A sustainable development approach - from Industrial Ecology to Sustainable urban metabolisms

Paulo Ferrão
Human development and resource productivity

<table>
<thead>
<tr>
<th>Era</th>
<th>School</th>
<th>Main Productivity factors</th>
<th>Main Actors</th>
<th>Wealth perception</th>
<th>Perception of Environment</th>
</tr>
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<tr>
<td>Up to the 18th Century</td>
<td>Fisiocrats</td>
<td>Land, agriculture, Natural Resources</td>
<td>Farmers</td>
<td>Crop value</td>
<td>Main production factor</td>
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### Human development and resource productivity

#### Era
End of the 18th Century and middle 19th Century

#### School
- Adam Smith, Karl Marx

#### Main Productivity factors
- Work on Manufacturing

#### Main Actors
- Companies and commerce

#### Wealth perception
- Objective assets, capital

#### Perception of Environment
- Secondary production factor, supporting labor

### Graph
- **Y-axis**: Importância relativa (Relative Importance)
- **X-axis**: Ano (Year)
- **Graph Lines**:
  - Green: Environment
  - Blue: Labor
  - Red: Capital

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<td>End of the 19th Century, 20th Century</td>
<td>Neoclassics</td>
<td>Labor: manufacturing, administration, research and development</td>
<td>Market and companies</td>
<td>Different subjective values determined by market</td>
<td>Value totally overcome by capital and labour</td>
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<td>Contemporary</td>
<td></td>
<td>Multifactors</td>
<td>Markets, companies and technologies</td>
<td>GDP</td>
<td></td>
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</tbody>
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Unemployment and overexploitation of environment are factors that determine the major relevance of the Productivity of Natural Resources.
Conventional Model of the Economy

Families → Consumption → Market → Companies → Monetary → Families
The ECOLOGICAL FOOTPRINT is a resource management tool that measures how much land and water area a human population requires to produce the resources it consumes and to absorb its wastes under prevailing technology.

• The Ecological Footprint, human demand, and biocapacity, ecosystem supply, are both measured in units of global hectares, a hectare normalized to the average productivity of all bioproductive hectares on Earth.
• As of 2003, there are approximately 11.2 billion global hectares of area available. In that same year, humanity demanded products and services from the equivalent of 14.1 billion global hectares.
• Excel file

Available in: http://www.footprintnetwork.org
Ecological Footprint

Humanity's Ecological Footprint

Earth's biological capacity

Total Ecological Footprint

Carbon Footprint

Available in: http://www.footprintnetwork.org
Ecological Footprint

Countries have been stretched to indicate their effective consumption based upon 2005 Global Footprint Network and CIA World Fact Book data. Original basemap is an ESRI ArcWorld geometry converted to the Mollweide equal area projection. Created with ArcMap 9, MAPresso & Perl.

Jeriad Pierce 12/05 jpierce@cpnn.org

Available in: http://www.footprintnetwork.org

2005 World Consumption Cartogram
http://pthbb.org/natural/footprint/

Blue represents insufficient data.
Real Economy

Extraction → Processing → Manuf. → Consumption

→ Residues → Recycling → Environment

→ Processing

→ Externalities
Extended product responsibility

Eco-efficiency
Design for Environment
Life Cycle Assessment

Process oriented

EIA, Energy audits, Envir. audits

Product oriented

LCA
Life cycle thinking
Life cycle thinking

Product Life Cycle

Resources → Components → Assembly → Use → Waste

Car
EEE
MSW
Others
Environment
Industrial Ecology

Creating loop closing industrial ecosystems
Promoting waste exchanges
Cascading energy utilization

EIA, Energy audits, Envir. audits

Eco-efficiency
Design for Environment
Life Cycle Assessment

LCA

Compliance with regulation
Pollution prevention

Process oriented

Product oriented

Systems Oriented

Historical pattern of Environmental Strategies

Time and Space

Extended product responsibility

Business-as-usual
### Natural and Industrial Economies

**Industrial Economy**
- Driven by economic issues
- Centralized Production
- Monocultures
- Linear system based on production
- Emphasis on Production
- Residues without value

**Natural Economy**
- Driven by the Sun
- Decentralized Production
- Diversity
- Circular System
- Emphasis on Reproduction
- Recycling
Material Flow Analysis

