Consumption of plywood and sawn timber for concrete formwork in the Chinese construction industry

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Abstract

China is currently New Zealand's largest market for logs, and the major end use of sawn timber and plywood made from New Zealand logs is for concrete formwork by the Chinese construction industry. A recent study estimated that, in 2015, 47% of the volume of New Zealand logs was used for construction formwork. This end use merits further study because of its importance to the New Zealand forestry sector. This research was carried out to derive estimates of the amount of plywood and sawn timber used in this industry in China, and relate these to published data on construction activity. Fifteen construction sites in China were visited and interviews were conducted with engineers, project managers, carpenters and quantity surveyors.

Results were used to generate a formwork material consumption rate model. The average estimated consumption rates of plywood and sawn timber were 11.3 m^3 per 1,000 m^2 of floor area and 1.7 m^3 per 1,000 m^2 of floor area, respectively. Comparison of total historical plywood and sawn timber consumption in China with historical formwork consumption estimated from this research suggests that formwork uses most of the plywood, but only a small proportion of the sawn timber consumed in China.

Introduction

The goal of this study was to estimate consumption rates of plywood and sawn timber formwork in the Chinese construction industry. In 2003, 41% of the total volume of New Zealand logs imported into China were made into plywood and sawn timber for use in formwork and other temporary construction applications (Katz, 2004). Manley and Evison (2015) estimated that 47% of the total volume of logs imported from New Zealand to China in 2015 went into construction lumber and plywood.

Information related to plywood and sawn timber consumption from 15 construction sites in different provinces in China was collected, and a formwork material consumption model was developed. Demand for plywood and sawn timber from the Chinese construction industry between 1998 and 2013 was also generated based on model results and compared with total plywood and sawn timber consumption estimated from data provided by the Food and Agriculture Organization of the United Nations (2015). The potential for substitution of plywood and sawn timber by other materials is discussed.

Over 80% of the multi-storey buildings constructed in China use on-site concrete casting techniques (Cai & Zhang, 1998), which entails temporary construction of formwork into which concrete is poured. While various materials are used worldwide to make formwork (including steel and plastic), plywood and sawn timber are currently used almost exclusively in China.

The products most commonly used in concrete formwork are 19 mm film-faced plywood and 19 mm resin-faced plywood, and various dimensions of sawn timber, with the most common cross-section being 90 x 50 mm^2 (see first photo). The building process includes the erection of formwork, securing reinforcing steel according to the specification, and pouring the concrete. When the concrete has cured, the formwork is removed and, where possible, reused in subsequent floors of the building (see second photo).

Samples of timber formwork material collected from a construction site. From left to right are 19 mm resin-faced plywood, 19 mm film-faced plywood and 38*88 mm^2 sawn timber

One construction site in Shanghai using sawn timber and plywood to erect concrete support formwork

A formwork set that can hold fresh concrete of a whole floor is constructed from plywood sheets, supported by sawn timber, which are cut to the required sizes. Installation, removal and relocation of formwork set components are all carried out by carpenters.

The decision on whether to reuse or discard a piece of formwork material after the formwork is removed is made by the carpenter. Material that is not reused directly may be trimmed on-site to remove damaged areas, and pieces that are not regarded as suitable are discarded (and often sold for alternative use). The number of times timber formwork materials, especially plywood, are reused has been reported in several studies. Liu (2013) reported that 77.9% of timber plywood that was used for 41 different Beijing Olympic studio construction projects has been reused less than three times. Wu (2002) estimated the maximum number of times a piece of resin-faced plywood would be reused is three to five. However, Wang and Jiang (2007) suggested that resin-faced formwork plywood would be reused five to six times and film-faced plywood over 10 times.

Method

Data collection

A pilot interview with a senior civil engineer was first conducted in New Zealand in July 2015, to determine a method for the estimation of plywood and sawn timber consumption rate for a construction site. This information was used to develop a timber formwork consumption model and a questionnaire that was used when visiting Chinese construction sites.

