Cradle-to-Grave Sustainability Analysis: Comparing Prefabricated and Cast-in-Place High-Rise Building Construction

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Abstract – Construction industry holds a critical position in global carbon emissions and energy consumption, with its significance reflected not only in its substantial carbon footprint and energy demand share but also in its critical role in carbon reduction and sustainable development. This paper conducts comprehensive Life cycle assessment (LCA) research on a prefabricated public housing project and a cast-in-place public housing project in Hong Kong. The study quantifies the environmental performance gap between prefabricated and cast-in-place buildings throughout their life cycles. This investigation encompasses all phases of the life cycle, including material production, construction, usage and maintenance, as well as demolition and disposal. Results show that the greenhouse gas emissions generated by prefabricated buildings during their entire life cycle is reduced by 3.66% compared to cast-in-place buildings. The most significant GWP reductions occur in the construction phase (22.28% reduction) and the use and maintenance phase (2.65% reduction). Based on these findings, targeted recommendations are proposed to enhance the environmental performance of prefabricated buildings, and future research directions are explored.

Keywords – Life Cycle Assessment, Prefabricated Buildings, Global Warming Potential, Sustainable Construction.

1 Introduction

The construction industry significantly impacts global sustainable development. By 2050, the global population is projected to reach 10 billion, and this rapid population growth is expected to further stimulate construction demand. According to projections by the International Energy Agency (IEA), the global building floor area will double by 2050, exceeding 415 billion square meters. This increase in construction demand inevitably intensifies major conflicts concerning population, resources, and the environment [1]. Concurrently, rapid socio-economic development drives the construction industry towards trends of being cost-effective with accelerated timelines [2]. Against this backdrop, prefabricated construction emerges as an innovative building method. Prefabricated building construction refers to structures constructed by dividing buildings into standardized components and modules, manufacturing them in factories, transporting them to the construction site, and assembling them through mechanical connections. Their essence lies in an industrialized construction model of manufacturing plus assembly. Its characteristic feature involves producing building components in specialized facilities and then transporting them to construction sites for assembly into buildings [3], effectively enhancing construction sustainability and efficiency [4].

Pan et al. [5] divide the full life cycle stages into temporal, spatial, functional, and methodological dimensions, including raw material acquisition and transportation, building material production and transportation, prefabrication, construction, operation and maintenance, renovation, demolition, and material recovery. Jaillon et al. [6] investigated the application of prefabrication technology in Hong Kong's residential buildings. Case study results indicate that, compared to traditional cast-in-place construction, prefabricated buildings enhance construction quality, reduce on-site noise, shorten construction time by approximately 20%, and reduce on-site labor requirements by about 9.5%. Zhang et al. [7] conduct research on building projects employing prefabricated construction methods. Their results show that, compared to cast-in-place methods, wood usage decreases by 87%, water consumption reduces by 70%, and construction waste diminishes by 30%.

Apart from energy, natural resources, and waste reduction benefits, it is necessary to investigate the environmental benefits. Among environmental impacts, Global Warming Potential (GWP), primarily manifested as carbon emissions, is one of the most critical aspects and a key focus of this dissertation. Regarding building life cycle carbon emissions, scholars both domestically and internationally conduct relevant research and achieve substantial results. Chen et al. [8] establish a framework using a multi-scale input-output method to analyze

