Research on Component Recycling Based on Steel Structure Prefabricated Building

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Abstract. The steel structure building system is a system suitable for resource recovery. This paper studies the carbon emission calculation model and economic analysis method for the recovery process of steel structure prefabricated building components. And a steel structure sales office is selected for verification calculation. The results show that the use of recycled components within a reasonable transport distance can not only reduce carbon emissions, but also reduce economic costs compared to the full use of new components.

1. Introduction
With the development of society and economic growth, Chinese population advantage is gradually weakening, which also leads to the rapid rise of labour costs. At the same time, traditional construction methods are also facing environmental pollution and waste of water resources and other increasingly prominent problems. In order to solve these problems, the construction industry needs to change the mode of production. As the core of upgrading and transformation, assembly building is an important step in construction transformation and upgrading[1]. It is undoubtedly that the steel structure building system that is most suitable for recycling and reuse in the structure system of assembly construction mode. Among them, the construction of the steel structure sales office is to promote and support the sale of commercial residential facilities[2]. After the completion of the sale, the dismantled building components of the steel structure sales office can be used continuously to achieve recycling of the building components. Carbon emission calculation model and economic analysis method for recycled steel structure assembly building components are studied in this paper. And a steel structure sales office in Beijing is selected for verification calculation.

2. Carbon emission calculation model
In order to determine whether a component is worth recovering in terms of carbon emissions, it is necessary to compare the carbon emissions generated by the components in the recycling process with the carbon emissions generated by the production of the same amounts of new components. In this paper, the carbon emission coefficient method is used to calculate the carbon emission. The specific calculation formula is as follows.

Carbon emissions from the production phase of the component, including the amount of carbon dioxide converted from the input of raw materials to the energy consumed to produce the finished product, and the amount of additional carbon dioxide produced during the production process[3]. As shown in the formula (1):
In the equation:

\[ Q' = \sum_{i=1}^{n} q_i c_i \]  

In the equation:

\[ q_i \]—type i component usage, t;
\[ c_i \]—intensity value of carbon dioxide emitted from production process of type I component, t/t;
\[ n \]—total number of components used.

The carbon emissions from the component recovery process are divided into two parts: the carbon emissions from the demolition components and the carbon emissions from the transport components[4]. As shown in the formula (2):

\[ Q = Q_1 + Q_2 \]  

In the equation:

\[ Q \]—total carbon emissions from the process of recycling components, t;
\[ Q_1 \]—carbon emissions from dismantling components, t;
\[ Q_2 \]—carbon emissions from transport components, t.

By consulting the literature, it is known that the carbon emission from the dismantled component is about one third of the carbon emission from the production of the component[5]. As shown in the formula (3):

\[ Q_1 = \frac{1}{3} Q' \]  

Carbon emissions from component transportation refer to the amount of carbon dioxide converted from fuel consumed in the process of transportation of dismantled components to the construction site through vehicles and then back to the starting point[6]. As shown in the formula (4):

\[ Q_2 = \rho \times k_1 \times k_2 \times \frac{T_d}{1000} \]  

In the equation:

\[ Q_2 \]—carbon emissions from transport components, t;
\[ \rho \]—the density of diesel is 0.83～0.855 kg/L. Take 0.84kg/L in this paper.
\[ k_1 \]—the conversion factor of standard coal and carbon dioxide is 2.62kg/kgce.
\[ k_2 \]—the conversion factor between diesel and standard coal is 1.4571kgce/kg[7].
\[ T_d \]—total fuel consumed by transport components (diesel).

The calculation method of the total fuel (diesel) consumed in the transportation process is as shown in formula (5)[6]:

\[ T_d = \sum_{i=1}^{n} \frac{q_{ti}}{(G_i - G_{i0})} \times \frac{(P_i + P_{i0})(2D_i)}{100} \]  

In the equation:

\[ T_d \]—total fuel consumed by transport components (diesel), L;
\[ q_{ti} \]—the amount of transportation of the i-th components, t;
\[ G_i \]—total mass of loading of truck carrying the i-th components, t;
\[ G_{i0} \]—no-load quality of truck transporting i-th components, t;
\[ P_i \]—fuel (diesel) consumption limit corresponding to the total mass of the truck of the i-th components, L/100km;
\[ P_{i0} \]—fuel(diesel) consumption limit corresponding to the no-load mass of the truck of the i-th components, L/100km;
Di—the distance between the origin of the i-th building material and the construction site; km; 
n—total number of components used.