A survey covering 15 construction sites was conducted between 20 August and 4 September 2015. Due to the limitation of time and resources, the sites were selected because their project managers were willing to participate in this study. Managers, engineers, quantity surveyors and carpenters from these sites were interviewed. The following information associated with each site was collected:

- Structure design details, including building type, total floor area, number of standard and non-standard floors, number of buildings per site and formwork surfacing factors for floor and other structures such as walls, columns, stairs and elevator wells (as defined below).
- Formwork usage details, including type and quantity of plywood and sawn timber actually consumed (if available), proportion and amount of other formwork material used (if any), average number of reuses of sawn timber and plywood for standard and non-standard floors, dimensions of a piece of sawn timber and plywood, spacing between two pieces of sawn timber when installed, and proportion of formwork material budget to total construction budget.

Table 1: Information from 15 construction sites included in this study. Proportion of formwork area supported by other rib material was calculated as the ratio of the area of plywood supported by steel rib and the total formwork plywood area

Project number	Location	Project type	Formwork material budget/total construction budget	Total floor area (m^2)	Plywood type	Other formwork rib material	
						Type	Proportion of formwork area supported
1	Hubei	Heat exchange facility	4%	1,680	Resin-faced	No	0%
2	Hubei	Residential	–	518,000	Resin-faced	No	0%
3	Hubei	Office	10%	5,600	Resin-faced	No	0%
4	Hubei	Residential	1.5%	95,000	Resin-faced	No	0%
5	Hubei	Warehouse	5%	22,700	Resin-faced	No	0%
6	Shanghai	Residential	2–3%	80,000	Film-faced	Steel	Unknown
7	Shanghai	Residential	2–3%	12,000		Steel	Unknown
8	Jiangsu	Residential	–	116,240	Film-faced	No	0%
9	Sichuan	Residential+ Commercial	–	64,000	Film-faced	No	0%
10	Liaoning	Residential+ Commercial	–	31,304	Film-faced	No	0%
11	Liaoning	Residential	8.8%	6,571	Resin-faced	Steel	18%
12	Liaoning	Residential	8.4%	3,281	Resin-faced	Steel	21%
13	Liaoning	Residential	8.4%	3,889	Resin-faced	Steel	16%
14	Liaoning	Residential	8.5%	3,889	Resin-faced	Steel	16%
15	Liaoning	Residential	4.9%	8,809	Film-faced	Steel	9%

'Non-standard floor' means a floor whose design of walls, columns and other structural parts is different from the major structure of this building, and its usage is often different. For example, an underground carpark floor and commercial-zoned floor of a 30-floor residential building are non-standard floors.

Among the 15 construction sites, five sites are from Hubei province, six from Liaoning, two from Shanghai and two others from Sichuan and Jiangsu provinces. Twelve sites are for residential-related usage and the rest includes an office building, a warehouse and a heat-exchange facility affiliated to a power plant (Table 1). The information collected was used in a timber consumption model to estimate the plywood and sawn timber consumption rates on each site. Actual plywood and sawn timber consumption data was collected from seven sites.

Formwork timber consumption model

A timber consumption model was developed using data from the survey. In the model, sawn timber and plywood formwork consumption rates for a site are calculated in two different ways: reported consumption rate and predicted consumption rate.

Reported formwork consumption

Based on project manager, engineer and quantity surveyor's reports, the reported formwork consumption rates of plywood and sawn timber are calculated using:

$$\text{Reported plywood consumption rate} = \frac{\text{Actual plywood consumed}}{\text{Total floor area}} \quad (1)$$

$$\text{Reported sawn timber consumption rate} = \frac{\text{Actual sawn timber consumed}}{\text{Total floor area}} \quad (2)$$

Predicted plywood consumption

Based on information collected from construction sites, a timber consumption model is developed to predict plywood and sawn timber consumption rates separately. Carpenters and engineers reported that formwork material consumption in their sites was purely based on rule of thumb, therefore it is necessary to standardise this consumption estimation in order to estimate the formwork material consumption rate of a construction site. The model predicts the plywood consumption rate by using formula (3):

$$Rate_{ply} = \frac{\left(\frac{A_{non}}{Reuse_{non}^{ply}} + \frac{A_{std}}{Reuse_{std}^{ply}}\right) \times (F_{floor} + F_{other}) \times d_{ply} \times 110\%}{A_{non} + A_{std}} \quad (3)$$

