CONSTRUCTION INDUSTRY COUNCIL
建造業議會

Standing Committee on Concrete Technology Annual Concrete Seminar 2016

Carbon Footprint of Steel-Composite and Reinforced Concrete Buildings

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20 April 2016

Outline

National Reduction Targets

Country	2020 CO_2 Reduction Target	Base year
Australia	5-15%	2000
Canada	17%	2005
EU & Members States	20% -30%	1990
Hong Kong	19-33% 50-60% (in terms of carbon intensity)	2005
Japan	25%	1990
Norway	30-40%	1990
US	17%	2005
IPCC recommendation	25-40%	1990

Source: United Nations Framework Convention on Climate Change Quantified Economy-wide Emissions Targets for 2020

Buildings and Construction Contribution to GHG Emissions

#1. Building and Construction (>40%)

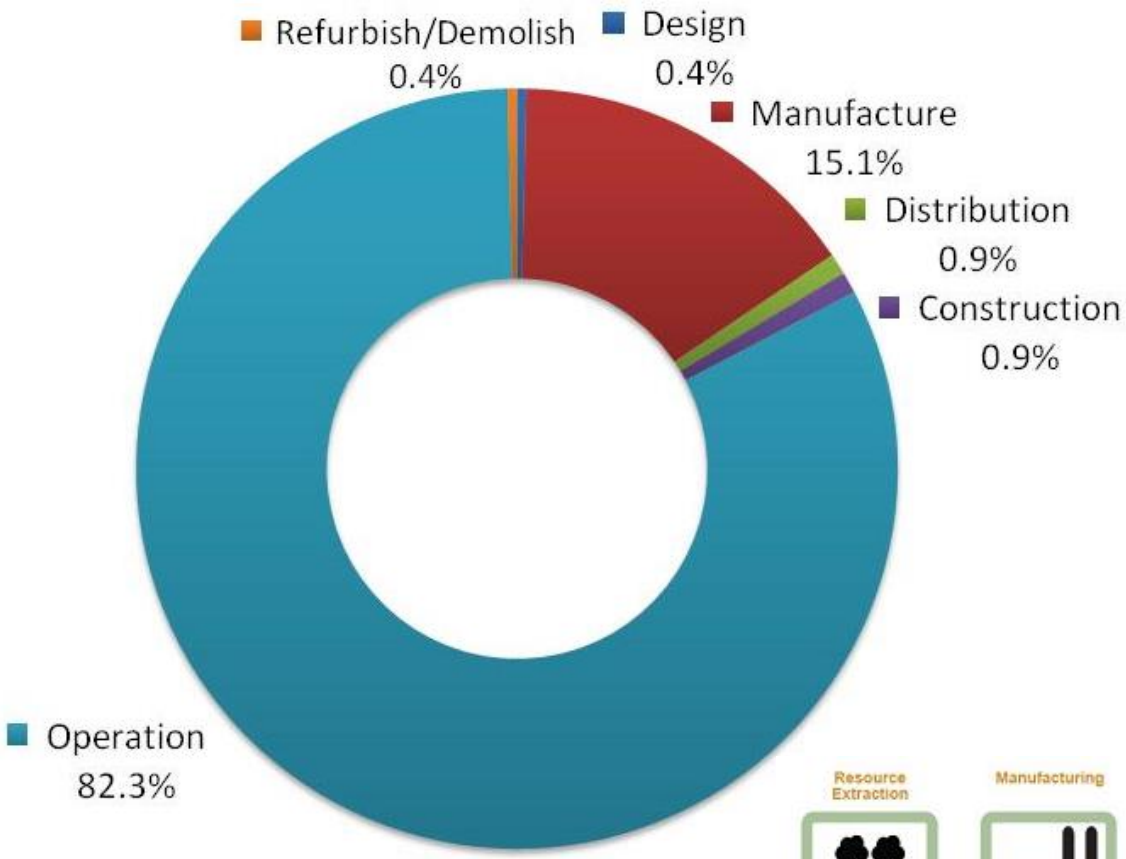
#2. Transportation (~20%)

#3. Industry (~20%)

Buildings in Hong Kong accounted for 60% of total local GHG emissions

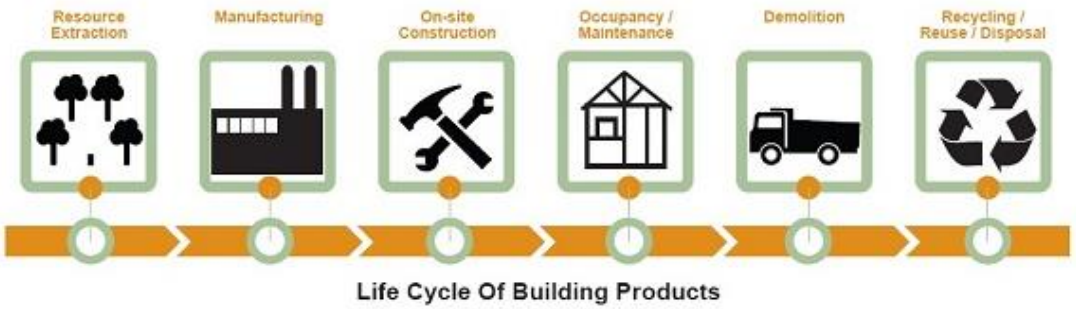
Source: International Energy Agency (2012) CO_2 Emissions from Fuel Combustion

Building's Carbon Footprint



Embodied Carbon of construction materials

The greenhouse gases (GHGs) emissions from the extraction of raw materials, manufacturing, and transporting the construction materials to the border of construction site



Source: RICS (2012), Methodology to Calculate Embodied Carbon of Materials, 1st edition, information paper, UK

Why we pursue low-carbon materials?

- Embodied carbon emissions of materials account for 15-20 % life-cycle carbon emissions

Selecting low-carbon materials
helps
reduce building carbon footprint

Outline

1 Background

2 Carbon Labelling Scheme for Construction Products

3 Low-carbon Design of Building Structures

4 The Way Forward

Development of the CIC Carbon Labelling Scheme

CIC Carbon Labelling Scheme for Construction Products
建築產品碳標籤計劃

launched in January 2014

Inspiration of Carbon Labelling for construction products
2009

HKU developed the carbon labelling framework for 6 types of construction products
2012

CIC Carbon Labelling Scheme Launched and open for applications
Jan 2014

Research Phase II commences (covering 10 additional product types incl. concrete, stainless steel, asphalt, etc.)
Mar 2014

Implementation& Development

- ✓ Promote the application and the use of low carbon materials
- ✓ Low-carbon design/construction
- ✓ Carbon tendering
- ✓ Export service on carbon certification

Carbon Labelling Scheme for Construction Materials

Aim & Scope

- **Aim**: Provide verifiable and accurate information on the carbon footprint of construction materials for users to make informed decision thereby to combat the climate change
- A voluntary eco-labelling programme with independent third-party verification
- Focuses on a single impact category: Global Warming Potential
- System boundary: cradle to site
- Stimulate the demand for and supply of low carbon construction materials

Materials Coverage
(as in March 2016)

Cement

Rebar

Structural Steel

Ready-mixed Concrete

- ✓ Research on development of frameworks for additional **12** carbon-intensive product categories:
  - **Stainless steel**
  - **Galvanized steel**
  - **Cast iron**
  - **Asphalt pavement**
  - **Precast concrete**
  - **Construction aggregate**
  - **Brick**
  - **Timber products / composite wood**
  - **Gypsum board**
  - **Tiles**
  - **Glass**
  - **Aluminium**

Carbon Rating and Carbon Label

Based on the carbon footprint of the assessed product, CIC shall issue the carbon label with corresponding class for a validity period of two years

