LCA Modeling for Building Construction Processes

Ya Hong Dong, S. Thomas Ng

Department of Civil Engineering
The University of Hong Kong

Outline

- Background
- Life cycle assessment
- Environmental modeling of construction (EMoC)
- Case study
- Summary

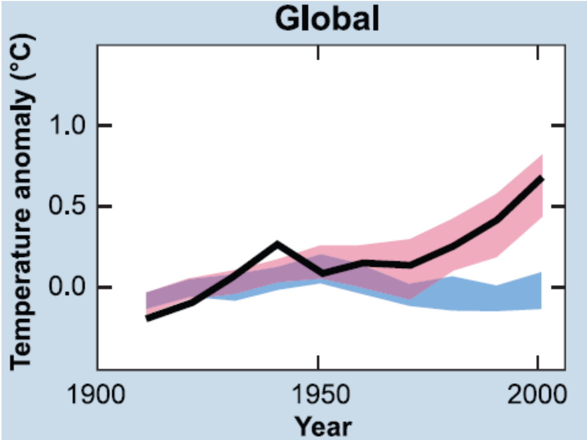
Background

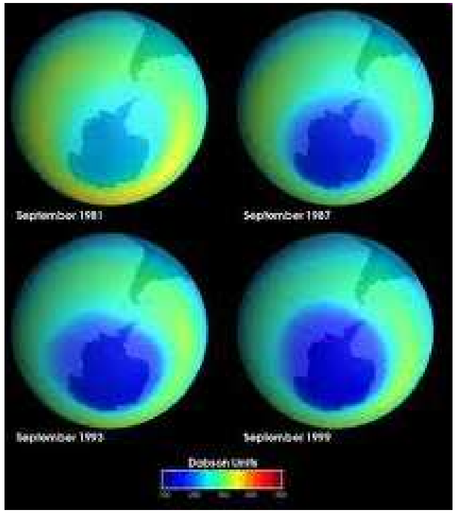
Sustainable development

Definition: The development that meets the needs of the present without compromising the ability of the future generations to meet their own needs

Background

The Environment





Background

Construction and the Environment

Positive environmental impacts

Improvement on the living environment, reclamation, landscape ecology …

Negative environmental impacts

- **Material consumption**: limestone, wood, metal
- **Fuel consumption**: diesel, gasoline
- **Water consumption**: cleaning, temperature control
- **CO_2 emission**: cement manufacturing (5%), steel manufacturing (3%)
- **Dust emission**: on-site, transportation of material
- **Waste generation**: temporary materials
- **Land occupation**: landfill, transformation of natural land
- **Other impacts** … …

Background

Green Actions in Construction Industry

Green Building Assessment Schemes	Region	Year
BREEAM	UK	1990
BEAM Plus	HK	1996/2010
LEED	USA	1998
CASBEE	Japan	2001
Green Star	Australia	2002
Green Mark	Singapore	2005
Green Building Label	China	2006
DGNB Certificate	Germany	2009

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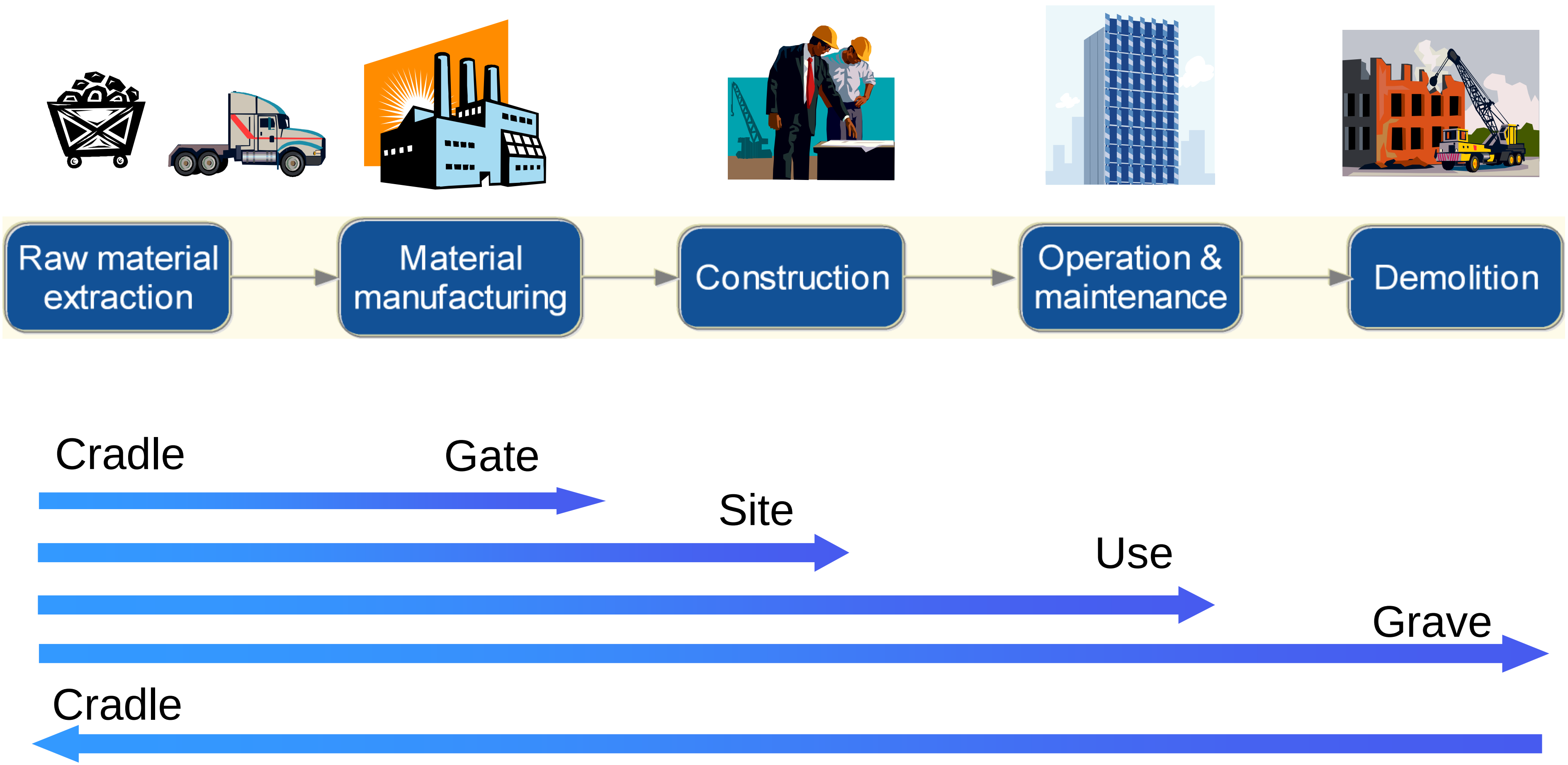
LCA

