum and minimum value collected from survey were used in sensitivity analysis as well. All results were included in Appendices 4 and 5.

	Trial index		Base model (single-storey-type model)	Base model (two-storey-type model)
Project information	Location			
	Project type		R	R+C
	Building number		1	1
	Average storey		16	16
	concrete surfacing area factor		2.86	2.86
	Proportion of formwork material budget		100%	100%
	Total floor area (m2)		17600	17600
	Completed or not		completd	completd
	Completed area		17600	17600
Non-stand storey	Storey number			2
	Building number			1
	Total floor area (m2)			2200
	Average floor area (m2)			1100
	Plywood reuse time			2
Stand storey	Storey number		16	14
	Building number		1	1
	Total floor area (m2)		17600	15400
	Average floor area (m2)		1100	1100
	Plywood reuse time		6.13	6.72
Plywood	length (m)		1.83	1.83
	width (m)		0.915	0.915
	thickness (m)		0.015	0.015
	Residual proportion of plywood		10%	10%
Sawn timber	width (m)		0.09	0.09
	thickness (m)		0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4
		vertical structure	4	4
	Reuse time		30	30
	Any other formwork material?		no	no
	Percent of sawn timber used as rib		100%	100%

Table 2 Assumptions used of two base models. Green cells were inputs and other cells were assumptions of the model.

5. RESULTS

5.1 Analysis of data from survey in China

These 14 projects are allocated in different places around the country (Appendices 3). Five are allocated two cities in Hubei provinces, six are from Liaoning province and others are from Shanghai, Sichuan and Jiangsu provinces (Figure 11). Information about projects 8 and 9 is provided by the manager of project 7. The building type is also diverse. Twelve projects are residential or having residential building as major component and one is an office building. The rest are two for other using purpose including a warehouse (project 4) and a heat exchange facility afflicted to a power plant (project 1). I used the model to predict the plywood and sawn timber consumption volume and rate and results are also included.

Figure 11 Locations of projects in China. Three stars from up to down are located at Liaoning, Shanghai and Hubei provinces

These 15 projects are different in many aspects. The floor area for residential and residential-commercial projects is between 298-1030m^2 and the average is 623.7 m^2.

The formwork material cost makes up 1.5-8.78% of total construction budget for all residential-related projects. Given the average cost of building completed in 2013 for Shanghai, Hubei and Liaoning are ¥4670/m^2 (NZ$1150/$m^2$) , ¥2313/$m^2$ (NZ$570/$m^2$) and ¥2423/$m^2$ (NZ$597/$m^2$) (National Bureau of Statistics, 2014), the residential buildings' formwork material cost would be between ¥46.3-231.3/m^2 (NZ$11.4-57.0/$m^2$) in Hubei, ¥934-1041/$m^2$ (NZ$230-256/$m^2$) in Shanghai and ¥105.2-212.7/m^2 (NZ$25.9-52.4/$m^2$) in Liaoning. The projects for office and other purposes tend to have lower surfacing area factor than residential projects which agrees with what project managers mentioned.

For the design of residential buildings, the number of non-standard storey is usually similar for different projects. For an apartment village, usually the first one to three storeys of buildings which are next to a street will be designed for commercial purposes such as dairy shop or restaurant (Figure 12). Therefore the average number of non-standard storeys is usually 2 and the average floor area of non-standard and standard storeys are similar. At the same time, if there will have underground carpark beneath each residential building, the carpark usually has one to two storeys. Because the average non-standard storey design data could not be found through literature review, an assumption was made that a residential building project has two non-standard storeys giving the average non-standard storey number for residential-related projects is 2.2[3].

[3] See note 7 in Appendices 3

Figure 12 A typical residential building with 2 non-standard storeys. The photo was taken at the site of project 2.

There are some differences for the dimensions of plywood and sawn timber used for different projects. All projects are using 1.83*0.915 m^2 plywood sheet on the site while two projects also use 2.44*1.22 m^2 sheet at the same time. But the thicknesses of plywood of same area used for different sites are different. The red plywood has the smallest thickness of 14mm and the biggest thickness of 20mm. The black plywood sheets used at different places are all 15mm thick. The dimensions of sawn timber, however, are different from one site to another and the cross section area rages from 3344mm^2 to 5000 mm^2. When it comes to the volume of sawn timber required to support each piece of plywood, the variation is less. Apart from the projects for other purposes, all projects have the average volume between 0.223 m^3 and 0.306 m^3. But the heat exchange building and the warehouse require 0.412 m^3 and 0.549 m^3 of sawn timber to support one piece of plywood. This might be because the thickness of floor and dimensions of vertical structure parts for heat exchange plant and warehouse are bigger than normal civil buildings.

5.2 Model results and comparison

The model provides the consumption rate estimation for plywood and sawn timber as well as the sum. The actual consumption rate of plywood and sawn timber are also calculated (Table 3). Here 'actual' consumption volume and rate were calculated based on the actual plywood and sawn timber consumption report from each project. The differences of predicted consumption rates as percentile to the actual rates are calculated by dividing the absolute difference between prediction and actual consumption rate by the actual consumption rate. Table 2 showed that the project 4 which is a residential village has the lowest actual timber consumption rate for both timber materials, and the model prediction differences of this project is also the biggest apart from projects 11-15. The accuracy of actual timber consumption rate of project is problematic because the data were provided based on memory and gut feeling.

For projects 6-10 only, the total timber consumption rates were predicted well and the difference were all within 6.8% with the average as 3.6%. An average prediction difference for plywood consumption rate was 4.6% and the minimum and maximum value were 1.2% and 8.5%. The average, minimum and maximum prediction differences for sawn timber consumption rate were 6.0%, 0.4% and 14.9%. Given the sawn timber consumption rate is usually less than 20% of the plywood consumption rate, influence of impreciseness of sawn timber prediction would not have major impact for the total timber consumption rate prediction.

	Actual consumption rate (m3/m2)			Predicted consumption rate (m3/m2)			Differences percentile of prediction		
Project number	plywood	sawn timber	total	plywood	sawn timber	total	plywood	sawn timber	total
1				0.00858	0.00213	0.01071			
2				0.00797	0.00245	0.01043			
3				0.00523	0.00109	0.00632			
4	0.00619	0.00077	0.00696	0.01160	0.00157	0.01841	87.4%	103.9%	164.5%
5	0.00959	0.00220	0.01179	0.01687	0.00215	0.01902	75.9%	2.3%	61.3%
6	0.00644	0.00229	0.00873	0.00636	0.00234	0.00870	1.2%	2.2%	0.4%
7	0.01151	0.00275	0.01426	0.01188	0.00234	0.01422	3.2%	14.9%	0.3%
8	0.00841	0.00195	0.01035	0.00794	0.00190	0.00983	5.6%	2.6%	5.1%
9	0.00996	0.00247	0.01243	0.00911	0.00248	0.01159	8.5%	0.4%	6.8%
10	0.00689	0.00179	0.00868	0.00660	0.00161	0.00821	4.2%	10.1%	5.4%
11	0.00634			0.01800	0.00024	0.01824	184%		
12	0.00680			0.01800	0.00028	0.01830	165%		
13	0.00636			0.01874	0.00021	0.01900	195%		
14	0.00632			0.01874	0.00021	0.01890	197%		
15	0.00662			0.00733	0.00012	0.00745	11%		

Table 3 Predicted timber materials consumption rate of all projects and actual consumption rate based on available data[4]

Table 4 provided the average, minimum, maximum and the standard deviation of plywood and sawn timber actual consumption rates as well as the predictions from model. For the actual consumption rate, project 7 which was a four-storey high-grade apartment project was the highest for plywood. Its project manager mentioned that this type of high-grade apartment which is similar with townhouse would have higher plywood consumption rate. The structure designs of the first and third floors are similar and the second and fourth floors are similar. And a large proportion of red plywood used for the formwork in the first floor cannot be re-used for the second floor's formwork but the third floor's formwork. When roof is finished they have to stop re-using all plywood even some plywood are still re-useable. Therefore all floors are non-standard floors and plywood consumption will be higher. To simplify the model for project 7, I assumed the average reuse time of plywood for this project would be 5 because the remaining plywood after the structure part of this project is finished is still consumed in later work for this project. When it comes to actual sawn timber consumption rate, project 4 was an outlier which brought down the average and enlarged the standard deviation from 0.00203 to 0.00224 (10%) and 0.00035 to 0.00064 (45%).

Projects 11-14 have much higher plywood consumption rate compared with other projects (Table 3). These rates should be higher than reality because the actual

[4] See notes 5-8 in Appendices 3 for further information.

plywood reuse time of these projects were all less than 1, which means the total consumed plywood volume might be misreported or recorded wrong.

	Actual consumption rate (m3/m2)		Predicted consumption rate (m3/m2)		Differences percentile of prediction for project 6-10	
	plywood	sawn timber	plywood	sawn timber	plywood	sawn timber
average	0.00762	0.00203	0.01153	0.00141	26.6%	19.5%
min	0.00619	0.00077	0.00523	0.00012	1.2%	0.4%
max	0.01151	0.00275	0.01874	0.00248	87.4%	103.9%
standard deviation	0.00180	0.00035	0.00510	0.00095	37.8%	37.6%
95% lower boundary	0.00402	0.00134	0.00132	-0.00049		
95% upper boundary	0.01122	0.00273	0.02174	0.00331		

Table 4 Statistical analysis of the actual and predicted timber material consumption rate

The histogram of actual consumption rate for both materials and the sum (Figure 13) suggested the three types' data had four hierarchies and the proportion of these hierarchies were constant for three types of data. However the predicted consumption rates were more randomly distributed (Figure 14). From Table 3, both actual and predicted sawn timber consumption rate had lower standard deviation compared plywood consumption rates. These might indicate that:

- The actual plywood and sawn timber consumption rate will be similar for projects having similar management and construction techniques. And the techniques used in construction industry across the country are similar, mentioned by a project manager. The 6 projects which had 0.006-0.0065 m^3/m^2 actual plywood consumption rate were the project 4 from Hubei, project 6 from Shanghai and projects 11, 13 and 14 from Liaoning. Projects 11, 13 and 14 which have 0.0065-0.007 m^3/m^2 actual plywood consumption rate are all from the construction site which provided project data 11-15.
- Sawn timber consumption rates had less variation compared with plywood as not only the standard deviations for predicted and actual sawn timber consumption rates were smaller than that of plywood, but also their 95% confidential intervals were very similar.

- The predictions of plywood and saw timber had more fluctuation and larger 95% confidential interval because the model was based on design information about standard and non-standard floors, plywood properties and rib requirement per piece of plywood for every project. Each project has its unique design therefore the prediction results will vary. And these design differences seemed to have more impact on the predictions to plywood consumption rate than on sawn timber consumption rate.