Where $Rate_{ply}$ = predicted plywood consumption rate in a construction site (m^3/m^2 construction floor area);

$A_{non} + A_{std}$ = floor area for non-standard and standard floors (m^2). Sum of two is the total floor area of a construction site;

$Reuse_{non}^{ply}$ & $Reuse_{std}^{ply}$ = average number of reuses of plywood used for non-standard and standard floor construction;

F_{floor} & F_{other} = floor and other structure surfacing factor (m^2 formwork/m^2 floor/other structure);

d_{ply} = average plywood sheet thickness (m).

According to the carpenters, when the structural part of a building is finished, usually 10% of plywood sheets are still in good condition and would be consumed in subsequent construction. However, the average number of reuses of plywood collected from a construction site did not factor all the subsequent construction procedures which utilized a further 10%. Total consumed plywood volume is therefore the volume of plywood consumed in formwork multiplied by 110%.

F_{floor} and F_{other} are both estimated empirically from the structure design by carpenters and engineers on a construction site. They indicate the average formwork area erected to support 1 m^2 of floor and other structure area based on their experience.

Predicted sawn timber consumption

The model predicts the sawn timber consumption rate by using formula (4):

$$Rate_{sawn} = \frac{[(N_{floor} \times F_{floor}) + (N_{other} \times F_{other})] \times P \times A_{sawn}}{W_{ply} \times Reuse_{sawn}} \quad (4)$$

Where $Rate_{sawn}$ = predicted sawn timber consumption rate in a construction site (m^3/m^2 construction floor area);

$Reuse_{sawn}$ = average number of times sawn timber is reused;

N_{floor} and N_{other} = number of sawn timber ribs per plywood sheet on floor and other structure formwork;

W_{ply} = width of each piece of standard plywood sheet (m);

P = proportion of formwork rib made from sawn timber (%);

A_{sawn} = cross-section area of each sawn timber formwork rib (m^2).

A piece of sawn timber could be reused for many floors on a building, and on two or three sites. Engineers and carpenters from the construction sites suggested 30 is a good estimate of the average number of reuse times for sawn timber taking possible offcut waste into account.

Proportion of sawn timber rib P is the ratio of formwork surface area using sawn timber rib to support plywood over total formwork surface area. Because seven construction sites used both sawn timber and steel bar as formwork rib material, this factor is introduced to calculate the actual sawn timber volume used for these construction sites. The length of a piece of sawn timber is assumed to be equal to the length of plywood, because the total consumption of sawn timber is calculated based on the number of sawn timber pieces per plywood sheet and the total number of plywood sheets used for formwork erection.

N_{floor} and N_{other} coefficients (number of ribs per m^2 of plywood) were both determined by carpenters on-site, and they are both negatively correlated to the cross-section area of sawn timber used on the site. Both

coefficients are very similar across different construction sites (Table 2). Unfortunately not every site reported the cross-section of sawn timber used in formwork, and two sites used more than one type of sawn timber.

Table 2: Number of construction sites applying different rib density

	3 ribs per sheet	4 ribs per sheet	5 ribs per sheet	6 ribs per sheet	Total site number
N_{floor}	8 sites	5 sites	1 sites	1 sites	15
N_{other}	7 sites	1 sites	1 sites	6 sites	15

Results

Timber formwork consumption rates

Predicted and reported consumption rates of plywood and sawn timber for 15 sites are shown in Table 3. The differences between two consumption rates are calculated by dividing the difference between the predicted and reported consumption rate by the reported consumption rate. Not all data is free from error. Data for sites 11–15 was provided by a construction industry auditing company. The timber consumption model suggested that the average number of reuses of plywood on sites 11–15 was less than one. This indicated that data from these five sites might be subject to error, as the auditing company suggested the plywood should have been reused about five times. Information from sites 4 and 5 was also based on memory without support from written records.