Life cycle of a building



LCA

Introduction to LCA

What is LCA?

compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040)

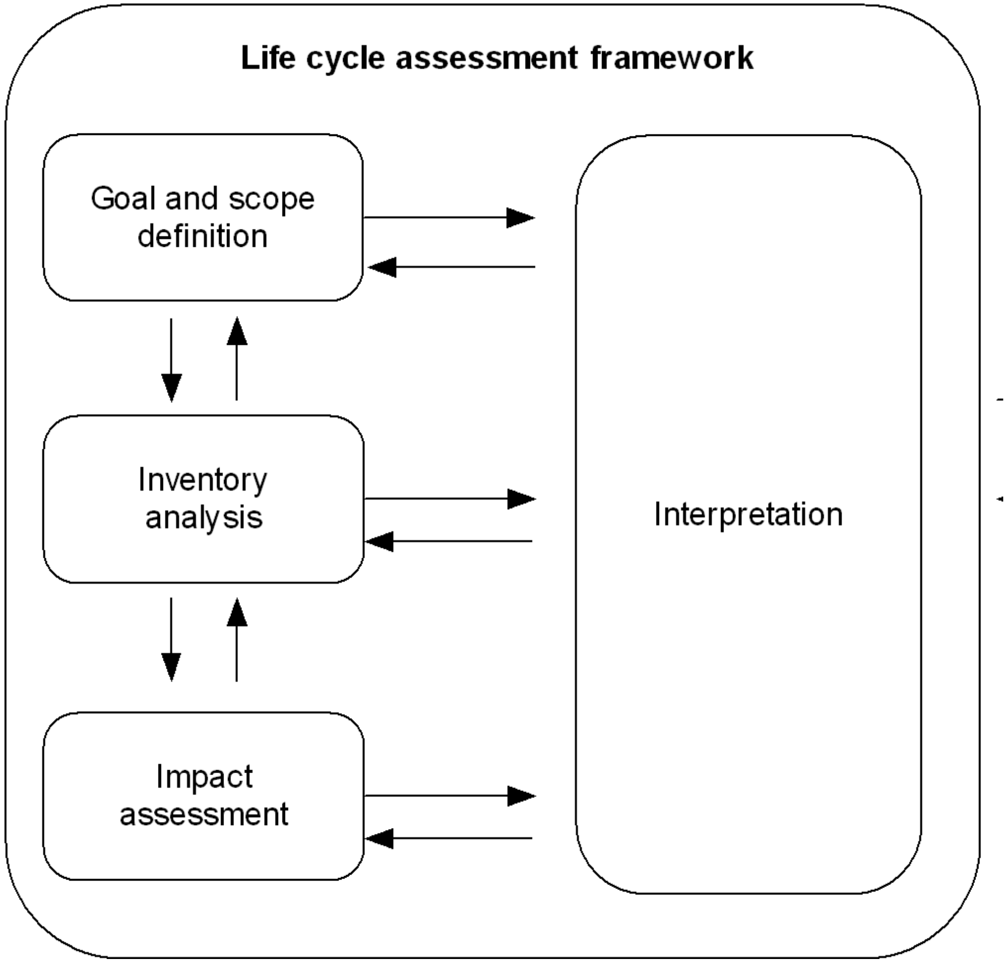
History

1960s Coca-Cola

1990s Intensive development

1996 Int J LCA

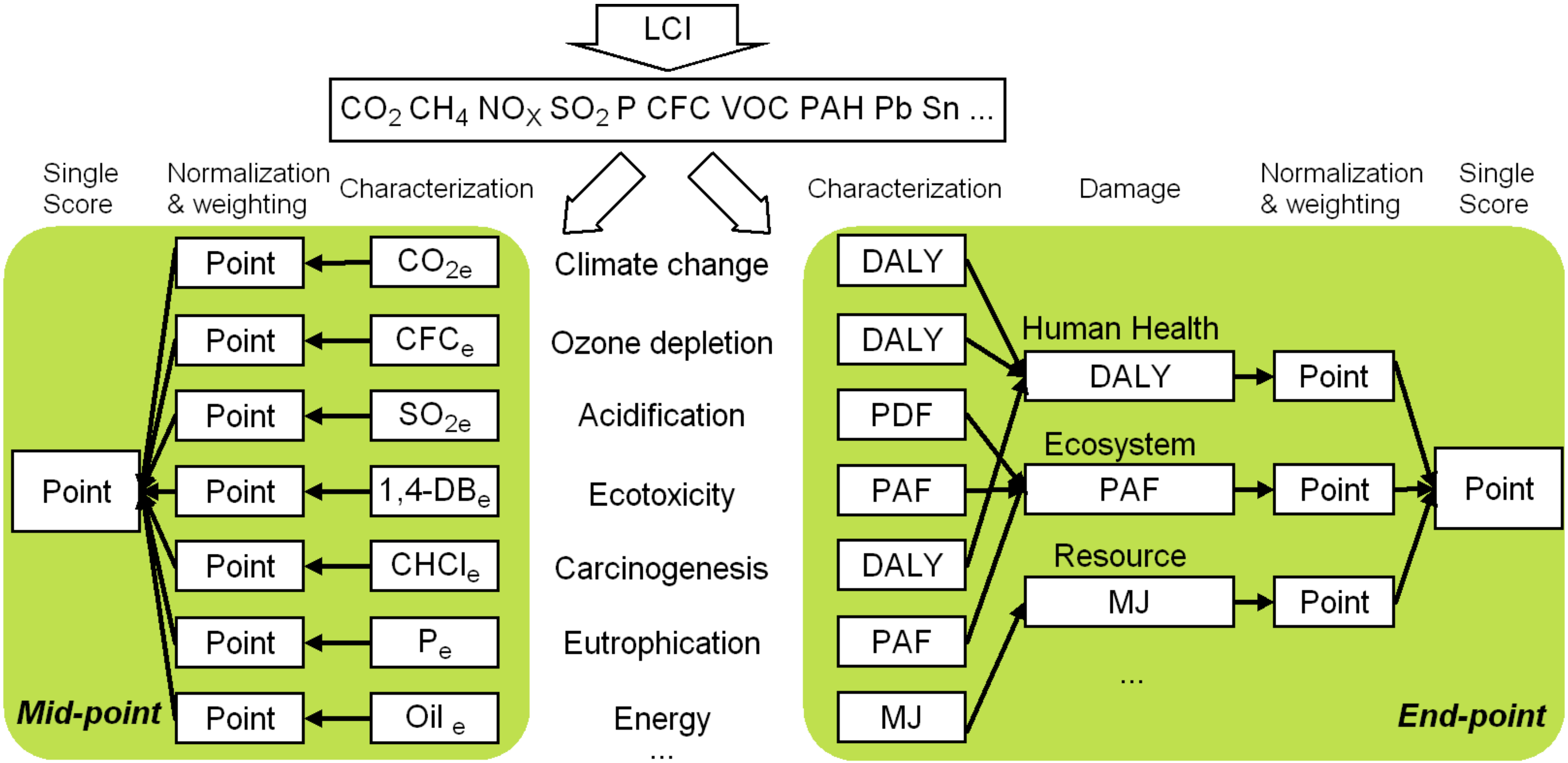
1997/2006 ISO 14040 series



ISO 14040

LCA

Life cycle impact assessment (LCIA)



Methods
- *CML, Eco-indicator 99, TRACI 2, IMPACT 2002+, LIME, ReCiPe*
- *USEtox, IPCC, Ecological footprint*

LCA

LCA in Construction - International

LCA analysis of construction materials

Software: SimaPro, GaBi, eBalance, BEES … …

LCA analysis of entire buildings

Software: Athena, Eco-Quantum, eQUEST … …