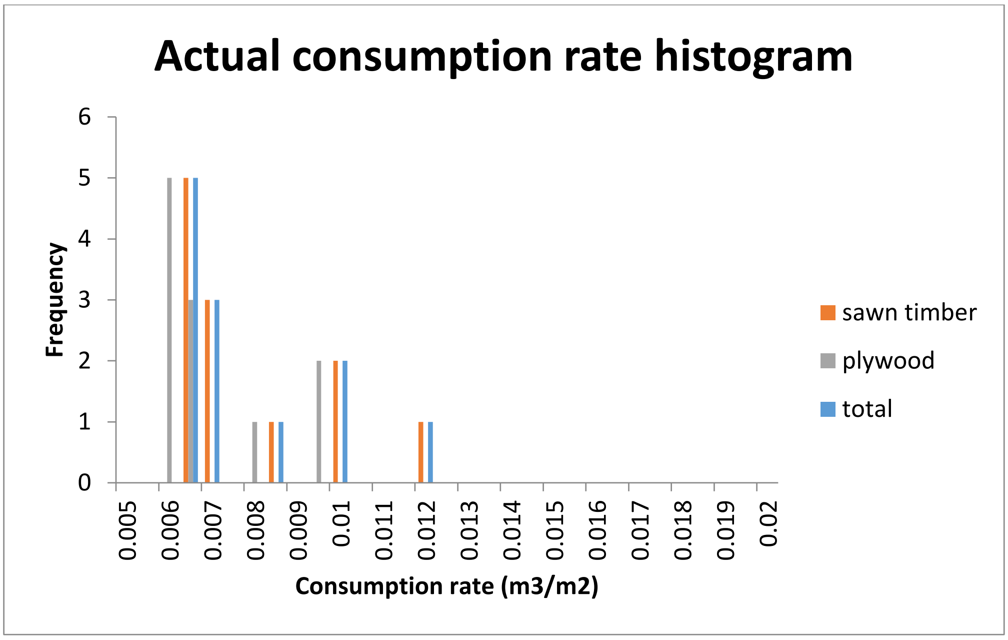

Figure 13 Histogram of Actual timber consumption rate distribution

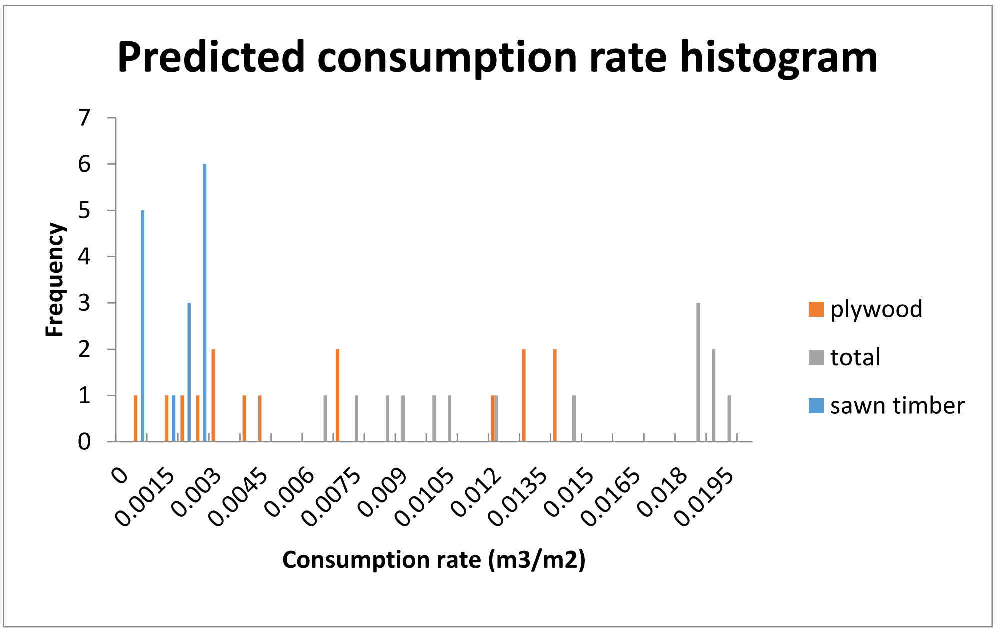

Figure 14 Histogram of model predicted timber consumption rate distribution

5.3 Standard model and sensitivity analysis

The single-storey-type model suggested that total plywood and sawn timber consumption would be 135.39 m^3 and 29.69 m^3 and the consumption rates of them were 0.00769 m^3/m^2 and 0.00169 m^3/m^2. Figure 15 and 16 were the total consumed volumes and consumption rates of sixteen sensitivity analysis trials for single-storey-type model. These two figures suggested that both the plywood consumed volume and consumption rate were most sensitive to:

- Concrete surfacing factor
- Plywood reuse time
- Plywood depth (volume of a piece of plywood)

10% change for the above inputs would influence the consumption volume and rate of plywood by about 10.0%, 11.1% and 10.0%.

Sawn timber consumed volume and rate were also most sensitive to:

- Concrete surfacing factor
- Sawn timber reuse time
- Number of sawn timber per plywood sheet
- Sawn timber cross section (volume of a piece of sawn timber)

10% change of the above inputs would influence the consumption volume and rate of sawn timber by 10.0%, 11.1%, 10.0% and 10.0%. Similar results were found in the sensitivity analysis to two-storey-type model (Figure 17 and 18).

In real-world construction project timer material reuse time was varying the most. This factor can be influenced by many factors including some 'soft' factors such as altitude of labour and management skills (Ling & Leo, 2000) and 'hard' factors such as quality and storey number mentioned in Figure 1 and section 3.3. This makes the estimation of reuse time of plywood and sawn timber hard. This is also a reason why the model predicted consumption rates of plywood and sawn timber had bigger standard deviation and 95% confidential interval compared with actual consumption rates.

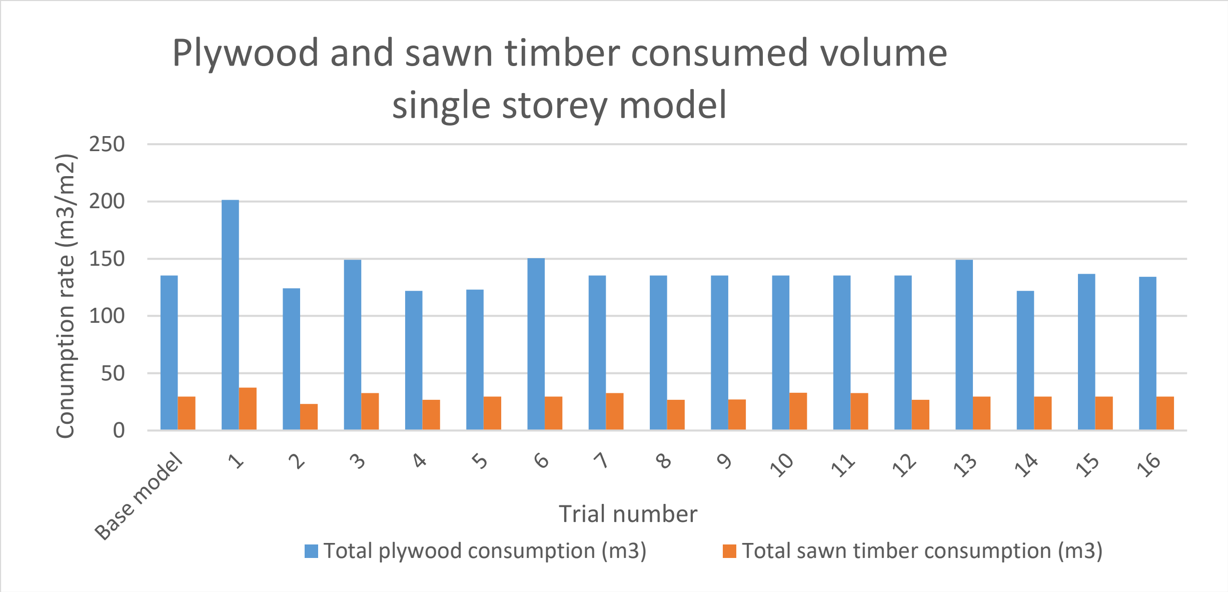

Figure 15 Plywood and sawn timber consumed volumes of sensitivity analysis to the single-storey-type model. Data abstracted from Appendices 4

Figure 16 Plywood and sawn timber consumed rates of sensitivity analysis to the single-storey-type model. Data abstracted from Appendices 4

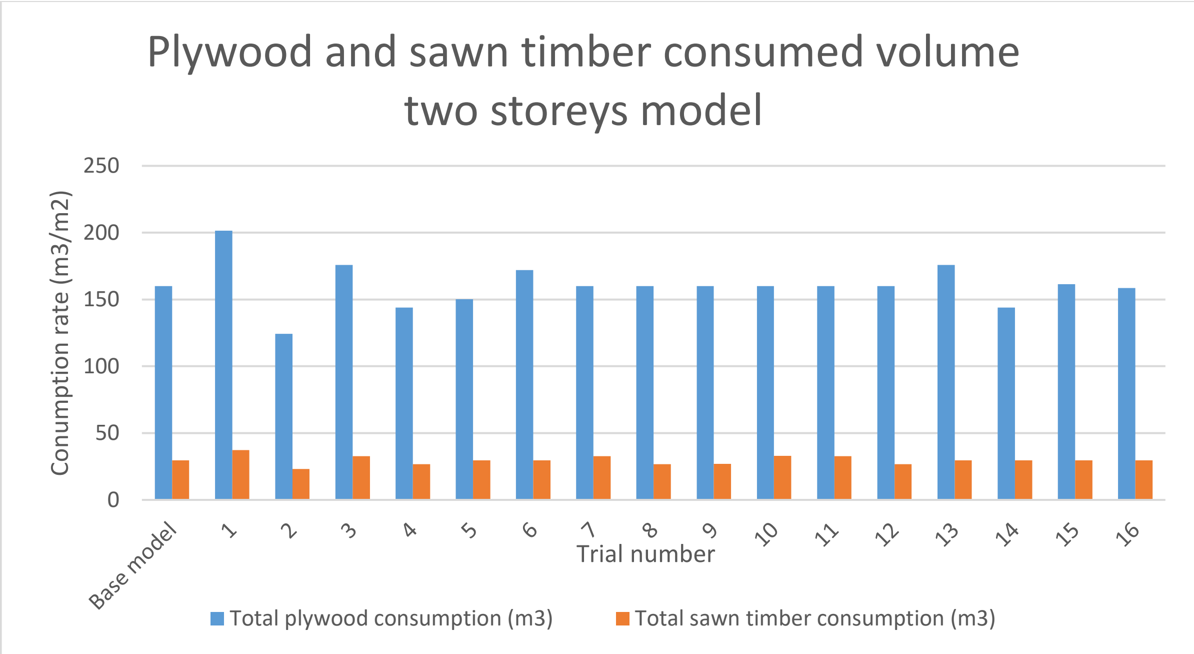

Figure 17 Plywood and sawn timber consumed volumes of sensitivity analysis to the two-storey-type model. Data abstracted from Appendices 5

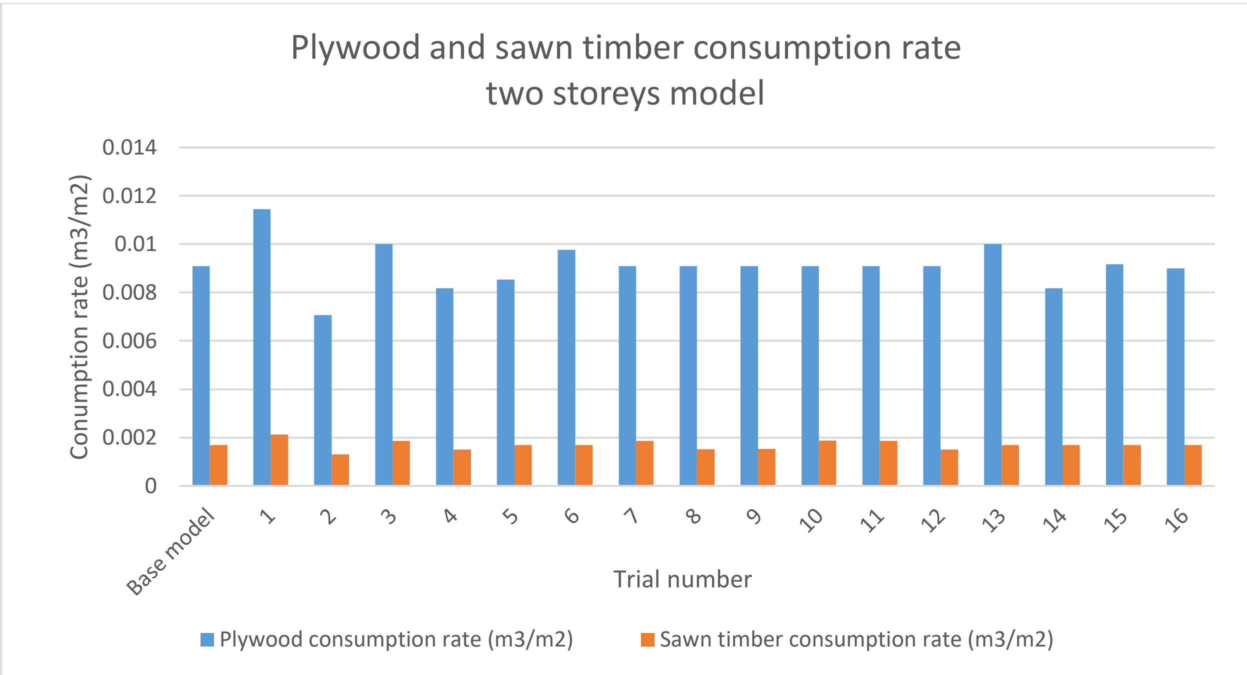

Figure 18 Plywood and sawn timber consumed rates of sensitivity analysis to the two-storey-type model. Data abstracted from Appendices 5

The comparison between sensitivity analyses results of two models were reported in Figure 19 and 20. The sawn timber consumption volumes and rates were identical comparing both models but two-storey-type model's plywood consumption rate and volume were always no less than the single-storey-type model. This was because the non-standard storeys would have higher plywood consumption compared with standard storeys under same condition due to low reuse time. Plywood and sawn timber consumption volumes and rates were sensitive to same factors at same magnitude.

