Comparing carbon emissions of precast and cast-in-situ construction methods -
A case study of high-rise private building

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The carbon emission for precast façade is 647 kg CO₂ eq

Precast façade performs 6.3% better than cast-in-situ façade in terms of the carbon emissions
GHGs
Emissions of greenhouse gases

CO2
Anthropogenic GHG

Auditing and controlling carbon emissions –
A key strategy to achieve sustainable development

1. INTRODUCTION

KYOTO PROTOCOL
from 2013 to 2020
37 industrialized countries and European Community
reduce GHG emissions by 18% below the 1990’s level.

CHINA
from 2005 to 2020
12th Five-year Plan
40–45% reduction in carbon intensity

from 2020 to 2050
195 countries
limit global warming to less than 1.5°C compared to pre-industrial levels

HONG KONG
from 2005 to 2020
50–60% carbon reduction strategy
Buildings are contributors to carbon emissions

Major source of carbon emission in buildings:
1. Concrete
2. On-site construction method
1. INTRODUCTION

Sustainable building design and practices are the solution

Potential to reduce
- energy use by 30-50%
- GHG emissions by 35%
- waste outputs by 70%

Sustainable buildings are essential in promoting resource conservation and material life cycles.

Photo Source: http://www.ticotimes.net/2016/05/10/international-sustainable-building-congress-2016
Prefabrication
Sustainable construction method of improved quality control, improved environmental performance, improved site safety, reduction of labor demand and construction time

Limited Land

High Land Cost

High Development Rate

High-rise is common in HK

Precast concrete has been adopted to construct residential buildings in HK
GOAL
To investigate the carbon emissions of precast and cast-in-situ construction methods for high-rise residential buildings

In this study

• A case study
To compares the carbon emissions of precast and cast-in-situ construction methods through a private residential building in Hong Kong

• Life cycle assessment (LCA)
To calculate carbon emissions with the upstream processes from ‘cradle to end of construction’ being considered
2. METHODS

2.1. SCOPE DEFINITION

The project adopts precast façade which accounts for 6% of total concrete volume.

A typical private building project in Hong Kong is studied:
• 3500 units
• site area: 96,800 m²
• Buildings: 30–35 floors with 8 apartments per floor

A and H:
• 3-bedroom apartments
• symmetrical layout design
• 3 different precast façade elements

The analyses in this research will focus on apartments A and H.

Fig. 1. Layout plan of a typical floor of the studied residential project.
2.2 LIFE CYCLE INVENTORY

FOUR-PHASE STRUCTURE OF LCA

(i) Goal and scope definition
(ii) Life cycle inventory
(iii) Impact assessment
(iv) Interpretation

2. METHODS

Life cycle assessment (LCA)
- implemented to calculate carbon emissions of precast and cast-in-situ concrete
- widely used method to estimate environmental performance throughout a product’s life cycle

Full LCA
consider all the life cycle stages of a product, i.e. cradle-to-grave.

Partial LCA
consider one or a few stages such as gate-to-gate, cradle-to-gate, cradle-to-site, etc.
Fig. 2. Schematic illustration of the study systems for scenarios; (a) IS scenarios: S1-IS, S3-IS, S5-IS, and S7-IS
Fig. 2. Schematic illustration of the study systems for scenarios; (b) PC scenarios: S2-PC, S4-PC, S6-PC, and S8-PC.
2.2.1. Collection of data

LCA research:
combination of site-specific data and existing databases

A. Site-specific data
• Questionnaire survey
• Factory visit
• On-site construction visit

B. Ecoinvent database
• provide the secondary data of upstream processes when the site-specific data cannot be found
• Way of using Ecoinvent:
  1. The datasets in Ecoinvent are directly used and no adjustment is made
  2. Change certain variables in datasets using the available site-specific data
2. METHODS

2.2.2. MODEL DEVELOPMENT

The comparison between precast and cast-in-situ construction methods
- 4 levels each includes 2 scenarios of precast concrete (PC) and in-situ (IS) concrete
2.3. LIFE CYCLE IMPACT ASSESSMENT

The LCA model is established in **SimaPro 8 - 203 project processes** for this study.

- Developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBSCD)
- Based on the global warming potential (GWP) factors published by IPCC [24]

**The indicator**
- Carbon dioxide equivalent (CO2 eq)

**Focus on Fossil based carbon**
- The carbon emissions of a building apartment are mainly generated due to the combustion of fossil fuel

**Model structure is designed according to...**
- the components of apartment A/H and the supply chain system
- validated by overseas LCA experts through several rounds of telephone meetings
3.1. One cubic meter concrete

1. Main carbon emissions to produce concrete: cement and rebar (about 60% of the emission)

2. Location of precast yard in mainland China complicates the logistic system

3. Total carbon emissions of precast are lower than cast-in-situ

4. Different type of formwork lead to better performance of precast concrete
3.2. A façade element

1. Less difference between S3-IS and S4-PC compare to a cubic meter of concrete

2. Carbon emission:
   - Cast-in-situ façade: 1005 kg CO2 eq
   - Precast façade: 941 kg CO2 eq (6.3% less than cast-in-situ façade)

3. The difference is mainly caused by formwork types

Fig. 4. Carbon emissions of concrete façade element 10 (IS: cast-in-situ concrete; PC: precast concrete).
3.3. Façade element group

1. The façade group includes three façade elements

2. Carbon Emission:
   PC: 2870 kg CO₂ eq (6.5% less)
   IS: 3070 kg CO₂ eq

3. The three elements share similar carbon emissions, as the materials used are similar in terms of type and quantity
   Carbon emissions:
   • 70% concrete (including reinforcing bar)
   • over 20% Aluminum frame
   • Tile and glass are less significant

Fig. 5. Carbon emissions of concrete façade group (IS: cast-in-situ concrete; PC: precast concrete).
3.4. A residential apartment

1. Apartment A/H
   - floor area: 96 m²
   - carbon emission of precast: 64,263 kgCO₂ eq.
   - 669 kg CO₂ eq. per one square meter

2. Carbon emission:
   - 42% Façade 400
   - 16% beam & column
   - 14% slab 150
   - 4–5% precast façade group

3. 200 kg CO₂ eq difference between S7-IS and S8-PC
   - caused by the difference between façade groups
   - accounts for 0.31% of the whole apartment.