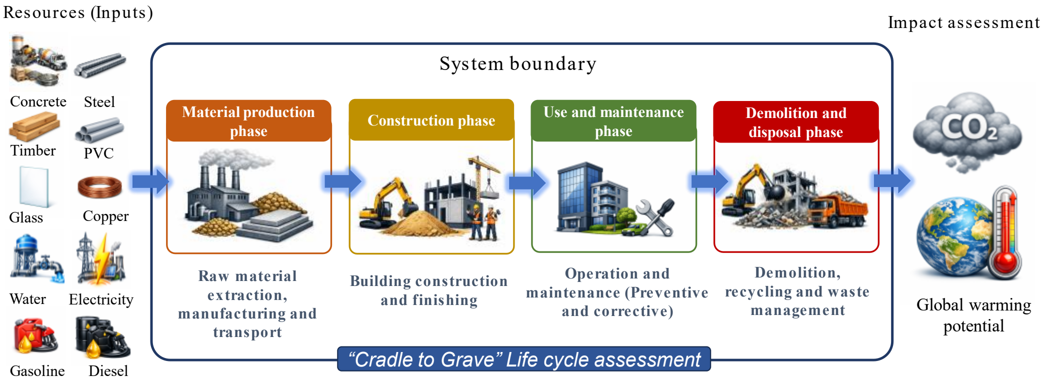


Figure 1. System boundary for cradle to grave life cycle assessment adopted in this study.

building carbon emissions. This framework covers the materials, equipment, energy, and labor inputs required throughout the building life cycle. Fortuna et al. [9] compare cast-in-place construction methods with prefabricated construction techniques. The results indicate that prefabricated construction generates lower carbon emissions. Teng et al. [10] based on life cycle theory, studied the carbon emissions of over 20 prefabricated building cases and compared them with cast-in-place building cases. Their research finds that the prefabricated construction method reduces material-related carbon emissions by 15.6% compared to the cast-in-place construction method. Cao et al. [11] conduct a case study on two residential projects. The results show that prefabricated buildings demonstrate advantages in environmental impact assessment, including reducing health damage by approximately 6.6%, reducing ecosystem damage by about 3.5%, and reducing resource consumption by approximately 35.8%. Tian et al. [12] compare the performance of prefabricated and cast-in-place construction methods for residential buildings based on indicators such as soil acidification and toxicity. Evaluations across all categories show that the prefabricated construction method performs significantly better than the cast-in-place method.

Based on a comprehensive literature review, existing investigations into the environmental potential of prefabricated construction have been confined to the material perspective during the construction phase. Consequently, the present study seeks to examine and evaluate various quantification methods for the life cycle inventory of prefabricated buildings. This investigation encompasses all phases of the life cycle, including material production, construction, usage and maintenance, as well as demolition and disposal. Leveraging the inventory data, this dissertation computes and analyzes the associated life-cycle impacts. Moreover, a comparative case study of Hong Kong juxtaposes prefabricated and cast-in-situ buildings, thereby quantifying the relative merits and drawbacks of prefabrication at each life-cycle stage. The research expands the theoretical framework for life-cycle assessment of prefabricated buildings and promotes sustainable development within the construction industry.

2 Methodology

The overall research methodology comprises four steps. Step 1 centers on the analysis of the research background and global research status. This part of the research is covered in section 1. Step 2 introduces the fundamental theory of building life cycle assessment. Step 3 is dedicated to two case studies and comparative analysis. Stage 4 draws conclusions and outlines future prospects based on the results of Step 3.

2.1 Life cycle assessment

Life Cycle Assessment (LCA) is a systematic and quantitative methodology for evaluating the potential environmental impacts of a product, service, or system throughout its entire life cycle. The assessment scope encompasses all stages of the subject's life cycle, including production, use, and end-of-life disposal. LCA adheres to the framework established by the International Organization for Standardization (ISO) standards ISO 14040 and 14044. By identifying and quantifying the materials, energy consumption, and waste emissions associated with a product or system, LCA analyzes its environmental impacts across the life cycle and provides recommendations for improvement [13].

2.1.1 Goal and scope definition

The building life cycle consists of four distinct stages: 1) Material Production, which includes raw material supply, transportation, and manufacturing; 2) Construction, involving the transportation of materials to sites and the on-site construction processes; 3) Use and Maintenance, which encompasses material maintenance, replacement during occupancy, and energy consumption of building systems; and 4) End-of-Life, comprising demolition, transportation of waste, and recycling and disposal. A notable difference between prefabricated and cast-in-place buildings occurs in the construction phase, where prefabricated buildings shift construction activities to production, transportation, and assembly of components. This study evaluates all four stages in the life cycle assessment of both prefabricated and traditional construction buildings, as shown in Figure 1.

