Sustainable Engineering: The Importance of Structures

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End of Life Design

- **30 million computers are thrown away each year (only ~14% are recycled now)**
- **Tackling waste flows can reduce environmental impact and save money**
- **The electronics and automobile industry are beginning to design for the end of life (MIT Materials Systems Laboratory)**

Outline of Lecture

- Introduction
- Materials Selection
- Case Studies
- Sustainable Structural Design
- Conclusions
- Future Challenges

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)

Construction and the Environment

US Primary Energy Consumption:

Buildings	**37%**
Industry	**36%**
Transportation	**28%**

Source: US Dept. of Energy

Spending on Construction

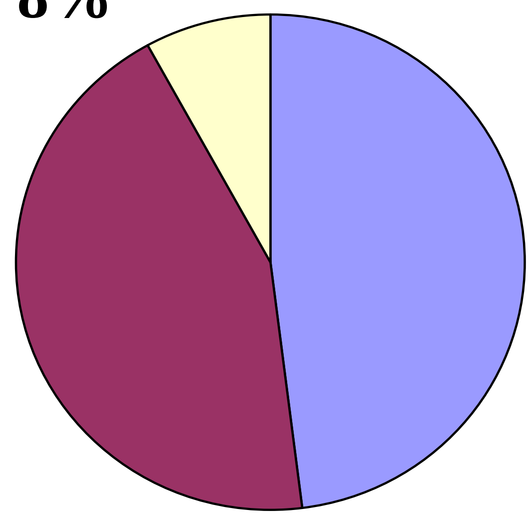
In industrialized nations, construction contributes more than 10% of the Gross Domestic Product (GDP)

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

Source: Daratech (2001)

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



Goals of Structural Design

- Efficiency
- Economy
- Elegance
- But all must consider the environmental impact as well

19th Century Design Concern

EFFICIENCY IS IMPORTANT: New materials in construction, such as wrought iron and steel, lead to greater concern for efficiency

20^{th} Century Design Concern

MAINTENANCE IS IMPORTANT:
The initial design is important, though we must also design for maintenance throughout operating life

21st Century Design Concern

“END OF LIFE” IS IMPORTANT:
Waste from the construction industry is a vast consumer of natural resources on a global scale