Table 3: Predicted timber materials – consumption rate of all projects and reported consumption rate based on available data

	Reported consumption rate (m^3/1000 m^2)		Predicted consumption rate (m^3/1000 m^2)		Differences percentile	
Project number	Plywood	Sawn timber	Plywood	Sawn timber	Plywood	Sawn timber
1			8.58	2.13		
2			7.97	2.45		
3			5.23	1.09		
4	6.19	0.77	11.60	1.57	–87.4%	–103.9%
5	9.59	2.20	16.87	2.15	–75.9%	2.3%
6	6.44	2.29	6.36	2.34	1.2%	–2.2%
7	11.51	2.75	11.88	2.34	–3.2%	14.9%
8	8.41	1.95	7.94	1.90	5.6%	2.6%
9	9.96	2.47	9.11	2.48	8.5%	–0.4%
10	6.89	1.79	6.60	1.61	4.2%	10.1%
11	6.34		18.00	0.24	–183.9%	
12	6.80		18.00	0.28	–164.7%	
13	6.36		18.74	0.21	–194.7%	
14	6.32		18.74	0.21	–196.5%	
15	6.62		7.33	0.12	–10.7%	

Average, minimum, maximum and standard deviation of all consumption rate data are shown in Table 4. On the one hand, current construction techniques are mature and construction crews around China have many years of experience, and the majority of construction sites are managed in a similar way using similar techniques and crew. On the other hand, the consumption model is established based on the technical design and each project was unique in this aspect. As a consequence, the standard deviation of reported consumption rates of different projects is smaller than that of predicted consumption rates.

Table 4: Descriptive statistics of the reported and predicted timber material consumption rate for all projects

	Reported consumption rate (m^3/1000 m^2)		Predicted consumption rate (m^3/1000 m^2)	
	Plywood	Sawn timber	Plywood	Sawn timber
Average	7.62	2.03	11.53	1.41
Minimum	6.19	0.77	5.23	0.12
Maximum	11.51	2.75	18.74	2.48
Standard deviation	1.80	0.64	5.10	0.95

Timber consumption model generalisation

To estimate plywood and sawn timber consumption by the Chinese residential construction industry, the formwork timber consumption model was generalised. Coefficients in formulas (3) and (4) were generalised using the average data of 12 residential construction sites (Table 5).

Table 5: Formwork timber consumption model coefficients' value setting for national residential construction industry formwork demand estimation

Coefficients	Average value
A_{non}/A_{std}	0.12
$Reuse_{non}^{ply}$	2.4
$Reuse_{std}^{ply}$	7.1
F_{floor}	1.2
F_{other}	1.8
d_{ave}^{ply}*	0.019 m
N_{floor}	3.4
N_{other}	4.3
P**	1.00
A_{sawn}***	0.004 m^2
W_{ply}	0.915 m
$Reuse_{sawn}$	30

Note: * Standardization Administration of China (2008) does not specify the thickness of 915*1830 mm^2 plywood used for concrete

formwork. Instead, the thickness is determined by negotiation. The thickness of plywood was assumed to be 19 mm as this is the most common thickness used nationally.

** The value is set to be 1 as the actual ratios of construction sites that had used other material were not collected from site visits.

*** To reflect the national average, sawn timber cross-section area is assumed to be 90*50 mm² as it is the most common size of sawn timber.

The consumption rate of plywood and sawn timber may be calculated by re-arranging formulas (3) and (4):

$$Rate_{ply} = \frac{\left(\frac{0.12A_{std}}{2} + \frac{A_{std}}{7.1}\right) \times (1.2 + 1.8) \times 0.019 \times 110\%}{0.12A_{std} + A_{std}} = 11.3 \text{ m}^3/1{,}000 \text{ m}^2$$

$$Rate_{sawn} = \frac{[(3.4 \times 1.2) + (4.3 \times 1.8)] \times 1 \times 0.004}{0.915 \times 30} = 1.7 \text{ m}^3/1{,}000 \text{ m}^2$$

Historical plywood and sawn timber demand

Several different data series might be used to represent the Chinese historical real estate development. According to the National Bureau of Statistics (2014), there are four possible data series:

- Table 10-7: Value and Floor Space of Buildings under Construction and Completed in the Whole Country
- Table 14-15: Floor Space of Buildings Constructed by Construction Enterprises
- Table 15-7: Floor Space and Cost of Buildings Developed by Enterprises for Real Estate Development
- Table 15-13: Number of Flats of Residential Buildings Completed and Sold by Enterprises for Real Estate Development.