2.1.2 Functional unit

The functional unit serves as the fundamental reference unit quantifying a building's performance throughout its life cycle phases of material production, construction, use and maintenance, and end-of-life disposal. Within the LCA framework of this study, the entire building is defined as a complete functional unit.

2.1.3 Life cycle inventory analysis

The building life cycle comprises four phases: the material production phase, the construction phase, the use and maintenance phase, and the demolition and disposal phase. The calculation of the building life cycle inventory is shown in Eqs. 1 to 5.

$$I = \sum_{i=1}^{4} I_i \quad (1)$$

I: Sum of inventory data across all life cycle stages
Ii: Inventory data for life cycle stage i
i: Stage index (i = 1, 2, 3, 4)

Material production phase (2)

$$I_1 = \sum_{j=1}^{J} Q_j \times E_j + \sum_{j=1}^{N}\sum_{m=1}^{M} P_{j,m} \times Q_m \times E_j$$

J: Number of material types in the cast-in-place portion
Qj : Production quantity of material type j in the cast-in-place portion
Ej: Life cycle impact coefficient for impact category E of material type j
M: Number of prefabricated component types
N: Number of material types in the prefabricated portion
Pj,m: Required quantity of material type j for prefabricated component type M
Qm: Production quantity of component type M

Construction phase (3)

$$I_2 = \sum_{n=1}^{N}\sum_{j=1}^{a} M_n \times N_n \times P_n \times L_n \times E_j + \sum_{c=1}^{k}\sum_{j=1}^{b} P_C \times T_C \times N_C \times E_j$$

N: Number of material or prefabricated component types during transportation
a: Number of resource or energy types consumed during transportation
Mn: Mass of material/prefabricated component type n per transport trip
Nn: Number of transport trips for material/prefabricated component type n
Pn: Resource/energy consumption per unit mass per unit distance for transporting material/prefabricated component type n
Ln: Transport distance for material/prefabricated component type n
Ej: Life cycle impact coefficient for impact category E of resource/energy type j
k: Number of construction machinery types at the construction site
b: Number of resource or energy types consumed at the construction site
Pc: Resource/energy consumption per unit time for operating construction machinery type c
Tc: Operating time of construction machinery type c
Nc: Number of operational units of construction machinery type c

Use and maintenance phase (4)

$$I_3 = \sum_{j=1}^{J} Q_j \times E_j + \sum_{t=1}^{T}\sum_{j=1}^{N} P_j \times E_j$$

J: Number of material types in the repair and replacement stage
Qj: Total consumption of material type j during the repair and replacement stage
Ej: Life cycle impact coefficient for impact category E of material/energy/resource type j in the life cycle inventory database
T: Life cycle assessment period (T = 50 years in this study)
N: Number of energy/resource types consumed during the use stage
Pj: Annual consumption of energy/resource type j

Demolition and disposal phase (5)

$$I_4 = \sum_{c=1}^{k}\sum_{j=1}^{b} P_C \times T_C \times N_C \times E_j + \sum_{n=1}^{N}\sum_{j=1}^{a} M_n \times N_n \times P_n \times L_n \times E_j + \sum_{j=1}^{e} Q_j \times E_j$$

k: Number of machinery types in the demolition stage
b: Number of resource or energy types consumed in the demolition stage
Pc: Resource/energy consumption per unit time for operating machinery type c
Tc: Operating time of machinery type c
Nc: Number of operational units of machinery type c
Ej: Life cycle impact coefficient for impact category E of material/energy/resource type j in the life cycle inventory database
N: Number of demolition waste types during transportation
a: Number of resource or energy types consumed during transportation
Mn: Mass of demolition waste type n per transport trip
Nn: Number of transport trips for demolition waste type n
Pn: Resource/energy consumption per unit mass per unit distance for transporting demolition waste type n
Ln: Transport distance for demolition waste type n
e: Number of recyclable material types
Qj: Quantity of recyclable material type j