3. Case analysis

3.1. Engineering survey

A steel structure sales office in Beijing is taken as the calculation model. The list of materials is summarized in Table 1.

| Material                        | Number | Unit of measurement |
|---------------------------------|--------|---------------------|
| Steel                           | 32.00  | t                   |
| Paint                           | 26.30  | t                   |
| Fire retardant coating          | 400.00 | m²                  |
| Polyvinyl chloride              | 20.00  | m                   |
| Bolt                            | 6.00   | t                   |
| Polystyrene board               | 1.74   | t                   |

According to statistics, the steel occupied area in this case is 470 m². The 400 m² polystyrene board contains about 1.74 t of steel. Therefore, this paper will mainly analyze the recovery of steel and polystyrene board, and other materials will not be analyzed. It can be obtained from Table 1, steel 32.00t, polystyrene board 1.74t.

3.2. Carbon emissions from recycling components

According to formula (2), it is known that the carbon emission of the component removal and recovery stage consists of two parts, $Q_1$ and $Q_2$. According to the literature[7], the carbon dioxide intensity values of steel and polystyrene boards in the production process are 2.79 t/t and 3.13 t/t, respectively. It can be obtained from formula (1). In this example, the carbon emissions of steel and polystyrene boards in the production process are 89.28t and 5.45t, respectively. Therefore, the total carbon emissions of the components in this example during the production process is 94.73t, which is $Q' = 94.73$ t. According to formula (3), the carbon emission of the demolished components in this case is about 31.57t, which is $Q_1 = 31.57$ t. In this example, four trucks of the type CGC1160D5BAEA are used for transporting steel, and four trucks of type AB5252JSQ are used for transporting polystyrene boards. It is assumed that the transport distance between steel and polystyrene board is the same as $D$ km. According to the formula (5), it can be found that the transportation steel consumes 3.36 $D$ L of diesel, the transport polystyrene board consumes 4.25 $D$ L of diesel, and the total consumption of diesel is 7.61 $D$ L. According to formula (4), the carbon emission generated during the transportation of recycled components can be calculated to be 0.025$D$t, which is $Q_2 = 0.025D$ t. In this example $Q = Q_1 + Q_2 = 31.57 + 0.025D$ t.

3.3. Calculation and Analysis of Carbon Emissions

The carbon emissions produced by the new components produced in the same number of components recovered as in this paper are $Q$. Carbon emissions from component factories to construction sites should also be considered when using new components. But in order to simplify the calculation, assuming that the construction site is near the component factory, the carbon emissions from transporting new components can be neglected. Just consider the carbon emissions from the production of new components. When $Q \leq Q'$, it is indicated that the use of recycled components produces less carbon emissions, consumes less energy, and saves production materials compared to the use of new components, so it is worth recycling. As the transportation distance increases, $Q_2$ gradually increases, causing $Q$ to gradually increase. If $Q > Q'$, it means that the use of recycled components produces more carbon emissions than the use of new components, so it is not worth
After calculation, when the transportation distance \( D_{\text{max}} \) is 2526km, \( Q \) is equal to \( Q' \). If the transportation distance continues to increase, the components are not worth recycling. In this example, the calculation results of carbon emissions from the recovery components with transport distances of 1000km, 1400km, 1800km and 2200km and the production of equal number of new components are summarized in Table 2.