However, data from Table 15-7 is selected for the following reasons. First, Table 10-7 only covers the building areas under construction and completed area for each year. Considering the construction period of each site could vary tremendously, information from Table 10-7 might double count the completed real estate floor area. Secondly, the 'construction enterprises' used in Table 14-15 refers to 'all the construction enterprises of various types of ownership with qualification certificates and independent accounting systems' (National Bureau of Statistics, 2014). While the data in Table 15-7 and 15-13 covers all legal entities engaged in real estate development, Table 15-13 does not cover non-real estate buildings. Table 15-7 is therefore selected to estimate the historical plywood and sawn timber demand by Chinese construction industry (Figure 1).

Multiplying the data in Figure 1 with the consumption rate of plywood and sawn timber derived from formula (3) and (4) provides an estimation of historical Chinese plywood and sawn timber demand in construction. Figure 2 indicates that estimates from the plywood consumption model are similar to historic plywood demand calculated from Food and Agricultural Organization data, suggesting that plywood in China is mostly used in construction formwork. Figure 3, on the other hand, suggests that the construction industry uses only a small proportion of the sawn timber consumed in China. Both of these findings require further study.

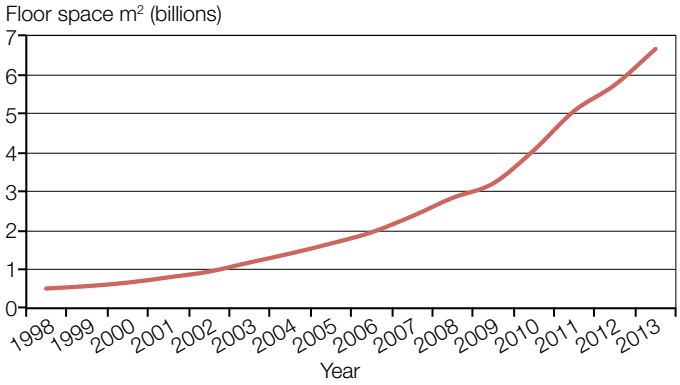

Figure 1: Total floor space of buildings under construction for China 1998–2013. Data from Table 15-7 National Bureau of Statistics (2014)

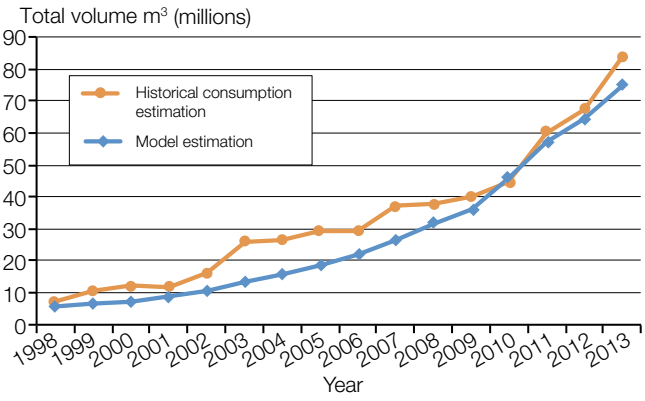

Figure 2: Chinese historical plywood consumption and estimated plywood demand from construction industry, 1998–2013. Historical plywood consumption was from the Food and Agriculture Organization of the United Nations (2015)

