Optimization Study on Carbon Emissions Reduction of Tram Stations Based on Life Cycle Assessment

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Abstract. As one of the largest carbon emissions sector in China, the transportation sector accounts for about 10% of the total carbon emissions in China. Urban rail transit plays a pivotal role in promoting the green development of the transportation sector, yet it also contributes to carbon emissions. Studying the life cycle carbon emissions of urban rail transit stations is crucial for achieving China's dual carbon goals. This paper focuses on a tram station in Guangzhou, applying life cycle assessment (LCA) theory to compute and analyze its total carbon emissions. Furthermore, it proposes carbon reduction strategies and quantitatively assesses their potential. The analysis reveals that the life cycle carbon emissions amount to 5,475,431.8 kg CO_{2e}, with a potential reduction of 1,109,824.5 kg CO_{2e}, corresponding to a 20.3% reduction potential. The findings aim to provide insights for energy conservation and emissions reduction at urban rail transit stations, fostering the green development of the sector and supporting China's strategies for Carbon peak and Carbon neutrality.

Keywords: Urban rail transit, Tram station, Life cycle assessment, Reduction potential.

1 Introduction

Currently, as China's urbanization level rapidly advances, environmental issues caused by the sharp emissions of greenhouse gases such as carbon dioxide have garnered widespread attention. The transportation sector, as one of the four major sectors contributing to China's carbon emissions, accounts for 10% of the total national emissions. Reducing carbon emissions in this sector is crucial for achieving China's goals of Carbon peak and Carbon neutrality. In early 2020, the CHINA ASSOCIATION OF METROS released the " Development Outline of Smart Urban Rail Transit in China." [1]. Urban rail transit, as a green mode within the transportation sector, plays a significant role in promoting low-carbon development. Studies indicate that carbon emissions from urban rail transit stations constitute a substantial portion of the total emissions within the urban rail transit system.

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Therefore, conducting research on carbon reduction optimization for China's urban rail transit stations is of great significance. It not only provides references for the low-carbon construction of these stations but also significantly impacts the low-carbon development of the transportation sector overall.

A substantial body of research has already addressed the carbon emissions associated with urban rail transit systems, focusing primarily on the life cycle assessments and operation phase carbon emissions of entire lines or specific stations. Domestically, J Long et al. have developed models for calculating carbon emissions during the operation phase of metro vehicles and stations, with practical applications tested on the Shanghai and Guangzhou metro systems [2]. Ao Qin et al. have offered targeted suggestions for carbon emissions reduction during both the materialization and operation phases of a metro station on Chengdu's Metro Line 3 [3]. S Qian et al. have calculated the LCA carbon emissions of an urban rail transit station and provided qualitative energy-saving and emission-reduction measures [4]. X Li et al. have calculated the LCA carbon emissions of a new metro line in Beijing, quantitatively assessing its carbon reduction potential [5]. Internationally, Sanches de Andrade et al. have calculated the LCA carbon emissions of the Brazilian metro system, comparing it with emissions from private cars and buses [6]. Jasti et al. have identified the best carbon emissions reduction strategy for two transportation modes on Mumbai's Metro Line 1 in India [7].

Despite the considerable body of research, few studies have directly focused on the LCA carbon emissions of urban rail transit stations and their potential for carbon emissions reduction optimization. Therefore, this paper targets an urban rail transit station, specifically a tram station in Guangzhou, as its research subject. Employing LCA theory, this study calculates and analyzes the station' s LCA carbon emissions. It also quantitatively assesses the potential for carbon emissions reduction optimization. The aim is to provide insights for energy-saving and emission-reduction at urban rail transit stations, promote the green development of the urban rail transit and support China's strategies for Carbon peak and Carbon neutrality.

2 LCA Carbon Emissions Calculation Model for Tram Stations

Based on the LCA theory, the carbon emissions accounting for tram stations can be divided into the design, materialization, operation and demolition phases. Carbon emissions during the design phase represent a minimal fraction of the LCA carbon emissions and are difficult to quantify. Currently, there is a lack of case data for the demolition phase, which necessitates the use of simplified calculations for estimation. Therefore, in the LCA carbon emissions accounting of tram stations, the focus should primarily be on the materialization and operation phases, with the demolition phase accounted for through simplified calculations, and the design phase excluded. This paper uses CO_2 as the base emission unit, converting other greenhouse gases to CO_2 equivalents (CO_{2e}) for calculation purposes. The calculation method follows the " Standard for building carbon emission calculation (GB/T 51366-2019)."