[Company Name]
[Company Address]
[Prodcut Name]

Carbon Footprint (tonneCO_2e/tonne)

Total	**XX**
Raw Material Acquisition	XX
Production	XX
Transportation	XX

Label ID: CIC-CLS-XX-XXX-XX
Valid Period: DD/MM/YYYY - DD/MM/YYYY

Involved Stakeholders / Organisations

Development Bureau
The Government of the Hong Kong Special Administrative Region

HONG KONG HOUSING AUTHORITY

Alliance 友盟

MTR

香港 國際機場 HONG KONG INTERNATIONAL AIRPORT

HKGBC 香港綠色建築議會

HKPC

BUSINESS ENVIRONMENT COUNCIL 商界環保協會

有利集團有限公司 Yau Lee Holdings Limited

K. WAH CONSTRUCTION MATERIALS 嘉華建材

財團法人 台灣綠色生產力基金會 Taiwan Green Productivity Foundation

حديد الإمارات emirates steel a SENAAT company إحدى شركات صناعات

HKQAA HONG KONG QUALITY ASSURANCE AGENCY 香港品質保證局

bsi.

Gammon

Siam Yamato Steel Co.,Ltd.

和利鋼鐵有限公司 Wo Lee Steel Co. Ltd.

中龍鋼鐵 DRAGON STEEL

SGS

俊和發展集團 CHUN WO DEVELOPMENT HOLDINGS LIMITED

環科工程顧問股份有限公司 Environmental Science Technology

Implementation Strategies

Integrating the Scheme into BEAM Plus

Liaison with HKGBC

Listing Labelled Products

Launching an Online Listing Service

Specifying the Use of Low Carbon Materials in Public Works

Liaison with DevB, MTRC, HKHA,

Implementation Strategies

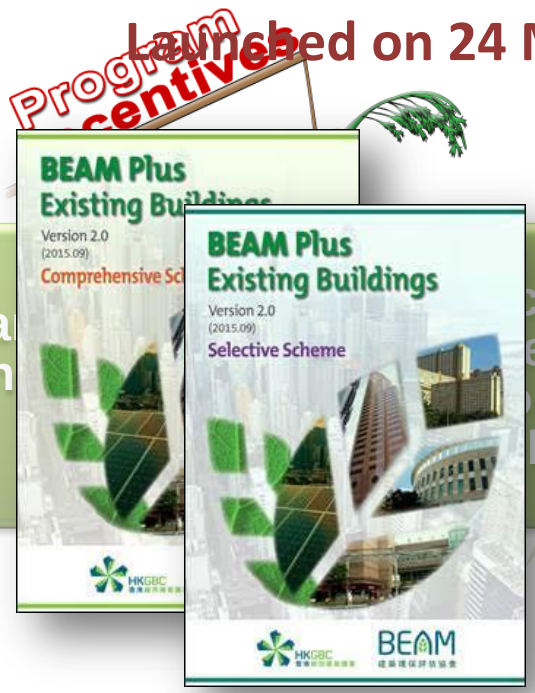
Integrating the Scheme into BEAM Plus

Liaison with HKGBC

BEAM Plus Existing Buildings Version 2.0:
Comprehensive Scheme & Selective Scheme
Launched on 24 March 2016

Listing Labelled Products

Launching a
Online Listin
Service



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CONSTRUCTION INDUSTRY COUNCIL CARBON LABELLING SCHEME

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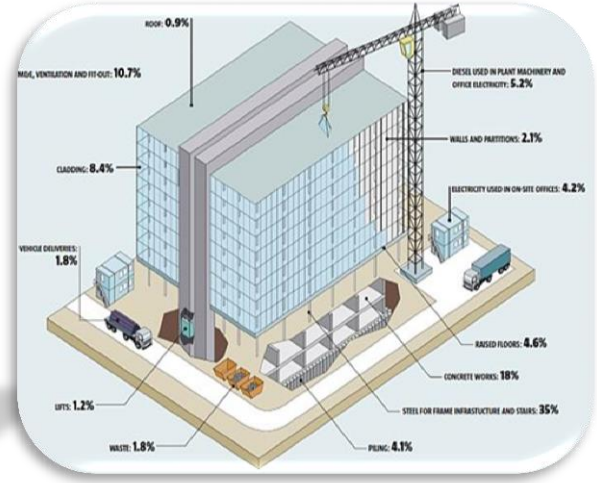
3 Low-carbon Design of Building Structures

4 The Way Forward

What about the embodied carbon of a building structure?

What we know:-

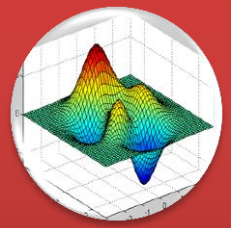
- **Material Use – Associated with Embodied Carbon & Energy**
- **Optimised Structural Design is Saving Material Consumption**
- **Carbon Labelling Scheme is Promoting Manufacture and Use of Low-carbon Materials**



What is missing:-

- **Optimised Structure Design ≠ Lowest Carbon Footprint of Building Structure**
- **Selection and Use of Low-carbon Material ≠ Lowest Carbon Footprint of Building Structure**

Low-carbon Design of Building Structures



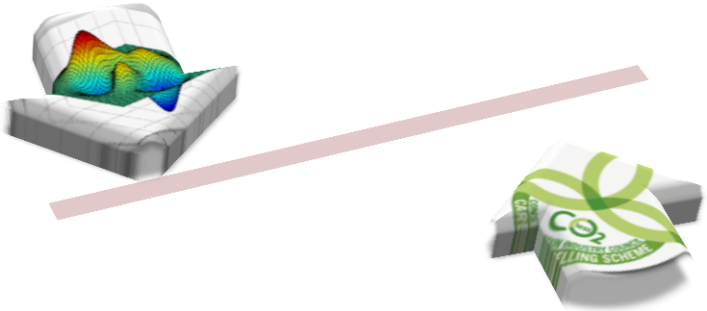
Optimised Structure Design

+

Select low-carbon Materials

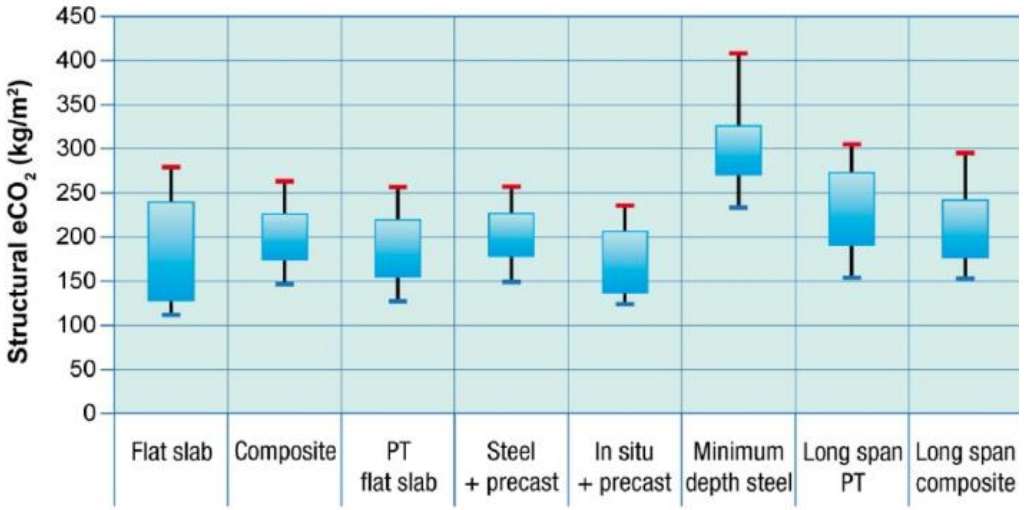
=

Lowest Carbon Footprint of Structure



Low-carbon design of structure around the world

Concrete Centre & Arup, 2012



Comparison of embodied carbon (superstructure + substructure) for structural framing options across all the building types