Life cycle inventory including building components

Database: Ecoinvent, US LCI, ICE, IVAM, … …

LCA analysis of construction stage

Software: CEDST, Bilec's Model

LCA

LCA in Construction – Hong Kong

- Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) Study of Building Materials and Components (HKHA, 2005)
- Study on Life Cycle Energy Analysis of Building Construction (EMSD, 2006)
- … …

- Construction processes are simply included with few details or breakdowns. A holistic and up-to-date LCA model which can help evaluate the environmental performance of local construction processes is hence in lack.

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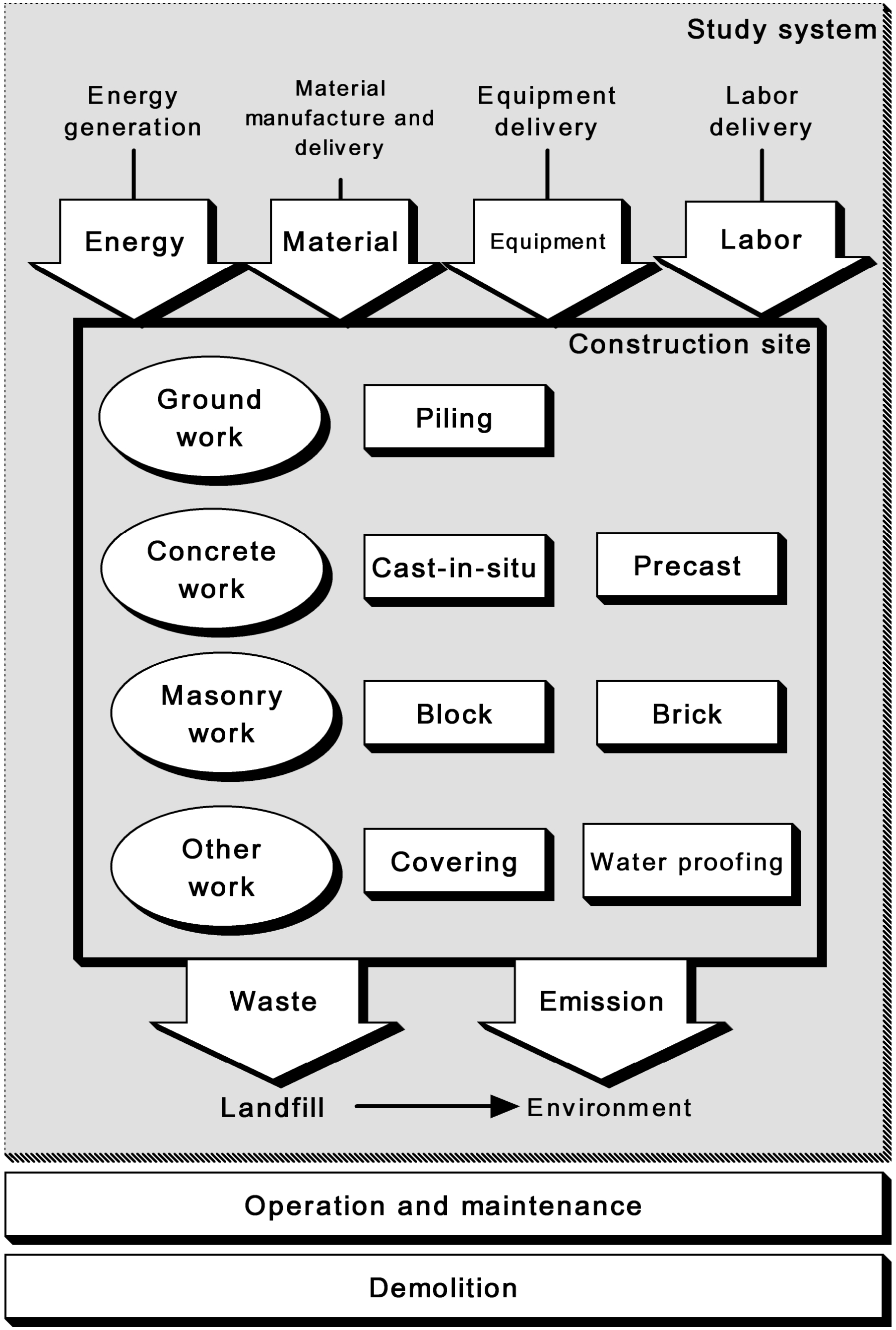
EMoC