Buildings are Not Permanent

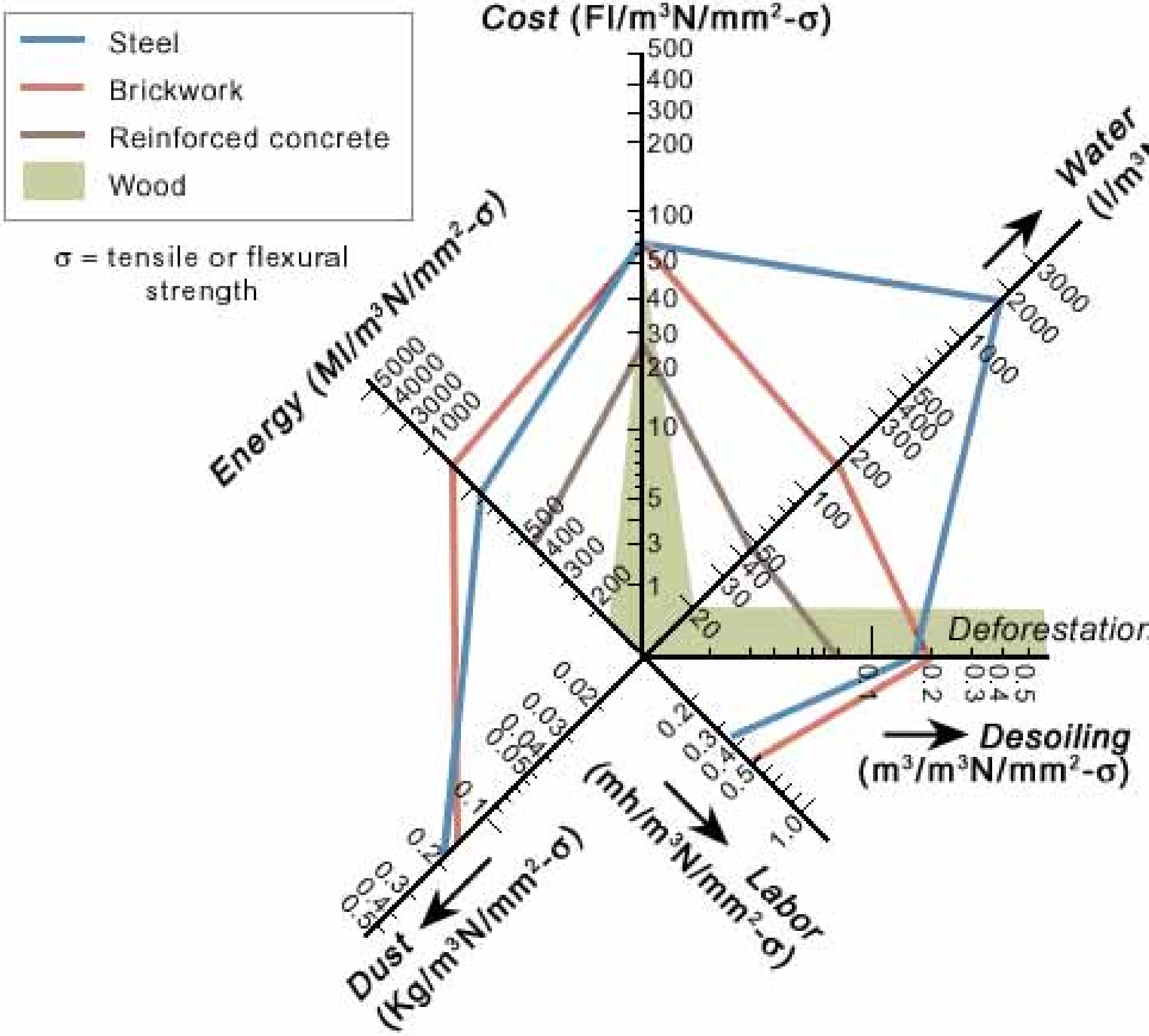
- **Stone pinnacles of cathedrals are replaced ~200 years**

- **Buildings are *waste in transit***

Choosing Materials

- Environmental Impact
- Durability
- End of Life

Ecological Profile of Materials



Ecological profile of various material properties expressed per unit strength.

The Institution of Structural Engineering

Is concrete a green material?