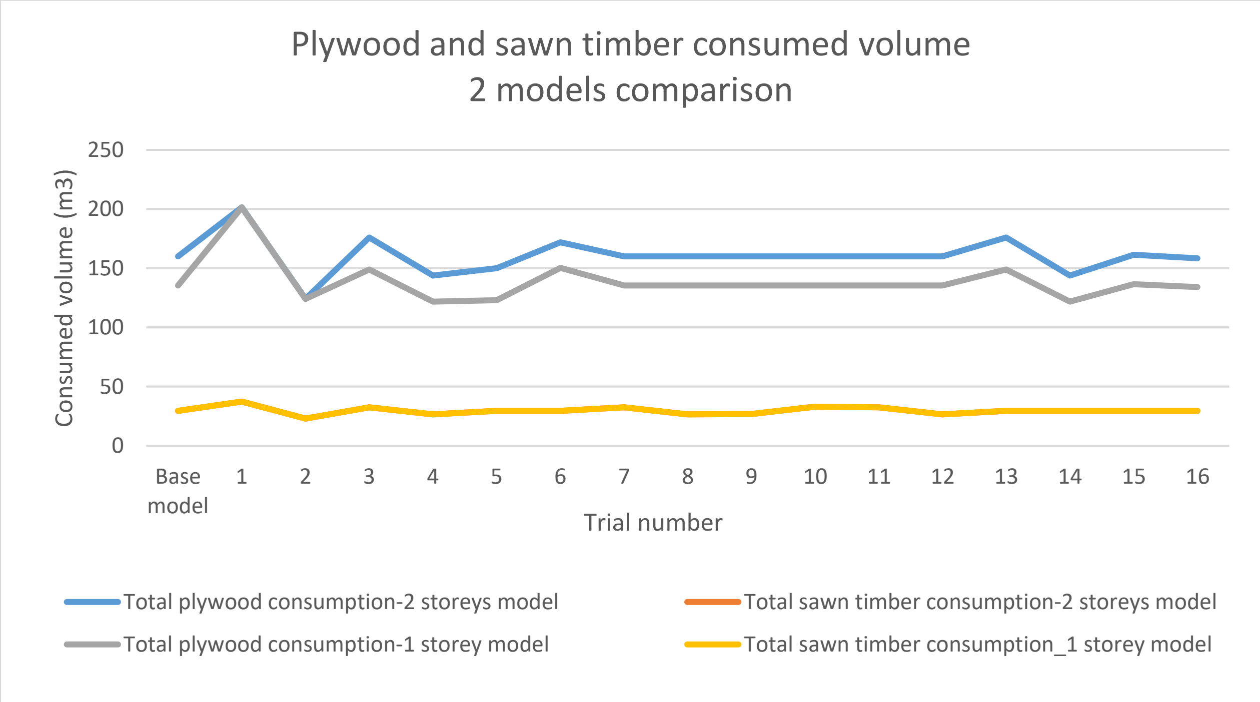

Figure 19 Comparison of plywood and sawn timber consumed volumes between two models

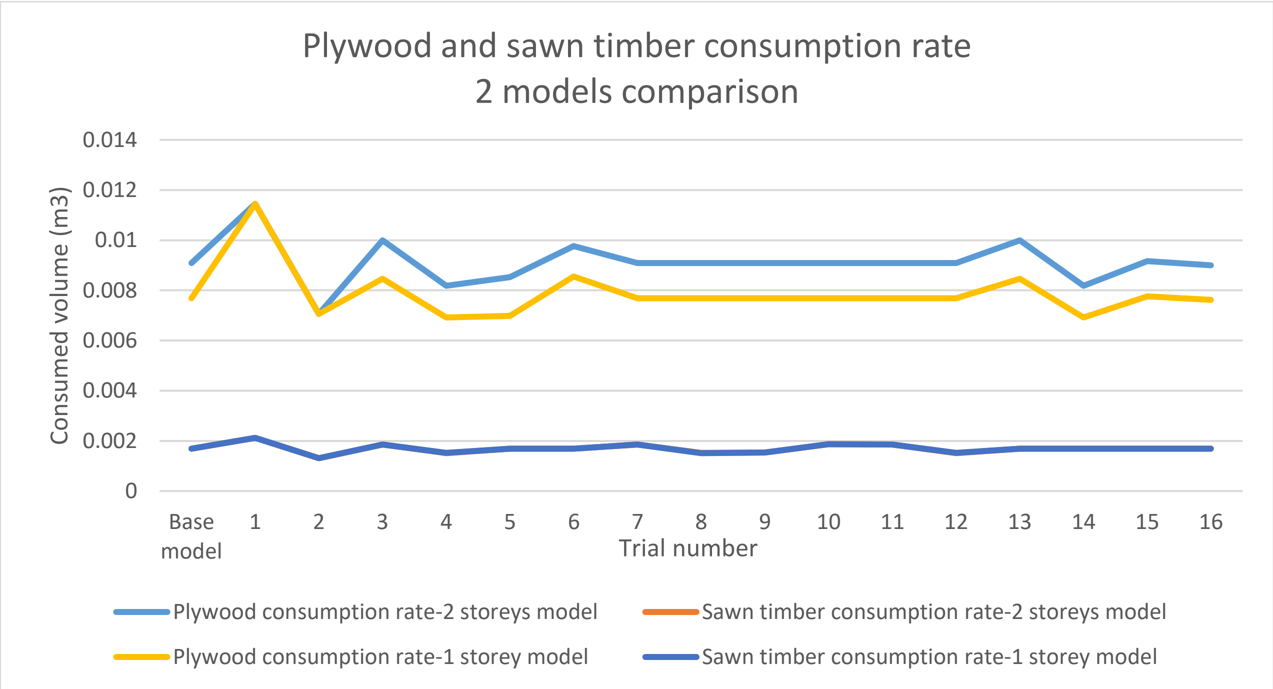

Figure 20 Comparison of plywood and sawn timber consumption rate between two models

5.4 Historical plywood and sawn timber demand

Given the total floor space under construction of China between 1998 and 2013 (Figure 3), historical plywood and sawn timber demands were predicted by multiplying the total floor space of each year with the average, minimum, maximum and 95% confidential boundaries of the actual and predicted consumption rates (Figures 21-24). Figure 21 and 23 suggested that, on average, total plywood demand for formwork used in construction industry in 2013 would be about 50.7 million m^3 based on actual consumption rate and 76.7 million m^3 based on model prediction. Model prediction gave higher prediction because the plywood consumption rates of projects 11-14 were higher than that of other projects. Comparing with the actual plywood consumption data, demand predicted using the actual consumption rate was more feasible compared with the demand predicted using model results. Both predictions indicated that the major end-use of plywood in China would for formwork, but Wan (2009) suggested that hard plywood were also used for other purposes including wood floors moulding, wall panels, doors window and kitchen cabinets. Because there was no data related to the proportion of each of these end-uses, the actual feasibility of predictions of historical plywood demand could not be checked. Further research should be done to find actual market share of plywood and sawn timber used for construction formwork.

Sawn timber demand predicted by two different ways were both feasible when compared with actual sawn timber consumption (Figure 22 and 24) and it seemed that formwork rib might not be a major end-use of sawn timber. The demand prediction from model results were less accurate given the project 11-15 were mainly using steel as formwork rib.

For plywood and sawn timber demand predictions based on actual and predicted consumption rates, the maximum and minimum values were all laid within the 95% confidential interval. The maximum plywood and sawn timber demands predicted from actual data were very close to the upper 95% confidential boundary.

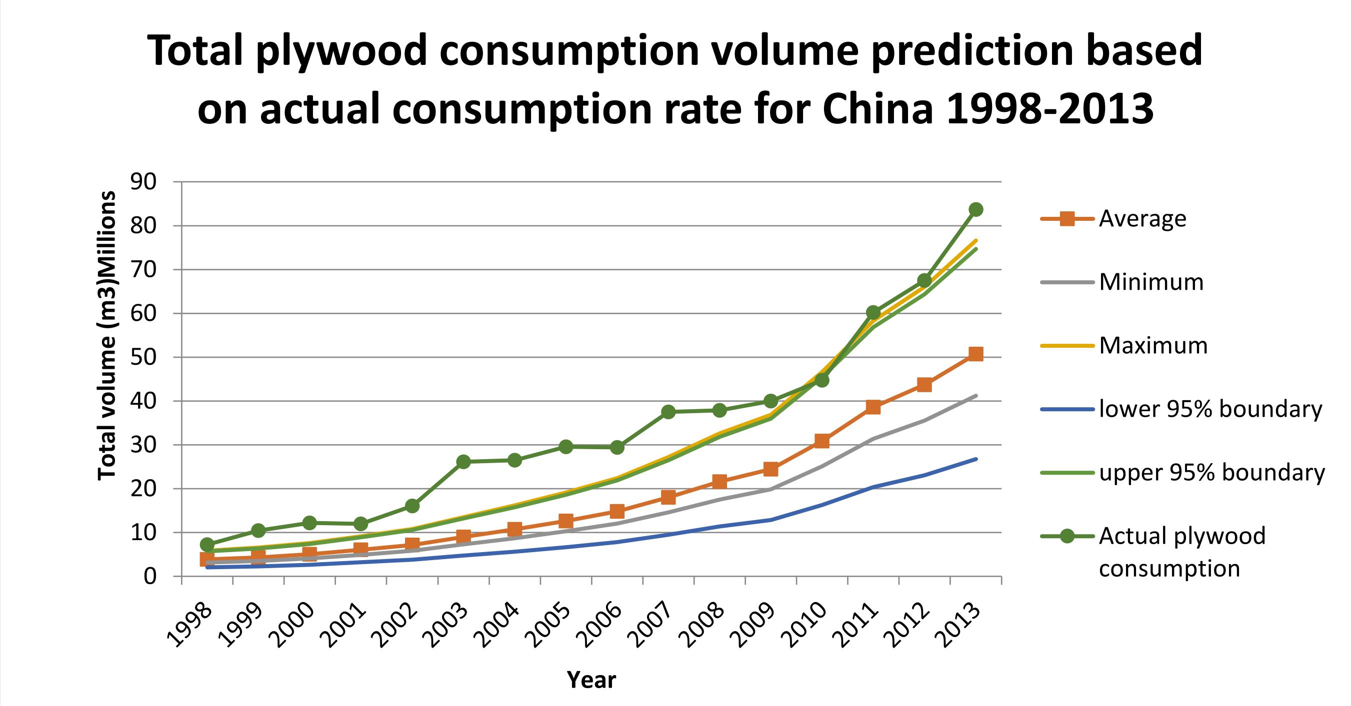

Figure 21 Total plywood demand prediction based on actual plywood consumption rate. Actual plywood consumption was from Food and Agriculture Organization of the United Nations (2015)