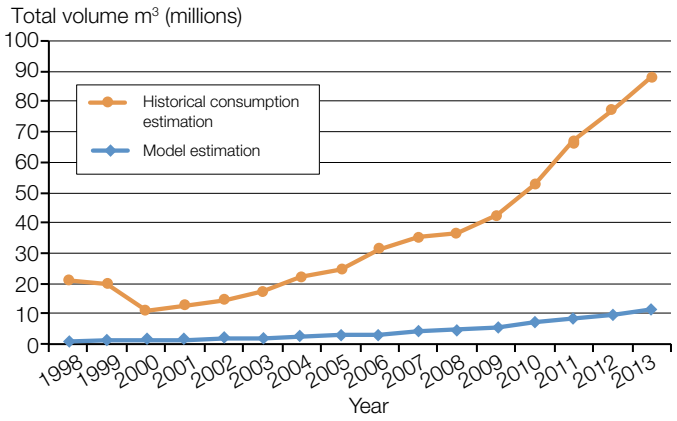

Figure 3: Chinese historical sawn timber consumption and estimated sawn timber demand from construction industry, 1998–2013. Historical sawn timber consumption was from the Food and Agriculture Organization of the United Nations (2015)

Discussion

Factors affecting formwork material reuse

Human resource management and building structure design were the two most important factors influencing formwork material reuse time and therefore consumption rate (Ling & Leo, 2000; Poon, Yu & Jaillon, 2004). If building structure design does not take material availability into account, a formwork layout design might be complex and formwork modification often required (Cai & Zhang, 1998; Poon et al., 2004). Modification usually reduces reuse of formwork material.

At a construction site, a highly-skilled, motivated carpenter installs and removes formwork efficiently and carefully (Ling & Leo, 2000) to minimise damage and increase reuse. A senior carpenter mentioned that reuse of sawn timber was effectively increased when carpenters are fined for discarding sawn timber longer than 1 m. Several managers and engineers mentioned that quality of formwork material, construction deadline, and importance of the building and construction budget might all influence the reuse rate of formwork materials. These factors might explain the diversity of plywood and sawn timber consumption rates at the 15 sites.

Potential data errors

At a construction site, the consumption rate of plywood and sawn timber is always estimated by rule of thumb, because formwork material constitutes only a minor component of total construction cost (Song & Wang, 2007). No manager or site engineer from these projects had accurately monitored plywood or sawn timber consumption rates before. This might be a factor affecting the accuracy of estimates provided by survey participants.

Apart from the possible lack of accuracy of data collected from interviews, the accuracy of public-domain construction and other data has also been questioned. According to the National Bureau of Statistics (2014) and the Ministry of Housing and Urban-rural Development of the People's Republic of China (2000), the concept of 'total floor space under construction' does not include all construction activities in this industry, therefore the total plywood and sawn timber demand from construction industry may be underestimated. Mao and Wu (2015) suggested that the statistics of the total plywood production volume published by the National Bureau of Statistics of China, and available from the Food and Agriculture Organization of the United Nations, might be overestimated.

Assumptions in the formwork material consumption model

The following assumptions were made when developing the timber formwork consumption model and predicting historical demand of timber formwork material:

1. Formwork used to construct the foundation, stairs, floors, walls and other parts of a structure were all taken into account.
2. No damage happened in relocating and storing formwork materials.
3. Plywood used for non-standard floors was used only once, while sawn timber was reused.
4. Average thickness of plywood was 19 mm.
5. The number of times sawn timber was reused was assumed to be 30.
6. The model assumed other construction activities for a construction project would increase total plywood volume consumed by 10%.
7. When estimating historical plywood and formwork consumption by the Chinese construction industry, no recycled material had re-entered the formwork material market and no alternatives for timber formwork material were used.
8. These 15 sites were representative of the Chinese construction industry regarding formwork usage.

The first seven assumptions were made to simulate the formwork material consumption procedures at a construction site. For the last assumption, the study used all available data from site visits in China. It should be recognised this study relies on survey methods and is subject to the potential drawbacks of these methods, such as selection bias.

Steel formwork material

All interviewed project managers suggested that plywood and sawn timber will be gradually replaced by other materials, with steel formwork material being the most competitive alternative. Sites 4 and 11–15 have used steel to replace sawn timber for part of or all formwork ribs. Steel formwork has been used since the 1980s and now one of the biggest residential construction companies, China Wanke Co. Ltd,

reported it had already replaced plywood and sawn timber with steel formwork for all its construction sites.

