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Calculation of Carbon Emissions throughout the Lifecycle of Buildings Based on BIM Technology

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Abstract: *This paper comprehensively discusses the carbon emissions of steel structures and the application of Building Information Modeling (BIM) in the construction industry. Carbon emissions from steel structures are crucial for global climate change and sustainable development. BIM models utilize computer technology to manage architectural information, playing a significant role in both design and construction phases. Life Cycle Assessment (LCA) is a systematic approach to evaluating the environmental impacts of products, processes, or activities throughout their entire lifecycle, providing scientific basis for environmental management. By integrating BIM models with LCA methodology, it is possible to achieve more efficient and environmentally friendly energy utilization and emission reduction goals, thereby driving the construction industry towards a more sustainable direction.*

Keywords: *LCA technology; carbon emissions; BIM model; energy conservation and emission reduction; steel structures*

1. Introduction

1.1. Current Status of Carbon Emissions in the Construction Industry

The construction industry stands as one of the primary contributors to global greenhouse gas emissions, accounting for approximately one-third of the total emissions. This is primarily due to the substantial carbon dioxide emissions generated throughout the construction, operation, and dismantling processes of buildings[1]. Certain building materials, such as cement and steel, exhibit high carbon footprints due to the extensive energy requirements during their production processes. Many nations and regions have implemented regulations and policies aimed at reducing carbon emissions within the construction industry. These measures may encompass energy efficiency standards, carbon pricing mechanisms, as well as regulatory and reporting requirements concerning carbon emissions. Consequently, mitigating carbon emissions within the construction industry has become a crucial global endeavor in climate change mitigation.

1.2. Current Research Status of Carbon Emissions Domestically and Internationally

1.2.1. Research Status of Carbon Emissions in the Production Phase of Buildings

Internationally, researchers have established carbon emission inventories specifically targeting the production processes of buildings, meticulously documenting the carbon emissions generated during the production of various building materials[2]. Such inventories aid in evaluating the carbon footprint of building materials and guide architectural design and material selection. Researchers are actively investigating and developing more environmentally friendly building materials to reduce carbon emissions during the production process[3]. This includes the utilization of renewable materials, adoption of low-carbon production technologies, or exploration of alternative materials. Implementing energy-efficient and carbon reduction technologies during the production phase can mitigate carbon emissions. Measures such as employing clean energy supplies and improving process workflows can effectively reduce carbon emissions[4]. Some international standards and policy directives have begun to necessitate considerations of carbon emissions during the production phase within the construction industry. The implementation of these standards and policies has propelled research and attention towards carbon emissions in building production.

Domestically, research on carbon emissions during the production phase of buildings is gradually deepening, with scholars striving to establish carbon emission inventories for building material production processes[5]. They are exploring assessment tools such as Life Cycle Assessment (LCA) and

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carbon footprint analysis to comprehensively evaluate the carbon emissions of various building materials. Simultaneously, research efforts are also focused on the development and application of environmentally friendly building materials, the application of energy efficiency and carbon reduction technologies in the production process, and alignment with policy standards[6]. These endeavors aim to facilitate the transformation of the construction industry towards a low-carbon development model.

1.2.2. Research Status of Carbon Emissions in the Transportation Phase of Buildings

Research on carbon emissions during the transportation phase of buildings is increasingly garnering attention, with scholars focusing on assessing the carbon emissions of building materials during transportation from production sites to construction sites. These studies encompass comparisons of carbon emissions across different transportation modes (such as road transport, rail transport, water transport, etc.), the relationship between transportation distance and carbon emissions, and the impact of enhancing transportation efficiency and applying carbon reduction technologies on carbon emissions[7]. Furthermore, researchers are also attentive to the optimization of transportation networks, implementation of green logistics policies, and the application of renewable energy in the transportation sector, aiming to provide scientific support and policy recommendations for carbon reduction within the construction industry.

1.2.3. Research Status of Carbon Emissions in the Demolition Phase of Buildings

The research status of carbon emissions in the demolition phase of buildings is exhibiting a growing level of attention[8]. Scholars are delving into the carbon emissions generated during the demolition, disposal, and recycling processes of buildings, primarily focusing on aspects including the handling, transportation, and reuse or disposal of demolition materials. The research encompasses the establishment of carbon emission inventories, assessment of the carbon footprint during the demolition process, and the application of carbon reduction technologies[9]. Simultaneously, there is an exploration of formulating relevant policies and standards to reduce carbon emissions in the demolition phase, thus propelling the construction industry towards more environmentally friendly and sustainable practices.