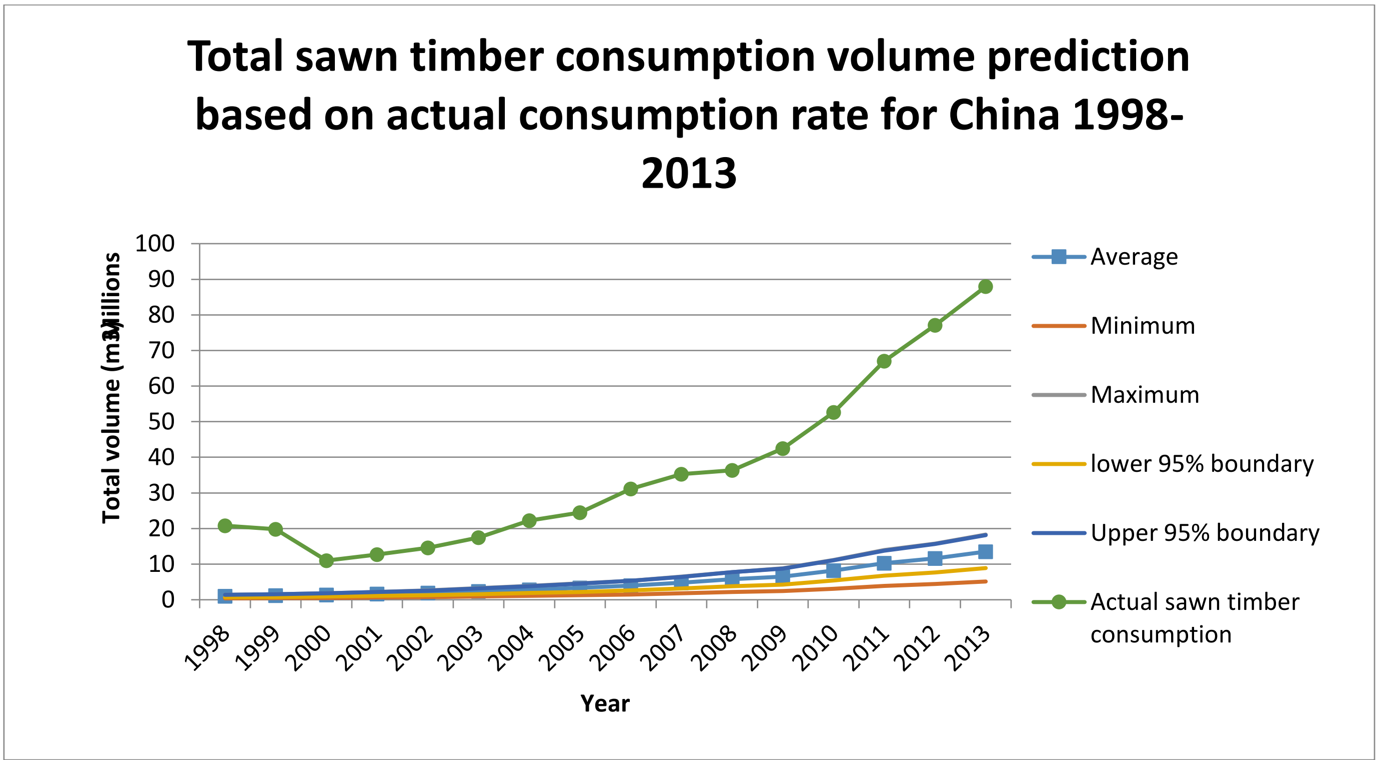

Figure 22 Total sawn timber demand prediction based on actual sawn timber consumption rate. Actual sawn timber consumption was from Food and Agriculture Organization of the United Nations (2015)

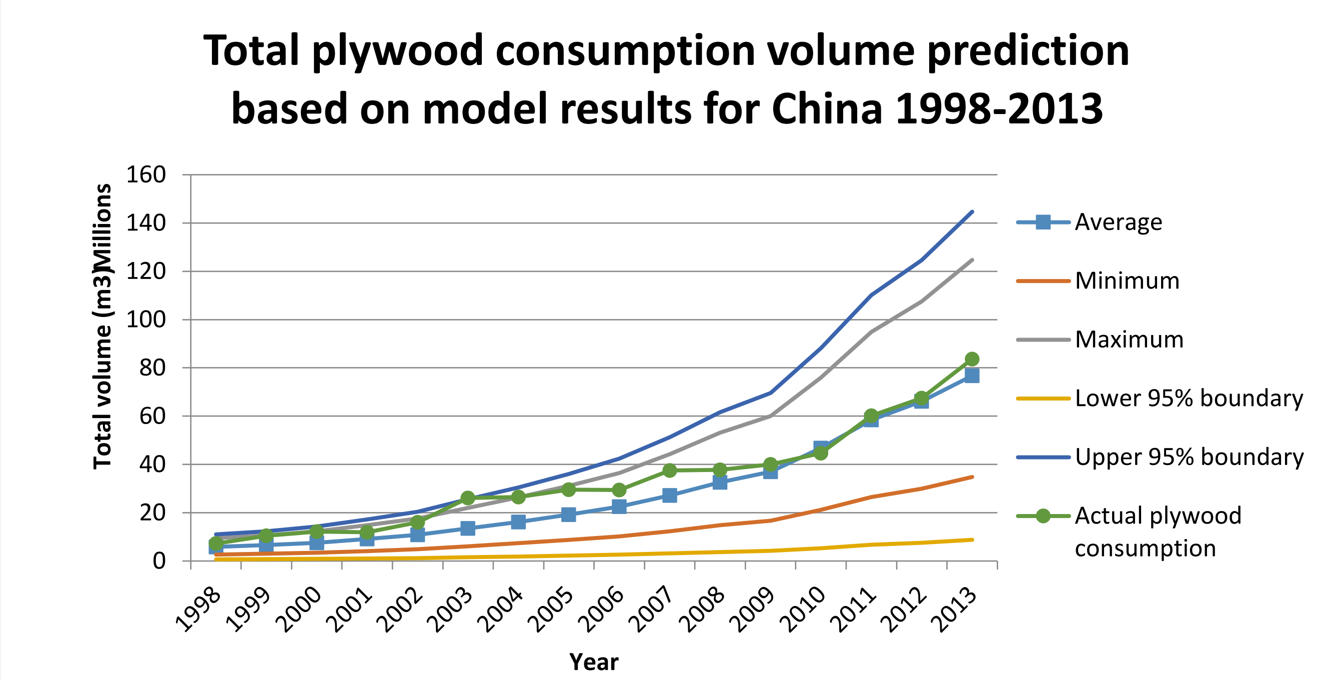

Figure 23 Total plywood demand prediction based on model predicted plywood consumption rate. Actual plywood consumption was from Food and Agriculture Organization of the United Nations (2015)

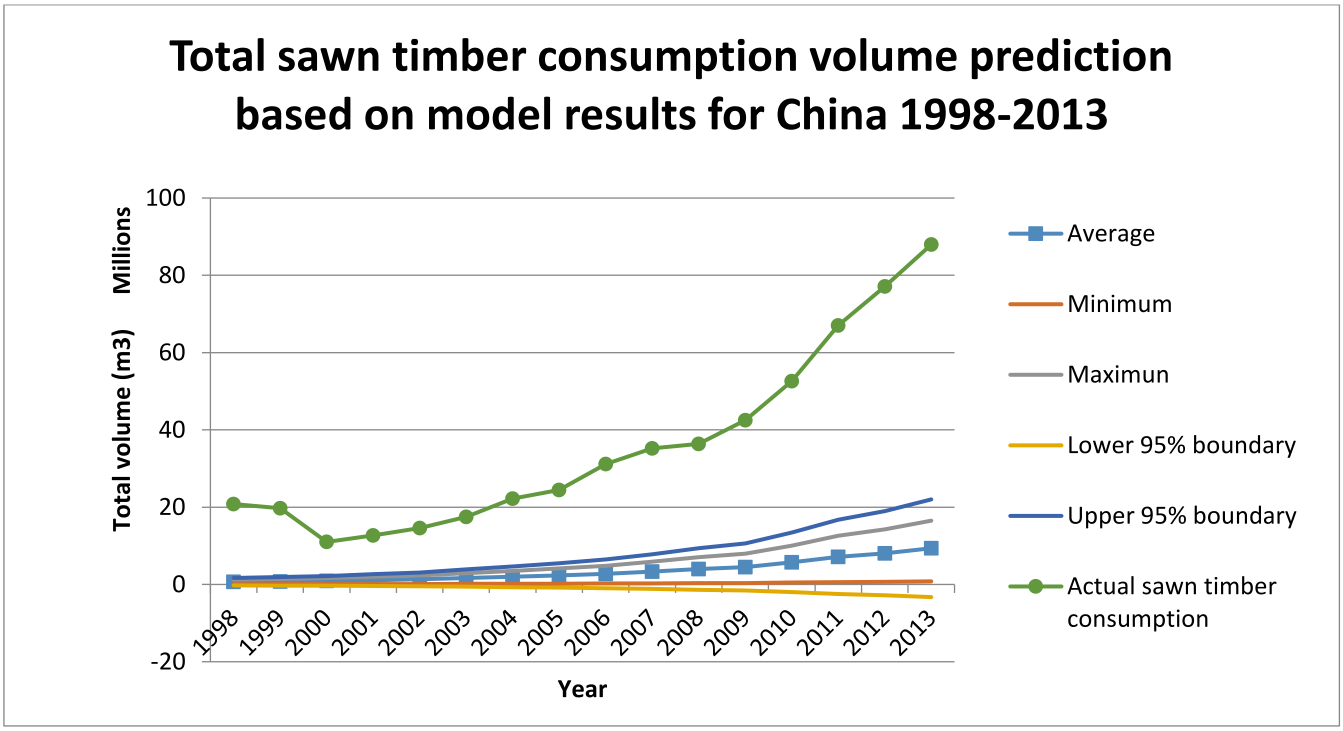

Figure 24 Total sawn timber demand prediction based on model predicted sawn timber consumption rate. Actual sawn timber consumption was from Food and Agriculture Organization of the United Nations (2015)

6. DISCUSSIONS

6.1. The limitation and uncertainties of available data

6.1.1. Uncertainties of data from projects

When making prediction about historical demand of plywood and sawn timber, *total floor space under construction for China* was the only data used. According to National Bureau of Statistics (2014), this data 'refers to the total space area of the buildings under construction in the year by real estate development companies' (P 458). According to Ministry of Housing and Urban-rural Development of the People's Republic of China (2000), '*real estate development company'* seems only to include companies that are developing residential-related buildings, which could not be confirmed with limited knowledge about Chinese law. If this were true, the total plywood and sawn timber demand would be underestimated because commercial-related buildings were not taken into account.

The reliability of data for some projects is also not good. Managers of project 2 could not provide the accurate total and finished floor area of the project; instead they gave the floor area from the advertisement. The proportions of sawn timber with different dimensions used in the project 1 and 3 were unclear because the managers and the quantity surveyors did not collect that data. The manager and quantity surveyor of projects 4 and 5 did not have records of actual plywood and timber consumption volume and they provided the value based on memory and gut feeling, and these might be a major source of the differences.

The data for projects 11-15 is less reliable than others because the actual average reuse time of plywood for projects 11-15 is less than the other projects (Appendices 3). This means the data provided is the plywood demand rather than plywood consumption volume, or the second party misreported the total consumed plywood volume to the third party. Apart from that, the actual plywood consumption rates of projects 11-15 are all smaller than the actual average plywood consumption rate and close to the minimum. This could mean the data accuracy of all projects may have limitation or bias. If projects 11-15 were excluded, the average plywood and sawn timber consumption rates would change to 0.00921 m^3/m^2 and 0.00201 m^3/m^2. It is not uncommon for a construction company to misreport, sometimes wilfully, the some parts or the total cost of the project thereafter they may get higher payment or higher loan, mentioned by a chief engineer.