2.1.4 Life cycle impact assessment

Impact categories represent the indicators used in life cycle impact assessment (LCIA). These indicators provide quantifiable data on various environmental impacts throughout a building's life cycle. In this study, the life cycle impact has been assessed through i) global warming potential (GWP), which assesses the greenhouse effect contribution of carbon dioxide, methane, nitrous oxide, and other greenhouse gases. Using carbon dioxide as the reference gas, it converts emissions of other GHGs into equivalent amounts of CO_2, with results expressed in kg CO_2 eq.

3 Case study

3.1 Prefabricated building construction

For the prefabricated building construction case study, Luk Tin house (Block 5) of Yan Tin Estate in Hong Kong was selected. Hong Kong Housing Authority (HKHA) serves as the owner and designer, while a local Hong Kong construction company acts as the general contractor. Specifications of the prefabricated building construction are provided in Table 1.

Table 1. Prefabricated building construction project details.

Description	Specification
Gross floor area	30196 m²
Number of floors	37
Building height	117 m
Layout	Cross-shaped (4 wings)
Residential units	18 units per floor
Prefabricated components	External wall panels, stairs, composite slabs
Prefabrication rate	60%

3.1.1 Material production phase

The main precast concrete components used in Luk Tin House include precast floor slabs, precast external wall panels, precast internal wall panels, precast beams, precast staircases, and prefabricated air-conditioning support slabs. The materials consumed by each type of precast component are shown in Table 2. Apart from precast elements, other materials, including cast-in-place concrete, rebars, aluminum, glass, copper, timber, polyethylene, and thermal insulation mortar, are also considered for the life cycle assessment.

Table 2. Materials consumed by each type of precast component.

Precast component	Concrete (m^3)	Rebar (t)
Precast floor slab	1514	151.1
Precast external wall panel	327.8	27.9
Precast internal wall panel	283.9	24.1
Precast beam	255.2	38.3
Precast staircase	254.2	34.3
Precast air conditioning support slab	69.1	12.8

3.1.2 Construction phase

The construction phase encompasses the transportation of building materials and precast components, as well as on-site construction processes. In this public housing project, all precast components are manufactured in Huizhou, Mainland China, and transported to the construction site in Tuen Mun, New Territories, Hong Kong, with a total transportation distance of approximately 140 km. Other building materials are produced locally in Hong Kong and subsequently delivered to the construction site.

During the construction process, on-site equipment consumes significant amounts of electricity, fuel, and water, the environmental impacts of which cannot be overlooked. The electricity consumption, water usage, and gasoline and diesel consumption at the construction site are detailed in Table 3. During construction, material wastage occurs due to factors such as transportation logistics, worker proficiency, and construction sequencing, which are also considered for all material types.

Table 3. Resource/energy consumption at the construction site.

Resource type	Quantity
Electricity consumption	1250000 kWh
Water usage	31500 m³
Gasoline consumption	29600 L
Diesel consumption	181000 L

3.1.3 Use and maintenance phase

During the usage and maintenance phase, Luk Tin House has an annual total energy consumption of approximately 1,560,000 kWh and an annual total water consumption of about 63,000 m³. Concurrently, based on the service life and actual conditions of building components and materials, maintenance or replacement is performed. The annual maintenance and replacement rates for various building materials and systems are detailed in Table 4.

Table 4. Annual maintenance and replacement rates for various building materials and systems.