Environmental Modeling of Construction (EMoC)

- Up-to-date datasets
- Involvement of construction materials accounting >80% environmental burden
- Involvement of the local concrete LCI data
- Evaluation of different concrete methods
- Capability to analyze 18 impact categories
- Analysis on both midpoint and endpoint levels
- Options of waste treatment methods
- Options of truck emission standards
- … …

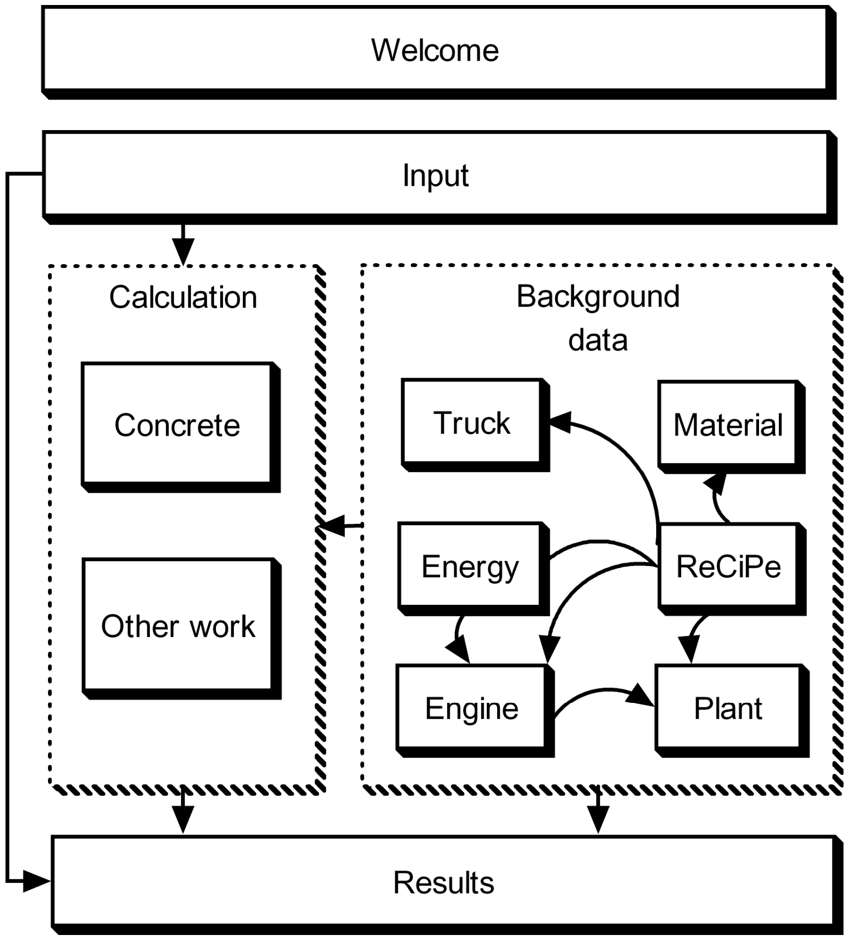
EMoC
Overview

- Boundary: 'Cradle to site'
- LCIA: ReCiPe 2008
- UI: Microsoft Excel
- Size: 30 MB



EMoC

Model Structure



EMoC

Welcome

Environmental Modeling of Construction (EMoC)

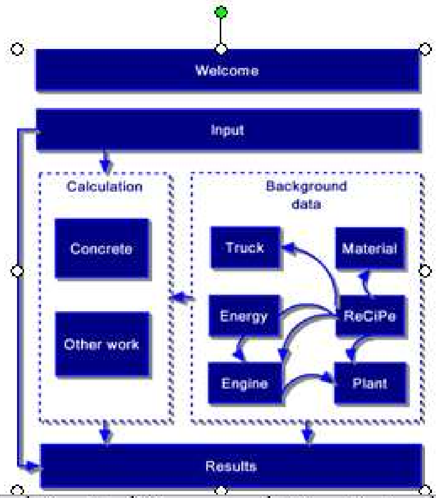
香 港 大 學

THE UNIVERSITY OF HONG KONG

Environmental Modeling of Construction (EMoC) is a 'cradle-to-site' life cycle assessment (LCA) model to simulate the environmental impact in and before construction phase. Model results from EMoC can be used to compare the greeness between options of a project, so that a more environmental friendly alternative can be selected in design phase. The model can also be used to estimate the overall performance of a concrete structure building project.

The model includes several important processes from raw material extraction, through manufacturing materials, to on-site construction activities. Precast and cast-in-situ methods can be estimated in EMoC. 'ReCiPe' is utilized as the life cycle impact assessment (LCIA) method. It provides assessment in 18 impact categories at both midpoint and endpoint levels.

This is the first worksheet of EMoC with the general description of the model structure. The model is composed of 11 worksheets and the structure is illustrated as below:



Welcome / Input / Result / Concrete / OtherWork / Material / Engine / Plant / Truc

EMoC

Input Worksheet – How to use the model?

