***Comparative Embodied Carbon Analysis of the Volumetric Prefabrication Elements and In-situ Elements in Residential Building Development of Hong Kong***

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**Abstract**
This paper reviews the greenhouse gas emissions of volumetric prefabrication elements for residential development in Hong Kong. Volumetric prefabrication becomes a common practice in residential development in Hong Kong and is considered as a green approach. In Hong Kong, volumetric prefabrication took place at factories in Pearl River Delta. Although volumetric prefabrication reduces construction wastage, it might generate more greenhouse gas emission from transportation and manufacturing processes. This study attempts to measure the "cradle to site" greenhouse gas emission from volumetric prefabrication elements for a public housing development in Kai Tak area. The findings could help further reduction of greenhouse gas emissions through process improvement.

Keywords: Volumetric prefabrication, greenhouse gas emission, cradle-to-site, residential development.

## Introduction

Volumetric prefabrication becomes a common practice in residential development in Hong Kong. Hong Kong will run out of landfill area for municipal solid waste within ten years (Environmental Protection Department, Hong Kong, 2011). To reduce the construction wastage of the municipal solid waste in Hong Kong, volumetric prefabrication is one of the ways to reduce waste on site. In recent years, public housing development adopts products, such as precast façade, precast wall, precast stair, precast tie beam and precast landing, to reduce construction waste. The application of prefabrication attempts to reduce construction wastage, enhance quality, workmanship and safety during construction.

Most of the local studies concern the reduction of construction wastage from prefabrication during construction stage. However, it seems there is no study concerning the greenhouse gas emission from volumetric prefabrication from "cradle to site" stage that includes raw-material extraction, prefabrication manufacturing, and transportation from extraction location to factory and from factory to site.

Although volumetric prefabrication reduces construction wastage, it might generate more greenhouse gas emission. In Hong Kong, volumetric prefabrication took place at factories in Pearl River Delta. Some of the raw-materials might source from Hong Kong. The travel distance will be double-up as raw-materials will travel from Hong Kong to Pearl River Delta and to Pearl River Delta and back to the construction site in Hong Kong. The real benefit from volumetric prefabrication on the reduction of "cradle to site" greenhouse gas emission in Hong Kong's context is unclear.

This study attempts to measure the "cradle to site" greenhouse gas emission from volumetric prefabrication elements (volumetric precast kitchen, volumetric precast bathroom) for a public housing development in Kai Tak area. The volumetric prefabrication factory was located at Shenzhen, China. The greenhouse gas emission from the raw-material extraction, prefabrication manufacturing, and transportation from extraction to factory and from factory to site was accounted. Improvement scheme would be proposed in this paper to reduce the greenhouse gas emission of volumetric prefabrication elements.

## Methodology

The accounting of the greenhouse gas emission commences on March 2011. We follow the Life Cycle Assessment methodology for the accounting and reporting of the greenhouse gas emission for the "cradle to site" stages, including:

- Raw-material extraction,
- Transportation of raw-materials to prefabrication factory,
- Prefabrication manufacturing, and
- Transportation of prefabrication factory to construction site

Volumetric prefabrication elements used in the Kai Tak construction site comprises of volumetric precast kitchen and volumetric precast bathroom. The volumetric precast elements were basically reinforced concrete components prefabricated in factory with rebar exposed at the end. Volumetric precast bathrooms and kitchens would install with aluminium window frame. Glasses will be installed on site later after delivery.

