Lecture 2

Sustainable Design: The Role of the Construction Industry

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First three lectures by JAO

1) Global challenges (9/15)

2) Construction industry (9/22)

3) Individuals (9/29)
Urgency?

UK Consumption of Resources (1998)

World, hectares bn
- Built-up land
- Energy
- Forest
- Grazing Land
- Fishing ground
- Cropland

Number of planets needed to sustain global consumption in 2050 if all countries consumed as Britain

Hectares per person, 1999

- United States
- High-income countries
- Middle-income countries
- China
- Low-income countries

*Land needed to meet human needs

Source: WWF Living Planet Report 2002
“In England, consumers discard 84% of all cans, which means that the overall rate of aluminum waste, after counting production losses, is 88%. The United States still gets three fifths of its aluminum from virgin ore, at twenty times the energy intensity of recycled aluminum, and throws away enough aluminum to replace its entire commercial aircraft fleet every three months.”

(Natural Capitalism)
Why does this seem ‘cost-efficient’?

- We (as consumers) pay (directly) only for the end product:
- the ‘price’ does not include the cost of ‘externalities’….
- social, environmental, resource use and health costs:

- so the ‘cost’ signals to manufacturers’ are incomplete
- we have a ‘linear thinking’ mind-set:
- each part of the process is separately ‘optimized’
- But we don’t look at the process as a whole...
End of Life Design

- 12 million computers are thrown away each year (less than 10% are recycled now)

- 300-700 million computers will be obsolete in the US in the next few years

- The electronics and automobile industry are beginning to design for the end of life

  - Source: National Safety Council
What happens to discarded computers?

- 2002 Report by the *Clean Computer Campaign: Exporting Harm: The High-Tech Trashing of Asia*

- Giuyu, China: 100,000 migrant workers disassemble electronics for precious metals

- Lead, mercury, and other heavy metals are a hazard to local environment and workers
Problems with Electronics

- Designers are not responsible for end of life design

- Product manufacturing does not consider the entire lifetime of the product

- Result is waste
  - Economically inefficient
  - Environmentally harmful
  - Socially irresponsible

→ UNSUSTAINABLE
Outline of Lecture

- Introduction

- What is unsustainable about construction?
  - Energy
  - Materials

- Comparison of Materials

- Kyoto Protocol

- Conclusions
Energy Basics

Supply Side: Where does energy come from?

Demand Side: Where does energy go?
Energy Consumed by Buildings

US Primary Energy Consumption:

- Buildings 37%
- Industry 36%
- Transportation 27%

Buildings: The real SUV’s

In the United States, buildings account for:

- 37% of total energy use
  (65% of electricity consumption)

- 30% of greenhouse gas emissions
Residential Energy Use in US

- Space Heating: 51%
- Water Heating: 19%
- Air Conditioning: 4%
- Refrigeration: 4%
- Lighting & Appliances: 22%

Source: US Department of Energy
Heat Loss Through Windows

4-7% of developed nation energy consumption is due to heat losses from domestic windows alone.

In EC countries, at least one-quarter of the domestic heating bill is due to the thermal energy loss through windows because they are the weakest thermal component in the exterior envelope.
## Energy and Buildings

<table>
<thead>
<tr>
<th>Need</th>
<th>Current Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Electric lights</td>
</tr>
<tr>
<td>Heating</td>
<td>Power grid (from fossil fuels)</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air-conditioning</td>
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</tbody>
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## Energy and Buildings

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<th>Need</th>
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<tr>
<td>Lighting</td>
<td>Lights</td>
<td>Daylight</td>
</tr>
<tr>
<td>Heating</td>
<td>Power grid</td>
<td>Better insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable energy</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air-conditioning</td>
<td>Natural ventilation</td>
</tr>
</tbody>
</table>

What is required?  → *Better DESIGN*
Construction and the Environment

In the United States, buildings account for:

- 37% of total energy use
  (65% of electricity consumption)
- 30% of greenhouse gas emissions
- 30% of raw materials use
- 30% of waste output (136 million tons/year)
- 12% of potable water consumption

Source: US Green Building Council (2001)
Embodied vs. Operating Energy

*Embodied Energy*: energy consumed during production (including extraction, manufacturing, transportation, installation, etc.)