1	**Input Worksheet**						
2		Discription of items	Input here (if no data, leave as blank)				
3	Respondent						
4		Contact person					
5		Position					
6		Address					
7		Phone No.					
8		Fax No.					
9		Date information collected (dd / mm / yyyy)					
10	General project information						
11		Project name					
12		Project region					
13		Project location					
14		Total gross floor area (m2)					
15		Total site area (m2)					
16		No. of blocks					
17		No. of units					
18		Project start date (dd / mm / yyyy)					
19		Project end date (dd / mm / yyyy)					
20	Total resource consumption during construction						
21		Electricity consumption (kWh)					
22		Diesel consumption (L)					
23		Water consumption (L)					
24		Petrol consumption (L)					
25		Rebar consumption (tonne)					
26		Concrete consumption (m3)					
27	Concrete						
28	Concrete type	C20 (m3)					
29		C30 (m3)					
30		C35 (m3)					
31		C40 (m3)					
32		C45 (m3)					
33	Formwork	Wood (kg)					
34		Steel (tonne)					
35		Steel formwork: Recycle or not					
36		Cast-in-situ/precast ratio (volumn)					
37	Cast-in-situ concrete	/aste percentage of concrete (%)					
38		Recycle or not					
39	Rebar	Waste percentage of rebar (%)					
40		Recycle or not					
41		Item	percent(%)	Type	Concrete amount (m	Rebar amount (kg	No. of elements
42		Column					

Welcome / Input / Result / Concrete / OtherWork / Material / Engine / Plant / Truck / Energy / ReCiPe

EMoC

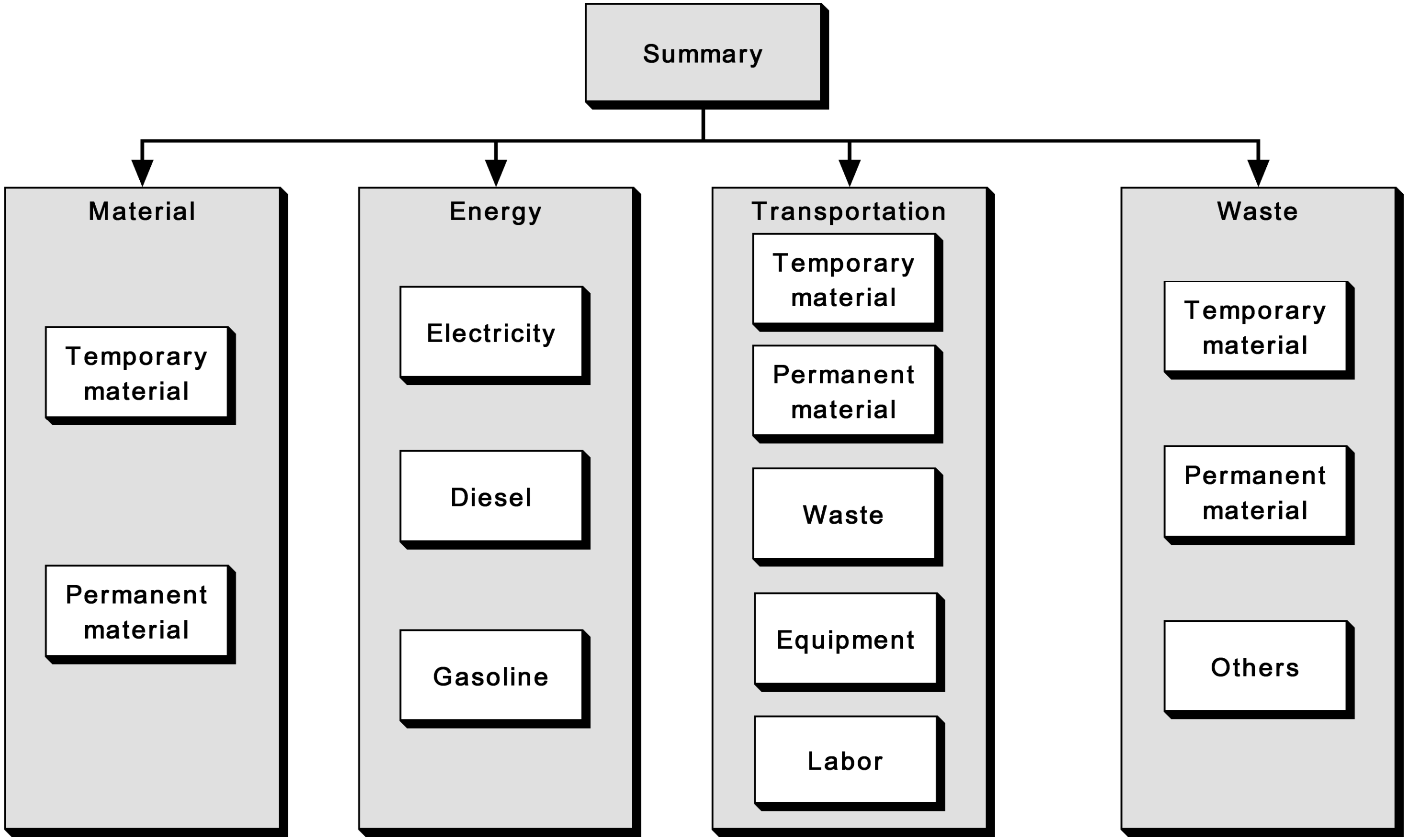
Input Worksheet – How to use the model?