Although steel formwork has many advantages, drawbacks such as high upfront investment, low on-site modification flexibility and heavy weight have restricted its usage. Currently, formwork is installed and removed manually. Modification of standard formwork material is always required and metal formwork cannot fit these construction techniques. Carpenters who have used the current construction techniques for over 30 years might resist a change to steel formwork. The engineer who was interviewed in the pilot survey mentioned that in developed countries construction companies use steel formwork for all standard structures, and this trend was expected to be seen in other countries, including China.

Further work

Further work in different areas is required to better understand timber formwork demand in the Chinese construction industry. Instead of using surveys, tracking the complete construction procedures of an active construction site would provide more accurate data about the formwork material reuse rate, actual material consumption and the formwork surfacing factor. Tracking changes in labour costs, material cost and the building code for the Chinese construction industry may be helpful to predict the substitution of timber formwork material.

Conclusions

A method for estimating the plywood and sawn timber consumption rate (or transfer ratio) of a Chinese construction site was developed. The average transfer ratio for the Chinese construction industry for plywood and sawn timber was estimated to be 11.3 m^3/1,000 m^2 and 1.7 m^3/1,000 m^2 of floor area, respectively. It would be possible to use forecasts of future construction activity (measured by floor area), combined with the transfer ratio, to forecast future demand for plywood and sawn timber in this end use. Comparison of historical Chinese consumption data for sawn timber and plywood with estimated historical Chinese construction industry formwork material consumption suggests that multi-storey residential building construction is the major use of plywood, but a minor use of sawn timber, in China.

A number of suggestions have been made for further work to confirm these estimates and to test the model assumptions they are based on. These suggestions apply both to the estimation of timber consumption rate for a construction site and the estimate of timber formwork demand for the Chinese construction industry in aggregate.

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References

Cai, S. and Zhang, J. 1998. Discussions About Utilization and Development of Construction Formwork. *Pearl River Modern Construction*, 3(6): 2. (In Chinese)

Food and Agriculture Organization of the United Nations. 2015. *FAOSTAT Forestry Production and Trade Statistics Data*. Retrieved from: http://faostat3.fao.org/download/F/FO/E.

Katz, A. 2004. Log Export Markets and their Log Requirements. *NZ Journal of Forestry*, 49(1): 21–25.

Ling, Y.Y. and Leo, K.C. 2000. Reusing Timber Formwork: Importance of Workmen's Efficiency and Attitude. *Building and Environment*, 35: 9. (In Chinese)

Liu, N. 2013. Future Development Forecase of Bamboo Plywood Construction Formwork Based on Demand. *News of Chinese Construction Material*, 1. (In Chinese)

Manley, B.R. and Evison, D.C. 2015. Material Flow and End Use of Harvested Wood Products Produced from New Zealand Log Exports. Retrieved from: www.mpi.govt.nz/news-and-resources/publications/.

Mao, Q. and Wu, S. 2015. Overview of Plywood Industry in China. *China Wood-based Panels*, 22(2): 5. (In Chinese)

Ministry of Housing and Urban-rural Development of the People's Republic of China. 2000. *Regulations about Qualification of Real Estate Development Company*. Retrieved from: www.mohurd.gov.cn/zcfg/jsbgz/200611/t20061101_158984.html. (In Chinese)

National Bureau of Statistics. 2014. *China Statistics Yearbook*. National Bureau of Statistics of the People's Republic of China.

Poon, C.S., Yu, A.T.W. and Jaillon, L. 2004. Reducing Building Waste at Construction Sites in Hong Kong. *Construction Management and Economics*, 22: 10.

Song, Y. and Wang, G. 2007. Advantages of Engineered Timber Products in Construction Formwork Application. *Science and Technology Consulting Herald*, 4(29): 1. (In Chinese)

Standardization Administration of China. 2008. *Plywood for Concrete Form*. Standardization Administration of China. (In Chinese)

Wang, L. and Jiang, C. 2007. *Research About Precast Concrete Formwork*. (Master of Structural Engineer), Wuhan University of Technology. (In Chinese)

Wu, S. 2002. Challenges and Opportunities of Bamboo Plywood Formwork for Concrete Pouring. *China Wood-based Panels*, 9(11): 3. (In Chinese)

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