



Environmental benefits of renewable building materials: A case study in Taiwan



Chien-Li Lo

Graduate School of Architecture and Interior Design, Shu-Te Univ., Taiwan, ROC

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ABSTRACT

As the global economy develops and population increases, substantial fossil energy use has caused a sizable increase in greenhouse gas emission and the subsequent greenhouse effect, leading to global warming. Reducing greenhouse gas emission and forest resource consumption is imperative. Producing, manufacturing, and using construction materials such as concrete, steel, and formworks consume abundant energy and produce considerable waste, affecting the natural environment. Specifically, formwork engineering, which involves substantial forest resource harvesting and waste production in manufacturing and using timber formworks, requires attention. Currently, formwork engineering in Taiwan has typically adopted timber formworks. In 2013–2015, the annual average total floor area of reinforced concrete buildings was 30,950,383 m² in Taiwan. Converting this number to the number of timber formworks revealed that a staggering 1,843,437 cedar trees aged 30 years were required annually for the aforementioned total area, excluding other types of engineering such as bridges and retaining walls. This study sought to reduce the use of timber formworks to decrease deforestation, preventing forest resource depletion. Specifically, plastic formworks exhibit considerably improved reusability, low manufacturing costs, and favorable recyclability. The recyclability of plastic formworks enables the reuse of the material and purpose of environmental sustainability.

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1. Introduction

At the 2016 Oscar ceremony, DiCaprio won the award for Best Actor. He used his acceptance speech to express his appreciation and worry for the environment when he said: “Climate change is real, it is happening right now.” The fundamental reason is to continue pursuing economic development, people have overexploited the finite natural resources of earth [1,2]. Overexploitation and use of natural resources, such as deforesting for croplands and mining fossil fuels such as coal, petroleum, and natural gas, have caused an increase in carbon dioxide (CO₂) in the atmosphere and the subsequent greenhouse effect, leading to global warming [3,4].

Although the concept of sustainable construction has been acknowledged worldwide, population increase and economic development have continued to exhaust earth resources [5,6]. Since the Industrial Revolution, the CO₂ concentration in the atmosphere has increased by 28%. Although the use of natural resources and advanced technology has considerably improved, people have damaged their relationship with Mother Nature in pursuing eco-

nomical development, changing from one of interdependence to oppositional. The second assessment report by the Intergovernmental Panel on Climate Change of the United Nations indicated that, if no preventive measures are executed, by 2100, the surface temperature of earth would increase from 1 °C in 1990–3.5 °C, and the sea level would rise by 15–95 cm [7]. The effects of the greenhouse effect on the entire ecology, including earth, the water bodies, and human economy and societies, and the global climate would be irreversible and unpredictable [8,9].

The primary greenhouse gas is CO₂. To mitigate global warming, the atmosphere must be stabilized. Specifically, the increase in CO₂ in the atmosphere must be halted. However, on the premise that the economies continue to develop, achieving this objective is difficult [10,11]. A joint study by Austria, Brazil, and the United States in the Proceedings of the National Academy of Sciences indicated that preventing deforestation is the most economical and practical means of controlling climate change [12–14]. Forests are the largest and most vital ecosystems and the largest repository of greenhouse gases on Earth. The primary natural mechanism of forests is photosynthesis, through which plants absorb CO₂, store carbon in plant tissues, and release oxygen [15,16].

Carbon sequestration is the carbon-fixation function of forests. Through photosynthesis, green plants convert water and CO₂ to

E-mail address: camel@stu.edu.tw

glucose by absorbing light energy and releasing oxygen. This is the source of the other organic carbon compounds in the bodies of animals and plants [17].

Trees perform photosynthesis through their physiological properties, absorbing CO₂ and releasing oxygen. According to the equation of photosynthesis, each additional metric ton (MT) of biomass in a tree requires 1.6 MT of CO₂ and subsequently enables releasing 1.2 MT of oxygen. The CO₂ is then converted to organic carbon, which is stored in the tree body. (source: Forestry Bureau, Council of Agriculture, Executive Yuan)

People must prevent the destruction of the existing forests and lay plans for systematic reforestation to purify the atmosphere. Currently, the tropical forests are being substantially deforested [18]. Satellite imagery has indicated that approximately 0.5% of the tropical forests are deforested annually. Initially, 0.5% might seem nonsignificant, but such a proportion encompasses approximately 100,000 km² of the forests, which is nearly 3 times the area of Taiwan. At such a rate of deforestation, the primary tropical forests will become extinct by the next century [19].