	A	B	C	D	E	F	G
43		Beam					
44		Façade					
45		Semi-precast slab					
46		Staircase					
47	Concrete element	Partition wall					
48		Balcony					
49		Bathroom					
50		Refuse chute					
51		Hanger wall					
52		Others					
53		Advantage of precast concrete					
54		)isadvantage of precast concrete					
55	Transportation						
56		Item	One way (km)	Truck model	Emission Standard		
57		Ready mix					
58		Precast					
59		Formwork					
60		Rebar					
61	Environmental protection						
62		Dust control level					
63	Other work						
64		Concrete for piling (m3)					
65	Ground work	Rebar (tonne)					
66		Excavated soil (tonne)					
67		Item	Applied area (m2)	Item size (L*W*I	Density (kg/m2)	Waste (%)	Oneway distance (kn
68	Masonry	Brick					
69		Block					
70		Item	Area (m2)	Amount (kg)	Waste (%)	Oneway distance	Utilization
71		Aluminium window frame					
72		inium (excluding window frame)					
73		Cement					
74	Surface work and external	Door (wood)					
75		Glass					
76		Mortar					
77		Plaster					
78		PVC window frame					
79		Tile					
80	Equipment						
81	Machine	Type	Operation Hours	Number of equipments			
82		Small excavator					
83	Excavator	Medium excavator					
84		Large excavator					
85	Forklift	N.A.					
86		> 4 tonne					

Welcome / Input / Result / Concrete / OtherWork / Material / Engine / Plant / Truck / Energy / ReCiPe

EMoC

Result Worksheet – How to use the model?



EMoC

Result Worksheet – How to use the model?

Result

Summary	Midpoint Characterization								
	Climate change	Ozone depletion	Human toxicity	Photochemical oxidant formation	Particulate matter formation	Ionising radiation	Terrestrial acidification	Freshwater eutrophication	Mari eutroph n
	kg CO2 eq	kg CFC-11 eq	kg 1,4-DB eq	kg NMVOC	kg PM10 eq	kg U235 eq	kg SO2 eq	kg P eq	kg N
Material									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	
Energy									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	
Transportation									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	
Waste									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	
Dust emission									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	
Total performance									
Total	0	0	0	0	0	0	0	0	
Per unit	0	0	0	0	0	0	0	0	
Per GFA (m2)	0	0	0	0	0	0	0	0	

Material	Amount	Unit	Midpoint Characterization								
			Climate	Ozone	Human	Photochemic	Particulate	Ionising	Terrestrial	Freshwater	Mari

EMoC

Result Worksheet – How to use the model?

	Material	Amount	Unit	Climate change kg CO2 eq	Ozone depletion kg CFC-11 eq	Human toxicity kg 1,4-DB eq	Photochemical oxidant formation kg NMVOC	Particulate matter formation kg PM10 eq	Ionising radiation kg U235 eq
31									
32									
33	**Material: Temporary material**								
34	Steel	0	tonne	0	0	0	0	0	(
35	Water	0	L	0	0	0	0	0	(
36	Wood	0	kg	0	0	0	0	0	(
37	**Total temporary material**			**0**	**0**	**0**	**0**	**0**	**(**
38									
39	**Material: Permenant material**								
40	**Cast in situ concrete**								
41	Column	0	m3	0	0	0	0	0	(
42	Beam	0	m3	0	0	0	0	0	(
43	Façade	0	m3	0	0	0	0	0	(
44	Semi-precast slab	0	m3	0	0	0	0	0	(
45	Staircase	0	m3	0	0	0	0	0	(
46	Partition wall	0	m3	0	0	0	0	0	(
47	Balcony	0	m3	0	0	0	0	0	(
48	Bathroom	0	m3	0	0	0	0	0	(
49	Refuse chute	0	m3	0	0	0	0	0	(
50	Hanger wall	0	m3	0	0	0	0	0	(
51	Pile	0	m3	0	0	0	0	0	(
52	Others	0	m3	0	0	0	0	0	(
53	**Total cast in situ concrete**	**0**	**m3**	**0**	**0**	**0**	**0**	**0**	**(**
54	**Precast concrete**								
55	Column	0	m3	0	0	0	0	0	(
56	Beam	0	m3	0	0	0	0	0	(
57	Façade	0	m3	0	0	0	0	0	(
58	Semi-precast slab	0	m3	0	0	0	0	0	(
59	Staircase	0	m3	0	0	0	0	0	(
60	Partition wall	0	m3	0	0	0	0	0	(

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Case Study

Description

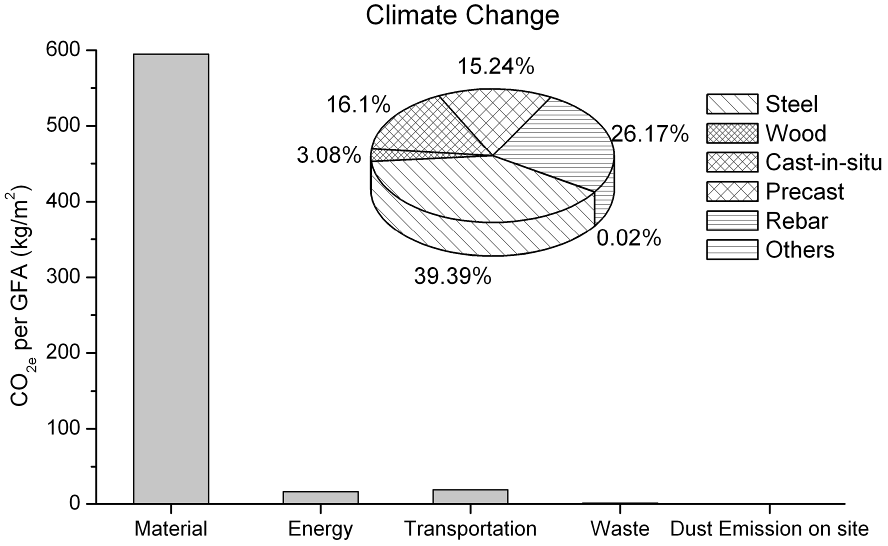
- **A public housing project (PRH) in Hong Kong**
- **Precast concrete accounts for 35% of total concrete volume, including façade, bathroom, semi-precast slab, etc.**
- **The input data is collected via questionnaire survey**