2.1 Carbon Emissions during Materialization Phase

The carbon emissions during the materialization phase of tram stations encompass building material production, building material transportation and on-site construction. The formula for calculating the carbon emissions during the materialization phase is as follows:

$$C_{\mathrm{wh}} = C_{\mathrm{sc}} + C_{\mathrm{ys}} + C_{\mathrm{jz}} \tag{1}$$

C_{wh} represents carbon emissions during the materialization phase of the tram stations, $kgCO_{2e}$; C_{sc} represents carbon emissions from building material production, $kgCO_{2e}$; C_{ys} represents carbon emissions from building material transportation, $kgCO_{2e}$; C_{jz} represents carbon emissions from on-site construction, $kgCO_{2e}$.

The carbon emissions from building material production and building material transportation should include the structural body, envelope structures and architectural components of the tram station. The formula for calculating the carbon emissions from building material production is as follows:

$$C_{\mathrm{sc}} = \sum_{i=1}^{n} M_i F_i (1 - \alpha_i) \tag{2}$$

C_{sc} represents carbon emissions from building material production, $kgCO_{2e}$; M_i represents the consumption of the i-th type of major building material, t; F_i represents the carbon emission factor of the i-th type of major building material, $kgCO_{2e}$/unit of material; α_i represents the recycling factor of the i-th type of major building material.

The formula for calculating the carbon emissions from building material transportation is as follows:

$$C_{\mathrm{ys}} = \sum_{i=1}^{n} M_i D_i T_i \tag{3}$$

C_{ys} represents carbon emissions from building material transportation, $kgCO_{2e}$; M_i represents the consumption of the i-th type of major building material, t; D_i represents the average transportation distance for the i-th type of building material, km; T_i represents the carbon emission factor for the transportation method of the i-th type of building material, $kgCO_{2e}/(t \cdot km)$.

The formula for calculating the carbon emissions from on-site construction is as follows:

$$C_{\mathrm{jz}} = \sum_{i=1}^{n} E_{\mathrm{jz},\, i} EF_i \tag{4}$$

C_{jz} represents carbon emissions from on-site construction, $kgCO_{2e}$; $E_{\mathrm{jz},\, i}$ represents the total energy consumption of the i-th type of energy, kWh or kg; EF_i represents the carbon emission factor of the i-th type of energy, $kgCO_{2e}$/kWh or $kgCO_{2e}$/kg.

2.2 Carbon Emissions during Operation Phase

The carbon emissions during the operation phase of tram stations encompass air conditioning, lighting, equipment and other systems. The formula for calculating the carbon emissions during the operation phase is as follows:

$$C_{\mathrm{yx}} = [\sum_{i=1}^{n} (E_i EF_i) - C_{\mathrm{p}}]y \tag{5}$$

$$E_i = \sum_{j=1}^{n} (E_{i,j} - ER_{i,j}) \tag{6}$$

C_{yx} represents carbon emissions during the operation phase of the tram stations, $kgCO_{2e}$; E_i represents the annual consumption of the i-th type of energy, kWh/a or kg/a; EF_i represents the carbon emission factor of the i-th type of energy, $kgCO_{2e}$/kWh or $kgCO_{2e}$/kg; $E_{i,j}$ represents the consumption of the i-th type of energy by the j-th system, kWh/a or kg/a; $ER_{i,j}$ represents the consumption of the i-th type of energy consumed by the j-th system that is provided by renewable energy systems, kWh/a or kg/a; C_{p} represents the annual green carbon sink amount of the tram station, $kgCO_{2e}$/a; y represents the designed lifespan of the tram station,a.

2.3 Carbon Emissions during Demolition Phase

The carbon emissions during the demolition phase of tram stations encompass building demolition, building waste transportation and building waste disposal. According to research, the carbon emissions from building demolition can be estimated as 90% of it from on-site construction during the materialization phase. The carbon emissions from the building waste transportation can be estimated as 90% of it from building material transportation during the materialization phase [8]. Because the carbon emissions from building waste disposal has already been calculated through the recycling factor during the building material production phase, it is not recalculated in this phase. Therefore, the formula for calculating the carbon emissions during the demolition phase is as follows:

$$C_{\mathrm{cc}} = \left(C_{\mathrm{jz}} + C_{\mathrm{ys}}\right) \times 90\% \tag{7}$$

C_{cc} represents carbon emissions during the demolition phase of the tram stations, $kgCO_{2e}$; C_{jz} represents carbon emissions from on-site construction, $kgCO_{2e}$; C_{ys} represents carbon emissions from building material transportation, $kgCO_{2e}$.