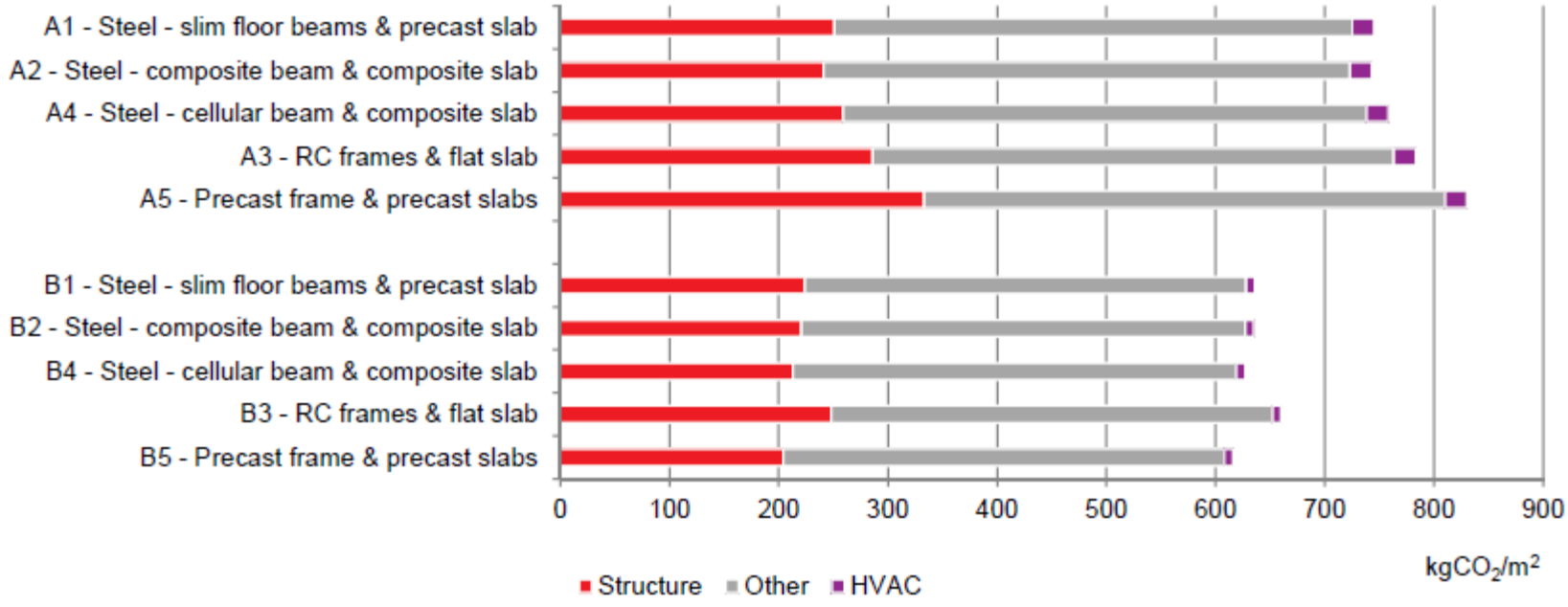
	$kgCO_2/m^2$
Whole office building	300~410
Superstructure only (excluding foundations & ground slab)	110~220
Total structure	170~280
Non-structural elements (excluding construction & services)	92~98

Range in calculated embodied carbon for office buildings

(Sarah Kaethner and Jenny Burridge (2012), Embodied CO_2 of Structural Frames, The Structural Engineer)

Low-carbon design of structure around the world

Eaton & Amato, 1998



Embodied carbon of different building structures

(K J Eaton and A Amato (1998), A Comparative Environmental Life Cycle Assessment of Modern Office Buildings, SCI)

Low-carbon design of structure around the world

Other studies on low-carbon design of structure:

David Bennett (2010), Sustainable Concrete Architecture, RIBA Publishing

Target Zero (2012) Embodied Carbon from Target Zero: Guidance on the Design and Construction of Sustainable Low Carbon Office Buildings , Report V2.0

Embodied Carbon of Steel versus Concrete Buildings (2013), Cundall Johnston & Partners LLP

Hong Kong's research on Low-carbon Design

Research Aim and Objectives

Aims to examine the potential of embodied carbon reduction through optimising different RC and steel structural designs.

- ***Nonlinear Optimization Method*** - to optimise the structural design
- ***Embodied carbon data of ready-mixed concrete and steel (overseas & local data)*** - to calculate the overall carbon footprint of the optimised building structures
- ***Comparison*** - to investigate the impact of structure design and material usage on the building carbon footprint

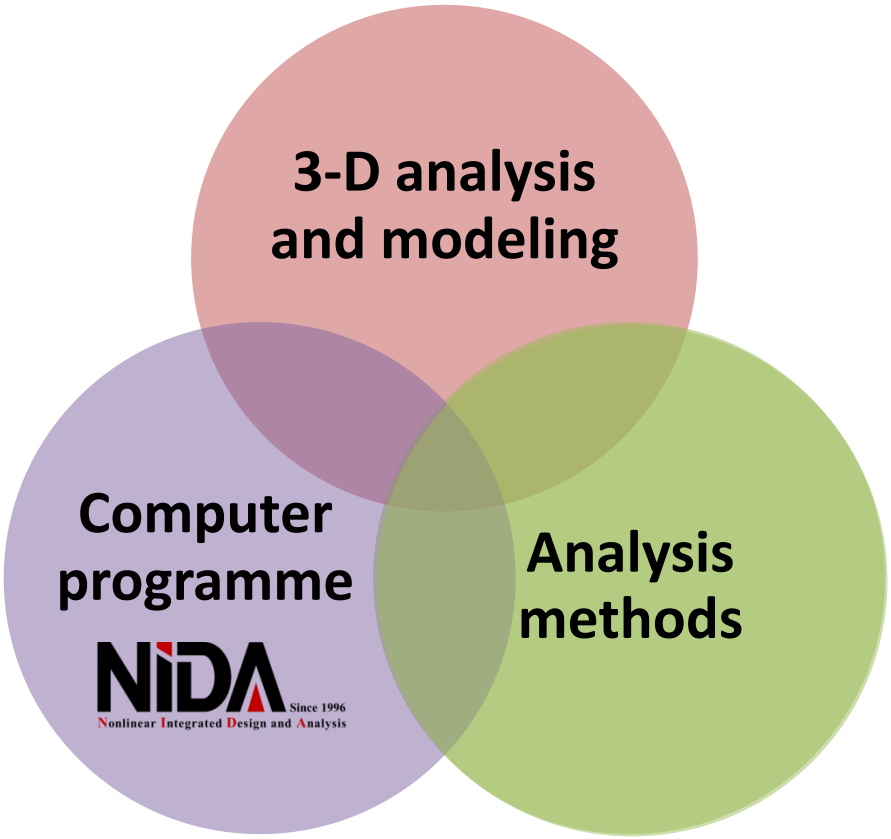
Methodology
Building Configurations & Requirements