- **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.**

Energy Required for Concrete

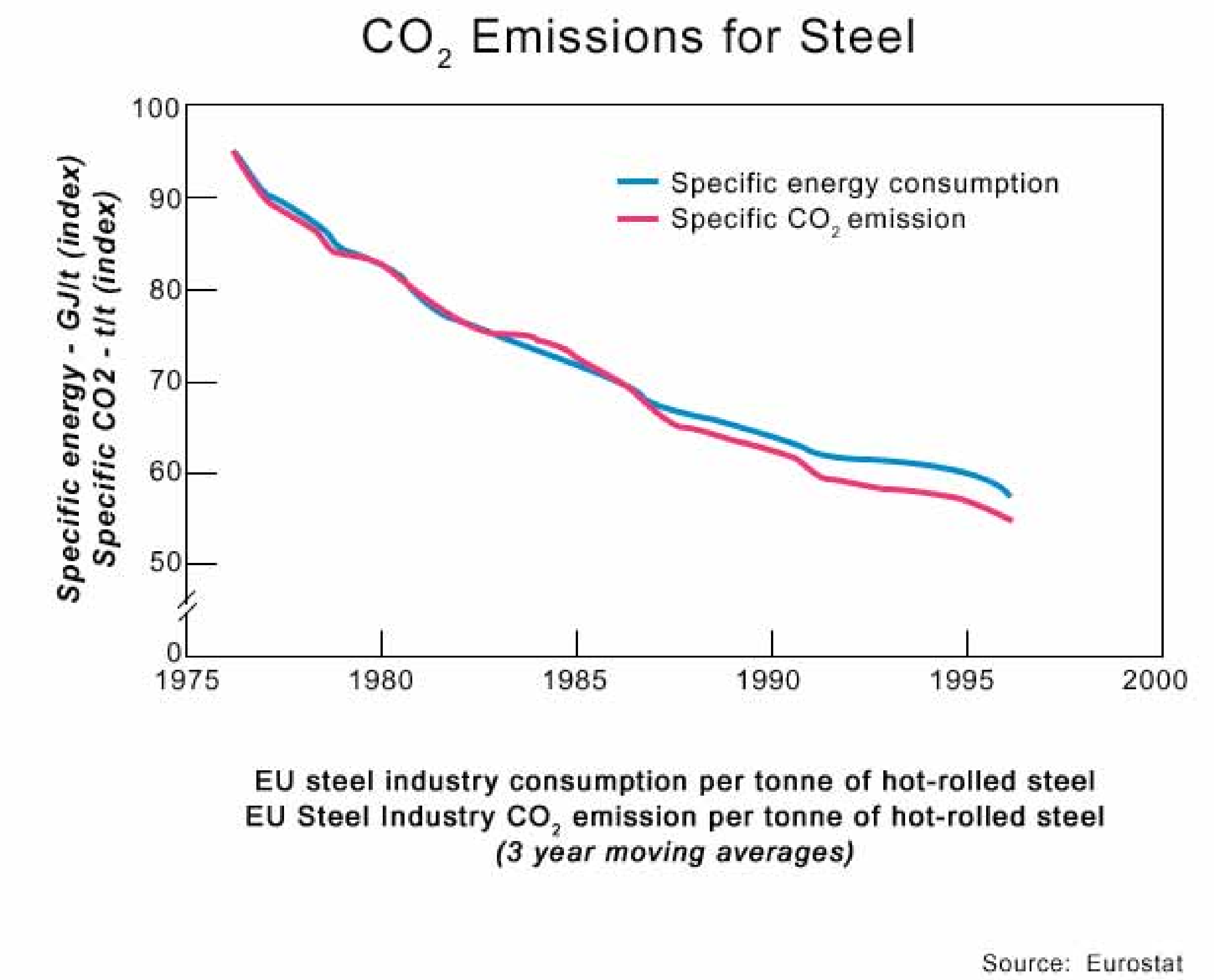
Component	Percent by weight	Energy %
Portland cement	12%	92%
Sand	34%	2%
Crushed stone	48%	6%
Water	6%	0%

Each ton of cement produces ~ 1 ton of CO_2

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**

Energy Consumption for Steel



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**

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

- Aims to reduce CO_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_2/year
- This quantity of CO_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*"**

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%.

-American Wood Council

Planting trees?

- A healthy tree stores about 13 pounds of CO_2 per year -- NOT MUCH!
- Would require nearly 3,000 trees per person to offset CO_2 emissions
- Specifying timber reduces CO_2 emissions compared to steel and concrete, but carbon sequestration is a small contribution to this reduction
- Main advantage is that wood does not produce nearly as much CO_2 as steel and concrete

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.**

Steel and Concrete

- **Energy intensive materials**
- **High associated CO_2 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**

Energy Savings from Recycling

	Energy required to produce from virgin material (million Btu/ton)	Energy saved by using recycled materials (percentage)
Aluminum	250	95
Plastics	98	88
Newsprint	29.8	34
Corrugated Cardboard	26.5	24
Glass	15.6	5

Source: Roberta Forsell Stauffer of National Technical Assistance Service (NATAS), published in *Resource Recycling*, Jan/Feb 1989).