**Table 2. Carbon emissions of recycled components and new components at different transport distances**

| Transportation distance (km) | \( Q' (t) \) | \( Q_1 (t) \) | \( Q_2 (t) \) | \( Q (t) \) | \( \frac{Q}{Q'} \) (%) |
|-----------------------------|-------------|-------------|-------------|-------------|-------------------|
| 1000                        | 94.73       | 31.57       | 25          | 56.57       | 59.71             |
| 1400                        | 94.73       | 31.57       | 35          | 66.57       | 70.27             |
| 1800                        | 94.73       | 31.57       | 45          | 76.57       | 80.82             |
| 2200                        | 94.73       | 31.57       | 55          | 86.57       | 91.38             |

### 3.4. Economic Analysis

This paper studies the difference of economic cost between using recycled components to construct new buildings and using new components to construct new buildings[8].

New buildings built with new components need to consider the cost of purchasing new components. The average market price of steel purchased is 4,000 RMB/t; in this case, a total of 32 tons of steels are required. The average market price of polystyrene board is 90 RMB/m². In this case, the polystyrene boards need a total of 400m². After calculation, a total of 164,000 RMB is needed.

The use of recycled components to build new buildings requires consideration of demolition and transportation costs. The demolition cost is 100 RMB/m² according to the market average price. In this case, the steel area is 470m², and the area of polystyrene board is 400m². After calculation, a total of 87,000 RMB is needed. Transportation costs include the rental fee for the vehicle, the driver’s salary, and the cost of purchasing fuel (diesel). As shown in the formula (6):

\[
M = 2n_1xwP + 2P(n_1s_1 + n_2s_2) \quad \text{in} \quad vT
\]

In the equation:

- \( M \)—cost of transportation process, RMB;
- \( P \)—transportation distance, km;
- \( n_1 \)—number of rental vehicles;
- \( n_2 \)—number of drivers employed;
- \( x \)—diesel consumption per kilometer of transport vehicles[9], L/km;
- \( w \)—the price of diesel is 6.5~8.5 RMB/L, in this case, take 7 RMB / L;
- \( s_1 \)—daily rental fee per vehicle, RMB;
- \( s_2 \)—driver’s daily salary per person, RMB;
- \( v \)—average speed of transport vehicles, in this case, take 80km/h;
- \( \tau \)—the driving time of the transport vehicle, in this case, take 24h.

According to the formula (6), the economic cost calculation results of the transportation distances of 1000 km, 1400 km, 1800 km, and 2200 km, respectively, are summarized in Table 3.

**Table 3. Economic costs of recycled components at different transport distances**

| Transportation distance (km) | Daily rental fee per vehicle (RMB) | Number of rental vehicles | Driver's daily salary per person (RMB) | Number of drivers employed | Transportati on costs (RMB) | Demolition costs (RMB) | Total price (RMB) |
|-----------------------------|-----------------------------------|---------------------------|----------------------------------------|---------------------------|---------------------------|------------------------|-------------------|
| 1000                        | 300                               | 8                         | 400                                    | 16                        | 51200                     | 87000                  | 138200            |
| 1400                        | 300                               | 8                         | 400                                    | 16                        | 64640                     | 87000                  | 151640            |
| 1800                        | 300                               | 8                         | 400                                    | 16                        | 77080                     | 87000                  | 164080            |
| 2200                        | 300                               | 8                         | 400                                    | 16                        | 100320                    | 87000                  | 187320            |
By comparison, it can be seen that when the transportation distance is 1800 km, the cost of completely using the recycled component is approximately equal to the cost of using the new component. And 1800km is equal to 70% $D_{max}$. That is to say, when the transportation distance is less than 1800 km, the use of the recovery component is not only less than the carbon emission generated by using the new component, but also requires lower economic cost. When the transportation distance is more than 1800 km and less than 2526 km, the use of the recovery component is only smaller than the carbon emission generated by using the new component, but the economic cost required is higher.

4. Conclusion
This paper researches and discusses the recovery of steel structure assembly building components, and the following conclusions are drawn:
(1) Reducing carbon emissions and economic costs by using recycled components to build new buildings within a reasonable transportation distance. Therefore, it is feasible to recycle steel structural assembly building components.
(2) In the case of this paper, when the transportation distance of the component recovery process is less than 1800 km, the use of the recovery component not only produces less carbon emissions than the use of new components, but also requires less cost.

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