Considering all relevant phases, the formula for calculating the LCA carbon emissions of the tram stations is as follows:

$$C_{LCA} = C_{\mathrm{wh}} + C_{\mathrm{yx}} + C_{\mathrm{cc}} \tag{8}$$

C_{LCA} represents the LCA carbon emissions of the tram stations, $kgCO_{2e}$; C_{wh} represents carbon emissions during the materialization phase of the tram stations, $kgCO_{2e}$; C_{yx} represents carbon emissions during the operation phase of the tram stations, $kgCO_{2e}$; C_{cc} represents carbon emissions during the demolition phase of the tram stations, $kgCO_{2e}$.

3 LCA Carbon Emission Calculation and Analysis for Tram Stations

3.1 Basic Case Information

This study selects a standard side-platform station on Line 2 of the tram system in Huangpu District, Guangzhou as the case. The station has a total length of 58 m, a width of 12.65 m, an effective platform length of 40 m on one side, a width of 3m, and a canopy height of 4.69 m. The platform area is 240 m^2, with a total constructed area of 523 m^2.The station plan is shown in **Fig.1** and the aerial view is shown in **Fig.2**.The main components of the station include the platform, canopy, accessible ramp and tram track sections. Since parts of this line are still under construction and not fully operational, with only the northern section having completed trial operations, this paper predicts the LCA carbon emissions for this station as a reference for future calculations when the line is fully operational.

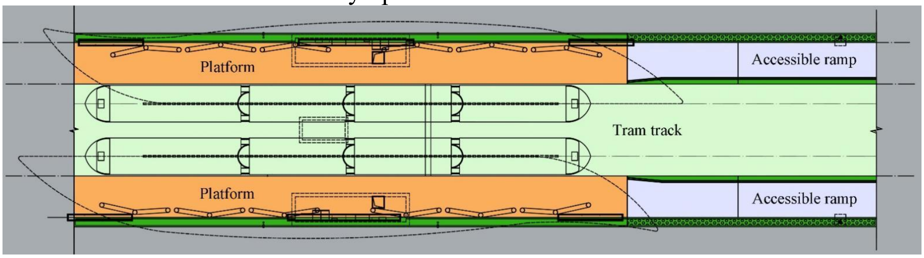

Fig.1. The station plan.

Fig.2. The station aerial view.

3.2 Carbon Emissions during Materialization Phase

For the materialization phase of the tram station in this case study, the material boundaries are confined to the architectural aspects of the tram station. The tram track sections within the design scope of the station, which do not fall under the architectural category, are excluded from consideration. Based on the engineering design drawings and other relevant technical documents of the case station, the consumption of building materials for the canopy structure, platform layer and ramps has been quantified. Using the LCA carbon emission calculation model for tram stations, the carbon emissions during the materialization phase of the case station are calculated.

Carbon Emissions from Building Material Production. The calculation of carbon emissions from building materials production for the tram station is based on the quantities consumed and the carbon emission factors. For materials where carbon emission factors are not specified in the " Standard for building carbon emission calculation (GB/T 51366-2019)," factors from other scholarly research within China are referenced. According to the formula (2), the carbon emissions of the main building materials used in the case station including steel reinforcement, steel pipes, aluminum, concrete, cement, sand, crushed stone and ceramic tiles are calculated. The total carbon emissions from building materials production for the case station amount to 82,859 kg CO_{2e}, as shown in the **Table 1**.

Table 1. Carbon Emissions from Building Material Production.

Material name	Quantity	Unit	Carbon emission factor (kgCO2e/Unit)	Recycling factor	Carbon emissions (kgCO2e)
Steel reinforcement	1.74	t	2340	0.4	2443
Steel pipes	56.9	t	3150	0.85	26885.3
Aluminum	7.74	t	28500	0.85	33088.5
Concrete 20	13.92	m^3	265	0.7	1106.6
Concrete 30	100.22	m^3	295	0.7	8896.5
Cement	14.36	t	795	0.48	5936.4
Sand	43.1	t	2.51	0.5	54.1
Crushed stone	201.6	t	2.18	0.5	219.8
Ceramic tiles	288	m^2	15.96	0.08	4228.8
Total					82859

As is shown in the **Fig.3**, during the building materials production of the case tram station, the carbon emissions from aluminum are the highest, while it from sandstone are the lowest. The carbon emissions from steel and aluminum significantly outweigh those from other building materials. According to **Fig.4**, steel accounts for 35.4% of the carbon emissions, while aluminum accounts for 39.9%, with the emissions from other materials account for less than 25% of the total. This distribution is due to the design specifics of the case, where the overhead canopy is supported by steel pipes and shielded with aluminum profiles, resulting in high usage of these materials and their high carbon emission factors. Therefore, it is crucial to focus on the use of steel and aluminum in the construction process. Efforts should be made to minimize waste and consider the adoption of more environmentally friendly materials to achieve carbon reduction targets.