25 floors
Height = 97.6m
Plan Area = 27.69m x 23.26m

Steel Building
- Steel Beam + Steel Columns
- Concrete Core Wall

Reinforced Concrete Building
- RC Beams + RC Columns
- Concrete Core Wall

Methodology
Computer Analysis Method



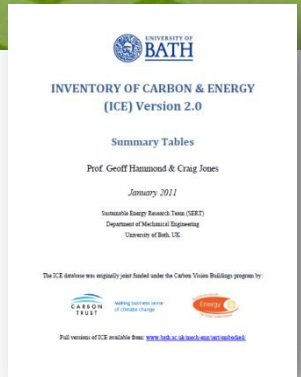
Steel Building

- Second-order plastic (P-Δ-δ) analysis

RC Building

- Linear elastic analysis

Embodied Carbon Data


UNIVERSITY OF BATH

INVENTORY OF CARBON & ENERGY (ICE) Version 2.0

Summary Tables

Prof. Geoff Hammond & Craig Jones

January 2011

Sustainable Energy Research Team (SERT)
Department of Mechanical Engineering
University of Bath, UK

The ICE database was originally joint funded under the Carbon Vision Buildings program by:

CARBON TRUST — Making business sense of climate change — Energy

Full versions of ICE available from: www.bath.ac.uk/mech-eng/sert/embodied

Inventory of Carbon and Energy (ICE), UK

The Carbon footprint data of concrete applied in this study (unit: kg CO_2e/m^3) :

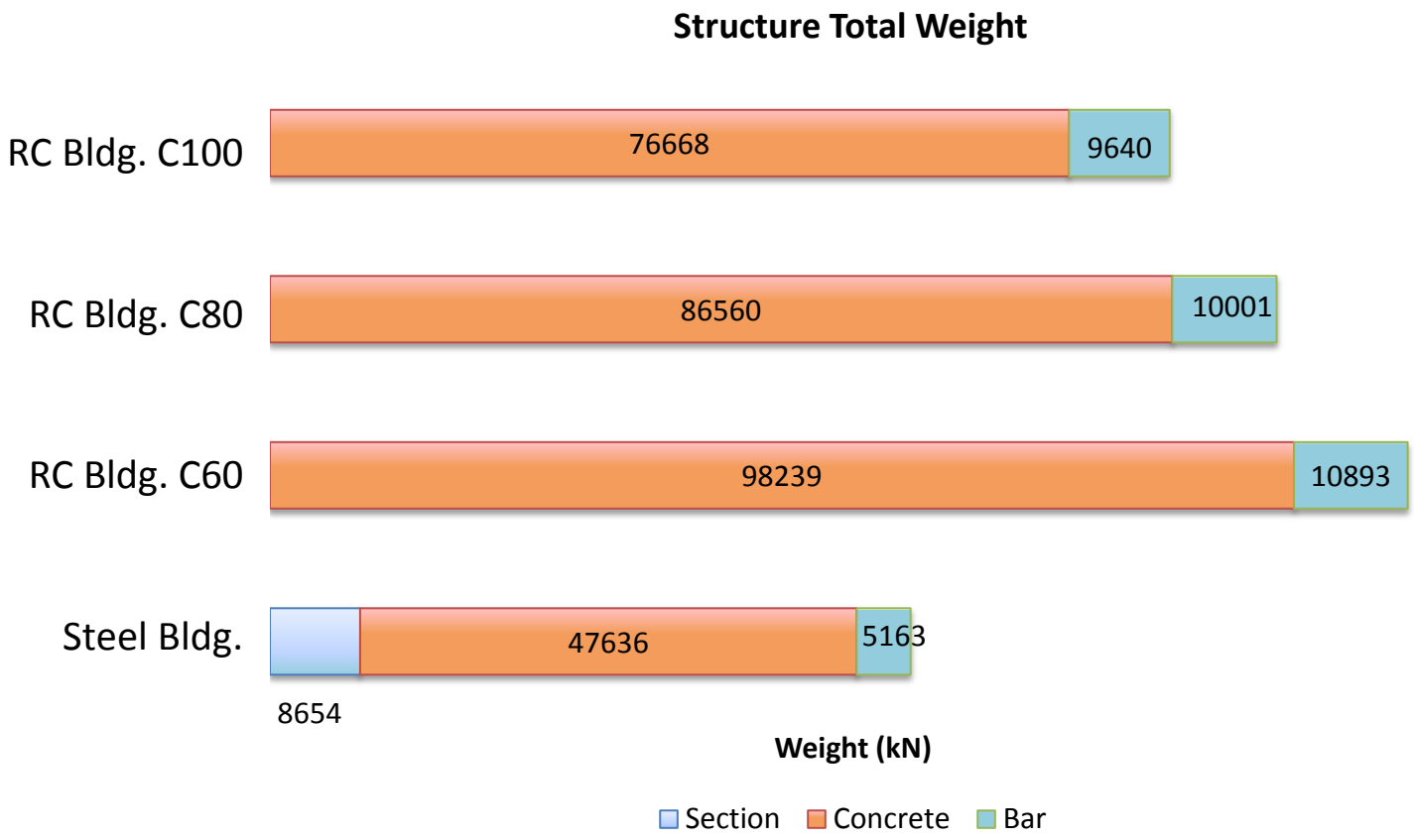
Concrete Grade	100% OPC	50% GGBS	Average Value
C60	491	306	413
C80	598	381	507
C100 *	598	381	507

*The carbon footprint value of super high strength concrete will not be increased with the increasing strength but tending to be steady. It is assumed that the carbon footprint of C100 the same as the C80.

The Carbon footprint data of steel applied in this study (unit: kg CO_2e/kg) :

Steel Type	Virgin steel	39% recycled scrap	59% recycled scrap
Section	3.03	2.03	1.53
Bar	2.77	1.86	1.40

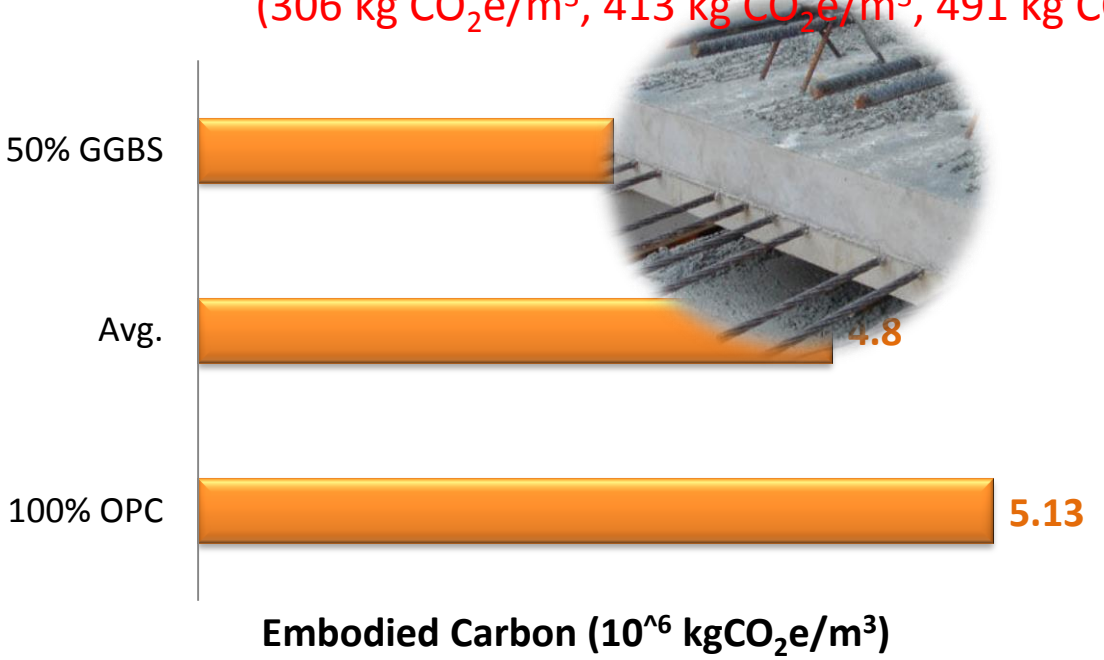
Superstructure Total Weight - Optimised Design