6.1.2. Assumptions in the model results

The plywood and sawn timber consumption prediction model had multiple assumptions and they might have impact on accuracy of its results and the prediction of historical plywood and sawn timber demand generated based on the results. The assumptions included:

- By multiplying the total floor area with concrete surfacing factor, the concrete used in foundation, stair and other parts of structure were all taken account for formwork material consumption calculation.
- In transporting and storing process, no timber formwork material is damaged or depleted.
- If the project included non-standard storey, the plywood used to assemble formwork for these floors were assumed to be completely depleted when non-standard storey finished, but sawn timber were assumed to be reused when formwork for standard storey were assembled.
- During reusing, sawn timber was assumed not to be cut shorter but the whole piece of sawn timber would be depleted immediately after it was reused for 30 times. This was to simulate the downgrading process of sawn timber. A similar assumption was also used to simulate the downgrading process of plywood.
- The model assumed 10% additional plywood would be consumed in the project because the used plywood removed from the roof would be then used for following installation or other construction activities until becoming depleted.
- In the standard model, it was assumed to prepare plywood that would be sufficient to build two floor’s formwork, which is usually not true. For example project 1, 3, 5 and 7 only prepared one set of formwork because the storey number is relative low.
- When making prediction to historical plywood and sawn timber demand of Chinese construction industry, no plywood was assumed to be recycled when depleted from construction site. And all construction activities were assumed to only use timber materials to assemble formwork. Therefore the sawn timber demand for formwork would be overestimated because steel ribs are used as an alternative to timber. Plywood historical demand estimation had similar

problem as the manager of project 4 suggest that bamboo plywood is still been used for some construction projects in recent years and historically although the market share of bamboo plywood could not be found.

- The prediction assumed these 15 projects are a represent of the construction industry in China.

The model and the prediction based on model results were generated based on these assumptions. Some of these assumptions were strong but this research could not find the influence of these assumptions to prediction results. Future research is required.

6.1.3. Uncertainties of public-domain data

According to Mao and Wu (2015), even the statistics data of the total plywood production volume published by the Nation Bureau of Statistics of China and collected by the Food and Agriculture Organization of the United Nations (2015) were not true:

> "*According to the State Forestry Administration of the People's Republic of China, the total plywood[5] production volume in 2012 and 2013 were 109.8 and 137.25 million m³. But in 2013 the total industrial timber production volume[6] was 78.37 million m³ and total imported log volume was 45.16 million m³. Obviously, the total production was even more than the total available raw material which was impossible. The total plywood production volume should be far more than the actual plywood volume. Us and other forestry industry experts all agreed that the total plywood[7] production volume in 2012 and 2013 should be about 45 million m³" (*Mao and Wu, 2015, p1-2, translated)

Without discussing the accuracy of 45 million m³ estimation, the industrial round production and import volume were indeed unable to support the plywood industry if the above data were correct. But there was no citation to provide the reference of the database or published literatures which mentioned where the total plywood production volume, the total and imported industrial timber were coming from. At the

[5] The original document used '胶合板' at here. http://define.cnki.net/WebForms/WebDefines.aspx?searchword=%E8%83%B6%E5%90%88%E6%9D%BF (assessed 14 Oct. 15), this phrase could mean 'plywood', 'veneer' or 'glued board'. But author did not specify the definition in this paper.

[6] The original document used "商品木材产量" at here.

[7] The original document used '胶合板' at here.

same time, the 'correct' total plywood production volumes of 2012 and 2013 were only provided by "opinions of the authors and experts within the industry" which sounds unprofessional.

Following the above paragraph, Mao and Wu (2015) also commented on why the total plywood production volume data was hard to be collected:

> *"The reasons why the data associated with [condition and number of] plywood production factories were hard to be collected included:*
>
> - *The volume of plywood production was large and the factories were allocated at different places across the country*
> - *There was no requirement for administration access of this industry and factories open and shut down often*
> - *A lot of registered plywood production plants were only producing single-layer veneer*
>
> *According to our statistical analysis in recent years, the number of registered plywood producing plants around the country was over 10000, but only 4000 of them were currently producing plywood"* (Mao and Wu, 2015, page 2, translated).

Again, the authors did not provide any reference to support the data or information they provided. The Impact Factor of the journal *China Wood-based Panel* on which this literature was published could not be found from English Impact Factor website[8] but China Knowledge Resource Integrated Database[9] (CNKI) suggested its comprehensive Impact Factor is 0.416[10]. This five-page literature has no reference or footnote to provide citation on data or materials that it mentioned or referred. This type of problem happens not only in this literature but also happens to all other literatures that were published in Chinese that were referred in this dissertation.

[8] Searched at http://www.journal-database.com/

[9] See http://oversea.cnki.net/, http://www.intellogist.com/wiki/CNKI

[10] See http://search.cnki.net/KNavi/oldNavi/n_list.aspx?NaviID=1&Field=cykm$%%22{0}%22&Value=%E4%B8%AD%E5%9B%BD%E4%BA%BA%E9%80%A0%E6%9D%BF&selectIndex=0&NaviLink=%E6%A3%80%E7%B4%A2%3a%E4%B8%AD%E5%9B%BD%E4%BA%BA%E9%80%A0%E6%9D%BF&ListSearchFlag=1&Flg (In Chinese)

6.2. Substitutions of current formwork material

Since the beginning of the 21st century, plywood and sawn timber have occupied the absolute dominant position in formwork material market. With development of construction technology, some alternative materials have become recognized by the industry and there are already some trials to use them in China. For formwork board, substitutions include steel, multiple types of plastics and aluminium. Steel formwork has already been used since 1980’s and now one of the biggest residential construction company, China Wanke Co Ltd, has already replaced the plywood with steel board using self-climbing formwork system, although this company might be the only company using steel board commercially in large scale. In Chinese bridge construction industry, however, the steel formwork has already widely used therefore it would not be very hard to transfer the technology into the building construction industry. There is no evidence showing that other materials except steel has been widely used in replacing plywood in China.

Figure 25 Demonstrations of Steel rib used for sheer wall construction, pictures cited from marketing materials of Shengchuan Constriction Material Ltd. (www.shenchuanjc.com)

Sawn timber has already been competing with steel rib for several years, suggested by a project manager that I talked to. And two of the projects that I approached were using steel pipe as the rib of vertical structure parts. Managers of these two projects both suggested that steel rib would be more cost-effectively after re-used for two or three projects. Steel is the only material commercially used in substitution of sawn timber (Figure 25 and 26). However, another alternative is using steel or timber structure to replace the reinforced concrete structure and then both timber plywood and sawn timber would be obsoleted.

There are advantages and drawbacks for the substitutional materials. All substitution materials have much higher reuse time and lower average emission rate per using-time compare with timber board and rib. Therefore the average cost of each time using them would be lower. Compared with timber, metal and plastic both are easier to be recycled at the end of using stage therefore they could help to reduce the amount of solid waste produced at site. Aluminium formwork board has lighter density than timber and Liu (2013) suggested a labour can install or remove this type of formwork board 20-30 m^2 per day which

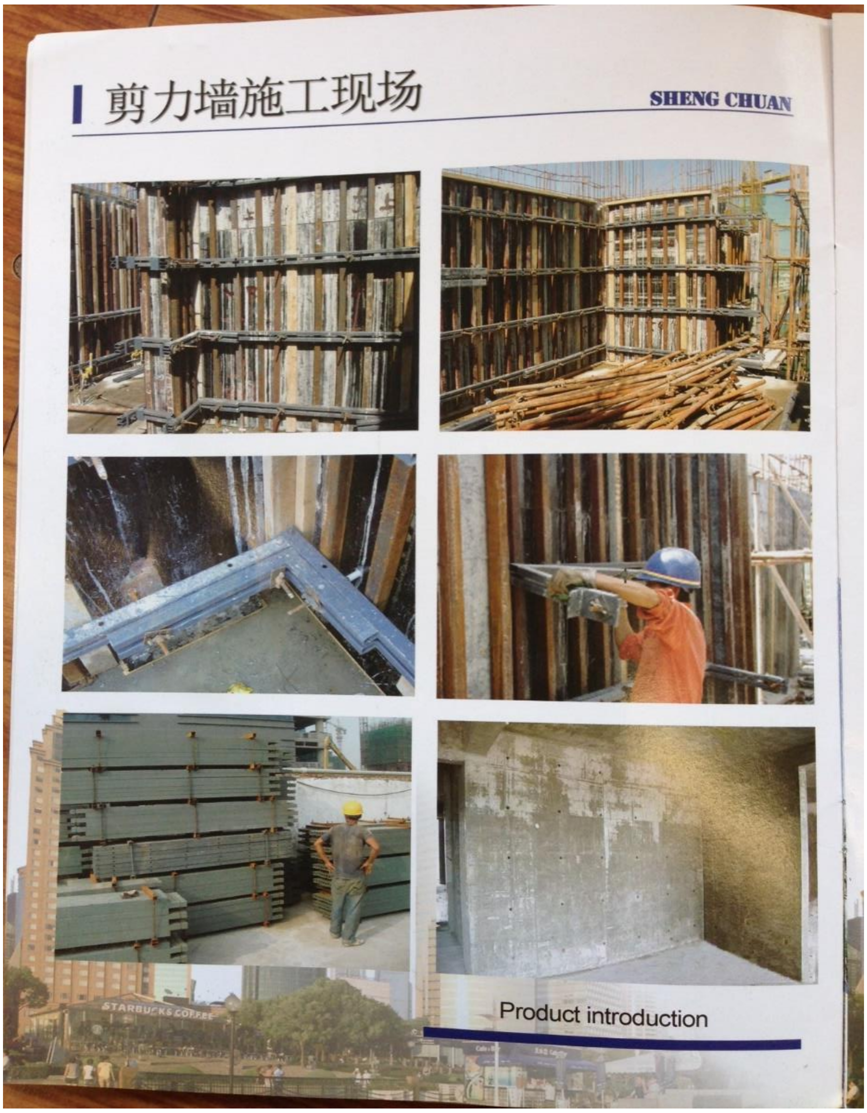

Figure 26, Demonstrations of steel rib used for sheer wall constriction, pictures cited from marketing materials of Shengchuan Constriction Material Ltd. (www.shenchuanjc.com) is two or three times more efficient compared with using plywood board.

The drawbacks of substitutional material are also important. During using and re-using processes, the load from concrete may cause more severe permanent deform or buckle to metal rib and board because the elasticity of material is much lower than timber (Wu, 2002). Another problem is the density of steel formwork board is much higher than timber therefore it can hardly be installed and removed by manpower which is the core component of currently used construction techniques. Thirdly, the price per square meter of steel board is several hundred Yuan which is much more expensive than plywood. Replacing plywood with steel board would not only require the company to change construction technology but also require a big upfront investment. The Chinese government has strictly control the loan to construction companies so they may not be able to afford this. Another drawback was the design of the series of sites it will be used cannot have major change. Otherwise it is impossible to modify steel board on site and new board of specific design must be brought. The last point is about hesitation of learning from carpenters. Because the current construction methodology has been widely used for over 30 years and all carpenters have a lot of experience associated. Because it is very hard to modify or cut the metal formwork and it is also very hard to joint plastic or metal material on site efficiently, carpenters lose almost all the flexibility provided by timber materials and learning to use new technology is also another big barrier for them. Because of these carpenters may hesitate or refuse to change the formwork material.

6.3. Future research directions

Based on results of current research, there are four main future research directions in order to reveal formwork material consumption rate and total demand in China. Firstly, a long-term tracking survey and interview about plywood and sawn timber consumption should be carried out for major contractors in one or even multiple areas. This research only provided some snapshots about timber consumption within one construction project at current time. The long-term tracking data collection would reveal how formwork materials are re-used within one site and across sites. Long-term survey and data collection could provide comprehensive consumption details for different types of construction projects at different locations.