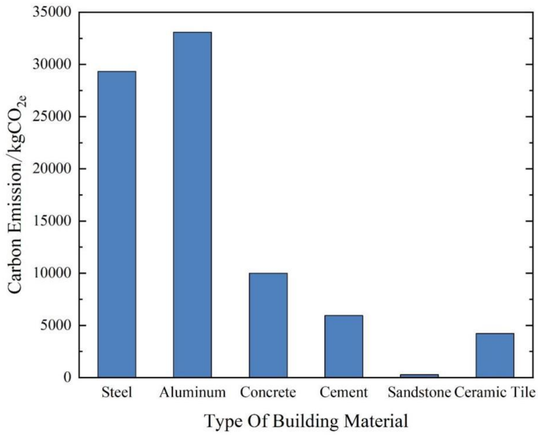

Fig.3. Carbon Emissions from Major Building Material Production.

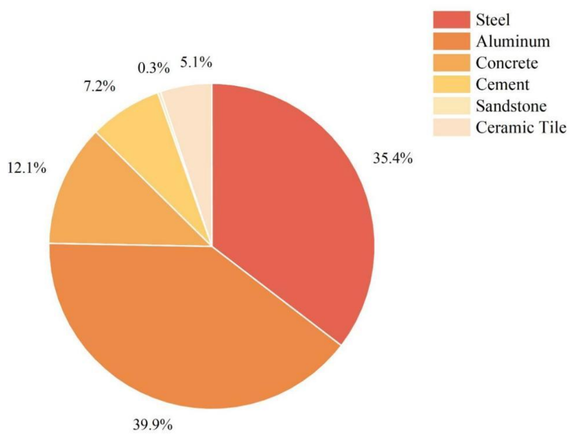

Fig.4. Distribution of Carbon Emissions from Major Building Material Production.

Carbon Emissions from Building Material Transportation. Based on field research, the average transportation distance for materials such as concrete, cement and sandstone are approximately 40 km; for other materials, the average distance is about 100 km. The primary mode of transportation is by road using diesel fuel. The carbon emissions from building material transportation are calculated based on the quantity of materials, the transportation distances and the transportation carbon emission factors. Where the " Standard for building carbon emission calculation (GB/T 51366-2019)." lacks specific transportation carbon emission factors, those from other scholarly research within China are referenced. According to the formula (3), the carbon emissions from building material transportation are detailed in the **Table 2**, with the total carbon emissions for this case amounting to 3007.7 $kgCO_{2e}$.

Table 2. Carbon Emissions from Building Material Transportation.

Material name	Quantity (t)	Distance (km)	Transportation methods	Carbon emission factor ($kgCO_{2e}$/t·km)	Carbon emissions ($kgCO_{2e}$)
Steel reinforcement	1.74	100	Heavy-Duty diesel truck (30t)	0.078	13.6
Steel pipes	56.9	100	Heavy-Duty diesel truck (30t)	0.078	443.8
Aluminum	7.74	100	Heavy-Duty diesel truck (30t)	0.078	60.4
Concrete 20	33.41	40	Concrete mixer truck ($12m^3$)	0.098	131
Concrete 30	255.56	40	Concrete mixer truck ($12m^3$)	0.098	1001.8
Cement	14.36	40	Tanker truck (30t)	0.035	20.1
Sand	43.1	40	Heavy-Duty diesel truck (18t)	0.129	222.4
Crushed stone	201.6	40	Heavy-Duty diesel truck (18t)	0.129	1040.3
Ceramic tiles	5.76	100	Heavy-Duty diesel truck (18t)	0.129	74.3
Total					3007.7

As is shown in the **Fig.5**, during the building material transportation of the case tram station, the carbon emissions from sandstone are the highest, while it from cement are the lowest. The carbon emissions from concrete and sandstone significantly exceeding it from other materials. According to **Fig.6**, concrete accounts for 37.7% of the carbon emissions, sandstone accounts for 42%, and other materials account for about 20%. This is due to the large total mass of concrete and sandstone required for the construction, necessitating the use of more vehicles and thus generating higher carbon emissions. Therefore, adopting more environmentally friendly and low-carbon transportation methods, using locally sourced materials and reducing transportation distances are crucial for decreasing carbon emissions from building material transportation.