*Operating Energy*: energy consumed during the *life* of a product
Embodied Energy and Operating Energy for Buildings
Typical Building Embodied Energy

Breakdown of Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures

Average Total Initial Embodied Energy 4.82 GJ/m²
## Range in Embodied Energy

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
<th>Low value</th>
<th>High value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural aggregates</td>
<td>1500 kg/m³</td>
<td>0.05 GJ/m³</td>
<td>0.93 GJ/m³</td>
</tr>
<tr>
<td>Cement</td>
<td>1500 kg/m³</td>
<td>6.5 GJ/m³</td>
<td>11.7 GJ/m³</td>
</tr>
<tr>
<td>Bricks</td>
<td>~1700 kg/m³</td>
<td>1.7 GJ/m³</td>
<td>16 GJ/m³</td>
</tr>
<tr>
<td>Timber (prepared softwood)</td>
<td>~500 kg/m³</td>
<td>0.26 GJ/m³</td>
<td>3.6 GJ/m³</td>
</tr>
<tr>
<td>Glass</td>
<td>2600 kg/m³</td>
<td>34 GJ/m³</td>
<td>81 GJ/m³</td>
</tr>
<tr>
<td>Steel (sections)</td>
<td>7800 kg/m³</td>
<td>190 GJ/m³</td>
<td>460 GJ/m³</td>
</tr>
<tr>
<td>Plaster</td>
<td>~1200 kg/m³</td>
<td>1.3 GJ/m³</td>
<td>8.0 GJ/m³</td>
</tr>
</tbody>
</table>

Source: BRE, UK, 1994
High vs. Low Embodied Energy?

- Materials with the lowest embodied energy intensities, such as concrete, bricks and timber, are usually consumed in large quantities.

- Materials with high energy content such as stainless steel are often used in much smaller amounts.

- As a result, the greatest amount of embodied energy in a building can be either from low embodied energy materials such as concrete, or high embodied energy materials such as steel.
### Energy Savings from Recycling

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy required to produce from virgin material (million Btu/ton)</th>
<th>Energy saved by using recycled materials (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>250</td>
<td>95</td>
</tr>
<tr>
<td>Plastics</td>
<td>98</td>
<td>88</td>
</tr>
<tr>
<td>Newsprint</td>
<td>29.8</td>
<td>34</td>
</tr>
<tr>
<td>Corrugated Cardboard</td>
<td>26.5</td>
<td>24</td>
</tr>
<tr>
<td>Glass</td>
<td>15.6</td>
<td>5</td>
</tr>
</tbody>
</table>

Construction Waste

- US Environmental Protection Agency (EPA) estimates 136 million tons of waste generated by construction each year.
- Most from demolition or renovation and nearly half the weight is concrete.
In industrialized nations, construction contributes more than 10% of the Gross Domestic Product (GDP)

An estimated 47% of total spending on construction is for renovation.

Source: Daratech (2001)
Buildings are Not Permanent

- Stone pinnacles of cathedrals are replaced ~200 years

- Buildings are waste in transit
Use of Raw Materials in the US
Materials Selection

- How to choose the best material?
  - Energy
  - Environment
  - Cost
  - Durability
  - Strength
  - etc
Concrete is made from local materials.

Concrete can be made with recycled waste or industrial byproducts (fly ash, slag, glass, etc).

Concrete offers significant energy savings over the lifetime of a building. Concrete’s high thermal mass moderates temperature swings by storing and releasing energy needed for heating and cooling.
Environmental Disadvantage of Concrete

- Cement production is responsible for about 5% of global CO2 emissions
- High energy requirements and release of CO2 during calcination of lime
- Cement production is rising rapidly worldwide
Energy Required for Concrete

Each ton of cement produces ~ 1 ton of CO2

Trends in Steel and Cement Production

Year | Metric Tonnes
--- | ---
1900 | 0
1903 | 0
1906 | 0
1909 | 0
1912 | 0
1915 | 0
1918 | 0
1921 | 0
1924 | 0
1927 | 0
1930 | 0
1933 | 0
1936 | 0
1939 | 0
1942 | 0
1945 | 0
1948 | 0
1951 | 0
1954 | 0
1957 | 0
1960 | 0
1963 | 0
1966 | 0
1969 | 0
1972 | 0
1975 | 0
1978 | 0
1981 | 0
1984 | 0
1987 | 0
1990 | 0
1993 | 0
1996 | 0
1999 | 0

Cement - U.S. Apparent Consumption
Cement - World Production
Steel - U.S. Apparent Consumption
Steel - World Production
Each ton of cement produces ~1 ton of CO₂.
Environmental Advantages of Steel

- Lower weight reduces foundation requirements
- Highly recycled and can continue to be recycled indefinitely
- Durable, if protected from corrosion
- Can be salvaged for reuse, in some cases to 95%
Energy Consumption for Steel

EU Steel Industry Energy Consumption per Tonne of Hot-rolled Steel
EU Steel Industry CO2 Emission per Tonne of Hot-rolled Steel
3-year moving averages
Environmental Disadvantages of Steel

- Very high energy use, predominantly from fossil fuels → produces pollution
- Lightweight, so lower thermal mass compared to concrete → requires more insulation
- Is susceptible to corrosion
The Greenest of Them All?