Fig. 1 Volumetric Precast Kitchens    Fig. 2 Volumetric Precast Bathrooms

The Life Cycle Assessment (LCA) was carried out for the manufacturing and transportation phase of 741 numbers of volumetric precast kitchens and 4910 volumetric precast bathrooms during the production period of April 2011. The LCA took account of all the background information, like raw material extraction, manufacturing and transports (cradle to site). For data source, checklists were sent to the following the prefabrication factory responsible for the production of prefabrication elements for the public-housing development of Kai Tak area. Data request comprised of quantities and types of raw-materials, fuel, waste and equipments used in the production of 741 numbers of volumetric precast kitchens and 4910 volumetric precast bathrooms for production period. As per the information of factory, 12 sets of steel formwork were used for the production of 4,910 volumetric precast bathrooms while 3 sets of steel formworks were used for the production 741 volumetric precast kitchens. Fig. 3 shows the quantities of the raw-materials and the quantity of the steel formwork used in the production of the volumetric prefabrication elements in the public housing development in Kai Tak Area. Fig. 4, Fig. 5 and Fig. 6 shows the quantity of fuel, solid wastage and recycled waste of the volumetric prefabrication elements in the public housing development in Kai Tak area. Fig. 7 shows the truck transport distance from raw-material extraction to prefabrication factory and from prefabrication factory to the construction site in Kai Tak area.

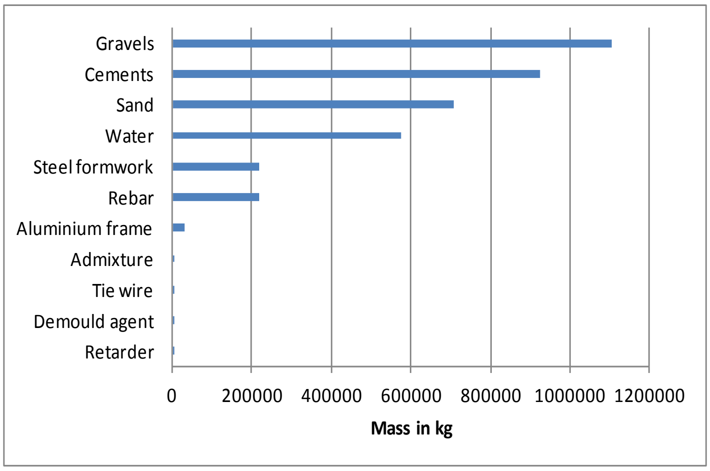


Fig. 3 The quantities of raw-materials or primary products of volumetric prefabrication elements for a public housing development in Kai Tak area

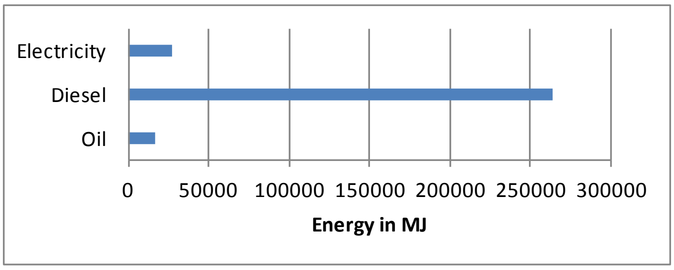


Fig. 4 The quantities of fuel used in the construction of volumetric prefabrication elements for a public housing development in Kai Tak area

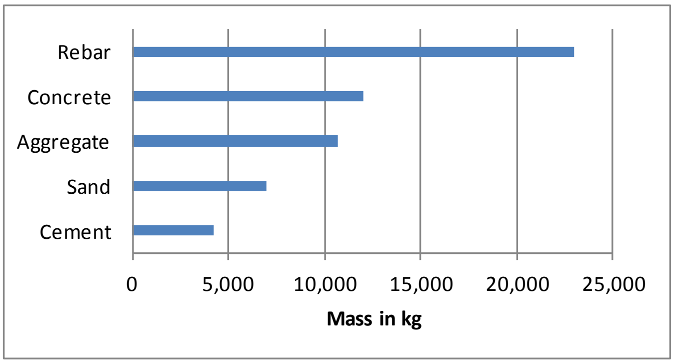


Fig. 5 The quantities of solid wastage from the production of volumetric prefabrication elements for a public housing development in Kai Tak area