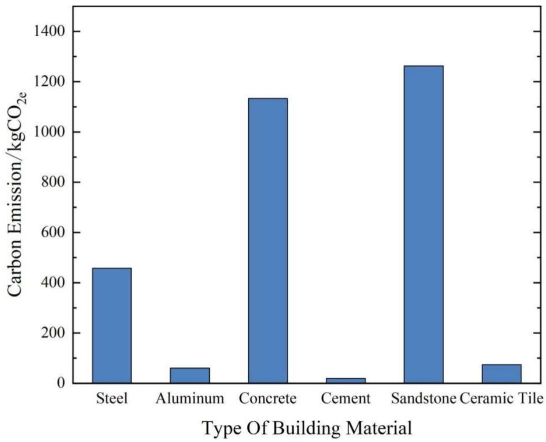

Fig.5. Carbon Emissions from Major Building Material Transportation.

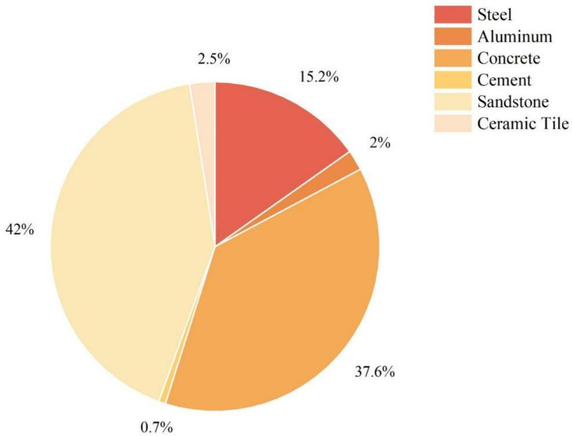

Fig.6. Distribution of Carbon Emissions from Major Building Material Transportation.

Carbon Emissions from On-site Construction. Based on the bill of quantities, carbon emissions generated by the energy consumption of construction machinery during the main construction processes are calculated, with an additional 5% estimated for carbon emissions from temporary facilities. According to the "Norms of Energy Consumption for Housing Construction and Decoration Engineering," the consumption for each unit of construction machine-team is determined. Then, according to the "Standard for Calculation of Building Carbon Emissions (GB/T 51366-2019)" for the energy usage of construction machine-team, the total carbon emissions from all energy consumed are calculated by formula (4). The primary energy sources for construction machinery are electricity and diesel. The carbon emission factor for electricity is 0.4715 $kgCO_{2e}$/kWh and diesel is 3.12 $kgCO_{2e}$/kg [9]. The carbon emissions for each construction machinery are shown in **Table.3**, resulting in a carbon emission of 461.8 $kgCO_{2e}$. The carbon emissions from temporary facilities is 23.1 $kgCO_{2e}$. Therefore, the total carbon emissions from the on-site construction of the case station amount to 484.9 $kgCO_{2e}$.

Table.3 Carbon Emissions from Construction Machinery

Type and model of machinery	Energy consumption	Unit	Carbon emission factor ($kgCO_{2e}$/t·km)	Carbon emissions ($kgCO_{2e}$)
Crawler single bucket hydraulic excavator (1m³)	19.53	kg	3.12	60.9
Electric tamper (250N·m)	8.3	kWh	0.4715	3.9
Crawler bulldozer (75kW)	21.47	kg	3.12	70.0
Crawler rotary drilling rig (1000mm)	43.97	kg	3.12	137.2
Crawler crane (10t)	5.65	kg	3.12	17.6
Truck (6t)	16.29	kg	3.12	50.8
Dump truck (15t)	3.29	kg	3.12	10.3
Mortar mixer (200L)	2.93	kWh	0.4715	1.4
Concrete spreader	13.65	kWh	0.4715	6.4
Steel bar cutter (40mm)	4.49	kWh	0.4715	2.1
Bar bending machine (40mm)	4.5	kWh	0.4715	2.1
Ac arc welding machine (32kV·A)	156.38	kWh	0.4715	73.7
Butt welder	53.92	kWh	0.4715	25.4
Total				461.8

In summary, during the materialization phase of the case tram station, the carbon emissions from the building materials production amount to 82,859 $kgCO_{2e}$, building material transportation amounts to 3,007.7 $kgCO_{2e}$ and on-site construction amounts to 484.9 $kgCO_{2e}$. Therefore, the total carbon emissions during the materialization phase are 86,351.6 $kgCO_{2e}$. The distribution of carbon emissions during the Materialization Phase is shown in **Fig.7**, and the majority of these emissions stem from the building materials production account for 95.8% of the total emissions. This is followed by building material transportation at 3.6%, and the smallest portion comes from the on-site construction, which represent only 0.6%.