Building materials/systems and their annual maintenance and replacement rate	
Precast concrete component (0.1%)	Power distribution system (1.1%)
Cast-in-place concrete (0.5%)	Stainless steel (0.6%)
Rebar (0.2%)	Copper (0.9%)
Aluminum alloys (1.2%)	Timber (4.2%)
PVC (1.8%)	Polyethylene (2.6%)
Masonry block (1.3%)	Ventilation system (6.5%)
Cement mortar (3.0%)	Glass (1.2%)
Thermal insulation mortar (2.1%)	Water distribution system (3.6%)
Waterproof membrane (4.5%)	Wastewater discharge system (4.2%)

3.1.4 Demolition and disposal phase

The demolition and disposal phase marks the final stage of a building's life cycle, signifying the conclusion of its entire lifespan. The demolition and disposal phase involves three main processes: demolishing structures, transporting waste, and recycling waste. In this study, an inventory analysis is conducted for various building materials and components during the demolition and disposal phase. Specific end-of-life (EOL) processes are detailed in Table 5, with data sourced from the One Click LCA database.

Table 5. EOL process for various building materials and systems.

Recycling	Inert landfill
Rebars, Aluminum alloys, PVC, Masonry Blocks, Cement mortar, Stainless steel, Timber, Copper, Metals from ventilation system, Metals from power and water distribution systems, Metals from wastewater discharge system, Metals from elevators	Concrete from precast and cast-in-place components, Thermal insulation mortar, Waterproof membrane, Glass, Polyethylene, Ventilation system, Power and water distribution systems, Wastewater discharge system, Elevators

3.2 Cast-in-place building construction

For the study of Hong Kong's cast-in-place public housing projects, this study selects the Leung King estate, Tuen Mun, Hong Kong due to its size similar to the prefabricated building. The contractor, Shun Shing Construction, employs pure cast-in-place concrete technology. The basic information of this residential block is listed in Table 6.

Table 6. Cast-in-place building construction project details.

Description	Specification
Gross floor area	30179 m²
Number of floors	35
Layout	Trident 4 (3 wings)
Residential units	18 units per

3.2.1 Material production phase

Based on the building records and construction drawings of Leung Kit House, the inventory of its various building materials is compiled as shown in Table 7.

Table 7. List of required building materials.

Materials	Quantity
Concrete	4256.3 m^3
Rebar	516.6 t
Aluminum alloy	1844.2 kg
PVC	186.9 kg
Masonry block	2767.9 m^3
Cement mortar	166995.2 kg
Waterproof membrane	17490.4 kg
Glass	36878.4 kg
Stainless steel	6452.9 kg
Copper	8138.8 kg
Timber	73.7 m^3
Polyethylene	2845.2 kg

3.2.2 Construction phase

According to statistics, the transportation distances of different types of building materials from factories to the construction site during the construction phase of Leung Kit House (Block 3) are as presented in Table 8. The transportation distances of different types of building materials from factories to the construction site during the construction phase of Leung Kit House (Block 3) are considered in the range 10~60 km.

Table 8. Resource and energy consumption at construction site.

Resource and energy	Quantity unit
Gasoline consumption	41200 L
Electricity consumption	1860000 KW*h
Water usage	38500 m^3
Diesel consumption	298000 L

3.2.3 Use and maintenance phase

During the use and maintenance phase, Leung Kit House in Leung King Estate consumes approximately 1,560,000 kWh of energy annually and uses about 63,000 m³ of water per year. Based on the operational history of Hong Kong public housing estates, climatic environmental impacts, and the maintenance policies of the Hong Kong Housing Authority (HKHA), Table 9 below presents the annual maintenance and replacement rates for various materials and systems over a period of time.

Table 9. Annual maintenance and replacement rates for various building materials and systems.

Building materials/systems and their annual maintenance and replacement rate	
Cast-in-place concrete (0.9%)	Power distribution system (3.1%)
Rebar (0.4%)	Copper (1.2%)
Aluminum alloy (4.2%)	Timber (6.1%)
PVC (3.6%)	Polyethylene (8.6%)
Masonry block (1.9%)	Ventilation system (6.5%)
Cement mortar (6.6%)	Stainless Steel (0.8%)
Waterproof membrane (5.5%)	Water distribution system (3.6%)
Glass (7.2%)	Wastewater discharge system (4.2%)

3.2.4 Demolition and disposal phase

This section conducts an inventory analysis of the recycling and treatment methods for various building materials during the demolition and disposal phase of Leung Kit House. The end-of-life (EOL) processes are detailed in Table 10 below, with corresponding environmental impacts calculated using the One Click LCA software.