RC Superstructure In Different Green Concrete

Materials –

- **Rebar – virgin steel** (2.77 kg CO_2e/kg)
- **Concrete – C60**
- **Concrete – 50% GGBS, Average , 100% OPC**
  (306 kg CO_2e/m^3, 413 kg CO_2e/m^3, 491 kg CO_2e/m^3)

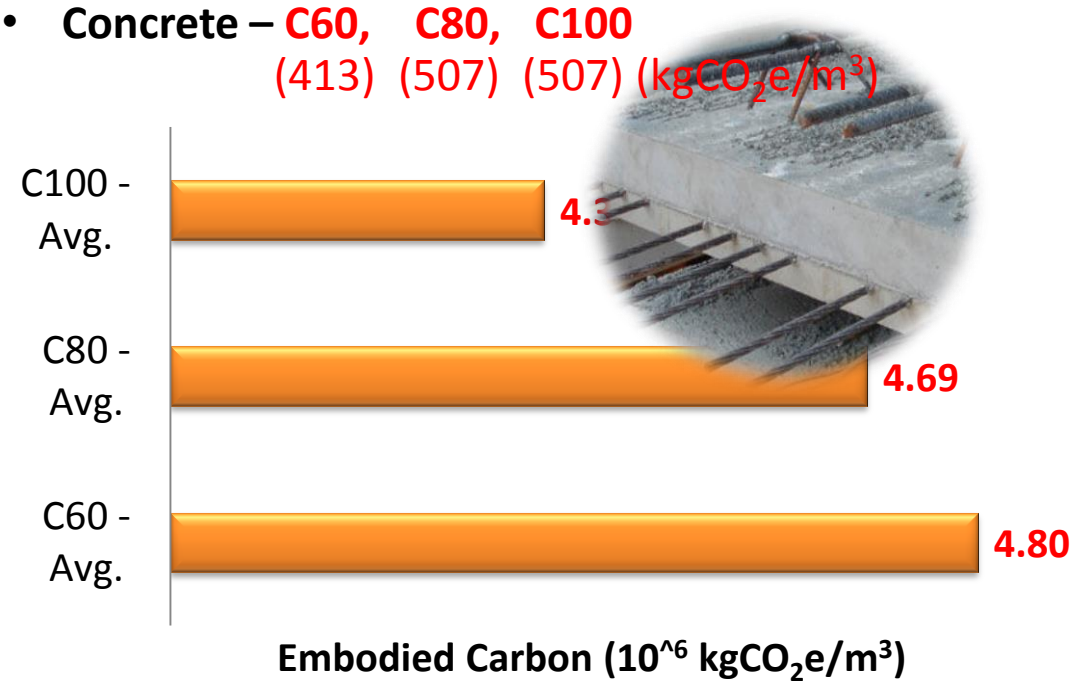


Use of Low-carbon Concrete = Total Embodied Carbon decreases

RC Superstructure In Different Concrete Grade

Materials –

- **Rebar – virgin steel** (2.77) ($kgCO_2e/kg$)
- **Concrete – average emissions factors (OPC + green concrete)**
- **Concrete – C60, C80, C100**
  (413) (507) (507) ($kgCO_2e/m^3$)

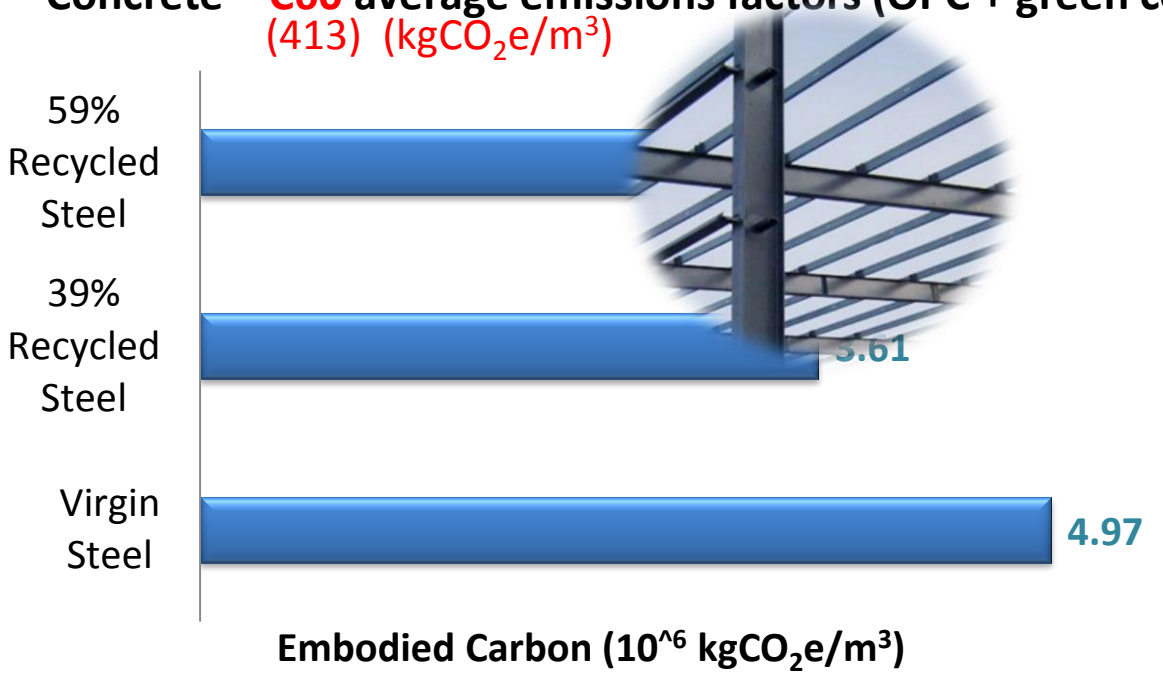


Concrete Grade Increases = Total Embodied Carbon decreases

Steel Superstructure In Different Green Steel

Materials –

- **Structural steel – virgin, 39% recycled, 59% recycled**
  (3.03) (2.03) (1.53) ($kgCO_2e/kg$)
- **Rebar – virgin, 39% recycled, 59% recycled**
  (2.77) (1.86) (1.40) ($kgCO_2e/kg$)
- **Concrete – C60 average emissions factors (OPC + green concrete)**
  (413) ($kgCO_2e/m^3$)



Use of Low-carbon Steel = Total Embodied Carbon decreases

What if we used the construction materials available in Hong Kong?