- Domestic environment
- Economy
- Exports
- Domestic Output, (DPO)
- DMI
- Stocks
- Domestic extraction
- IMPORTS
- Hidden flows
- TMR
- Environmental impacts

- Air
- Water

- Air
- Water
Env. Impact = (Population) \times (GDP/Capita) \times (Env. Impact / GDP)

Eco-efficiency
The European Context...

in the "good" old times

A Kuznets curve for resources consumption?

\[ dmi_{it} = \beta_0 + \beta_1 y_{it} + \beta_2 y_{it}^2 + \epsilon_{it} \]

Urbanization and Sustainability

URBAN WORLD 1980

Urban Population
- Greater than 75%
- 50% - 75%
- 25% - 50%
- Less than 25%

AN URBAN WORLD

This graphic depicts countries and territories with 2050 urban populations exceeding 100,000. Circles are scaled in proportion to urban population size. Hover over a country to see how urban it is (percentage of people living in cities and towns) and the size of its urban population (in millions).
Urbanization and Sustainability

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Urbanization and Sustainability

URBAN WORLD 2050

This graphic depicts countries and territories with 2050 urban populations exceeding 100,000. Circles are scaled in proportion to urban population size. Hover over a country to see how urban it is (percentage of people living in cities and towns) and the size of its urban population (in millions).
Urbanization and Per Capita GDP across Countries, 2000 (1996 US$)

• Gras (1992) proposes 4 stages of development for a metropolis, with Kennedy (2011) suggesting another one.
Urban Metabolism
Theory for metropolis growth dynamics – development stages
(Norman Gras, Saskia Sassen)

1. Commerce
   – Wholesalers rather than retailers

2. Manufacturing
   – Innovation driven, centre of innovation

3. Transport
   – Power over the hinterland

4. Finance
   – Capitalists begin having increasingly large share of business, stock exchange

5. Global Service activity – knowledge cities
   – The capacity to generate NEW work, attract the brightest

This corresponds to evolving metabolisms and require New Tools for the Redesign of Urban Infrastructures
Material Classes
- Harmonization of Imports, Exports and Extraction
- 28 categories of materials for 13,135 products
- Addressing material management issues
- Recycling potential and economic value of waste

Average lifespan in years for 13,135 products
Statistical distribution in time based on Weibull

Assignment of a phase for 13,135 products
Split between different product phases
livestock, raw materials, intermediate products, final goods and waste
### UMAN–MATCAT nomenclature

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fossil Fuels (FF)</strong></td>
<td>FF1 Low ash Fuels</td>
</tr>
<tr>
<td></td>
<td>FF2 High ash Fuels</td>
</tr>
<tr>
<td></td>
<td>FF3 Lubricants and Oils and Solvents</td>
</tr>
<tr>
<td></td>
<td>FF4 Plastics and Rubbers</td>
</tr>
<tr>
<td><strong>Metals (MM)</strong></td>
<td>MM1 Iron, Steel Alloying Metals and Ferrous Metals</td>
</tr>
<tr>
<td></td>
<td>MM2 Light Metals</td>
</tr>
<tr>
<td></td>
<td>MM3 Non-Ferrous Heavy Metals</td>
</tr>
<tr>
<td></td>
<td>MM4 Special Metals</td>
</tr>
<tr>
<td></td>
<td>MM5 Nuclear Fuels</td>
</tr>
<tr>
<td></td>
<td>MM6 Precious Metals</td>
</tr>
<tr>
<td><strong>Non-metallic minerals (NM)</strong></td>
<td>NM1 Sand</td>
</tr>
<tr>
<td></td>
<td>NM2 Cement</td>
</tr>
<tr>
<td></td>
<td>NM3 Clay</td>
</tr>
<tr>
<td></td>
<td>NM4 Stone</td>
</tr>
<tr>
<td></td>
<td>NM5 Other (Fibers, Salt, inorganic parts of animals)</td>
</tr>
<tr>
<td><strong>Biomass (forestry, crops and animal products) (BM)</strong></td>
<td>BM1 Agricultural Biomass</td>
</tr>
<tr>
<td></td>
<td>BM2 Animal Biomass</td>
</tr>
<tr>
<td></td>
<td>BM3 Textile Biomass</td>
</tr>
<tr>
<td></td>
<td>BM4 Oils and Fats</td>
</tr>
<tr>
<td></td>
<td>BM5 Sugars</td>
</tr>
<tr>
<td></td>
<td>BM6 Wood</td>
</tr>
<tr>
<td></td>
<td>BM7 Paper and Board</td>
</tr>
<tr>
<td></td>
<td>BM8 Non-Specified Biomass</td>
</tr>
<tr>
<td><strong>Chemicals and Fertilizers (CF)</strong></td>
<td>CF1 Alcohols</td>
</tr>
<tr>
<td></td>
<td>CF2 Chemicals and Pharmaceuticals</td>
</tr>
<tr>
<td></td>
<td>CF3 Fertilizers and Pesticides</td>
</tr>
<tr>
<td><strong>Others (O)</strong></td>
<td>O1 Non-Specified</td>
</tr>
<tr>
<td></td>
<td>O2 Liquids</td>
</tr>
</tbody>
</table>