Table 10. EOL process for various building materials and systems.

Recycling	Inert landfill
Rebar, Aluminum, PVC, Masonry blocks, Cement mortar, Stainless steel, Copper, Timber, Metals from ventilation system, Metals from power and water distribution systems, Metals from wastewater discharge system, Metals from elevators	Cast-in-place concrete, Waterproof membrane, Polyethylene, Glass, Ventilation system, Power and water distribution systems, Wastewater discharge system, Elevator

4 Results and discussion

In this section, first of all, GWP of two buildings with identical floor areas, similar building typologies, and comparable numbers of residential units has been investigated, considering all phases of building life cycle. Over a 50-year assessment period, the whole-life cycle GWP of prefabricated building is 6.58×10^7 kg CO_2 eq, with an associated social cost of carbon of approximately HKD 3.29×10^6. Compared to the cast-in-place building's whole life cycle GWP of 6.83×10^7 kg CO_2 eq., this represents a reduction of approximately 3.66%. Identical in both cases is that the use and maintenance phase contributes the largest share of GWP for both buildings, while the demolition and disposal phase contributes the smallest share. The biggest difference lies in the fact that for the prefabricated building, the construction phase's contribution to GWP is significantly smaller than that of the cast-in-place building. Figure 2 presents the breakdown of GWP contributions across different stages for both prefabricated and cast-in-place buildings.

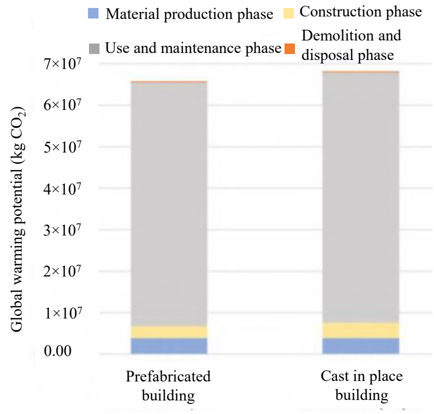
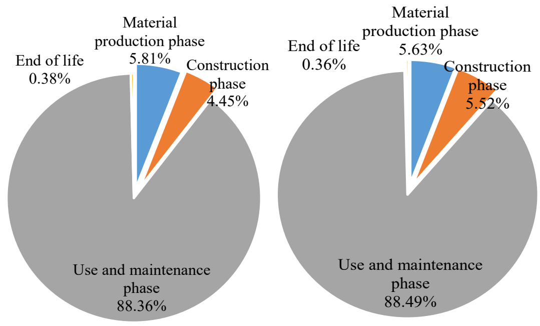


Figure 2. GWP comparison by phase between prefabricated and cast-in-place buildings.

The contributions of different phases of construction, including material production, construction, use and maintenance, and end of life phases, are considered. It has been observed that the use and maintenance phase contributes nearly 88% in the case of both building types, as shown in Figure 3. The use and maintenance phase dominates building life-cycle emissions because the persistent, cumulative energy demand for heating, cooling, lighting, and appliances over operational life exceeds the one-time impacts of all other phases, especially in regions served by fossil-intensive grids. Recurrent maintenance, repairs, and component replacements introduce further embodied emissions through additional materials and processes, progressively enlarging the phase's footprint as the building is kept functional. The extended duration amplifies these effects, mediated by external drivers such as grid carbon intensity and occupant behaviour, although advances in efficiency can reduce the phase's predominance.



(a) (b)

Figure 3. Contribution of different phases to GWP (a) prefabricated and (b) cast-in-place building.