4. For one square meter, the reduction of carbon emission due to the adoption of precast façade elements is 2.1 kg CO₂ eq.
4.1. Carbon reduction due to precast concrete

↑ Adopted precast concrete  
↑ Carbon reduction percentage

**Apartment A/H**
precast weight percentage: 3%, reduction percentage: 0.31%.

**1 m³ concrete**
precast weight percentage is 94%, reduction percentage: 10%

Adoption of more precast concrete in residential building project can reduce more carbon emissions

Fig. 7. Comparison on the influence from precast concrete percentage to the carbon emissions. The precast percentage is calculated based on the precast concrete weight and the total weight of the functional unit.
To cast 1 m³ concrete, the timber formwork emits about 10-time GHGs of steel formwork.
4.3. COMPARISON WITH PREVIOUS RESEARCH

Significant inconsistency attributed to ...

- inclusion of processes
- adoption of impact assessment methods
- actual difference in material type and quantity

### Table 9
Comparison with previous research on the carbon emissions of buildings.

<table>
<thead>
<tr>
<th>Item</th>
<th>Zhang, Wu [31]</th>
<th>Zhang, Shen [27]</th>
<th>Ng and Kwok [26]</th>
<th>Dong and Ng [18]</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building type</td>
<td>Office building in university</td>
<td>Commercial building</td>
<td>Public residential building</td>
<td>Public residential building</td>
<td>Private residential building</td>
</tr>
<tr>
<td>Region</td>
<td>Beijing</td>
<td>Hong Kong</td>
<td>Hong Kong</td>
<td>Hong Kong</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>System boundary</td>
<td>Material stage</td>
<td>Cradle to end of construction</td>
<td>Cradle to grave</td>
<td>Cradle to end of construction</td>
<td>Cradle to end of construction</td>
</tr>
<tr>
<td>kg CO₂ eq per m²</td>
<td>561*</td>
<td>409</td>
<td>560</td>
<td>637</td>
<td>669</td>
</tr>
</tbody>
</table>

*Calculated based on the data from the paper.

Comparing between this study with Studies [18]

- public residential building performs better than private residential building
- precast concrete volume percentage
  - private building 6%
  - public building 35%
- If the precast volume percentage in the private building project is 35% > 13 kg CO₂ eq per m² can be reduced
5. LIMITATIONS AND FUTURE WORK

Limitations:

This study establishes the model according to the structure of a building apartment to include details of concrete elements:
- hot-spots can be easily detected
- consumes large amount of time to collect data and calculate the material quantity
- LCA model only studies the carbon emissions of a residential apartment

Future Works:

1. To provide a more comprehensive analysis, Entire floor or the whole building project
2. To study buildings with various precast proportions
3. To investigate if the carbon reduction by using precast concrete can be included as one of the benefits of precast concrete
4. To investigate if precasting should be awarded more credits in BEAM Plus
6.1. CONCLUSION
Adoption of precast concrete can reduce the carbon emissions as compared with cast-in-situ concrete

- 1 m³ concrete
  - Carbon emission: 692 kg CO₂ eq
  - Precasting: 10% reduction of carbon emission

- A façade element/ façade element group
  - Precasting: 6.5% reduction of carbon emission

- Entire residential apartment
  - Precasting: 0.31% reduction of carbon emission

- Case studies
  - Apartment yields 669 kg CO₂ eq per m² GFA
  - Precasting: reduce 2.1 kg CO₂ eq per m²
6. CONCLUSIONS AND RECOMMENDATION

6.1. CONCLUSION

Formwork
- cast-in-situ construction adopts TIMBER formwork: reused <10 times
- STEEL formwork used to produce precast: reused >100 times

Cast 1 m³ concrete
- cast-in-situ concrete: 45.7 kg timber formwork
- precast concrete: 14.5 kg steel formwork
Carbon emission to produce the same amount of concrete:
- timber formwork > steel formwork

Highly recommended to adopt precast concrete to contribute to a more sustainable construction industry
6. CONCLUSIONS AND RECOMMENDATION

For One apartment:
- 200 kg CO2 eq difference between IS and PC

www.epa.gov
6. CONCLUSIONS AND RECOMMENDATION

Stock of Flats in public and private Housing

![Graph showing the stock of flats in public and private housing from 2006 to 2016. The graph indicates a steady increase in the number of flats over the years. The number of private permanent housing flats goes from 1,114 in 2006 to 1,519 in 2016, and the number of public permanent housing flats goes from 1,114 in 2006 to 1,188 in 2016.](www.housingauthority.gov.hk)
### 6.2. RECOMMENDATION

| Developer | • Adoption of more precast concrete → better environmental performance |
| Building industrial | • Highly recommended to adopt precast concrete incorporated into the Building Assessment Schemes |
| Government | • Government should provide more incentives to promote precasting |
| World | • Applicable to overseas high-rise building projects |
Thank You!

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