The second future direction is interviewing or surveying formwork material producers. Production data from all, or at least the major, formwork producers should be collected. These data should include:

- The volume of timber consumed for plywood and sawn timber production by species and by year.
- Volume of sells to each province and to each buyers of each producer.
- Historical data about percentage of New Zealand timber to total consumed timber.

These data should be able to give a comprehensive view about current and historical formwork timber material consumption volume for different provinces.

The third future research direction is collecting data from the Chinese Custom. Chinese Custom has detailed historical log import data and export data of all timber products by species. After collecting these data, adding to the statistical data from State Forestry Administration of the People's Republic of China about timber harvesting and manufacturing industry, the net volume of timber used for plywood and sawn timber production can be generated.

The forth direction is doing study towards plywood and sawn timber market in China. This should include interview to major plywood and sawn timber producers and timber market. The results would find the actual market share of plywood and sawn timber used for construction formwork to total consumption of these two materials.

7. CONCLUSIONS

The survey part of this research collected information about plywood and sawn timber used for concrete formwork from 15 projects at three difference provinces in China. These 15 projects are mainly for residential-related purposes. A model to estimate plywood and sawn timber consumption of a concrete building was developed based on information collected as well. The model suggested the average plywood and sawn timber consumption rate for all projects would be 0.01153 m^3/m^2. Based on available actual consumption data from projects, the average and standard deviation of plywood consumption rate were 0.00762 m^3/m^2. Average sawn timber consumption rates based on actual consumption data and model prediction were 0.00203 m^3/m^2 and 0.00141 m^3/m^2. Standard deviation, minimum, maximum and 95% confidential interval were all reported as well.

Comparing with the actual consumption rate and predicted consumption rate, the actual data were having less variation. Projects from different provinces had similar plywood and sawn timber consumption because the construction techniques were mature and management tools and structural hierarchies were similar. The model predictions, however, were based on detailed structure design and properties of plywood and sawn timber. These differences seemed to impact more to the plywood consumption rate than to sawn timber consumption rate.

Two standard models were implemented by using the average input values of those 15 projects. Sensitivity analysis found the concrete surfacing factor, reuse time and volume of single piece of plywood were the most sensitive factors to both model's plywood consumption rate. Apart from these three factors, sawn timber consumption would be also influenced significantly by the number of sawn timber required for each piece of plywood. Among these factors, reuse time had the biggest influence on consumption rates of plywood and sawn timber.

Historical plywood and sawn timber demands of Chinese construction industry based on total floor space under construction were found to be 50.7 million m^3 and 13.5 m^3 in 2013 based on average actual consumption rates. These demands predicted using model predicted consumption rates were 76.7 million m^3 for plywood and 9.4 million m^3 for sawn timber. The actual plywood and sawn timber consumption for China at 2013 were 91.1 million m^3 and 88.0 million m^3 (Food and Agriculture

Organization of the United Nations, 2015). Although historical demands predicted by using actual consumption rates had smaller 95% confidential interval and lower average, all demand predictions were feasible compared with actual plywood and sawn timber consumption.

Information and data used for developing the plywood and sawn timber consumption model and predicting historical demands are not free from uncertainties and inaccuracy. Because material costs of plywood and sawn timber were only two minor parts in total construction cost and there is no demand or requirement to record consumption of them, project managers and quantity surveyors were not recording their actual consumption volumes and reuse time. A few projects' consumption volumes were provided base on memory and no project manager, quantity surveyor or carpenter could provide accurate average reuse time of plywood and sawn timber. Information from projects 11-15 might subject to misreport and the actual consumption of plywood and sawn timber reported from these 5 projects might also bring some distortion to historical demand predictions. Uncertainties might also exist in the total historical total plywood consumed volume for China (Mao & Wu, 2015) but the evidence provided was not convincing.

Multiple substitutions of plywood and sawn timber have already been found used in construction industry but not in a large scale. It is important to keep monitoring the development of new construction technologies in China as this evolution will influence how timber formwork materials will be used in the future and their market share. At the end, research directions are also suggested in order to reveal how actually plywood and sawn timber are used in Chinese construction industry and their market share.

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Appendices 1 Main construction indexes for commercal and official buildings per 100 m2 construction area in China (Data is from Table 37-27, China Architecture & Building Press (2003))

Main construction index of 100 m2 construction area for commercal and office buildings around the country														
		Volume of concrete per 100 m2 construction area							Surface area per 100 m2 construction area					
Site number	City of the site	total construction area (m2)	Pile Foundation (m3)	Foundation (m3)	Grider and beam (m3)	Column (m3)	Floor (m3)	Wall (m3)	Outer wall (m2)	Inner wall (m2)	Average floor area (m2)	Roof surface (m2)	Underground storey number	aboveground storey number
1	Beijing	149737		17.5	2.3	2	16	28.7		15	95	3	3	3
2	Beijing	140684		24.7	5.5	8.1	21.5	23.3	15.6	53	88.2	7.6	3	16-18
3	Beijing	52277		13.2	15.4	5	12.1	14.3	7	28	82	5.9	3	18
4	Tianjing	33228	29	6	2	6	20	21		45	92	4	3	26
5	Tianjing	93616	8.4	11.5	9.1	5.2	10	26		50	22	5	3	47
6	Hebei	79255							14.5	51.6	83.2	8.5	2	32
7	Hebei	38590	4	7	22 (include floor)	7		14	31	98	80	8	2	26
8	Hebei	39610	0.03	7	9	5	15	14.2	35	93	87	10	2	23
9	Inner Mongolia	22514		6.6	8	5.1	11	11	22	45	87	10	2	19
10	Heilongjiang	28571	10	2	7.4	4.6	13	6	36	47	81	8	1	14
11	Heilongjiang	37377	3.6	3.6	8.5	6.3	10.2	10	23	59	85	6	4	28
12	Jilin	30564		12	2.7	7.5	20	7.4	59	60	38	16	4	28
13	Shanghai	59378	8.4	17.1	9.2	9.9	12.1	9.1	17.7	75.3	92	7	2	21
14	Shanghai	36071	21.5	13.5	3.2	6.3	11	11	18.8	50.3	83	5.5	1	28
15	Shanghai		16.6	8.9	6.4	6	12	13.9	20.9	47.3	89.2	5.4	1	19
16	Jiangsu	11236	20	4.64	8	9.7	12	4.7	46	97	93	24.3	1	7
17	Jiangsu	35003	14.8	8	12	7	16.2	10	5	43	87	6	2	24

Continus

18	Jiangsu	12533	19	5	7.8	7	14	11	36	69	96	8.8	1	20
19	Shandong	23561	3.6	13	5.5	2	10	35	18	67	90	7	1	17
20	Fujian	43157	6.2	13	6.8	5	16.4	14.5	10.9	20.2	95.4	4.2	2	30
21	Fujian	20857	4.7	9.1	19.8(include floor)	4.6		8.4	25.3	57	98	10	1	18
22	Fujian	21824	5-Jun	11		3.6	17.3	13.3	13	26.2	107.3	7.8	1	20
23	Fujian	98705	20	12	9	4	17	18		47	87	5	3	32
24	Fujian	24398	13	13	9.8	3.3	15.6	2	56	90	87	5.7	1	16
25	Henan	23000	8.39	11.13	16.3(include floor)	7.3		15.2		12	87.6	12.26	2	24
26	Hunan	39896	4	2	8	8	13	10	22	40	89	3	2	28
27	Hunan	22705	9	3		7.2	13.8	8	23	32	89	3	2	28
28	Hubei	28787		12.4	25.4(include floor)	9.2		15.4	13	51	87	6	1	18
29	Guangzhou	47626	18.4	5	7	5.5	11.9	13.7	9.9	50.5	90	5	2	29
30	Sichuang	69856		12.7	10.3	6.3	12.6	12.2	21	27	114	11	3	30
31	Guizhou	43085	10	5	12	9	19	11	34	45	90	6	1	29
32	Guizhou	25224	3	2.8	8	8.8	16	17	41	69	87	6	1	22
33	Guizhou	8493	12	4	18(inclde floor)		18		19	14	82	14	1	15
34	Yunnan	55637	4	20	13	4	11	18	16	37	94	16	2	34
35	Gansu	31554		4.2	7.2	5	13	17	28	47	85	9.5	1	26
36	Gansu	15155	1	9.6	11.9	5.4	18.2	10	35.2	62.1	43.7	6.6	2	20
37	Xinjiang	21600		8	4.52	6.99	19.14	13	35.85	59.3	86.6	6.13	3	22

Appendices 2 Main construction indexes for commercal and official buildings per 100 m2 construction area in China (Data is from Table 37-28, China Architecture & Building Press (2003))

Main construction index of 100 m2 construction area for residential buildings around the country														
		Volume of concrete per 100 m2 construction area						Surface area per 100 m2 construction area						
Site number	City of the site	total construction area (m2)	Pile Foundation (m3)	Foundation (m3)	Grider and beam (m3)	Column (m3)	Floor (m3)	Outer wall (m2)	Inner wall (m2)	Average floor area (m2)	Roof surface (m2)	Underground storey number	aboveground storey number
1	Beijing	2028		8.32		0.25	1.36	59.88	73.47	77.16	11.48	1	6
2	Beijing	9499		5.73		0.15	15.19	105.6 (inclde both)		100.49	7.6	2	12
3	Tianjing	17284		7.35	1.14	0.95	9.99	121.71 (include both)		91.54	3.12	1	32
4	Tianjing	9125		9.12	4.03	2.59	8.38	21.81	77.59	93.76	13.73		7
5	Hebei	5076		11.77	1.84	4.75	5.9	47.66	75.75	89.29		1	6
6	Cangzhou	17763	7.44	7.97	0.07		10.57	62.42	35.07	87.69	6.47	1	18
7	Shanxi	2918		11.25		0.7	9.54	40.08	98.36	88.5	18.74	1	6
8	Inner Mongolia	1698		27.15		0.24	7.32	54.64	94.84	93.51	24.58		5
9	Liaoning	5041		4.34			6.95	52.82	110.75	74.07	15.57		7
10	Liaoning	3749		3.34	4.34	6.92	8.64	53.35	105.1	71.13	13.45		8
11	Jilin	3102		7.88			6.64	22.49	21.67	73.31	18.34		6
12	Jilin	886		9.98			6.98	27.55	20.88	74.92	25.32		4
13	Harbin	4068		6.1	1.2	3.8	8.5	58.2	112	92.1	11.7		8
14	Shandong	3184		13.62	1.01	6.04	6.15	16.34	25.6	84.87	24.06		4
15	Jiangsu	16374		3.95			11.02	16.42	35.03	100.13	3.17	1	30
16	Anhui	1632		8.82		5.47	7.93	70	93.96	81.72	16.3		6
17	Anhui	3267		12.65			9.31	63.51	115.2	102.97	17.45	1	6

Contious

18	Jiangsu	2375		16.73		2.54	7.98	43.49	89.68	76.81	16.8		6
19	Fujian	2374	6.47	5.78	4.71		14.28	7.29	15.73	87.43	13.56		7
20	Fujian	3596	8.52	3.16	4.66		14.11	6.59	15.43	92.43	24.08		8
21	Shanghai	10078	9.79	6.92		0.02	9.71	20.93	61.69	95.99	5.43	1	18
22	Hubei	5345	8.61	7.67	5.2	7.19	9.33	40.61	86.16	78.54	12.63	1	7
23	Hunan	4503		6.58	0.87	2.11	5.78	49.5	119.72	82.25	12.44		7
24	Hunan	9976	1.01	10.53		0.7	10.55	0.3	15.68	86.38	6.63		15
25	Sichuan	14520		13.81	2.37	4.46	14.66	3.56	7.28	74.79	11.54	1	17
26	Sichuan	3835	1.44	3.03		2.26	8.57	49.46	85.74	100.58	27.52		7
27	Chongqing	29281	1.65	9.6		1.13	11.74	1	31.9	98	3.03	3	30
28	Guizhou	1845		15.94	0.74	2.65	7.38	72.47	76.15	104.77	17,46		6
29	Yunnan	1791	28.04	19.09			6.8	65.42	78.04	94.61	16.08	1	6
30	Shanxi	7190		8.88	8.24		5.99	41.08	92.57	84.61	12.08		7
31	Gansu	8978	16.1	0.72	7.83	11.83	11.92	41.66	78.79	87.81	15.81	1	7
32	Gansu	11279	4.2	13.25		1.46	9.26	44.89	78.86	78.25	7.9	2	18
33	Xinjiang	2407		14.1	3.1	4.3	9.6	87.84	96.25	108.1	20.2	1	5
34	Guangxi	2984		10		0.6	9	61	86.3	104.2	15.5		8

Appendices 3 Data collected from surveys in China. The data whose titles have star mark is results of the plywood and sawn timber consumption model.