1.3. Research Objectives

- Establishing BIM models for traditional prototype houses and cold-formed thin-walled steel structures in the region.
- Calculating carbon emissions through the extraction of detailed tables from precision models.

1.4. Research Significance

Compared to traditional prototype houses, cold-formed thin-walled steel structure prototype houses exhibit lower carbon emissions throughout the building's lifecycle and demonstrate higher performance levels while significantly reducing the demand for steel. Particularly in regions with limited transportation access like Plateau, their advantages are more pronounced, providing robust support for the promotion of low-carbon energy-efficient buildings. Therefore, the application of this technology is of significant importance for the construction industry to achieve peak carbon emissions and carbon neutrality goals at an early stage, facilitating the transition of the entire industry towards a more sustainable development model.

2. Analysis of Building Lifecycle Based on BIM Technology

2.1. Establishment of BIM Models

Create corresponding BIM models based on CAD drawings. (see *Figure 1)*

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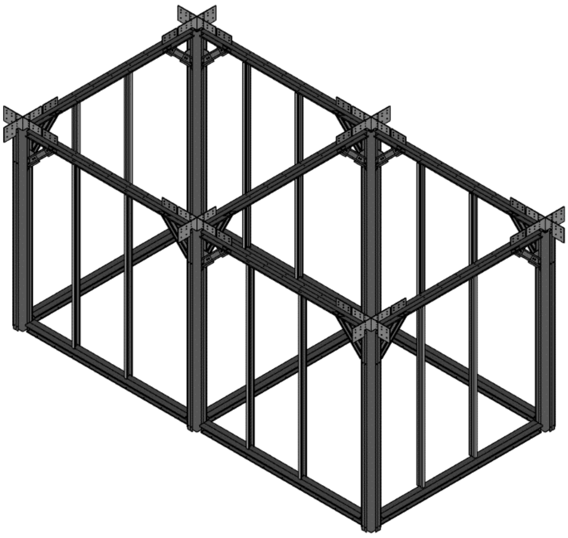
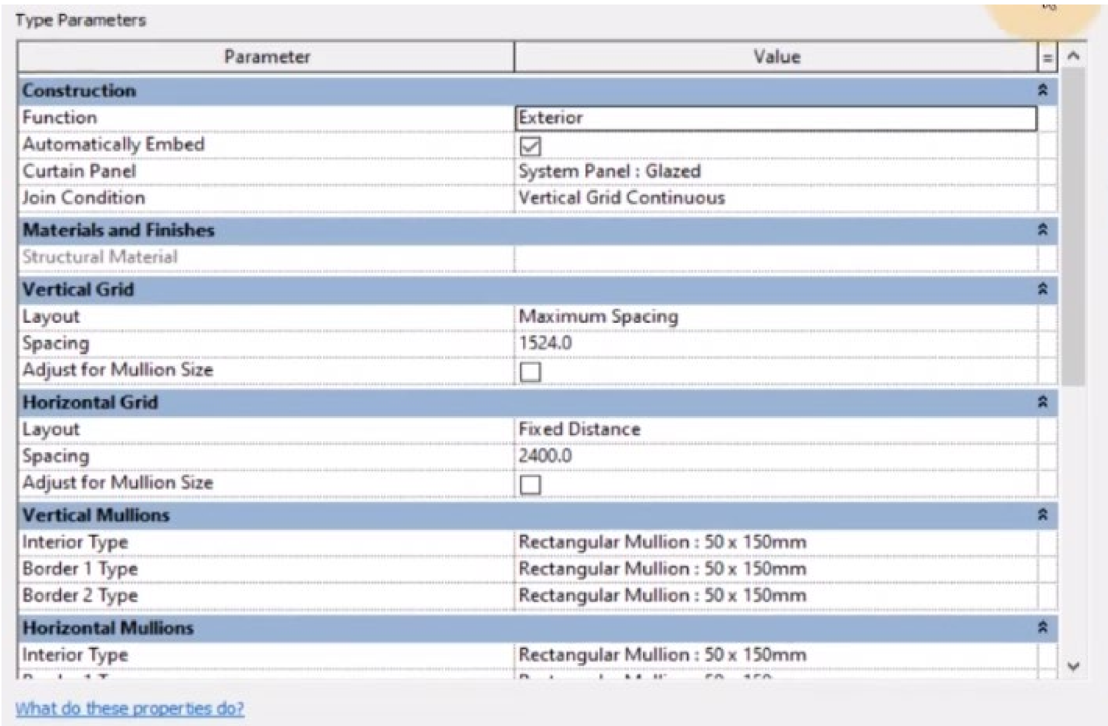


