China: the concrete dragon
a visual life cycle analysis

the impact of urbanizing 400 million people in 20 years
a comparative analysis
a comparative analysis
structural building materials
fascination
air pollution

what is the industrial impact of urbanizing 400 million people in 20 years?
2010 bachelor graduation

happy healthy school
Shanghai
bamboo air filtering - fast growing - building material - strong
building industry

30-40%

IPCC 2007, Birkeland 2002

building construction

22%

Birkeland 2002

building structures

11%

Hammond et al. 2008

concept
China 0.0  China 1.0  China 2.0
fascination
method
conclusion

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
fascination
method
conclusion

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
research

life cycle analysis
research

life cycle analysis
research

life cycle analysis

end-of-life
research

common structural materials
research

common structural materials + bamboo
research

kg/m²
research

material properties
smart by nature
design

traditional courtyard diversity
precedes
life cycle analysis
scientific
where does it come from?
where does it end up after use?

http://mytownsanantonio.ning.com/pottery/>An you can help solve the landfill crisis
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**Material**

- ![Material Icon]

**End of Life**

1. ![End of Life Icon]
2. ![Energy Production Icon]
3. ![Energy Production Icon]

**Energy Production**
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material

end of life

no fossil fuel
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fascination

method

conclusion

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
carbon positive

potential storage

transport

building energy use
concept
China 0.0
- social

China 1.0
- urban

China 2.0
- social
- urban
- ecological/growing
research

C2G / C2C
kg/m²
end of life
transport
lifespan
life cycle analysis
product
harvest

C2G / C2C
kg/m²
end of life
transport
lifespan
manufacturing
store

C2G / C2C
kg/m²
end of life
transport
lifespan
C2G / C2C
kg/m²
end of life
transport
lifespan
transport
a Visual Life Cycle Analysis  |  Michiel Kulik  |  Graduation  |  6-11-'13
offsetting

social
offsetting

environmental
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Sourcing + Manufacturing

+ Transport

Building Use

End of Life

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
Sourcing + Manufacturing
+ Transport

Building Use

End of Life

Cradle
Gate
Site

CO₂

Intro | Question | Method | Conclusion

Intro | Research: LCA, precedents, land use | Concept: Location, design, functions, construction, installations | Impact: Impressions
cradle to cradle
LCA databases
example LCA data

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied energy: MJ/kg</th>
<th>Embodied carbon: kgC/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>3</td>
<td>0.060</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General (1:2:4 as used in construction of buildings under three storeys)</td>
<td>0.95</td>
<td>0.035</td>
</tr>
<tr>
<td>Precast concrete, cement:sand:aggregate</td>
<td>2</td>
<td>0.059</td>
</tr>
<tr>
<td>1:1:2 (high strength)</td>
<td>1.39</td>
<td>0.057</td>
</tr>
<tr>
<td>1:1:5:3 (used in floor slabs, columns and load-bearing structures)</td>
<td>1.11</td>
<td>0.043</td>
</tr>
<tr>
<td>1:2:5:5</td>
<td>0.84</td>
<td>0.030</td>
</tr>
<tr>
<td>1:3:6 (non-structural mass concrete)</td>
<td>0.77</td>
<td>0.026</td>
</tr>
<tr>
<td>1:4:8</td>
<td>0.69</td>
<td>0.022</td>
</tr>
<tr>
<td>Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General, ‘typical’ (42.3% recycled content)</td>
<td>24.4</td>
<td>0.482</td>
</tr>
<tr>
<td>General, primary</td>
<td>35.3</td>
<td>0.749</td>
</tr>
<tr>
<td>General, secondary</td>
<td>9.5</td>
<td>0.117</td>
</tr>
<tr>
<td>Timber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>8.5</td>
<td>0.125</td>
</tr>
<tr>
<td>Glue laminated timber</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Hardboard</td>
<td>16</td>
<td>0.234</td>
</tr>
<tr>
<td>MDF</td>
<td>11</td>
<td>0.161</td>
</tr>
<tr>
<td>Particle board</td>
<td>9.5</td>
<td>0.139</td>
</tr>
<tr>
<td>Plywood</td>
<td>15</td>
<td>0.221</td>
</tr>
<tr>
<td>Sawn hardwood</td>
<td>7.8</td>
<td>0.128</td>
</tr>
<tr>
<td>Sawn softwood</td>
<td>7.4</td>
<td>0.123</td>
</tr>
</tbody>
</table>

ICE database (UK): Hammond et al., Bath University
The carbon related to the production of 1kg wood is 0.125kgC