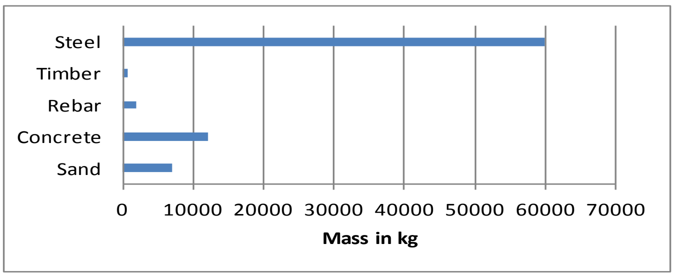


Fig. 6 The quantities of recycled wastage of volumetric prefabrication elements for a public housing development in Kai Tak area

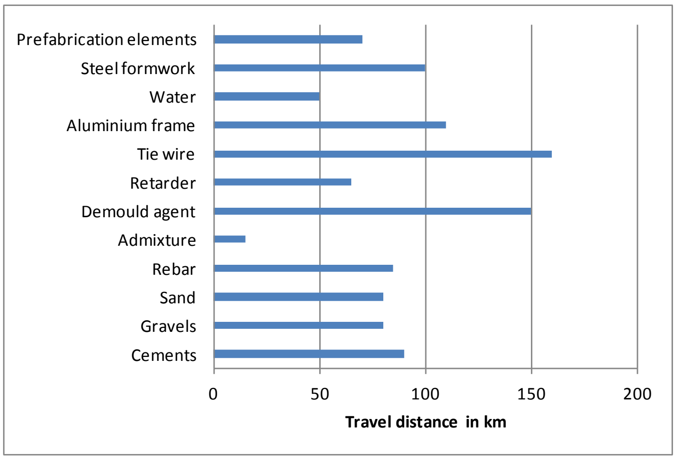

Fig. 7 The travel distance from raw-material extraction site to prefabrication factory for production of the volumetric prefabrication elements for a public housing development in Kai Tak area

## Hypothesis Basecase

To find out the benefit or drawback on carbon emission, a hypothesis base case was set up. The following table shows the cases, production period and "cradle to site" stages for comparison. Raw-materials including rebar and retarder, were sourced from Hong Kong. Fig. 9 shows the truck travel distance for the raw materials for in-situ construction of volumetric prefabrication elements.
Transport carbon coefficient ("gate to site") "cradle to gate" embodied carbon coefficient was referred to the figure from Department for Environment, Food and Rural Affairs (DEFRA) published by UK Government in 2008 and UK figures. The references of electricity carbon coefficient of China Light Power (CLP) electricity and electricity in Shenzhen is extracted from (Environmental Protection Department and the Electrical and Mechanical Services Department, 2010) and (Tinjian University, 2010), respectively.
Table I
The Design Case and Hypothesis Basecase

| Volumetric Prefabrication elements | Hypothesis Base |
|---|---|
| "cradle to site" stages<br>1. Raw-material extraction<br>2. Transportation from extraction site to prefabrication factory at Shenzhen<br>3. Manufacturing of prefabrication elements at prefabrication factory at Shenzhen<br>4. Transportation from prefabrication factory to construction site at Kai Tak area | "cradle to site" stages<br>1. Raw-material extraction<br>2. Transportation from extraction to construction site at Kai Tak area, Hong Kong<br>3. In-situ construction at Kai Tak area, Hong Kong |

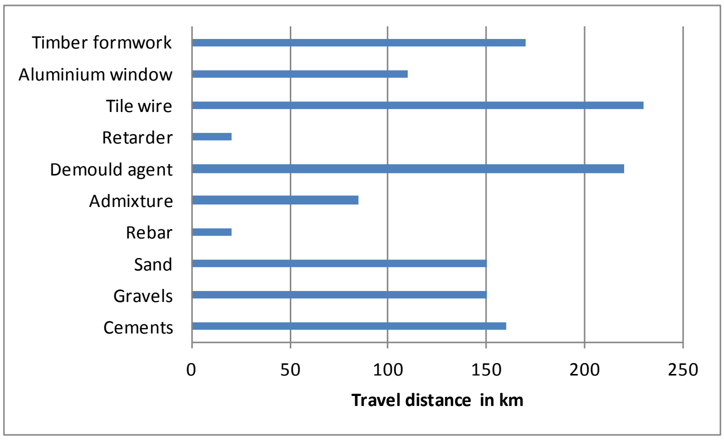


Fig. 8 The travel distance from raw-material extraction site to construction site for production of the in-situ elements for a public housing development in Kai Tak area