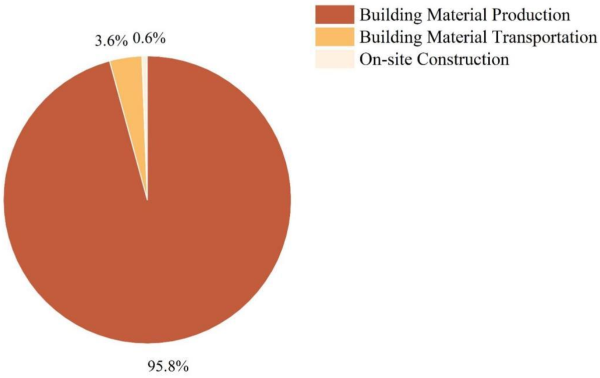

Fig.7. Distribution of Carbon Emissions during the Materialization Phase

3.3 Carbon Emissions during Operation Phase

The case tram station is an open-style station designed with a service life of 50 years and it operates daily from 7:00 AM to 9:00 PM. Based on field research, the significant sources of carbon emissions during operation phase include: lighting, tram charging equipment and other equipment. The station does not use air conditioning due to its open design, and carbon emissions reductions from landscaping and renewable energy are not included in this assessment. The station real-life photo is shown in the **Fig.8.**

Fig.8. The Station Real-life Photo

Based on the lighting requirements and regulations for the station, the lighting power density is set at $5W/m^2$ with a daily lighting duration of 2 hours. According to research papers and field studies, each tram consumes about 5 kWh of electricity per kilometer, and with approximately 150 trips per day, the total electricity consumption for tram charging can be calculated. Additionally, other equipment includes 4 PIDS screens, 4 advertising display screens and 2 automatic ticket machines, with power ratings of 70W, 250W, and 200W respectively, all operating for 14 hours per day. According to the formula (5), the total carbon emissions during the operation phase are calculated and shown in the **Table.4,** amounting to 5,385,960 $kgCO_{2e}$.

Table.4 Carbon Emissions during Operation Phase

System	Annual energy consumption (kWh)	Carbon emission factor (kgCO2e/kWh)	Annual carbon emission (kgCO2e)	LCA carbon emissions (kgCO2e)
Lighting	876	0.4715	413	20650
Charging equipment	219000	0.4715	103258.5	5162925
Other equipment	8584.8	0.4715	4047.7	202385
Total				5385960

As is shown in **Fig.9,** during the operation phase, the carbon emissions from tram charging equipment are significantly higher than those from lighting and other equipment. As is shown in **Fig.10,** tram charging equipment accounts for 95.6% of the carbon emissions, other equipment for 4%, and lighting for only 0.4%. To effectively reduce emissions during this phase, adopting more environmentally friendly options is recommended. This could include using high-efficiency LED lighting fixtures, installing photovoltaic systems on the canopy roofs to increase the use of renewable energy, and planting greenery within the station area to enhance green carbon sink. These measures can significantly contribute to reducing the carbon emissions of the station's operations.

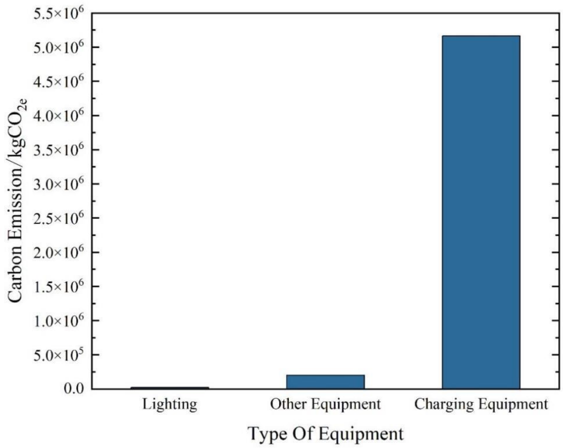

Fig.9. Carbon Emissions from Equipment Operation

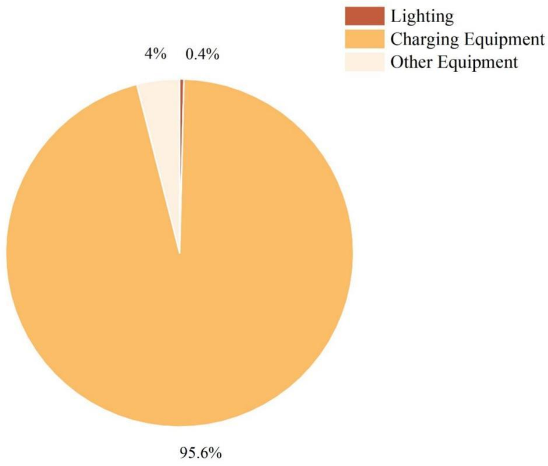

Fig.10. Distribution of Carbon Emissions during the Operation Phase

3.4 Carbon Emissions during Demolition Phase

The carbon emissions for the demolition phase of the case station are estimated by the formula (7). During the materialization phase, the carbon emissions from the building material transportation are 3007.7 $kgCO_{2e}$ and it from the on-site construction are 484.9 $kgCO_{2e}$. Therefore, the total carbon emissions for the demolition phase are 3143.3 $kgCO_{2e}$.