Figure 1:material information.

2.2. Parameter Setup

Configure parameter information for corresponding materials within the BIM model. (see *Figure 2)*



Type Parameters

Parameter	Value
Construction	
Function	Exterior
Automatically Embed	☑
Curtain Panel	System Panel : Glazed
Join Condition	Vertical Grid Continuous
Materials and Finishes	
Structural Material	
Vertical Grid	
Layout	Maximum Spacing
Spacing	1524.0
Adjust for Mullion Size	☐
Horizontal Grid	
Layout	Fixed Distance
Spacing	2400.0
Adjust for Mullion Size	☐
Vertical Mullions	
Interior Type	Rectangular Mullion : 50 x 150mm
Border 1 Type	Rectangular Mullion : 50 x 150mm
Border 2 Type	Rectangular Mullion : 50 x 150mm
Horizontal Mullions	
Interior Type	Rectangular Mullion : 50 x 150mm

What do these properties do?

Figure 2:material information.

2.3. Exporting Detailed Tables

Export detailed tables from the BIM model. (see *Figure 3)*

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Steel Consumption Details Table (Single Module - 19.7 m²)							
Component	Type	Unit	Volume	Density	Mass	Quantity	Total Mass (kg)
Column	Single Board - Middle Column	/m	846.84	7.85	6.65	24.00	159.54
	Single Board - Edge Column	/m	522.71	7.85	4.1	12.00	49.24
	Single Board - Corner Column	/m	517.75	7.85	4.06	24.00	97.54
Beam	Single Limb - Top Beam	/m	621.6	7.85	4.88	21.87	106.72
	Single Limb - Bottom Beam	/m	731.4	7.85	5.74	21.87	125.57
Crosspiece	Edge Column	/unit	4733.86	7.85	37.16	2.00	74.32
	Corner Column	/unit	1474.54	7.85	11.58	8.00	92.6
Column Spacer	Middle & Edge Column	/unit	6.24	7.85	0.05	112.00	5.49
	Corner Column	/unit	12.78	7.85	0.1	28.00	2.81
Beam Spacer	Top & Bottom Beam	/unit	60.53	7.85	0.48	5.00	2.38
Rectangular Square Tube	Rectangular Tube Connector	/unit	19.32	7.85	0.15	40.00	6.07
	70*50*3	/unit	2052	7.85	16.11	10.00	161.08
Purlin	C Shape	/bar	896	7.85	7.03	4.00	28.13
	L Shape Connector	/unit	4.51	7.85	0.04	16.00	0.57
Colored Steel Corner Column			1450.34	7.85	11.39	8.00	91.08
Total Mass							1003.13
Average Steel Consumption							50.92

Figure 3:Detailed Breakdown of Cold-formed Steel.

3. Calculation of Carbon Emissions throughout the Lifecycle

3.1. Production Phase

The carbon emissions during the production phase can be calculated by multiplying the consumption of building materials by the carbon emission factors specified in the norms for carbon emission factors of building materials. (see Figure 4)

Building Material Category	Carbon Emission Factor
C30 Concrete	295 kg CO_2e/m^3
C50 Concrete	385 kg CO_2e/m^3
Hot-rolled Carbon Steel - Small	2,310 kg CO_2e/t
Hot-rolled Carbon Steel - Medium	2.365 kg CO_2e/t
Hot-rolled Carbon Steel - H	2,350 kg CO_2e/t
Hot-rolled Carbon Steel - Rebar	2,340 kg CO_2e/t
Concrete Brick (240mmx115mmx90mm)	336 kg CO_2e/m^3
Autoclaved Fly Ash Brick	341 kg CO_2e/m^3

Figure 4:Carbon Emission Factors of Building Materials.