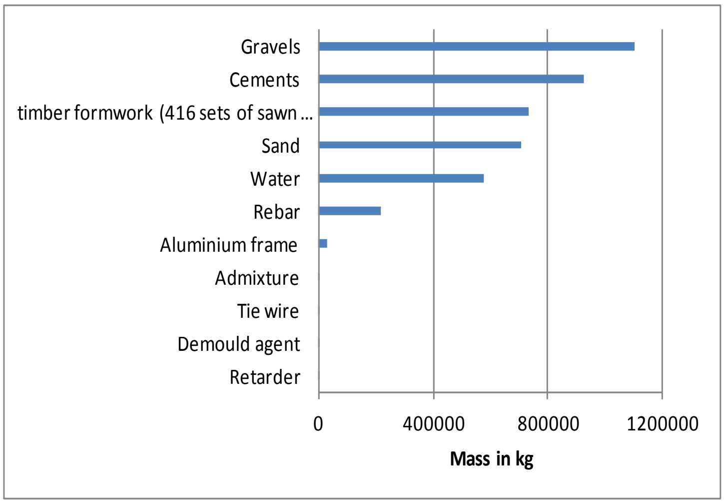


Fig. 9 The quantities of raw-materials or primary products of in-situ elements for hypothesis basecase

**Results**

Fig. 10, Fig 11 shows the total carbon emissions for 4,910 numbers of volumetric precast bathrooms, 741 numbers of volumetric precast kitchens and hypothesis in-situ elements (basecase) for raw-material extraction, prefabrication manufacturing and transportation stages. The 4,910 numbers of volumetric precast bathrooms emit a total of 24,422 tonne carbon emission. Compared with the hypothesis basecase (in-situ elements), the carbon emission is 2490 tonnes less than in-situ elements. It is equivalent to the carbon absorption of 108,261 numbers of trees per year. On the other hand, the 741 numbers of volumetric precast kitchens emit a total of 4,012 tonne carbon emission. Compared with the hypothesis basecase (in-situ elements), the carbon emission is 362 tonnes less than in-situ elements. It is equivalent to the carbon absorption of 15,738 numbers of trees per year.

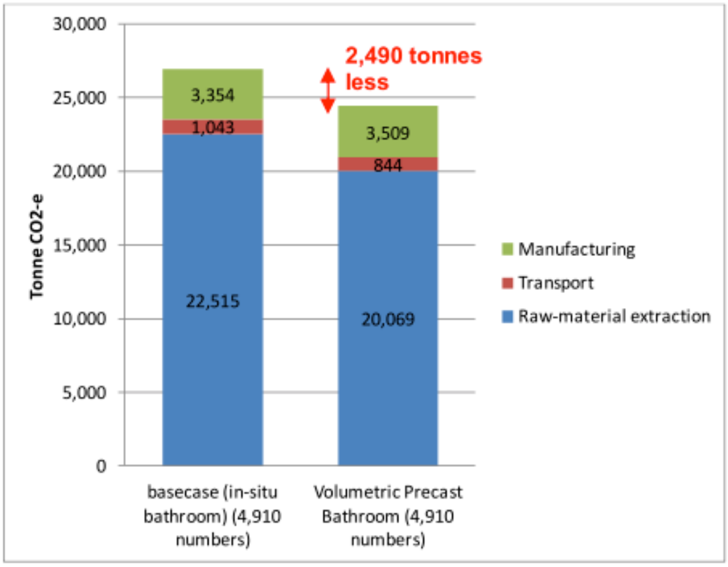


Fig. 10 The initial embodied carbon emission from the raw-material extraction to construction site for production of the 4910 volumetric bathroom elements for a public housing development in Kai Tak area