In both construction types, material production and construction phases contribute 5~6% to the overall GWP of the building emissions due to one-time energy and resource usage (at the beginning of construction). The end-of-life (EOL) phase normally registers the smallest share of GWP in a cradle-to-grave assessment—commonly <1 % of cumulative emissions over fifty years—because its impacts are concentrated in a single episode of deconstruction, transport, waste processing, and disposal, in contrast to the protracted energy demands of the use phase or the material-intensive upstream production stage. Energy requirements remain modest: demolition equipment operates only briefly, and haulage to local processing or landfill sites incurs limited fuel use relative to the extensive supply chains of preceding phases. Most structural materials (concrete, steel, glass) are chemically inert and, once landfilled, generate negligible biogenic methane, further suppressing GWP.

Moreover, recycling and reuse can deliver system-expansion credits, offsetting incurred emissions and, under high diversion rates, yielding a net negative GWP contribution. During the construction phase, a comparison of GWP between a prefabricated building and a cast-in-place building, as shown in Figure 4, reveals key differences. The total GWP is 2.93×10^6 kg CO_2 eq. for the prefabricated building, achieving a 22.28% reduction compared to the cast-in-place building's 3.77×10^6 kg CO_2 eq. These overall savings demonstrate the environmental benefits of prefabrication, despite trade-offs in certain areas. Transportation emissions stand out as a drawback for prefabrication. The GWP from transporting components and materials is approximately 9.95×10^4 kg CO_2 eq. for the prefabricated building—about 2.95 times higher than the cast-in-place building's 3.37×10^4 kg CO_2 eq. This increase results from shipping large prefabricated elements over long distances, such as from Huizhou in mainland China, whereas the cast-in-place building relies on shorter, local material deliveries, reducing logistics-related emissions. In contrast, on-site construction operations favour the prefabricated approach. Its GWP is 2.83×10^6 kg CO_2 eq, a 24.3% decrease from the cast-in-place building's 3.74×10^6 kg CO_2 eq. This efficiency arises because major components like walls, slabs, and staircases are factory-made, limiting on-site tasks to hoisting and assembly. This shortens construction timelines and cuts labour and resource use. The cast-in-place building, however, involves extensive on-site processes like formwork, rebar binding, and concrete pouring, extending durations and boosting consumption. Ultimately, while prefabrication incurs higher transportation GWP, its on-site reductions more than compensate, promoting sustainability in building practices.

From Table 11, it has been realized the energy consumption contribution to the GWP is significantly higher for both cases, as nearly the same number of residents were considered for both buildings for the same period of time, such as 50 years. Maintenance-related emissions remain lower than those of cast-in-situ counterparts because the modular geometry and factory-controlled fabrication of prefabricated components enhance durability, curtailing the incidence of repairs that plague site-cast elements vulnerable to defects such as cracking. Consequently, maintenance volumes—concrete, mortar, and allied products—contract, truncating upstream production and transport emissions. Superior thermal performance delivered by integrated insulation systems (e.g., sandwich panels) further constrains future refurbishment demand, consolidating the emission advantage.

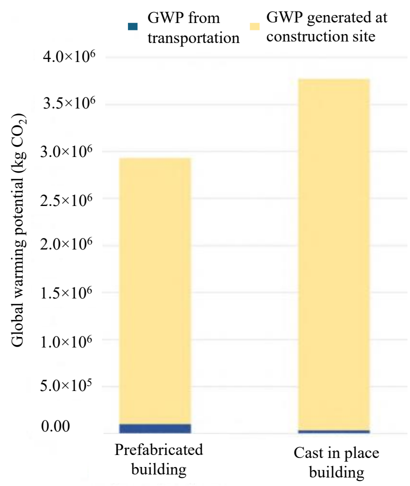


Figure 4. GWP comparison in the construction phase between prefabricated building and cast-in-place.

Table 11. Use and maintenance phase contributions to GWP.