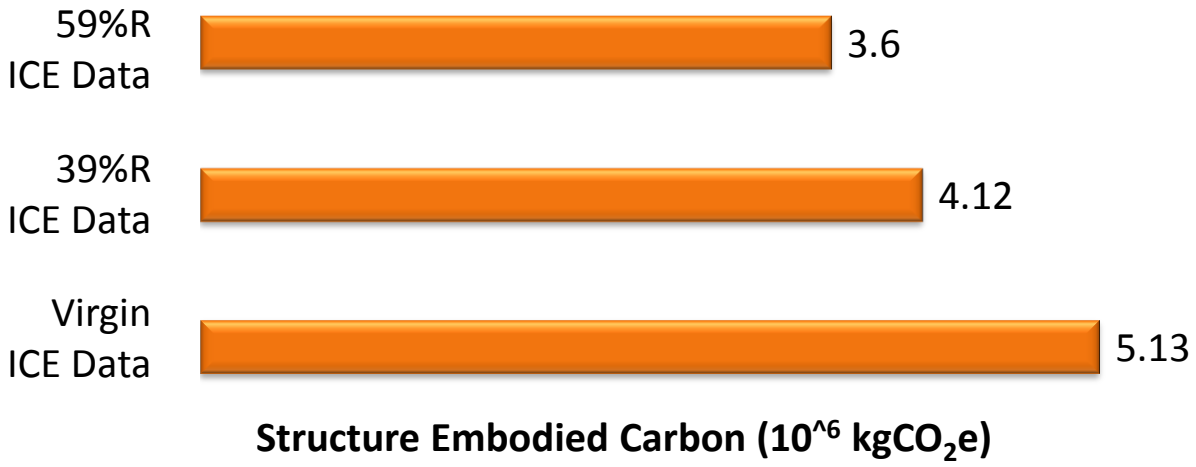
HK Local Embodied Carbon Data:

Applicant from	Product Category	Carbon Footprint Value
	Rebar and Structural Steel	Unit: $kgCO_2e/kg$
Thailand	Section	0.55
Mainland China	Pipe	2.95
Taiwan	Section	1.37
Middle East	Rebar	2.08
Middle East	Section	2.36
	Ready-mixed Concrete	Unit: kg CO_2e/m^3 concrete
Hong Kong	C60 (OPC)	530
Hong Kong	C60 (25% PFA)	413
Hong Kong	C60 (40% GGBS)	355

Low-carbon Design of Building Structures

RC Superstructure ICE Data VS Local Data

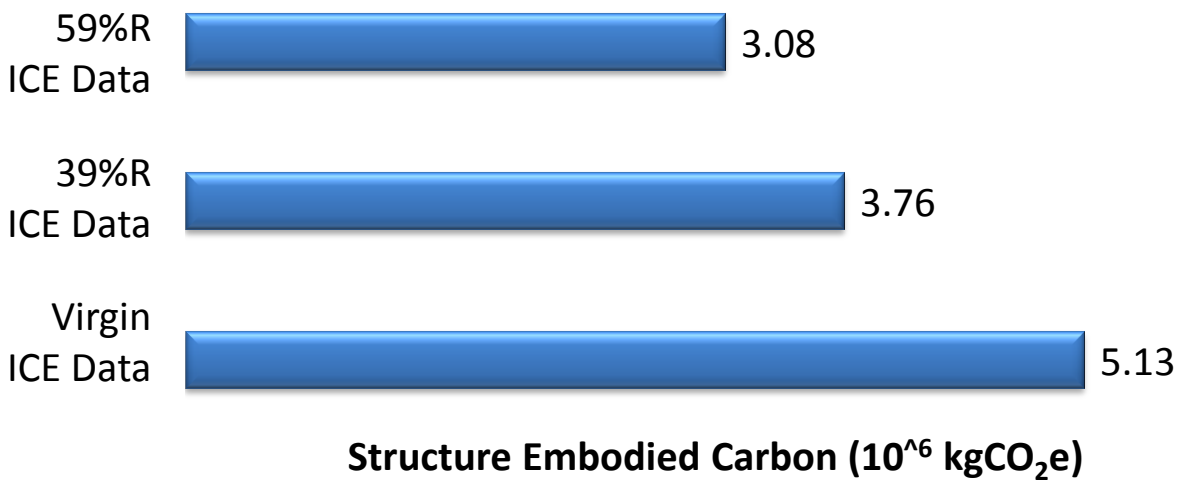
	Hong Kong Data	ICE Data		
Concrete	530 kg CO_2e/m^3 (C60 OPC)	491 kg CO_2e/m^3 (C60 OPC)		
Rebar	2.08 $kgCO_2e/kg$	59% Recycled	39% Recycled	Virgin
Structural Steel	0.55 $kgCO_2e/kg$	59% Recycled	39% Recycled	Virgin



Low-carbon Design of Building Structures

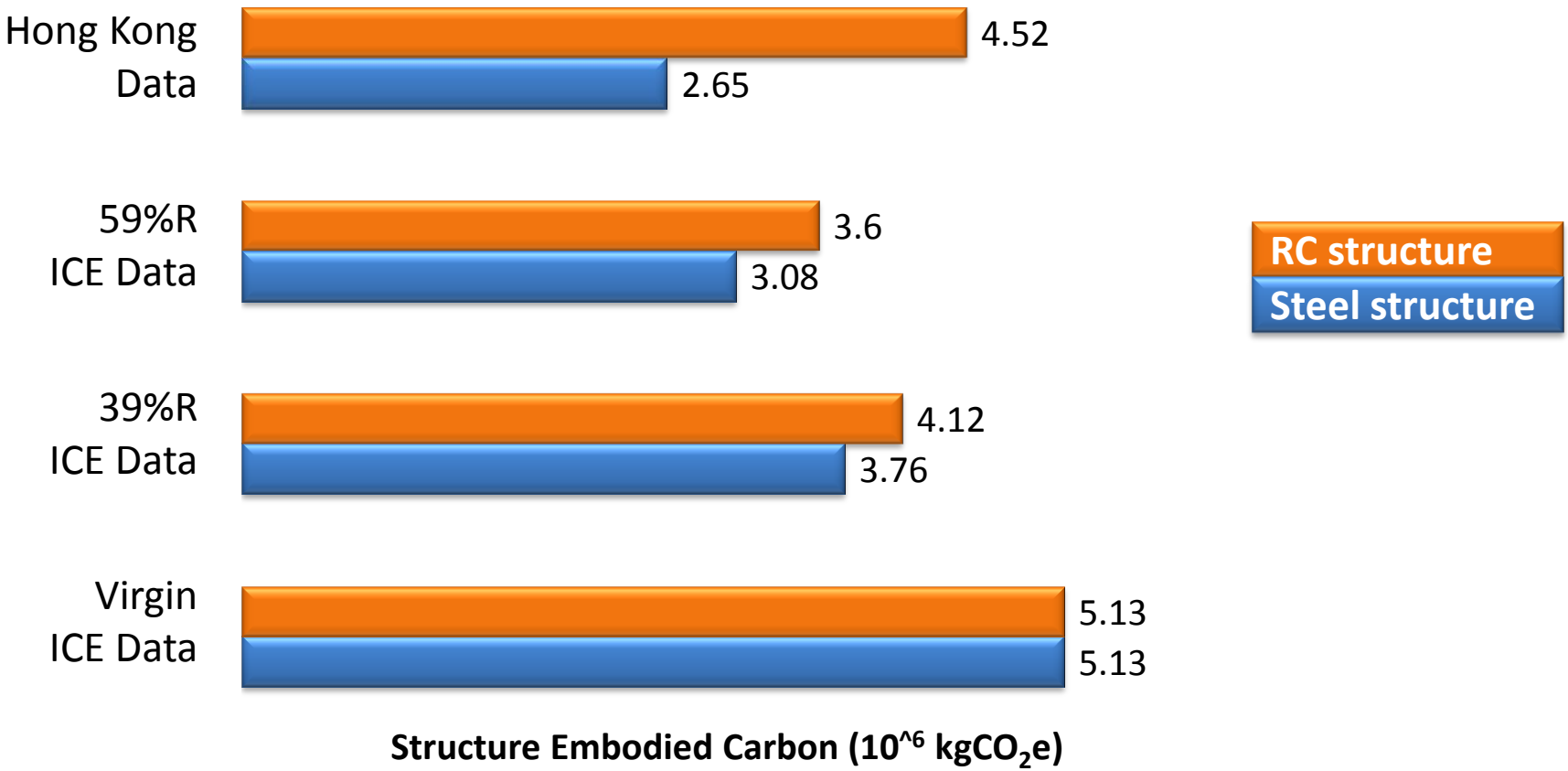
Steel Superstructure ICE Data VS Local Data