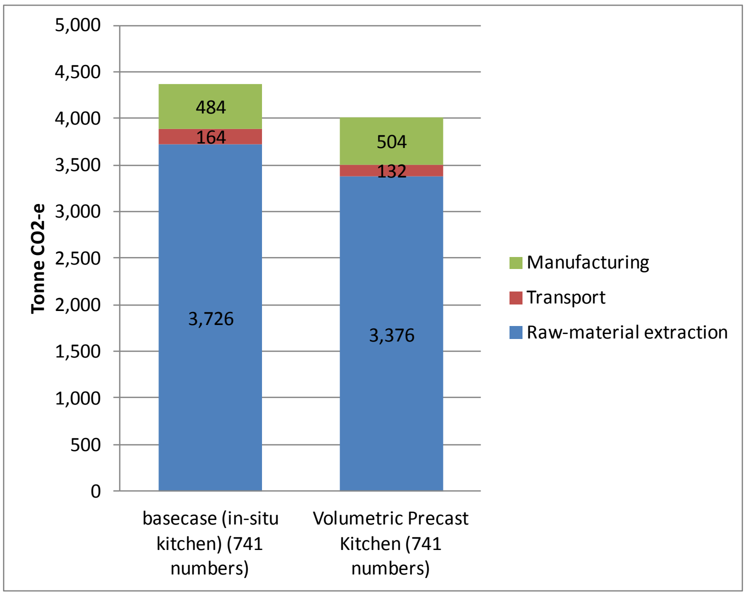


Fig. 11 The initial embodied carbon emission from the raw-material extraction to construction site for production of the 741 volumetric kitchen elements for a public housing development in Kai Tak area

Fig. 12 shows the breakdown of carbon emissions for volumetric prefabricated elements across the raw-material extraction, transport from extraction to factory, factory prefabrication, and transport from factory to site. 82% of the carbon emission comes from raw-material extraction. 15% of carbon emission comes from prefabrication-factory manufacturing. 2% of carbon emission comes from transportation (transports from raw-material extraction to factory and transports from factory to site). Raw-material extraction and prefabrication manufacturing contributed 97% of the carbon emissions. Transportation only contributed 2% of the indirect emissions. For process improvement, raw-material extraction drives the carbon emission for volumetric prefabricated elements.

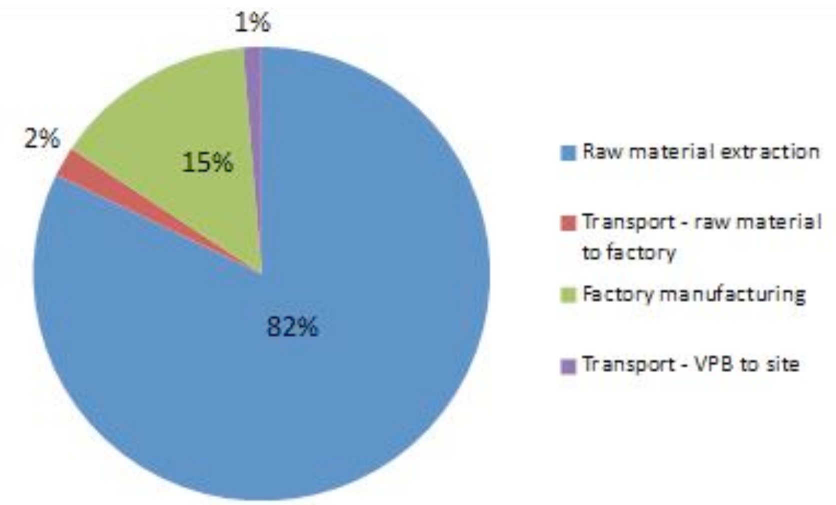


Fig. 12 The breakdown of carbon emissions for volumetric prefabricated elements across the raw-material extraction, transport from extraction to factory, factory prefabrication, and transport from factory to site