MATCAT associates lifetime and material composition to each product in Combined Nomenclature 2007. It considers 28 material subcategories, grouped in 6 material categories.
Lisbon Metropolitan Area

2005 Balance
Units: Million tons of materials per year

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Amount</th>
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<tr>
<td>Non-metallic minerals</td>
<td>15.96 Mt</td>
</tr>
<tr>
<td>Metallic minerals</td>
<td>14.71 Mt</td>
</tr>
<tr>
<td>Metallic minerals</td>
<td>1.43 Mt</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>1.07 Mt</td>
</tr>
<tr>
<td>Biomass</td>
<td>0.63 Mt</td>
</tr>
<tr>
<td>Other</td>
<td>0.09 Mt</td>
</tr>
<tr>
<td>Chemicals</td>
<td>0.02 Mt</td>
</tr>
<tr>
<td>Recycling</td>
<td>0.58 Mt</td>
</tr>
<tr>
<td>Air emissions</td>
<td>5.74 Mt</td>
</tr>
<tr>
<td>Dissipative</td>
<td>2.42 Mt</td>
</tr>
<tr>
<td>MSW &amp; IW</td>
<td>2.12 Mt</td>
</tr>
<tr>
<td>Cons. Waste</td>
<td>1.23 Mt</td>
</tr>
<tr>
<td>Solid fraction</td>
<td>0.07 Mt</td>
</tr>
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30.79 Mt

17.95 Mt

11.61 Mt
Throughput of metallic minerals from stocks accumulated in Lisbon Metro Area: 2003-2050, Units: Tons of materials per year
Urban mining

2kg of gold per 1 ton of ash from sewage sludge in Japan due to high concentration of high-tech urban waste


Photo - http://www.prototypen.com/blog/falk/archive/pics/siolo-proc02.jpg
Urban metabolism of Bangalore

- High export share, with 39% of the materials that pass through the city being exported
- The most material intensive sector is the textile products industry
- Low use of materials for Gross Fixed Capital Formation (buildings and infrastructure)
- Biomass materials are responsible for 66% of the DMI of Bangalore

BM1 – Agricultural biomass
BM2 – Animal biomass
BM3 – Textile biomass
BM4 – Oils and fats
BM5 – Sugars
BM6 – Woods
BM7 – Paper and board
BM8 – Unspecified biomass

CF1 – Alcohols
CF2 – Chemicals and pharmaceuticals
CF3 – Fertilizers and pesticides

FF1 – Low ash fuels
FF2 – High ash fuels
FF3 – Lubricants and oils and solvents
FF4 – Plastics and rubbers

MM1 – Iron, steel alloying and ferrous metals
MM2 – Light metals
MM3 – Non-ferrous heavy metals
MM4 – Special metals
MM5 – Nuclear fuels
MM6 – Precious metals