3.5 LCA Carbon Emissions

In summary, the LCA carbon emissions for the case are detailed in the **Table.5**, with a total amount of 5,475,431.8 $kgCO_{2e}$. The total built area of the structure is 523 m^2, resulting in a per square meter carbon emission of 10,469.3 $kgCO_{2e}/m^2$. The distribution of carbon emissions across different life cycle stages is shown in **Fig.11,** where the operation phase accounts for the highest proportion of 98.4%, followed by the materialization phase at 1.6%. The demolition phase accounts for the least, approximately 0%, and is negligible. Therefore, to optimize carbon emissions reduction throughout the LCA, particular attention should be focused on the operation phase. Targeted and rational carbon emissions reduction recommendations should be proposed based on this focus.

Table.5 LCA Carbon Emissions

Life cycle	Specific items	Carbon emission ($kgCO_{2e}$)	Carbon emissions subtotal ($kgCO_{2e}$)
Materialization phase	Building material production	82859	86328.5
	Building material transportation	3007.7	
	On-site construction	484.9	

Operation phase	Lighting Charging equipment Other equipment	20650 5162925 202385	5385960
Demolition phase		3143.3	3143.3
Total			5475431.8

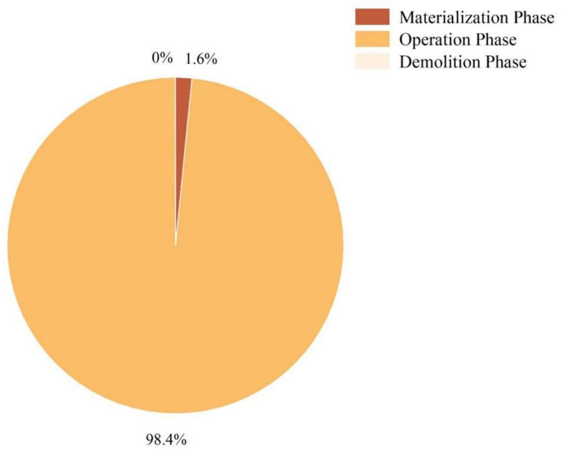

Fig.11. Distribution of Carbon Emissions during the LCA

4 LCA Carbon Emissions Reduction Potential Analysis for Tram Stations

4.1 Materialization Phase

Selection of High-Quality Building Materials. As is shown in the **Fig.4**, the carbon emissions from building material production account for the largest share during the materialization phase at 95.8%. Within this category, steel, aluminum, and concrete have significant carbon emissions, contributing 35.4%, 39.9%, and 12.1%. Therefore, technological optimization of building material production is key to reducing carbon emissions during the materialization phase.

Adopting high-strength steel and aluminum, which offer greater strength and durability, allows for reduced material usage while maintaining structural stability. Enhance the low-carbon evaluation and selection of steel, aluminum, and concrete. Optimize the concrete mix ratio to reduce cement usage under the premise of maintaining normal structural use, utilize low-carbon cement, and thereby decrease carbon emissions.

Optimize Transportation Methods. Select building materials close to the construction site to reduce transportation distances. Use new energy vehicles for material transport, such as natural gas-powered trucks for longer hauls and electric trucks for shorter distances, thereby reducing the carbon emissions. Assuming all building material transportation distances are reduced to 30km, the carbon emissions could be reduced by 1018.5 kgCO_{2e}.

Industrialized Construction. Industrialized construction involves building through prefabrication in factories and assembly on-site, representing a modern, efficient, and low-carbon construction method. Prefabricated components in industrialized construction allow for precise material usage, reducing waste. Factory-based production is generally more energy-efficient than traditional on-site construction, minimizing energy wastage. By employing standardized and modular designs, the construction process is optimized, construction duration is reduced, and environmental pollution during construction is minimized.

4.2 Operation Phase

Optimizing the Use of Station Equipment. Implement intelligent control systems that automatically adjust lighting brightness based on natural light conditions. Opt for high-efficiency, energy-saving electronic devices. For instance, PIDS screens can automatically adjust their display brightness according to natural light, reducing energy waste.