3.2. Transportation Phase

According to the "Standard for Calculation of Carbon Emissions from Buildings" (GBT 51366-2019), the calculation method for carbon emissions during the transportation phase of building materials is specified as follows:

$$C_{ys} = \sum_{i=1}^{N} M_i D_i T_i$$

In the formula: C_{ys} represents the carbon emissions during the transportation phase of building materials (kg Ce); Mi denotes the consumption amount of the ith major building material; Di signifies the average transportation distance of the ith building material (km);T_i indicates the unit weight transportation under the transportation mode of the respective building material. (see *Table 1,2)*

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Table 1: The Carbon Emission Factor of Electricity.

Power Grid Region	Electricity Carbon Emission Factor
North China	1.03
Northeast	1.11
East China	0.81
Central China	0.98
Northwest	0.97
South China	0.92

Table 2: The Carbon Emission Factor of Engineering Machinery.

Mechanical carbon emission factor, unit: kg CO2 e/m3.						
Machine	**Per m³ tonnage**	**Energy**	**Energy consumption per tonnage (kg, kwh)**	**Energy carbon emission factor**	**Carbon emissions**	**Total**
Hoist	0.928	Electric	33	0.81	25	425
Cutter	0.749	Electric	32	0.81	19	
Bender	1.529	Electric	13	0.81	16	
Arc welder	3.814	Electric	97	0.81	300	
Spot welder	0.655	Electric	122	0.81	65	

3.3. Recycling Phase

The carbon emissions during the recycling phase can be calculated based on the amount of steel recovered after demolition and the carbon emission factor for steel structures determined in section 3.1.

4. Case Study

This paper employs an actual project featuring a cold-formed thin-walled steel structure framework with dimensions of 5.8m × 3m × 3.9m × 2.8m. The carbon emissions can be calculated using the carbon emission factors and formulas provided in Chapter Three. (see *Table 3,4)*

Table 3: Cold-formed Steel Structure.

"The Lifecycle Carbon Emissions of a Cold-formed Thin-walled Steel Structure Frame of Dimensions 5.8m×3m×3.9m×2.8m" (Unit: Tons)	
Production Stage	13.4286
Transportation Stage	11.4631
Recycling Stage	8.4753

Table 4: Conventional Steel Structure.

"The Lifecycle Carbon Emissions of a Steel Structure Frame with Dimensions 5.8m×3m×3.9m×2.8m" (Unit: Tons)	
Production Stage	18.5631
Transportation Stage	11.8351
Recycling Stage	10.390 2

5. Conclusion and Improvements

5.1. Conclusion

(1)By comparing the carbon emissions of cold-formed steel structures with conventional steel structures, it can be concluded that the carbon emissions of cold-formed steel structures during the production phase are approximately two-thirds of that of conventional steel structures. This is because cold-formed steel requires less steel consumption per unit area compared to hot-rolled steel. Although the carbon emissions of hot-rolled steel during manufacturing processes are lower than those of cold-

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formed steel structures, the overall carbon emissions of cold-formed steel are lower.

(2)There is little difference between the two in the transportation phase. This is mainly because cold-formed steel components can be assembled in a jointed manner, which saves space compared to hot-rolled steel structures. By reducing the number of transportation vehicles, carbon emissions can be minimized. Therefore, the more materials required, the higher the carbon reduction. Cold-formed steel frameworks have a greater advantage.

(3)The carbon emissions during the recycling phase are low due to the fact that cold-formed steel structures are assembled using bolts, while hot-rolled steel structures are installed using welding. Therefore, during the demolition phase, the recovery rate of cold-formed steel structures is higher, resulting in lower carbon emissions.

5.2. Improvements

(1) Further research could explore additional factors affecting carbon emissions in each phase, such as energy consumption during production and transportation.

(2) Investigating alternative transportation methods and materials could provide insights into further reducing carbon emissions.

(3) Implementing policies and incentives to promote the use of cold-formed steel structures could encourage the adoption of more environmentally friendly building materials.

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