	Hong Kong Data	ICE Data		
Concrete	530 kg CO_2e/m^3 (C60 OPC)	491 kg CO_2e/m^3 (C60 OPC)		
Rebar	2.08 $kgCO_2e/kg$	59% Recycled	39% Recycled	Virgin
Structural Steel	0.55 $kgCO_2e/kg$	59% Recycled	39% Recycled	Virgin



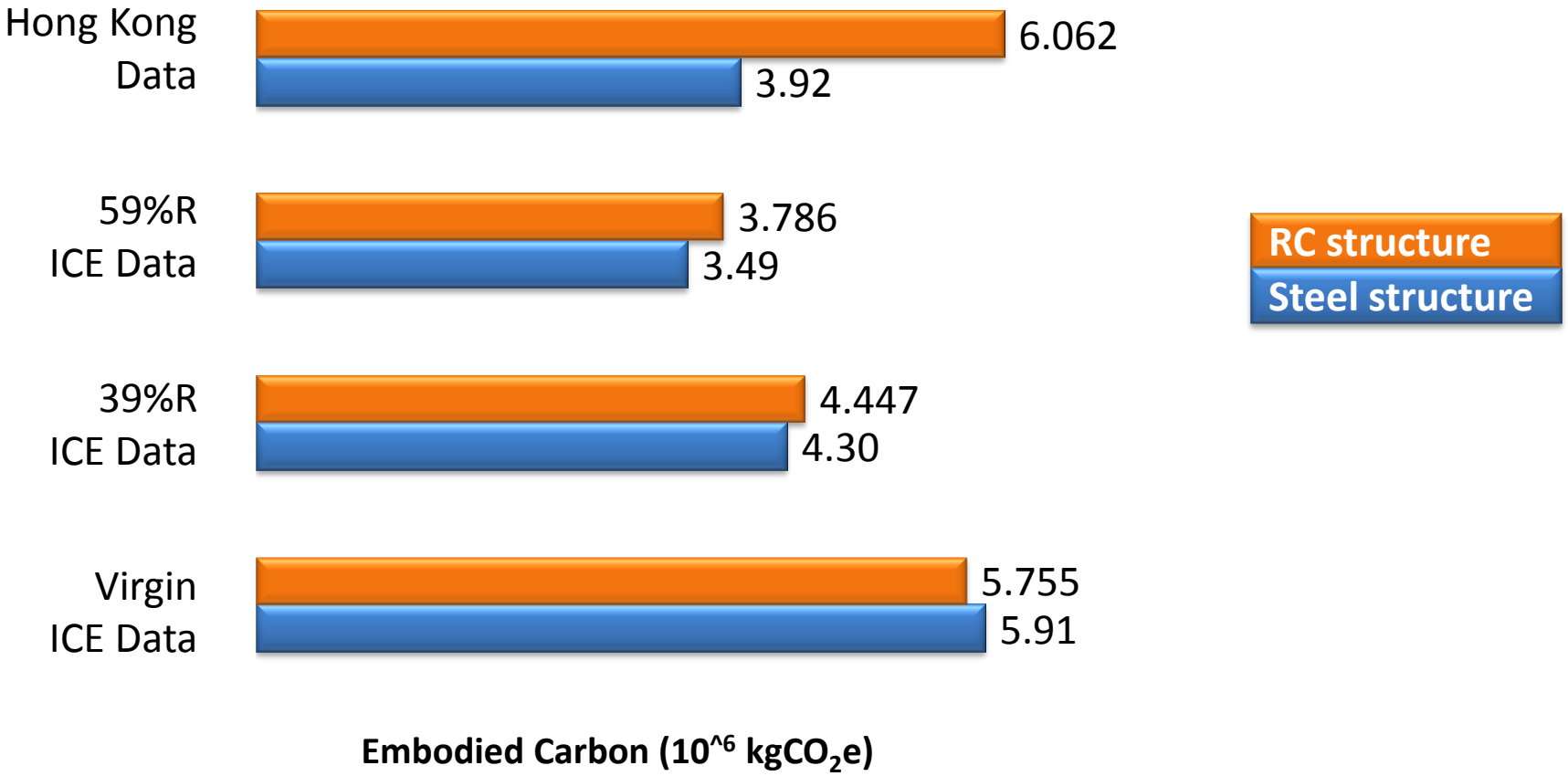
Low-carbon Design of Building Structures

RC vs. Steel Superstructure



What if we take foundation into consideration?

RC vs. Steel Superstructure+Foundation



Conclusions

- RC Building vs. Steel Building (Which one is lower carbon?)
  - ***Material properties and compositions*** (concrete grade, recycled contents, concrete with SCM such as PFA or GGBS, etc.)
  - **Structural design** (performance requirement, local factor, approach of optimisation)
  - **Geotechnical** (foundation) condition

- Composite Structure Building? *To be further investigated*

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3 Low-carbon Design of Building Structures

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Situations in Hong Kong

What hinder achieving lower carbon footprint of local concrete?

- Clients' requirements & local specifications
  - Durability requirement
  - Minimum cementitious / recycled aggregate content