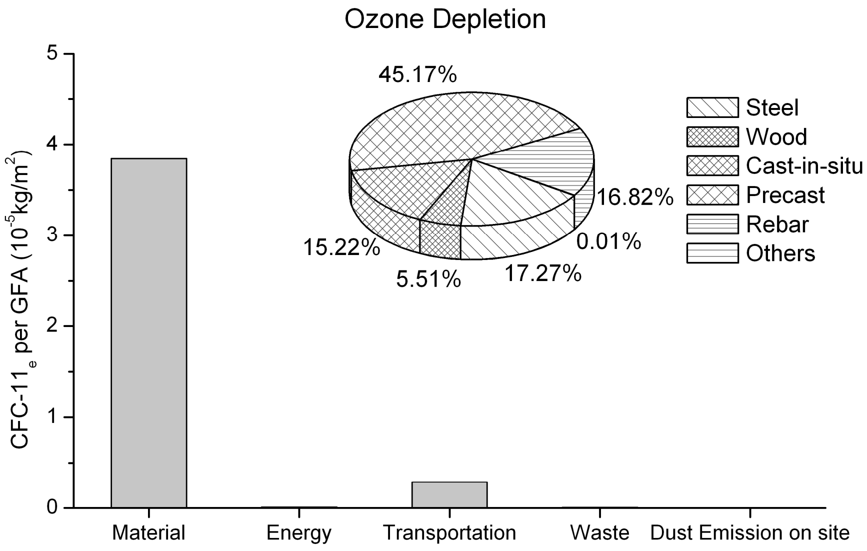
Case Study Midpoint results

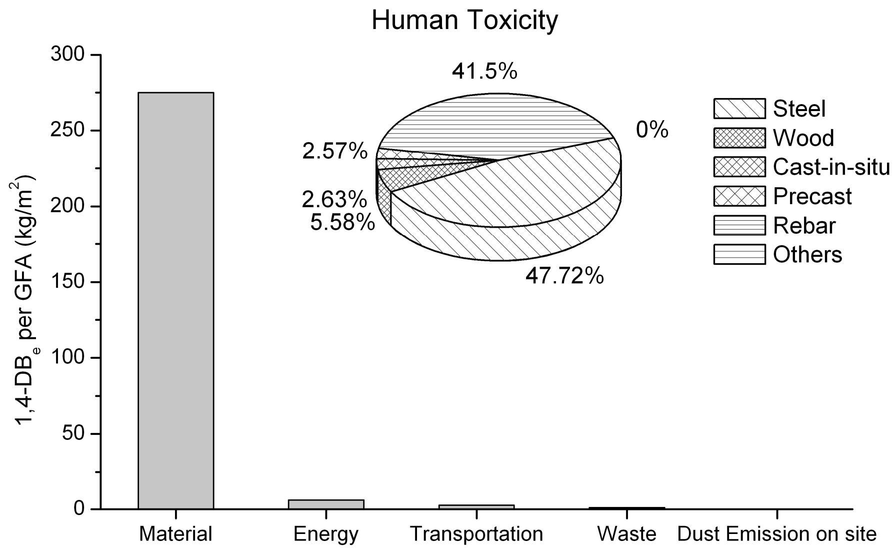
544 kg CO_{2eq}

Impact category	Unit per GFA (m^2)	Characterization	Normalization
Climate change	kg CO_2 eq	631.23	0.092
Ozone depletion	kg CFC-11 eq	4.15E-05	0.001
Human toxicity	kg 1,4-DB eq	284.84	2.427
Photochemical oxidant formation	kg NMVOC	2.24	0.046
Particulate matter formation	kg PM10 eq	1.84	0.131
Ionizing radiation	kg U235 eq	88.64	0.067
Terrestrial acidification	kg SO_2 eq	2.10	0.055
Freshwater eutrophication	kg P eq	0.27	0.919
Marine eutrophication	kg N eq	0.13	0.018
Terrestrial ecotoxicity	kg 1,4-DB eq	0.12	0.019
Freshwater ecotoxicity	kg 1,4-DB eq	9.68	2.235
Marine ecotoxicity	kg 1,4-DB eq	9.96	4.128
Agricultural land occupation	m^2a	273.70	0.050
Urban land occupation	m^2a	7.78	0.010
Natural land transformation	m^2	0.10	0.008
Water depletion	m^3	6.31	0.000
Metal depletion	kg Fe eq	648.42	1.456
Fossil depletion	kg oil eq	168.56	0.123