**Carbon footprint of raw-material extraction**

Compared with the carbon emission of the prefabricated elements with the in-situ elements, the carbon saving comes from raw-material extraction. It is because prefabricated elements adopt reusable steel formwork. As per the information of factory, 12 sets and 3 sets of steel formworks were used in the production of volumetric precast bathrooms and volumetric precast kitchens, respectively.
On the other hand, the hypothesis in-situ elements would use large amounts of sawn formworks. One set of sawn formwork can only reuse 6 times. For the same numbers of bathrooms and kitchens produced in the production period, approximately 942 sets of sawn formwork will be required. 2446 tonne more initial embodied carbon emission would emit during raw-material extraction and manufacturing of the formwork. It is equivalent to the carbon absorption of 106,348 numbers of trees per year.

**Carbon footprint of factory manufacturing**

Electricity in Shenzhen or most of China electricity is based on coal-fired (almost 74%), would have higher global warming potential. Volumetric prefabrication manufacturing of prefabrication elements had 175 tonne more carbon emissions than hypothesis in-situ construction. It is equivalent to the carbon absorption of 2087 numbers of trees per year.

**Carbon footprint of transportation**

Trucks were used to transport raw-materials and prefabrication elements to factory (and to site). Parts of raw-materials for volumetric prefabrication elements are sourced from Hong Kong. The raw-materials will travel from Hong Kong to Shenzhen and Shenzhen to Hong Kong again. The travel distance is slightly longer than in-situ construction. The transport distance is more direct if hypothesis in-situ construction uses the same local raw-materials. However, the excessive reduction of formwork usage in volumetric prefabrication. Therefore, construction of the volumetric prefabrication elements on-site would have 231 tonne less transportation carbon emissions than in-situ construction. It is equivalent to the carbon absorption of 8,043 numbers of trees per year.

**Carbon Reduction from Volumetric Prefabrication Elements**

Although volumetric prefabrication elements emit 58 tonne more carbon emission during factory-manufacturing stage, volumetric prefabrication elements reduces overall 2,852 tonne carbon emission from "cradle to site" – raw-material extraction, transportation and factor manufacturing as prefabricated elements reduce formwork at the raw-material extraction. It is equivalent of the carbon absorption of 124,000 numbers of trees per year.

**Conclusions**

This study takes account of the carbon emissions from volumetric prefabrication elements of Kai Tak construction site.

Most of the carbon savings of prefabrication elements come from raw-material extraction. Increase of carbon emission occurs from prefabrication factory manufacturing. It is because electricity in Shenzhen or most of China electricity is based on coal-fired (almost 74%). The prefabrication plan produced in Shenzhen utilizing China's electricity would have higher global warming potential. It increases the carbon footprint of volumetric-prefabrication factory manufacturing.

Housing projects can further reduce the carbon emissions for volumetric prefabrication elements. On factory manufacturing, China electricity using the high global warming potential can be reduced through applying renewable energy and low emission fuel, such as biodiesel. On transportation, fuel with low carbon emission can reduce the transport carbon reduction vehicle with higher energy efficiency can also reduce carbon emission. Low emission carbon materials could reduce the carbon emission during the raw-material extraction. For volumetric prefabrication elements, cement and rebar contributes 32.4% and 25.6% of the carbon emission. Pulverized Fly Ash (PFA) might use to substitute part of the cement to reduce the carbon emission. However, PFA would increase the radon emanation rate of concrete (Yu, 1994). Steel rebar and steel formwork contributed 38% of the raw-material extraction carbon footprint. Recycle or reuse steel from previous projects could reduce the carbon emission of raw-material extraction.

Volumetric prefabrication elements can reduce construction waste as well as greenhouse gas emissions. For a typical residential estate of public housing comprised of six 40-storey high blocks, 5,651 numbers of volumetric prefabrication elements can reduce 9% of the greenhouse gas emission compared with in-situ elements. Volumetric prefabrication element is a low carbon and low-waste solution although improvement can be introduced to further reduce the transportation and manufacturing carbon emission of volumetric prefabrication elements.

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