The greenhouse effect causes a continual rise in global temperature, and the subsequent climate change severely affects humankind. The rise in temperature has caused the melting of the caps, the raising of the sea levels, and the decreasing of land area. Climate zone shifts may one of reasons cause massive animal migrations and pandemics of encephalitis, rabies, dengue fever, yellow fever, and the recent Ebola [20,21]. Climate change is already having a noticeable impact on the environment and global health.

The use of timber by people for living has been habitual. Timber is acknowledged as optimal construction and equipment material [22,23]. Home decoration, furniture, paper, and firewood are made of timber from forests [24,25]. The daily needs of people have caused the continual use of the forest resource, and the subsequent deforestation has caused the release of CO₂ from trees and soil.

Reducing deforestation and promoting reforestation are critical in reducing greenhouse gas emission and halting the effects of the greenhouse effect on Earth [26]. As the human economy continues to develop, finding alternatives to timber for industries that consume substantial timber resources, such as construction engineering and formworks, is imperative. Currently, construction engineering has consumed the most forest resources in Taiwan. As the primary exporting countries of timber have begun banning timber exports, early countermeasures to the effect of the ban of timber exports to Taiwan are crucial [27].

2. Background

Civil construction is the foundation of all industries and has been named the “locomotive industry.” The basic material of civil construction engineering is reinforced concrete. Concrete is the premier construction material across the world, It is the most versatile and economical material available to the construction industry and its use can have many environmental effects.

One of the inseparable items for forming concrete is formwork activities [28]. A flaw in formwork assembly may cause its destruction during concreting, leading to financial loss and threatening the lives and safety of people. Therefore, formworks are critical materials in civil construction engineering [29].

2.1. Material property

Formworks are molds used for reinforced concrete structures. A satisfactory formwork must meet the following conditions [30]:

1. The formwork should be strong enough to withstand all types of dead and live loads.

2. The formwork should be rigidly constructed and efficiently propped and braced both horizontally and vertically, so as to retain its shape.
3. The joints in the formwork should be water-tight against leakage of cement grout.
4. Erection of formwork should permit removal of various parts in desired sequences without damage to the concrete.
5. The material of the formwork should be cheap, easily available and should be suitable for reuse.
6. The formwork should be set accurately to the desired line and levels. It should have plane surface.
7. It should be as light as possible.
8. The material of the formwork should not warp or get distorted when exposed to the elements.
9. It should rest on firm base.

The conventional formwork materials include the following [31]:

- (A) Timber Formwork
- (B) Plywood Formwork
- (C) Steel Formwork
- (D) Plastic Formwork
- (E) Corrugated & Flat Permanent Formwork

In Taiwan, more than 90% of the formworks used in construction work are manufactured using timber. The advantages of timber formworks include easy construction, economical materials, and easy molding. However, after repeated use, timber formworks begin to exhibit degradation in quality and strength. Typically, timber formworks are discarded after 4~6 times of repeated use [31,32], producing substantial waste and causing environmental pollution. Therefore, timber formworks do not satisfy the requirements of energy conservation and environmental protection, which have garnered increasing attention.

Formwork engineering in Taiwan has consumed abundant forest resources and is in enormous demand. However, a tree cannot be used entirely as a construction material. The timber utilization rate in Taiwan is approximately 45%, and the saw lumber rate is approximately 80%. Therefore, conscientious use of forest resources is crucial.

According to the Statistical Yearbook of Construction and Planning Agency, in 2013–2015, the average annual total floor area in the past 3 years was 36,997,019 m². The concrete and reinforced concrete structures comprised approximately 76.25% (28,209,717 m²) of the average annual total floor area, indicating that most of the existing structures in Taiwan are reinforced concrete structures (Fig. 1). The concrete building floor area would be 83.66% (30,950,383 m²) of the total if steel reinforced concrete structures were included (Table 1). There are four kinds of most typically used formwork scales in construction engineering in Taiwan (Table 2).

2.2. Calculation

The most typically used formwork scale in formwork engineering in Taiwan is 1820 × 600 mm (Fig. 2), which comprises an average of approximately 50%–70% of formwork usage. Calculation analysis of the volume of unsawn timber used for manufacturing timber formwork according to this scale is detailed as follows:

(1) The average height of a 30-year-old cedar tree is 17.85 m, and the average diameter is 30 cm [33,34]. According to the 45% timber utilization rate and 80% saw lumber rate [35,36], the volume of the usable material to be calculated using Eq. (1) as follows:

$$V_{\text{usable}} = V_{\text{whole}} \times R_{\text{utilization}} \times R_{\text{saw}} \quad (1)$$

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