Case Study Midpoint results

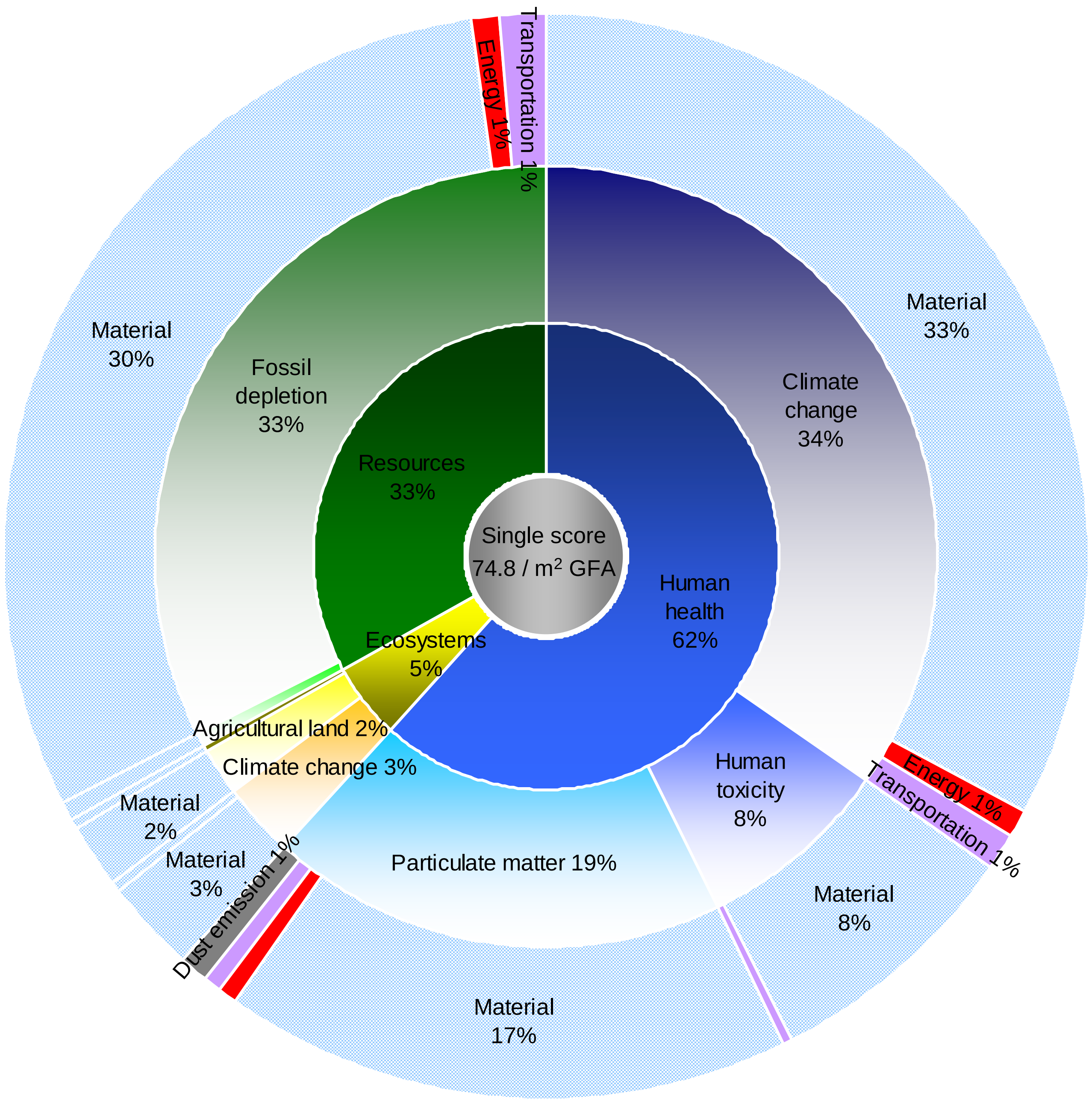






Case Study Endpoint results

Damage category	Unit / m2	Amount	Impact category	Amount
Human health	DALY	0.0015	Climate change Human Health	0.00088
			Ozone depletion	1.06E-07
			Human toxicity	0.00020
			Photochemical oxidant formation	8.71E-08
			Particulate matter formation	0.00048
			Ionising radiation	1.44E-06
Ecosystems	species.yr	8.38E-06	Climate change Ecosystems	4.98E-06
			Terrestrial acidification	1.21E-08
			Freshwater eutrophication	1.17E-08
			Terrestrial ecotoxicity	1.53E-08
			Freshwater ecotoxicity	2.52E-09
			Marine ecotoxicity	7.97E-12
			Agricultural land occupation	3.07E-06
			Urban land occupation	1.5E-07
			Natural land transformation	1.51E-07
Resources	$	2741.5	Metal depletion	46.4
			Fossil depletion	2695.1


Single score
74.8 / m² GFA
Human health 62%
Resources 33%
Ecosystems 5%
Climate change 34%
Human toxicity 8%
Particulate matter 19%
Fossil depletion 33%
Agricultural land 2%
Climate change 3%
Material 33%
Material 30%
Material 2%
Material 3%
Material 8%
Material 17%
Energy 1%
Transportation 1%
Energy 1%
Transportation 1%
Dust emission 1%

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Summary

The advantages of EMoC

- its ability to estimate the environmental impact of the precast and cast-in-situ concrete methods;
- the possibility to consider several waste treatment approaches;
- a separate estimation on manufacturing and combustion of fuels;
- an utilization of local concrete inventory;
- a comprehensive coverage on construction materials;
- an analysis on eighteen impact categories;
- the implementation of both midpoint and endpoint methods;
- the implementation of newly developed LCIA method ‘ReCiPe’; and
- a detailed breakdown of results.

Summary
Implementation of EMoC

- Location: HKSAR, mainland China, other areas (further development needed).
- Early design stage: to compare the environmental impact of alternatives for the selection on a more environmental friendly design option.
- Detail design and construction stage: to control the on-site environmental performance of construction processes.
- Integration with other energy or LCA models to evaluate the entire life cycle impact of a building construction projects.

Summary

The Way Forward

- Data collection of more building construction projects;
- Integration with other LCA models to facilitate the evaluation for the entire life cycle of buildings;

References

- Page 1: http://www.wallpaperpin.com/imageres/1366x768-wallpapers-nature-leaf-wet-forest-desktop-miriadna
- Page 3: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=287
- Page 4: Daily interesting facts (deforestation); planetearthakki.blogspot.com (ozone); http://madamenoire.com (ecosystem damage); eutrophication.yolasite.com (eutrophication); nation.com.pk (energy); IPCC, 2007. The Physical Science Basis. Cambridge University Press, Cambridge.Page 9: ISO, 2006. International Standard. In: Environmental Management - Life Cycle Assessment - Requirements and Guidelines. Geneva, Switzerland: International Organisation for Standardisation.
- Page 5: Huntzinger, D. N. and Eatmon, T. D., 2009. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. Journal of Cleaner Production, 17, 668-675.
- Page 10: Dong, Y. H., Ng, S. T. and Kumaraswamy, M. M., 2013a. Critical analysis of the life cycle impact assessment methods. *Environmental Engineering and Management Journal*. (*In press*)
- Page 12: EMSD, 2006. Consultancy Study on Life Cycle Energy Analysis of Building Construction. HKHA, 2005. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) Study of Building Materials and Components.
- Page 25: http://zh.wikipedia.org/wiki/File:Hong_Kong_Island_Skyline_2009.jpg

Thank you