Only one primary building material:

- comes from a renewable resource;
- cleans the air and water;
- utilizes nearly 100% of its resource for products;
- is the lowest in energy requirements;
- creates fewer air and water emissions; and is
- totally reusable, recyclable and biodegradable.

And it has been increasing in US net reserves since 1952, with growth exceeding harvest in the US by more than 30%.
The Greenest of Them All?

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-American Wood Council
Stiffness (E) per unit weight

Source: Biggs (1991)
Embodied Energy per Stiffness

Wood    Brick    Concrete    Steel    Aluminum

Source: Biggs (1991)
Embodied Energy per Stiffness

Source: Biggs (1991)
Steel and Concrete

- Energy intensive materials
- High associated CO₂ emissions
- Dominant structural materials
  - Industry standards
  - Many engineers have not designed with other materials
  - Economies of scale
  - Steel provides ductility, the ability to absorb energy before failing
- Many other materials can serve in place of steel and concrete
Ecological Comparison of Materials

- Each material has environmental advantages and disadvantages
- Choice of material will depend on the site and design problem
- Embodied energy is only one of many considerations
CO$_2$ Emissions in the US

- **US**: 5% of world population, 25% of greenhouse gases

- **UK**: commitment to cut CO2 emissions 60% by 2050 (well beyond the goals of the Kyoto Protocol)
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~33,000 lbs of CO$_2$/year/person (-7% from 1990)

- But individual contributions are only 1/3 of per capita contributions – rest is industry, agriculture, etc.

- So individual’s annual goal would be 11,000 lbs (though many scientists are calling for much greater reductions)
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is equivalent to:
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: $\sim$11,000 lbs of CO$_2$/year/person (-7% from 1990)
- This is equivalent to:

  2 coast to coast flights
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is equivalent to:

  Driving about 11,000 miles
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is equivalent to:

  16 cubic yards of concrete
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is equivalent to:

  14 cubic feet of steel
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is equivalent to:

  5 cubic feet of aluminum
Kyoto Protocol and CO$_2$

- To meet Kyoto Protocol: ~11,000 lbs of CO$_2$/year/person (-7% from 1990)

- This is approximately equivalent to:
  - Fly coast to coast twice (economy class)
  - Drive 11,000 miles (20 mpg)
  - Use 16 yds$^3$ of concrete
  - Use 14 ft$^3$ of steel
  - Use 5 ft$^3$ of aluminum
Kyoto Protocol and CO₂

- Driving an SUV which gets 20 mpg:

- Using this material = driving this distance (approximately)
  - 1 yd³ of concrete = 700 miles
  - 1 ft³ of steel = 800 miles
  - 1 ft³ of aluminum = 2200 miles
Kyoto Protocol

- Aims to reduce CO\textsubscript{2} emissions by 7\% over 1990 levels (though the UK has just committed to going much further – 60\% reductions of current emissions)

- Would limit personal carbon emissions to 11,000 pounds of CO\textsubscript{2}/year

- This quantity of CO\textsubscript{2} is produced by:
  - Two coast-coast flights (economy class)
  - Driving 11,000 miles (with 20 mpg fuel efficiency)
  - Casting 16 cubic yards of concrete
  - About 14 cubic feet of structural steel
  - About 5 cubic feet of virgin aluminum
Kyoto Protocol

- Aims to reduce CO$_2$ emissions by 7% over 1990 levels (though the UK has just committed to going much further)

- This requires approximate CO$_2$ emissions of 33,000 lbs/year for each person in the US

- Only about 1/3 comes from personal decisions, the rest is due to industry and services

- Architects and engineers contribute to the "industry and services"
Conclusions

- Construction industry is the biggest consumer of energy and materials

- Each material has environmental advantages and disadvantages

- Embodied energy is only one of many considerations

- Energy intensive materials like steel and concrete can be used more efficiently

- Alternative materials should be explored
Credits

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