Electronics Industry

- **30 million computers thrown away annually in the US**
- **Only 14% recycled**
- **Initial design must consider end of life**

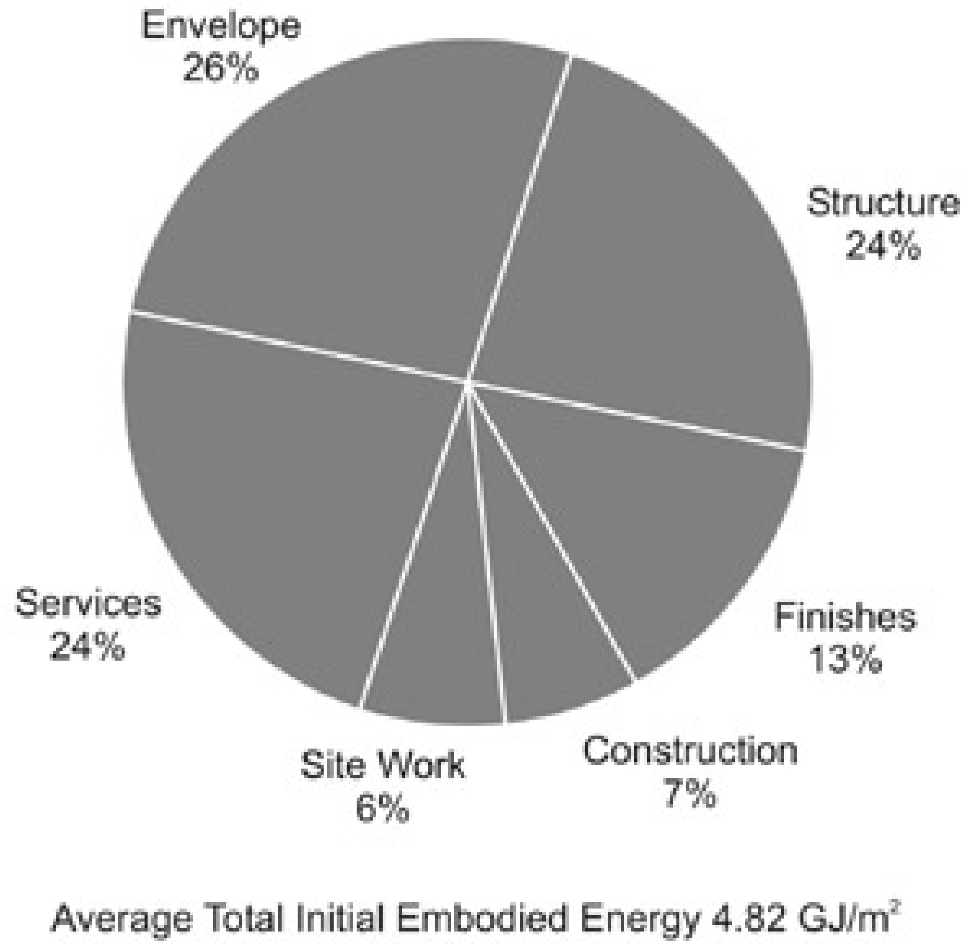
Embodied Energy vs. Operating Energy (3,750 sf home)

Home type, location	Heating Energy MM Btu/year (Gj/year)	Embodied Energy MM Btu (Gj)	Embodied Energy in years of heating energy
Conventional, Vancouver	101 (107)	948 (1,000)	9.4
Energy-efficient, Vancouver	57 (60)	1019 (1,075)	17.9
Conventional, Toronto	136 (143)	948 (1,000)	7.0
Energy-efficient, Toronto	78 (82)	1019 (1,075)	13.1

Source: Ray Cole, Univ. of British Columbia

Typical Building Embodied Energy

Breakdown of Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures [Cole and Kernan, 1996].



Range in Embodied Energy

Material	Density	Low value		High value	
	kg/m^3		GJ/m^3		GJ/m^3
Natural aggregates	1500		0.05		0.93
Cement	1500		6.5		11.7
Bricks	~1700		1.7		16
Timber (prepared softwood)	~500		0.26		3.6
Glass	2600		34		81
Steel (sections)	7800		190		460
Plaster	~1200		1.3		8.0

Source: BRE, UK, 1994

Reducing Waste

Design for Less Material Use
Use materials efficiently and maximize program use by combining spaces. (i.e., build smaller)

Design Building for Adaptability
Design multipurpose areas or flexible floor plans which can be adapted for use changes.