			1	2	3	4	5
	Site number		1	2	3	4	5
Project information	Location		Hubei	Hubei	Hubei	Hubei	Hubei
	Project type		Others	Residental	Office	R	Others
	Building number		1	15	1	11	1
	Average storey		5	33.5	7	15.6	3
	concrete surfacing area factor		2.6	2.5	2.22	2.5	2.25
	Proportion of formwork material budget to toal construction budget		4%	-	10%	1.50%	5%
	Total floor area (m2)		1680	518000	5600	95000	22700
	Completed or not		yes	no	Yes	no	yes
	Completed area		1680	288000	5600	68000	22700
Non-stand storey	Storey number		-	2		2	
	Building number		-	15		11	
	Total floor area (m2)		-	30925		8717.95	
	Average floor area (m2)		-	1030.85		484.33	
	Plywood reuse time		-	2		2	
Stand storey	Storey number		5	31.5	7	13.6	3
	Building number		1	15	1	11	1
	Total floor area (m2)		1680	487075	5600	59282.05	22700
	Average floor area (m2)		336	1030.85	800	484.33	7566.67
	Plywood reuse time		5	5	8	5.5	3
Plywood	length (m)		1.83, 2.44	1.83	1.83, 2.44	1.83	1.83
	width (m)		0.915, 1.22	0.915	0.915, 1.22	0.915	0.915
	thickness (m)		0.015	0.018	0.015	0.02	0.02
Sawn timber	width (m)		0.09	0.1	0.09	0.095	0.1
	thickness (m)		0.05	0.05	0.05	0.045	0.05
	Number of sawn timber per plywood used for *	Floor	5	3	3	3	6
		vertical structure	5	3	3	4	6
	Reuse time		30	30	30	30	30
	Any other formwork material?		no	no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%	100%
Actual timber consumption and plywood re-use time	Actual plywood consumption (piece)					12573	9000
	Actual plywood consumption (m2)		-	-	-	421.07	217.68
	Actual sawn timber consumption (m3)		-	-	-	52.39	50
	Actual plywood consumption rate (m3/m2) *					0.00619	0.00959
	Actual sawn timber consumption rate (m3/m2) *					0.00077	0.0022
	Actual total timber consumption rate (m3/m2) *					0.00696	0.01179
	Actual average plywood re-use times*					11.28	4.8
model prediction	Total plywood consumption (m3) *		14.414	2296.2	29.3	1102.56	382.87
	Total sawn timber consumption (m3)*		3.58	707.65	6.11	149.43	48.79
	Plywood consumption rate (m3/m2) *		0.00858	0.00797	0.00523	0.0116	0.01687
	Sawn timber consumption rate (m3/m2) *		0.00213	0.00245	0.00109	0.00157	0.00215
	Total timber consumption rate (m3/m2) *		0.01071	0.01043	0.00632	0.01841	0.01902
Sawn timber consumption per piece of plywood estimation	length of sawn timber per piece of plywood *	Floor	9.15	5.49	5.49	5.49	10.98
		vertical structure	9.15	5.49	5.49	7.32	10.98
	Volume of sawn timber per piece of plywood *	Floor	0.0412	0.0275	0.0247	0.0235	0.0549
		vertical structure	0.0412	0.0275	0.0247	0.0313	0.0549
		Average	0.0412	0.0275	0.0247	0.0274	0.0549

Continues

	Site number		6	7	8	9	10
Project information	Location		Shanghai	Shanghai	Jiangsu	Sichuan	Liaoning
	Project type		R	R:high-grad	R	R+Commer	R+C
	Building number		5	3	3	4	4
	Average storey		28.6	4	34	28,18,4,4	18
	concrete surfacing area factor		3.6	3.6	3	3	2.6
	Proportion of formwork material budget to		2-3%	2-3%	-	-	-
	Total floor area (m2)		80000	12000	116240	64000	31304
	Completed or not		yes	yes	yes	yes	yes
	Completed area		80000	12000	116240	64000	31304
Non-stand storey	Storey number		5		2	4	1
	Building number		5		3	2	4
	Total floor area (m2)		15500		26000	23500	1720
	Average floor area (m2)		620		4333.33	2937.5	430
	Plywood reuse time		5		2	4	1
Stand storey	Storey number		23.6	4	32	23	17
	Building number		5	3	3	2	4
	Total floor area (m2)		64500	12000	90240	40500	29584
	Average floor area (m2)		546.61	1000	940	880.43	410.89
	Plywood reuse time		11.8	5	16	6	8.5
Plywood	length (m)		1.83	1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.014	0.014
Sawn timber	width (m)		0.088	0.088	0.088	0.088	0.088
	thickness (m)		0.038	0.038	0.038	0.038	0.038
	Number of sawn timber per plywood used for *	Floor	4	4	4	4	4
		vertical structure	6	6	6	6	6
	Reuse time		30	30	30	30	30
	Any other formwork material?		Steel rib	Steel rib	No	no	no
	Percent of sawn timber used as rib		unknown	unknown	100.0%	100.0%	100.0%
Actual timber consumption and plywood re-use time	Actual plywood consumption (piece)		20520	5500	38900	27189	9200
	Actual plywood consumption (m2)		515.4	138.14	977.04	637.37	215.67
	Actual sawn timber consumption (m3)		183.26	32.99	226.4	158.2	56
	Actual plywood consumption rate (m3/m2) *		0.00644	0.01151	0.00841	0.00996	0.00689
	Actual sawn timber consumption rate (m3/m2) *		0.00229	0.00275	0.00195	0.00247	0.00179
	Actual total timber consumption rate (m3/m2) *		0.008733	0.0142608	0.0103531	0.012431	0.008678
	Actual average plywood re-use times*		8.38	4.69	5.35	4.22	5.28
model prediction	Total plywood consumption (m3) *		508.83	142.56	922.68	583.28	206.61
	Total sawn timber consumption (m3)*		187.12	28.06	220.9	158.64	50.34
	Plywood consumption rate (m3/m2) *		0.00636	0.01188	0.00794	0.00911	0.0066
	Sawn timber consumption rate (m3/m2) *		0.00234	0.00234	0.0019	0.00248	0.00161
	Total timber consumption rate (m3/m2) *		0.0087	0.01422	0.00983	0.01159	0.00821
Sawn timber consumption per piece of plywood estimation	length of sawn timber per piece of plywood *	Floor	7.32	7.32	7.32	7.32	7.32
		vertical structure	10.98	10.98	10.98	10.98	10.98
	Volume of sawn timber per piece of plywood *	Floor	0.0245	0.0245	0.0245	0.0245	0.0245
		vertical structure	0.0367	0.0367	0.0367	0.0367	0.0367
		Average	0.0306	0.0306	0.0306	0.0306	0.0306

Continues

			11	12	13	14	15
	Site number		11	12	13	14	15
Project information	Location		Liaoning	Liaoning	Liaoning	Liaoning	Liaoning
	Project type		R	R	R	R	R
	Building number		1	1	1	1	1
	Average storey		11	11	11	11	18
	concrete surfacing area factor		3	3	3	3	3
	Proportion of formwork material budget to		8.78%	8.44%	8.41%	8.49%	4.85%
	Total floor area (m2)		6571.25	3281.49	3889.13	3889.13	8809
	Completed or not		yes	yes	yes	yes	yes
	Completed area		6571.25	3281.49	3889.13	3889.13	8809
Non-stand storey	Storey number		2	2	2	2	
	Building number		1	1	1	1	
	Total floor area (m2)		1194.77	596.63	864.26	864.26	
	Average floor area (m2)		539.39	298.32	432.13	432.13	
	Plywood reuse time		2	2	2	2	-
Stand storey	Storey number		9	9	9	9	18
	Building number		1	1	1	1	1
	Total floor area (m2)		5376.48	2684.86	3024.87	3024.87	8809
	Average floor area (m2)		539.39	298.32	432.13	432.13	489.3
	Plywood reuse time		4.5	4.5	4.5	4.5	9
Plywood	length (m)		1.83	1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915	0.915
	thickness (m)		0.02	0.02	0.02	0.02	0.02
Sawn timber	width (m)		#REF!	0.092	0.092	0.092	0.092
	thickness (m)		#REF!	0.044	0.044	0.044	0.044
	Number of sawn timber per plywood used for *	Floor	3	3	3	3	3
		vertical structure	3	3	3	3	3
	Reuse time		30	30	30	30	30
	Any other formwork material?		Steel rib	Steel rib	Steel rib	Steel rib	Steel rib
	Percent of sawn timber used as rib		18.4%	20.8%	15.8%	15.7%	8.9%
Actual timber consumption and plywood re-use time	Actual plywood consumption (piece)		-	-	-	-	-
	Actual plywood consumption (m2)		416.49	223.22	247.3	245.68	583.26
	Actual sawn timber consumption (m3)		-	-	-	-	-
	Actual plywood consumption rate (m3/m2) *		0.00634	0.0068	0.00636	0.00632	0.00662
	Actual sawn timber consumption rate (m3/m2) *		-	-	-	-	-
	Actual total timber consumption rate (m3/m2) *		-	-	-	-	-
	Actual average plywood re-use times*		0.947	0.882	0.944	0.95	0.906
model prediction	Total plywood consumption (m3) *		118.28	59.07	72.89	72.89	64.6
	Total sawn timber consumption (m3)*		1.6	0.91	0.82	0.81	1.04
	Plywood consumption rate (m3/m2) *		0.018	0.018	0.01874	0.01874	0.00733
	Sawn timber consumption rate (m3/m2) *		0.000244	0.000277	0.00021	0.000207	0.00012
	Total timber consumption rate (m3/m2) *		0.01824	0.0183	0.19	0.0189	0.00745
Sawn timber consumption per piece of plywood estimation	length of sawn timber per piece of plywood *	Floor	5.49	5.49	5.49	5.49	5.49
		vertical structure	5.49	5.49	5.49	5.49	5.49
	Volume of sawn timber per piece of plywood *	Floor	0.0412	0.0275	0.0247	0.0235	0.0549
		vertical structure	0.0412	0.0275	0.0247	0.0313	0.0549
		Average	0.0412	0.0275	0.0247	0.0274	0.0549

Notes:

1. Sawn timber re-use time is reported to be a rough number therefore using 30 as an average value.
2. If the non-standard and standard floors have same average floor area then the project doesn't provide them separately.
3. In project type section, 'R' means residential, 'C' means commercial, and 'R+C' means some part of the project, usually the non-standard storeys, are for commercial purpose while the majority is for residential purpose.
4. The results title with '*' are results generated by the model.
5. The sawn timber width and thickness are not provided by the manager, I used the average value of other projects.
6. Project 6 and 7 are two parts of a big project, and I separate them into two parts because the structure design, formwork design and actual plywood and sawn timber consumption for these two projects are collected separately.
7. Projects 11-15 are belong to an apartment village and their data are provided separately by one manager from a third party company auditing construction cost of the village. The manager of the third party did not know how many sets of formwork materials were prepared and I assumed the number to be 2.
8. For project 11-15, most of plywood is using steel as rib and the model predicted sawn timber consumption based on proportion of plywood supported by sawn timber only.
9. For project 7, the non-standard storeys part is two blocks of independent sour-storey shopping centre. Therefore this project is excluded when calculating the average non-standard storey number for residential-related project.
10. For project 1, the width and thickness of sawn timber is the average value because it uses two types of sawn timber which have 50*80 mm^2 and 50*100 mm^2 cross sections. For project 3, the width and thickness is also the average of three types sawn timber which includes 40*60 mm^2, 40*80 mm^2 and 60*120 mm^2.
11. Because the proportion of steel rib in project 6 and 7 are unknown, I just assumed there is no other rib material in the model.