- Hong Kong's climate - exposure to marine condition

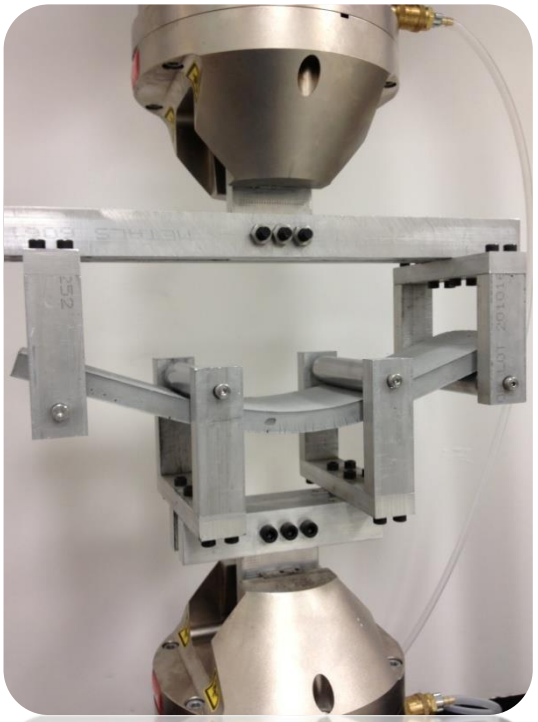
- Construction cycles requirements

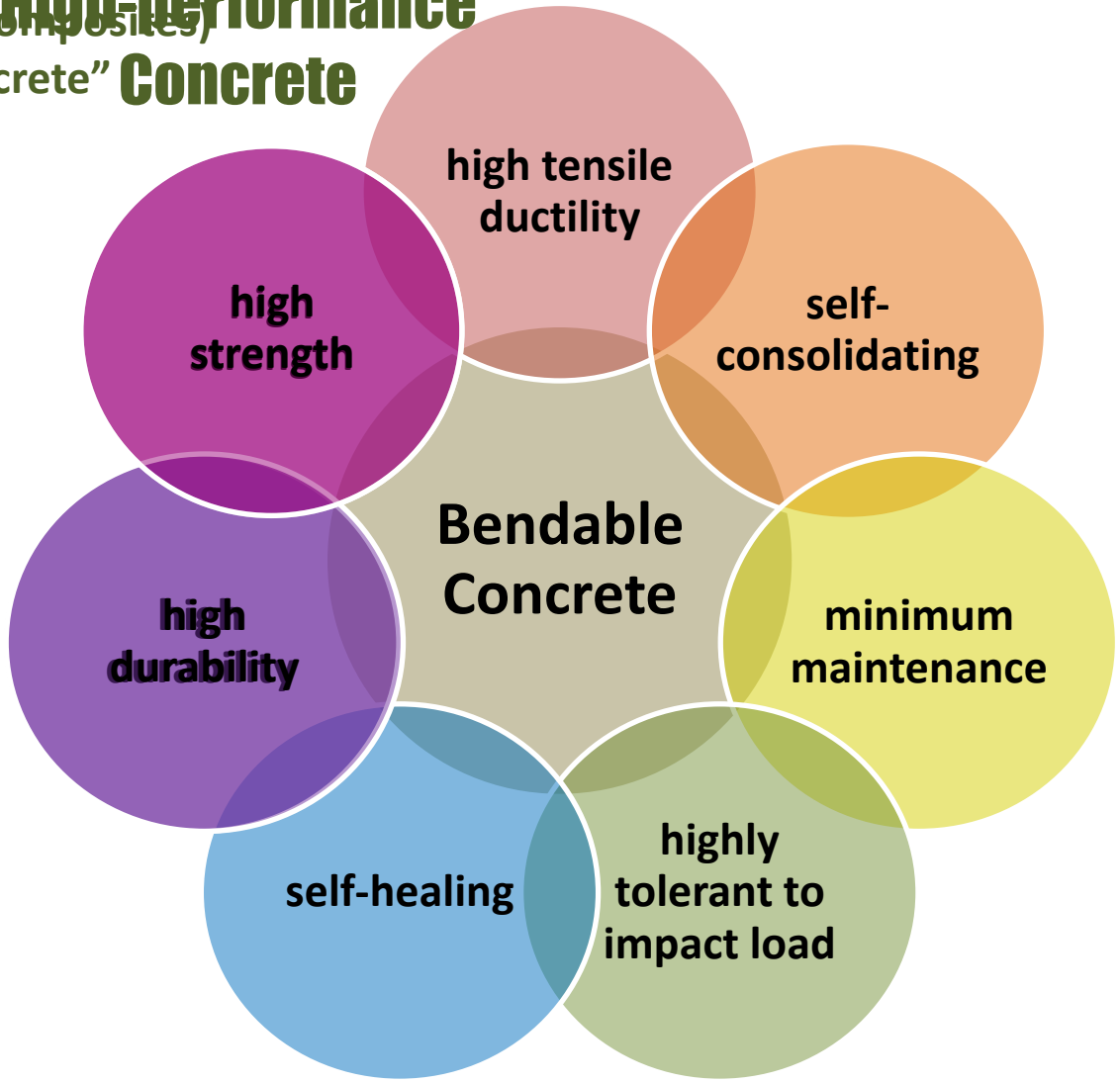
Source of Picture: https://en.wikipedia.org/wiki/Concrete_degradation
http://www.climbing-formwork.com/sale-1833027-auto-climbing-formwork-system-for-labor-saving-construction-form-work.html

The Way Forward

ECC (Engineered Cementitious Composites)
As know as "Bendable Concrete"

High-performance Concrete

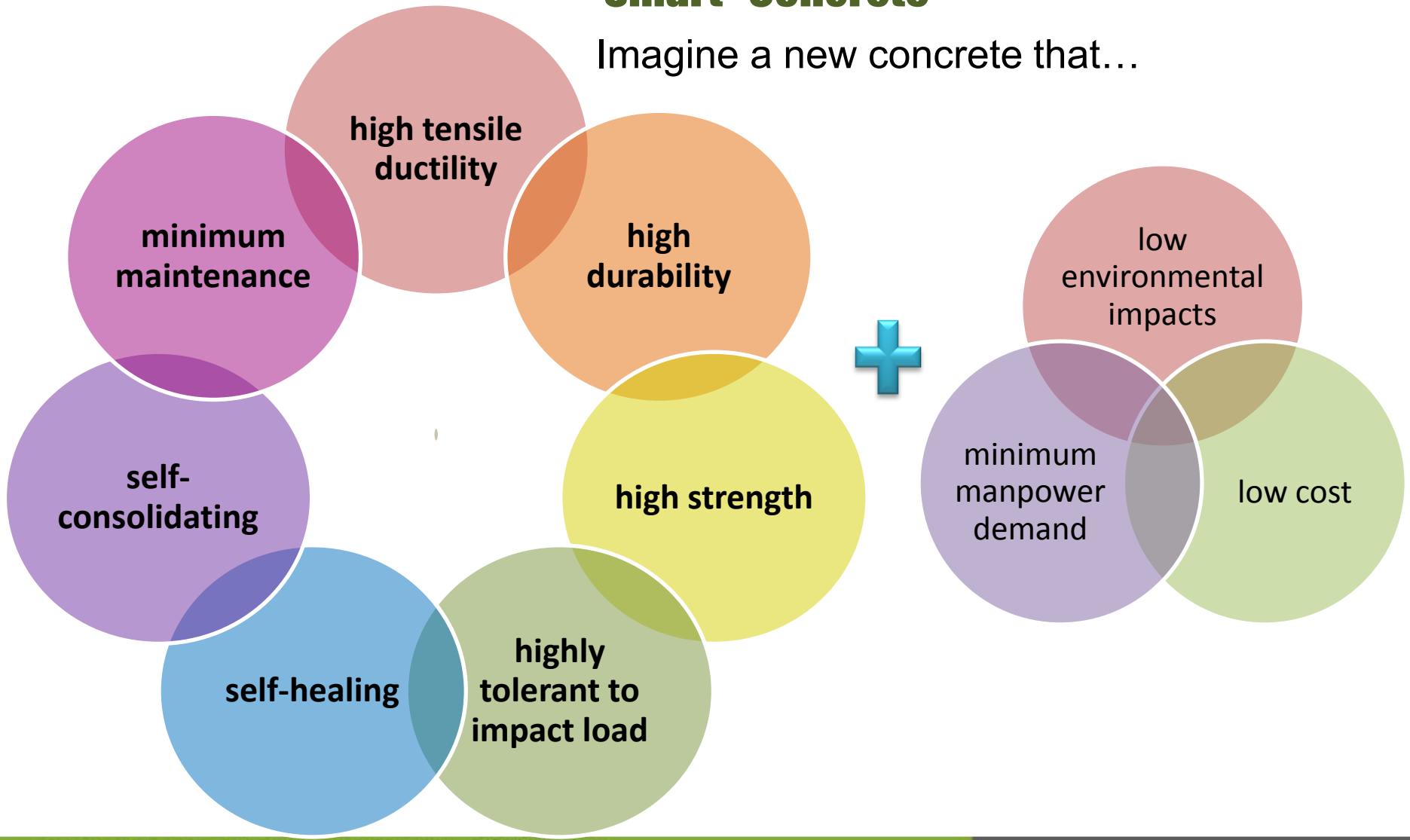




The Way Forward

"Smart" Concrete

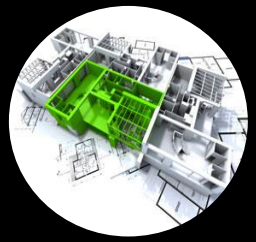
Imagine a new concrete that…



Green

ward

Green Building



Green Structural Design

Green Materials

sources of photos:
http://widedscreen.com/3d-architecture-wallpaper-2/
http://www.maximizingprogress.org/2008/11/singapore-green-buildings-in-garden.html
http://www.globalmayorsforum.org/en/citiesdetails.aspx?tid=115&id=129
http://blog.iqsdirectory.com/green-ideas-for-industry/construction-going-green-and-growing-greener/

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Thank You

Ir Julian LEE

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