Resource type	GWP (%)	
	Prefabricated building	Cast-in-place building
Water use	1.45	1.41
Energy consumption	94.05	91.53
Repair	3.06	5.74
Material replacement and refurbishment	1.44	1.31

From Table 12, it has been observed that "floor slabs, ceilings, roofing decks, beams and roofs" are primarily responsible for 28–30% of GWP at the material production phase for both prefabricated and cast-in-place buildings. Concrete and rebar serve as the primary sources of carbon emissions. Building systems and installations rank second, encompassing residential ventilation systems, electrical distribution, freshwater distribution, and wastewater discharge systems, with a contribution rate of 20.03~20.70%. Foundations, sub-surfaces, basements, and retaining walls constitute the third-largest GWP source at 12.76~12.84%, while windows and doors (2.04~2.19%) and finishes and coverings (2.83~3.10%) represent the two categories with the lowest contributions.

Table 12. Contribution of different building components to the GWP at the material production phase in (a) prefabricated (b) cast-in-place building.

Category	GWP (%age contribution)	
	Prefabricated building	Cast-in-place building
Foundation, sub-surface, basement and retaining walls	12.84	12.76
External walls and façade	7.57	7.32
Columns and load-bearing vertical structures	10.84	8.15
Internal walls and non-bearing structures	7.54	12.53
Floor slabs, ceilings, roofing decks, beams and roof	30.39	28.38
Windows and doors	2.19	2.04
Finishes and coverings	2.83	3.10
Building systems and installations	22.03	20.70
Other structures and materials	3.77	5.03

5 Conclusion

This study employs life cycle assessment (LCA) methodology to evaluate the environmental impacts of prefabricated and cast-in-place construction methods, using cradle-to-grave system boundaries and comprehensive inventories. Global warming potential (GWP) serves as the key indicator for comparing environmental performance across all life cycle stages. The analysis draws on two comparable public housing buildings in Tuen Mun, Hong Kong: a prefabricated building and a cast-in-place building, with similar floor areas, typologies, and unit counts.

Across both methods, the use and maintenance phase dominates GWP contributions, at 88.36% for the prefabricated building and 88.49% for the cast-in-place building. Material production follows at 5.81% and 5.63%, respectively, while construction accounts for 4.45% and 5.52%. Demolition and disposal contribute the least, at 0.38% and 0.36%.

The total life cycle GWP for the prefabricated building is 6.58×10^7 kg CO_2 eq, a 3.66% reduction compared to the cast-in-place building's 6.83 × 10^7 kg CO_2 eq. Significant savings occur in the construction and use/maintenance phases.

(1) Material Production Phase: Differences are negligible, with the prefabricated building at 3.82 × 10^6 kg CO_2 eq—a 0.52% reduction from the cast-in-place building's 3.84 × 10^6 kg CO_2 eq.

(2) Construction Phase: The prefabricated building generates 2.93 × 10^6 kg CO_2 eq, 22.28% less than the cast-in-place building's 3.77 × 10^6 kg CO_2 eq. This is driven by on-site efficiencies, where the prefabricated building's GWP is 2.83 × 10^6 kg CO_2 eq (24.3% lower than 3.74 × 10^6 kg CO_2 eq), due to factory-made components reducing on-site labor and resources.

(3) Use and Maintenance Phase: The prefabricated building's GWP is 5.88 × 10^7 kg CO_2 eq, a 2.65% decrease from 6.04 × 10^7 kg CO_2 eq, primarily from repair processes at 1.80 × 10^6 kg CO_2 eq (48.13% reduction versus 3.47 × 10^6 kg CO_2 eq).

(4) Demolition and Disposal Phase: Values are virtually identical, at 2.50 × 10^5 kg CO_2 eq for the prefabricated building and 2.49 × 10^5 kg CO_2 eq for the cast-in-place building.

In conclusion, the prefabricated construction method exhibits better overall environmental performance, particularly in reducing emissions during construction and maintenance, highlighting its potential for sustainable building practices.

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