Appedices 4 Sensitivity analysis results of single-storey model[11]

	Trial index		Base model (standard storey only)	Trial 1 max sufacing factor	Trial 2 min surfacing factor	trial 3 10% increment of surfacing factor
Project information	Location					
	Project type		R	R	R	R
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.86	3.6	2.22	3.14
	Proportion of formwork material budget		100%	100%	100%	100%
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number					
	Building number					
	Total floor area (m2)					
	Average floor area (m2)					
	Plywood reuse time					
Stand storey	Storey number		16	16	16	16
	Building number		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.13	6.13	6.13	6.13
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4
		vertical structure	4	4	4	4
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		135.39	201.47	124.24	148.93
	Total sawn timber consumption (m3)		29.69	37.39	23.06	32.65
	Plywood consumption rate (m3/m2)		0.00769	0.01145	0.00706	0.00846
	Sawn timber consumption rate (m3/m2) *		0.00169	0.00212	0.00131	0.00186
	Total timber consumption rate (m3/m2) *		0.00938	0.01357	0.00837	0.01032

[11] Cells highlighted with yellow colour were changed values when doing sensitivity analysis.

Continues

	Trial index		Trial 5 increase plywood reuse time by 10%	Trial 6 decrease plywood reuse time by 10%	Trial 7 increase number of sawn timber per plywood by 10%	Trial 8 decrease number of sawn timber per plywood by 10%
Project information	Location					
	Project type		R	R	R	R
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.858	2.858	2.858	2.858
	Proportion of formwork material budget		100%	100%	100%	100%
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number					
	Building number					
	Total floor area (m2)					
	Average floor area (m2)					
	Plywood reuse time					
Stand storey	Storey number		16	16	16	16
	Building number		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.74	5.52	6.13	6.13
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4.4	3.6
		vertical structure	4	4	4.4	3.6
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		123.09	150.44	135.39	135.39
	Total sawn timber consumption (m3)		29.69	29.69	32.65	26.72
	Plywood consumption rate (m3/m2)		0.00699	0.00855	0.00769	0.00769
	Sawn timber consumption rate (m3/m2) *		0.00169	0.00169	0.00186	0.00151
	Total timber consumption rate (m3/m2) *		0.00868	0.01023	0.00955	0.00921

Continues

	Trial index		trial 9 increase sawn timber reuse time by 10%	trial 10 decrease sawn timber reuse time by 10%	trial 11 increase sawn timber cross section area by 10%	trial 12 decrease sawn timber cross section area by 10%
Project information	Location					
	Project type		R	R	R	R
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.858	2.858	2.858	2.858
	Proportion of formwork material budget		100%	100%	100%	100%
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number					
	Building number					
	Total floor area (m2)					
	Average floor area (m2)					
	Plywood reuse time					
Stand storey	Storey number		16	16	16	16
	Building number		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.13	6.13	6.13	6.13
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.099	0.081
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4
		vertical structure	4	4	4	4
	Reuse time		33	27	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	200%
model prediction	Total plywood consumption (m3)		135.39	135.39	135.39	135.39
	Total sawn timber consumption (m3)		26.99	32.98	32.65	26.72
	Plywood consumption rate (m3/m2)		0.00769	0.00769	0.00769	0.00769
	Sawn timber consumption rate (m3/m2) *		0.00153	0.00187	0.00186	0.00152
	Total timber consumption rate (m3/m2) *		0.00923	0.00957	0.00955	0.00921

Continues

	Trial index		trial 13 increase plywood depth by 10%	trial 14 decrease plywood depth by 10%	Trial 15 Increase residual plywood proportion by 10%	Trial 16 Decrease residual plywood proportion by 10%
Project information	Location					
	Project type		R	R	R	R
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.858	2.858	2.858	2.858
	Proportion of formwork material budget		100%	100%	100%	100%
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number					
	Building number					
	Total floor area (m2)					
	Average floor area (m2)					
	Plywood reuse time					
Stand storey	Storey number		16	16	16	16
	Building number		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.13	6.13	6.13	6.13
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.0165	0.0135	0.015	0.015
	Residual proportion of plywood		10%	10%	11%	9%
Sawn timber	width (m)		0.081	0.081	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4
		vertical structure	4	4	4	4
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		200%	200%	100%	100%
model prediction	Total plywood consumption (m3)		148.93	121.85	136.62	134.16
	Total sawn timber consumption (m3)		29.69	29.69	29.69	29.69
	Plywood consumption rate (m3/m2)		0.00846	0.00692	0.00776	0.00762
	Sawn timber consumption rate (m3/m2) *		0.00169	0.00169	0.00169	0.00169
	Total timber consumption rate (m3/m2) *		0.01015	0.00861	0.00945	0.00931

Appendices 5 Sensitivity analysis results of two-storey-type model[12]

	Trial index		Base model (two-storey-type model)	Trial 1 max sufacing factor	Trial 2 min surfacing factor	trial 3 10% increment of surfacing factor
Project information	Location					
	Project type		R+C	R+C	R+C	R+C
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.86	3.6	2.22	3.14
	Proportion of formwork material budget		100%	100%	100%	100%
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number		2	2	2	2
	Building number		1	1	1	1
	Total floor area (m2)		2200	2200	2200	2200
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		2	2	2	2
Stand storey	Storey number		14	14	14	14
	Building number		1	1	1	1
	Total floor area (m2)		15400	15400	15400	15400
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.72	6.72	6.72	6.72
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4
		vertical structure	4	4	4	4
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		159.94	201.47	124.24	175.93
	Total sawn timber consumption (m3)		29.69	37.39	23.06	32.65
	Plywood consumption rate (m3/m2)		0.00909	0.01145	0.00706	0.01
	Sawn timber consumption rate (m3/m2) *		0.00169	0.00212	0.00131	0.00186
	Total timber consumption rate (m3/m2) *		0.01077	0.01357	0.00837	0.01185

[12] Cells highlighted with yellow colour were changed values when doing sensitivity analysis.

Contiues

	Trial index		trial 4 10% decrement of surfacing factor	Trial 5 increase plywood reuse time of standard storeys by 10%	Trial 6 decrease plywood reuse time of standard storeys by 10%	Trial 7 increase number of sawn timber per plywood by 10%
Project information	Location					
	Project type		R+C	R+C	R+C	R+C
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.57	2.858	2.858	2.858
	Proportion of formwork material budget		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number		2	2	2	2
	Building number		1	1	1	1
	Total floor area (m2)		2200	2200	2200	2200
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		2	2	2	2
Stand storey	Storey number		14	14	14	14
	Building number		1	1	1	1
	Total floor area (m2)		15400	15400	15400	15400
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.72	7.39	6.05	6.72
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4.4
		vertical structure	4	4	4	4.4
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		143.95	150.12	171.95	159.94
	Total sawn timber consumption (m3)		26.72	29.69	29.69	32.65
	Plywood consumption rate (m3/m2)		0.00818	0.00853	0.00977	0.00909
	Sawn timber consumption rate (m3/m2) *		0.00151	0.00169	0.00169	0.00186
	Total timber consumption rate (m3/m2) *		0.0097	0.01022	0.01146	0.01094

Continues

	Trial index		Trial 8 decrease number of sawn timber per plywood by 10%	trial 9 increase sawn timber reuse time by 10%	trial 10 decrease sawn timber reuse time by 10%	trial 11 increase sawn timber cross section area by 10%	trial 12 decrease sawn timber cross section area by 10%
Project information	Location						
	Project type		R+C	R+C	R+C	R+C	R+C
	Building number		1	1	1	1	1
	Average storey		16	16	16	16	16
	concrete surfacing area factor		2.858	2.858	2.858	2.858	2.858
	Proportion of formwork material budget		1	1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd	completd
	Completed area		17600	17600	17600	17600	17600
Non-stand storey	Storey number		2	2	2	2	2
	Building number		1	1	1	1	1
	Total floor area (m2)		2200	2200	2200	2200	2200
	Average floor area (m2)		1100	1100	1100	1100	1100
	Plywood reuse time		2	2	2	2	2
Stand storey	Storey number		14	14	14	14	14
	Building number		1	1	1	1	1
	Total floor area (m2)		15400	15400	15400	15400	15400
	Average floor area (m2)		1100	1100	1100	1100	1100
	Plywood reuse time		6.72	6.72	6.72	6.72	6.72
Plywood	length (m)		1.83	1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915	0.915
	thickness (m)		0.015	0.015	0.015	0.015	0.015
	Residual proportion of plywood		10%	10%	10%	10%	10%
Sawn timber	width (m)		0.09	0.09	0.09	0.099	0.081
	thickness (m)		0.045	0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	3.6	4	4	4	4
		vertical structure	3.6	4	4	4	4
	Reuse time		30	33	27	30	30
	Any other formwork material?		no	no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		159.94	159.94	159.94	159.94	159.94
	Total sawn timber consumption (m3)		26.72	26.99	32.98	32.65	26.72
	Plywood consumption rate (m3/m2)		0.00909	0.00909	0.00909	0.00909	0.00909
	Sawn timber consumption rate (m3/m2) *		0.00152	0.00153	0.00187	0.00186	0.00151
	Total timber consumption rate (m3/m2) *		0.01061	0.01062	0.01096	0.01094	0.01061

Continues

	Trial index		trial 13 increase plywood depth by 10%	trial 14 decrease plywood depth by 10%	Trial 15 Increase residual plywood proportion by 10%	Trial 16 Decrease residual plywood proportion by 10%
Project information	Location					
	Project type		R+C	R+C	R+C	R+C
	Building number		1	1	1	1
	Average storey		16	16	16	16
	concrete surfacing area factor		2.858	2.858	2.858	2.858
	Proportion of formwork material budget		1	1	1	1
	Total floor area (m2)		17600	17600	17600	17600
	Completed or not		completd	completd	completd	completd
	Completed area		17600	17600	17600	17600
Non-stand storey	Storey number		2	2	2	2
	Building number		1	1	1	1
	Total floor area (m2)		2200	2200	2200	2200
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		2	2	2	2
Stand storey	Storey number		14	14	14	14
	Building number		1	1	1	1
	Total floor area (m2)		15400	15400	15400	15400
	Average floor area (m2)		1100	1100	1100	1100
	Plywood reuse time		6.72	6.72	6.72	6.72
Plywood	length (m)		1.83	1.83	1.83	1.83
	width (m)		0.915	0.915	0.915	0.915
	thickness (m)		0.0165	0.0135	0.015	0.015
	Residual proportion of plywood		10%	10%	11%	9%
Sawn timber	width (m)		0.09	0.09	0.09	0.09
	thickness (m)		0.045	0.045	0.045	0.045
	Number of sawn timber per plywood used for *	Floor	4	4	4	4
		vertical structure	4	4	4	4
	Reuse time		30	30	30	30
	Any other formwork material?		no	no	no	no
	Percent of sawn timber used as rib		100%	100%	100%	100%
model prediction	Total plywood consumption (m3)		175.93	143.95	161.39	158.49
	Total sawn timber consumption (m3)		29.69	29.69	29.69	29.69
	Plywood consumption rate (m3/m2)		0.01	0.00818	0.00917	0.009
	Sawn timber consumption rate (m3/m2) *		0.00169	0.00169	0.00169	0.00169
	Total timber consumption rate (m3/m2) *		0.01169	0.00987	0.01086	0.01069

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