NM1 – Sand
NM2 – Cement
NM3 – Clay
NM4 – Stone
NM5 – Others

O1 – Non-specified
O2 – Liquids

S01 – Agriculture, hunting, forestry and fishing
S02 – Mining and quarrying
S03 – Food products, beverages and tobacco
S04 – Textiles, textile products, leather and footwear
S05 – Wood and products of wood and cork
S06 – Pulp, paper, paper products, printing and publishing
S07 – Coke, refined petroleum products and nuclear fuel
S08 – Chemicals and chemical products
S09 – Rubber and plastics products
S10 – Other non-metallic mineral products
S11 – Basic metals
S12 – Fabricated metal products except machinery and equipment
S13 – Machinery and equipment n.e.c
S14 – Office, accounting and computing machinery
S15 – Electrical machinery and apparatus n.e.c
S16 – Radio, television and communication equipment
S17 – Medical, precision and optical instruments
S18 – Motor vehicles, trailers and semi-trailers
S19 – Other transport equipment
S20 – Manufacturing n.e.c; recycling
S21 – Electricity, gas and water supply
S22 – Construction
S23 – Wholesale and retail trade; repairs
S24 – Hotels and restaurants
S25 – Transport and storage
S26 – Post and telecommunications
S27 – Finance and insurance
S28 – Real estate activities
S29 – Renting of machinery and equipment
S30 – Computer and related activities
S31 – Research and development
S32 – Other Business Activities
S33 – Public admin. and defence; compulsory social security
S34 – Education
S35 – Health and social work
S36 – Other community, social and personal services
SEXP – Exports

SFC – Final consumption
SGFCF – Gross fixed capital formation
Urban metabolism of Shanghai

- Low export share, with only 4% of the materials that pass through the city being exported
- Construction, hotels and restaurants, food and textile products are important sectors
- Very high use of materials (47% of DMI) for Gross Fixed Capital Formation (buildings and infrastructure)
- Non-metallic minerals (56% of DMI) and biomass (27%) are the main materials used
From Ho Chi Minh to Seoul

- Structural transformation vs. Environment
- Material intensity of the economy
Urban metabolism – “From Ho Chi Minh to Seoul”

The diagram illustrates the relationship between GDP per capita (thousand international US$ / cap) and DMI per capita (t/cap) for various cities, including Paris, Lisbon, Bangkok, Shanghai, Bangalore, Ho Chi Minh, and Seoul. The cities are plotted on a scatter plot, with the y-axis representing DMI per capita and the x-axis representing GDP per capita. The median value for each city is indicated by a green diamond. The scatter plot shows a tendency for cities with higher GDP per capita to also have higher DMI per capita, suggesting a correlation between economic development and waste generation.
From Ho Chi Minh to Seoul:
- The contribution from agriculture decreases
- Commerce and services and Manufacturing grow
From Ho Chi Minh to Seoul:
- First increase by non-metallic minerals and biomass
- Second increase by fossil fuels and metallic minerals
GDP/Tonne Resource productivity

From Ho Chi Minh to Seoul:
- Particularly low in Bangalore
- Tends to increase with economic development
Urban metabolism model - Emissions

Per capita CO$_2$ emissions

- Ho Chi Minh
- Bangalore
- Manila
- Shanghai
- Bangkok
- Seoul

- Oils and lubricants
- High ash fuels
- Low ash fuels
Urban typologies – beyond material consumption

- **Fossil fuels**
- **Metallic minerals**
- **Non-metallic minerals**
- **Biomass**
- **Others**

- **Bangalore**
- **Shanghai**
- **Lisbon**
- **Paris**
- **Bangkok**
- **Ho Chi Minh**
- **Manila**
- **Seoul**

Percentage distribution of material consumption in different cities.
• Cities cannot develop now and “clean-up later”!

Can we learn with lessons from other cities, if applicable, to better grow our cities?

– Comparison need to be consistent: typologies.

– **Characterize** development patterns in terms of **footprint** (spatially resolved – predictions based on spatial analysis):
  • Building typologies, population density, road network, energy consumption in households and in transportation, urban infrastructures.

– **Characterize** governance, social patterns, urban work

– **Characterize** global sustainability indicators
Can urban metabolism framework support efficient urban infrastructure design?

- Establish clusters of cities, correlating global indicators and spatial resolved urban properties.
- Develop correlations between variables such as (Population, Affluence, Density, Climate) and the consumption/generation of (fossil fuels, electricity, different materials, water, waste).
- Identify successes and failures in urban infrastructures and its socio-economic integration, for different typologies.
Can we design solutions to many of the global problems that confront cities?

– Adopt a systems perspective to promote sustainable urban pathways, in which spatial form and infrastructure are used to boost productivity, innovation and environmental performance, rather than sapping cities through congestion, pollution, water or energy shortage.

• Urban metabolism - a framework to promote the understanding on how major cities, in different contexts, have contributed to and will promote Structural Transformation and economy shifts ...towards sustainability?