Recycle Construction Waste
Wood, metal, glass, cardboard etc. can be salvaged in the construction process. Materials should be used and ordered conservatively.

Use Recycled Content Products and Materials

<u>High recycled content:</u>

Paper on both the face and the back of all drywall is a 100% recycled product.

Structural steel uses mostly recycled material (though it is still energy-intensive and responsible for harmful pollutants.)

<u>Example of an item that you can specify:</u>

Armstrong ceiling tiles contain 79% recycled material (cornstarch, newsprint, mineral wool, recycled tiles). Both the ceiling tiles and the suspension systems can also be reclaimed and recycled rather than dumped in a landfill.

Separating Waste

Australia: Waste Avoidance and Resource Recovery Act (2001)

Web site dedicated to Construction & Demolition waste minimization: onSITE

http://onsite.rmit.edu.au/

(Source of material for this lecture.)

Steel and Concrete

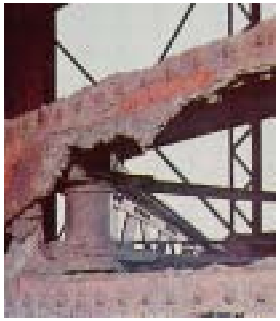
- **Can be designed for reuse (concrete pavers)**
- **Can reduce required quantities through efficient design**
- **We will return to the design of indeterminate structures and the importance of structural form**
- **Designers can use the constraints of economics, efficiency, and the environment to find new forms**

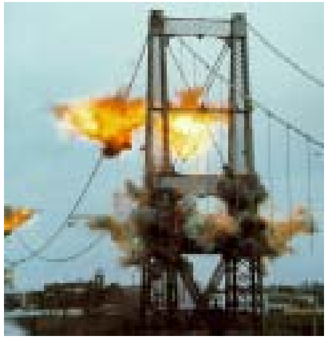
Ecological Comparison of Materials

- 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

Design Matters

- 19th Century: Efficient use of materials
- 20th Century: Maintenance matters
- 21st Century: End of life matters





Designing for Maintenance

- **Develop a maintenance plan for your structure**
- **Design components which are accessible and replaceable**
- **Avoid toxic materials which are hazardous for future maintenance operations**

Demolition: Lessons from History

- Sustainable structures must consider the "end of life" of the structure
- ~24% of solid landfill waste in the US is generated by the construction industry
- Up to 95% of construction waste is recyclable, and most is clean and unmixed

Two Extreme Approaches to Sustainable Structures

1. **Permanence: Very high quality construction, with materials which can be reused in future construction**

2. **Temporary: Less expensive construction, with a short life span. Materials must be low-impact.**

Two Sustainable Bridge Types

Inca suspension bridge

- High stresses
- High maintenance
- Short lifetime
- Low initial cost
- Renewable materials
- Low load capacity

Roman arch bridge

- Low stresses
- Low maintenance
- Long lifetime
- High initial cost
- Reusable materials
- High load capacity

Conclusions

- **Each material has environmental advantages and disadvantages: good design is local**
- **Recycle or reuse materials to decrease waste**
- **Consider end of life in the initial design**
- **History suggests sustainable solutions: Inca structures (temporary) and Roman structures (permanent) can both be sustainable**

Conclusions

- Construction industry generates enormous waste annually
- Individual designers can reduce this waste significantly
- Energy intensive materials like steel and concrete can be used more efficiently
- Alternative materials should be explored

Future Challenges

- Education of architects and engineers
  - Teaching design and analysis
  - Assessment of existing structures
  - Environment as a design constraint, not an opponent
- Maintenance and disposal plan for new structures
- Code improvements for the reuse of salvaged structures and new uses of traditional materials