During growth, 1kg wood takes up 0.45 – 0.5kgC
simplify
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| intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions |

structure

- 55 - 40%
- 25 - 50%
- 30 - 10%

finish

| foundation | 400 kg/m² | 440 wood | 420 bamboo |
| structure  | 600 kg/m² | 250 steel | 200 |
| finish     | 400 kg/m² | 300       | 200 |

kg/m²
structural weight

80% floors

20% columns
LCA parameters
energy $\equiv$ carbon $\equiv$ ecocost

* dramatic reenactment
energy
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intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions

renewable

http://www.pv-magazine.com/fileadmin/PV_website_pictures/
Canadian_Solar_photovoltaic_modules_German_solar_park_Image_Pressebox_Canadian_Solar.gif
coal

carbon

industrial revolution
1850 - 2012
30% transport
cement industry

5%
cement industry
5%

airplanes
1.6%
environmental burden

ecocost
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
“The question is not *if*, but *when* the environmental burden is taxed”

Joost Vogtländer
LCA specialist – TU Delft / Industrial Design
LCA results
C2G

C2G + End-of-life

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
<table>
<thead>
<tr>
<th>ecocost</th>
<th>€/m²</th>
<th>30</th>
<th>30</th>
<th>-2</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon</td>
<td>kgC/m²</td>
<td>32</td>
<td>29</td>
<td>-20</td>
<td>-9</td>
</tr>
<tr>
<td>energy</td>
<td>kWh/m²</td>
<td>333</td>
<td>625</td>
<td>-733</td>
<td>-480</td>
</tr>
</tbody>
</table>
life cycle inventory

(LCI)
# Process step

<table>
<thead>
<tr>
<th>Process step</th>
<th>amount</th>
<th>unit</th>
<th>ecocost €/unit</th>
<th>ecocosts €/FU</th>
<th>ecocosts €/kg</th>
<th>ecocosts %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cultivation and harvesting from plantation</td>
<td>0.224</td>
<td>litre / FU</td>
<td>1.04/litre</td>
<td>0.233</td>
<td>0.0056</td>
<td>1.7%</td>
</tr>
<tr>
<td>2. Transport from plantation to strip manufacturing facility; eco-costs of a 5 ton truck (transport of 23.1 FU/s)</td>
<td>30</td>
<td>km / truck</td>
<td>0.243/km</td>
<td>0.316</td>
<td>0.0076</td>
<td>2.3%</td>
</tr>
<tr>
<td>3. Strip making</td>
<td>1.38</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>0.150</td>
<td>0.0036</td>
<td>1.1%</td>
</tr>
<tr>
<td>4. Transport from strip manufacturing facility to factory; eco-costs of a 10 ton truck (transport of 77.6 FU/s).</td>
<td>600</td>
<td>km / truck</td>
<td>0.32/km</td>
<td>2.474</td>
<td>0.0593</td>
<td>18.0%</td>
</tr>
<tr>
<td>5. Rough planing</td>
<td>8.62</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>0.940</td>
<td>0.0225</td>
<td>6.8%</td>
</tr>
<tr>
<td>6. Strip selection</td>
<td>4.73</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>0.516</td>
<td>0.0124</td>
<td>3.7%</td>
</tr>
<tr>
<td>7. Carbonization</td>
<td>9.66</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>1.053</td>
<td>0.0253</td>
<td>7.7%</td>
</tr>
<tr>
<td>8. Drying carbonized strips</td>
<td>5.8</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>0.632</td>
<td>0.0152</td>
<td>4.6%</td>
</tr>
<tr>
<td>9. Fine planing</td>
<td>1.89</td>
<td>kWh / FU</td>
<td>0.109/kWh</td>
<td>0.206</td>
<td>0.0049</td>
<td>1.5%</td>
</tr>
<tr>
<td>10. Strip selection</td>
<td>2.58</td>
<td>ton.km / FU</td>
<td>0.033/ton.km</td>
<td>0.413</td>
<td>0.0099</td>
<td>3.0%</td>
</tr>
<tr>
<td>11. Glue application (1-layer boards)</td>
<td>0.894</td>
<td>ton.km</td>
<td>0.57/ton.km</td>
<td>0.510</td>
<td>0.0122</td>
<td>3.7%</td>
</tr>
<tr>
<td>12. Pressing strips to 1-layer board</td>
<td>1.62</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.177</td>
<td>0.0042</td>
<td>1.3%</td>
</tr>
<tr>
<td>13. Sanding 1-layer board</td>
<td>0.983</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.560</td>
<td>0.0124</td>
<td>3.7%</td>
</tr>
<tr>
<td>14. Glue application (3-layer board)</td>
<td>1.65</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.180</td>
<td>0.0043</td>
<td>1.3%</td>
</tr>
<tr>
<td>15. Pressing three layers to one board</td>
<td>0.29</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.032</td>
<td>0.0008</td>
<td>0.2%</td>
</tr>
<tr>
<td>16. Sawing</td>
<td>0.983</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.560</td>
<td>0.0124</td>
<td>3.7%</td>
</tr>
<tr>
<td>17. Sanding 3-layer board</td>
<td>0.86</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.094</td>
<td>0.0022</td>
<td>0.7%</td>
</tr>
<tr>
<td>18. Dust absorption (during all steps)</td>
<td>8.67</td>
<td>ton.km</td>
<td>0.109/ton.km</td>
<td>0.945</td>
<td>0.0227</td>
<td>6.9%</td>
</tr>
<tr>
<td>19. Transport from factory to harbour</td>
<td>12.51</td>
<td>FU</td>
<td>0.033/ton.km</td>
<td>0.413</td>
<td>0.0099</td>
<td>3.0%</td>
</tr>
<tr>
<td>20. Transport from harbour to harbour</td>
<td>800.9736</td>
<td>FU</td>
<td>0.0052/ton.km</td>
<td>4.165</td>
<td>0.0999</td>
<td>30.3%</td>
</tr>
<tr>
<td>21. Transport from harbour to warehouse</td>
<td>4.7955</td>
<td>FU</td>
<td>0.033/ton.km</td>
<td>0.158</td>
<td>0.0038</td>
<td>1.2%</td>
</tr>
<tr>
<td>TOTAL eco-costs (€)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Lugt, Vögtlander et al. 2012