Photovoltaic Power Generation. Photovoltaic power generation can provide tram stations with renewable energy, reducing reliance on traditional fossil fuels and consequently decreasing carbon emissions. By constructing a simplified model of the case station in Rhino and using the Ladybug Tools plugin set within the Grasshopper platform to call Radiance software, solar radiation simulation for the station can be performed. The annual Solar Radiation Simulation for the Case Station is shown in **Fig.12.** Subsequently, using PVsyst software to simulate the photovoltaic system's power generation potential, it is estimated that approximately 2,335,770 kWh of electricity can be generated over the 50-year design lifespan of the station. This generation could reduce carbon emissions by about 1,101,316 kg CO_{2e}.

Green Carbon Sinks. Integrating green spaces within the design perimeter of tram stations can leverage plants' ability to absorb CO_2, creating carbon sinks that reduce carbon emissions and promote the harmonious development of ecology and transportation. The design for the tram station can incorporate 440.6 m^2 of green space, which can reduce carbon emissions by approximately 149.8 kg CO_{2e} annually. Over the 50-year design life of the station, this could result in a total carbon reduction of 7,490 kg CO_{2e}.

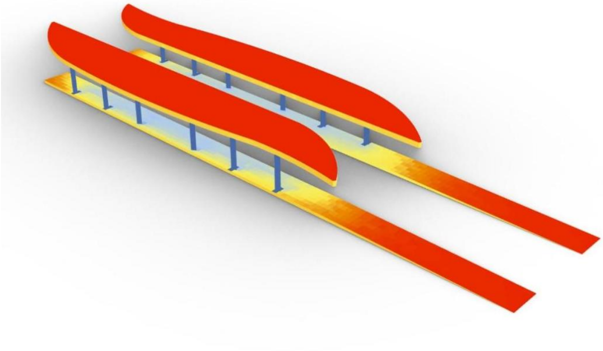

Fig.12 Annual Solar Radiation Simulation for the Case Station

4.3 Demolition Phase

As is shown in the **Fig.11**, the carbon emissions during the demolition phase account for approximately 0% of the total, making them negligible. Therefore, the potential for reducing carbon emissions in this phase is low, and carbon reduction optimization is not considered necessary for this stage.

Through the implementation of the above-mentioned optimization strategies, quantitative analysis shows that the case tram station can achieve a reduction of 1,109,824.5 kgCO_{2e}. With the LCA carbon emission of 5,475,431.8 kgCO_{2e}, this represents a carbon reduction potential of 20.3%. The detailed results of the LCA carbon reduction are presented in the **Table.6**.

Table 6. LCA Carbon Reduction

Life cycle	Carbon emission (kgCO_{2e})	Carbon reduction (kgCO_{2e})	Carbon reduction potential
Materialization phase	86328.5	1018.5	1.2%
Operation phase	5385960	1108806	20.6%
Demolition phase	3143.3	0	0%
Total	5475431.8	1109824.5	20.3%

5 Conclusion

In response to the growing carbon emissions associated with urban rail transit systems, this paper selected a tram station in Guangzhou as the subject of study. Based on the LCA theory, a comprehensive analysis of the station's LCA carbon emissions was conducted. Appropriate strategies were then proposed to analyze its carbon reduction potential, aiming to provide insights for low-carbon construction at other tram stations across China. The main conclusions are as follows:

A comprehensive LCA carbon emission model is developed for the tram stations.

The materialization phase emitted a total of 86,328.5 $kgCO_{2e}$, divided among building materials production (82,859 $kgCO_{2e}$), building materials transportation (3,007.7 $kgCO_{2e}$), and on-site construction (484.9 $kgCO_{2e}$). The operation phase is the most significant, with total emissions of 5,385,960 $kgCO_{2e}$, attributed mainly to tram charging equipment (5,162,925 $kgCO_{2e}$), other equipment (202,385 $kgCO_{2e}$), and lighting (20,650 $kgCO_{2e}$). The demolition phase contributed 3,143.3 $kgCO_{2e}$. Notably, the operational phase accounted for 98.4% of the LCA carbon emissions, highlighting the urgent need for focused carbon reduction strategies in this phase.

To address carbon emissions during the materialization and operational phases of the tram station, specific reduction strategies were proposed and their potential analyzed. During the materialization phase, emissions can be reduced through the selection of high-quality building materials, optimization of transportation methods, and the use of industrialized construction techniques. During the operational phase, emissions can be reduced by optimizing the use of station equipment, implementing photovoltaic power generation, and enhancing green carbon sinks. Collectively, these strategies offer a total carbon reduction potential of 20.3% over the tram station's LCA.

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