---

**moso bamboo**
transport LCI
wood vs. bamboo
strength + 30%
stiffness + 80%
annual production
(yield)
annual production
(yield)

x 3.3
3kg
= 1kg

2.4kg
= 1kg
precedents
Green & Waugh, Tall Wood

- 10 floors
- 20 floors
- 30 floors

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
"The combustibility of wood based materials is undeniable. However the casualties worldwide caused by war-induced, or other firestorms has been significantly less than those of earthquake-collapsed reinforced concrete buildings that were poorly constructed" (Timmer, 2011, p4)
murray grove

2250m²
30 appartment
9 floors

240kg_{wood}/m²
structure + finish

CEPO
soil
C storage

1 kg above ground + 0.25 kg under ground (Aalde, 2006)

1 kg above ground + 2.1 kg under ground (Zhou, 2004)
soil quality
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intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions

CEPO
soil
C storage
C.E.P.O.

Chinese
Environmentally - friendly
Plantation - bamboo
Organization

100 million structures
assumed 30m² pp, 180kg/m² - 20 years

CEPO
soil
C storage

intro 😼 research : LCA : precedents : land use 😼 concept : location : design : functions : construction : installations 😼 impact : impressions
225 million people housed

assumed 10m² pp, 240kg/m² finished building - 20 years

CEPO
soil
C storage
concept

location
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions

china
shanghai
moganshanlu
climate

china
shanghai
moganshanlu

intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
insolation (kWh/m²/day)
clearness, 0 - 1
temperature
wind speed (m/s)
precipitation (mm)
wet days
avg. wind direction
wind probability >= 4 BFT (%)

avg. wind speed (kts)

avg. air temp

windfinder.com
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
intro | research: LCA: precedents: land use | concept: location: design: functions: construction: installations | impact: impressions
intro | research : LCA : precedents : land use
| concept : location : design : functions : construction : installations
| impact : impressions

design
bioclimatic
wind & sun

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intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
prevailing wind in summer
termite hill, Australia

12h; no shadow
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
design
courthouse typology

simplified
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
cross ventilation
daylight penetration
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intro      |   research  :  LCA  :  precedents  :  land use   |   concept  :  location  :  design
          |   functions  :  construction  :  installations  |   impact  :  impressions

WIND

SUN

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west facade
functions
south-east view
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
construction
modules
27m²  55m²  110m²

modules
flexible
demountable

intro | research : LCA : precedents : land use | concept : location : design : functions : **construction** : installations | impact : impressions
Modules
flexible
demountable

construction
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
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intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions

modules
demountable
flexible
installations
cooling principle
intro   |   research : LCA : precedents : land use   |   concept : location : design : functions : construction : installations   |   impact : impressions
Living tower: 18,000 m²
- 480 people

Plantation: 6 kg/m²/year
- 21 m²/m² construction / 20 years

Pig tower

Greenhouse

Water storage in pond. Precipitation from roof.

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Intro | Research: LCA | Precedents | Land Use | Concept | Location | Design | Functions | Construction | Installations | Impact | Impressions
impact
400 m concrete

\[ +32 \text{ kg} \text{ C/m}^2 +32 \text{ kg} \text{ C/m}^2 +32 \text{ kg} \text{ C/m}^2 = 32 \text{ kg C/m}^2 \]

100 m bamboo, 300 m concrete

\[ -9 \text{ kg C/m}^2 +32 \text{ kg C/m}^2 +32 \text{ kg C/m}^2 = 22 \text{ kg C/m}^2 \]

200 m bamboo, 200 m concrete

\[ -9 \text{ kg C/m}^2 -9 \text{ kg C/m}^2 +32 \text{ kg C/m}^2 +32 \text{ kg C/m}^2 = 11.5 \text{ kg C/m}^2 \]

300 m bamboo, 100 m concrete

\[ -9 \text{ kg C/m}^2 -9 \text{ kg C/m}^2 -9 \text{ kg C/m}^2 +32 \text{ kg C/m}^2 = 1.25 \text{ kg C/m}^2 \]
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
impressions
intro | research : LCA : precedents : land use | concept : location : design : functions : construction : installations | impact : impressions
thank you!