Aalto University

Life-cycle analysis, Quality, Health & Safety

CIV-E1040 Construction Management

Lecture 4b

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Previous lecture

- **Cost estimation methods**
  - Conceptual estimating
  - Element based estimating
- **Cost estimation process**
- **Evolutionary estimating**
- **Use of parametrics and BIM**

Learning outcomes

After lecture student can:

- **Describe the process and input-output methods for life-cycle analysis of buildings**
- **Describe principles of life-cycle cost analysis**
- **Describe different definitions for quality in construction**
- **Describe quality and safety management methods and practices**

Life-cycle analysis (LCA)

Background

- **Strategy to stop every possible emission that is harming our shared environment**
- **Life-cycle assessment:**

  "a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling"

- **A carbon footprint:**

  "defines the total sets of greenhouse gas (GHG) emissions caused by organizations, events, products, individuals or regions"

  "Sum of all emissions of carbon dioxide (CO2), which were induced by all activities in a given time frame"

Carbon footprint assessment

- **One of a family of footprint indicators (others: water footprint, land footprint)**
  - Measure direct emissions of gases that cause climate change into the atmosphere
  - Individual / household / industry / product / region

- **CO_2 emissions are around 80 % of the greenhouse gas emissions (GHG)**
  - The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide (CO_2), methane, nitrous oxide, and ozone

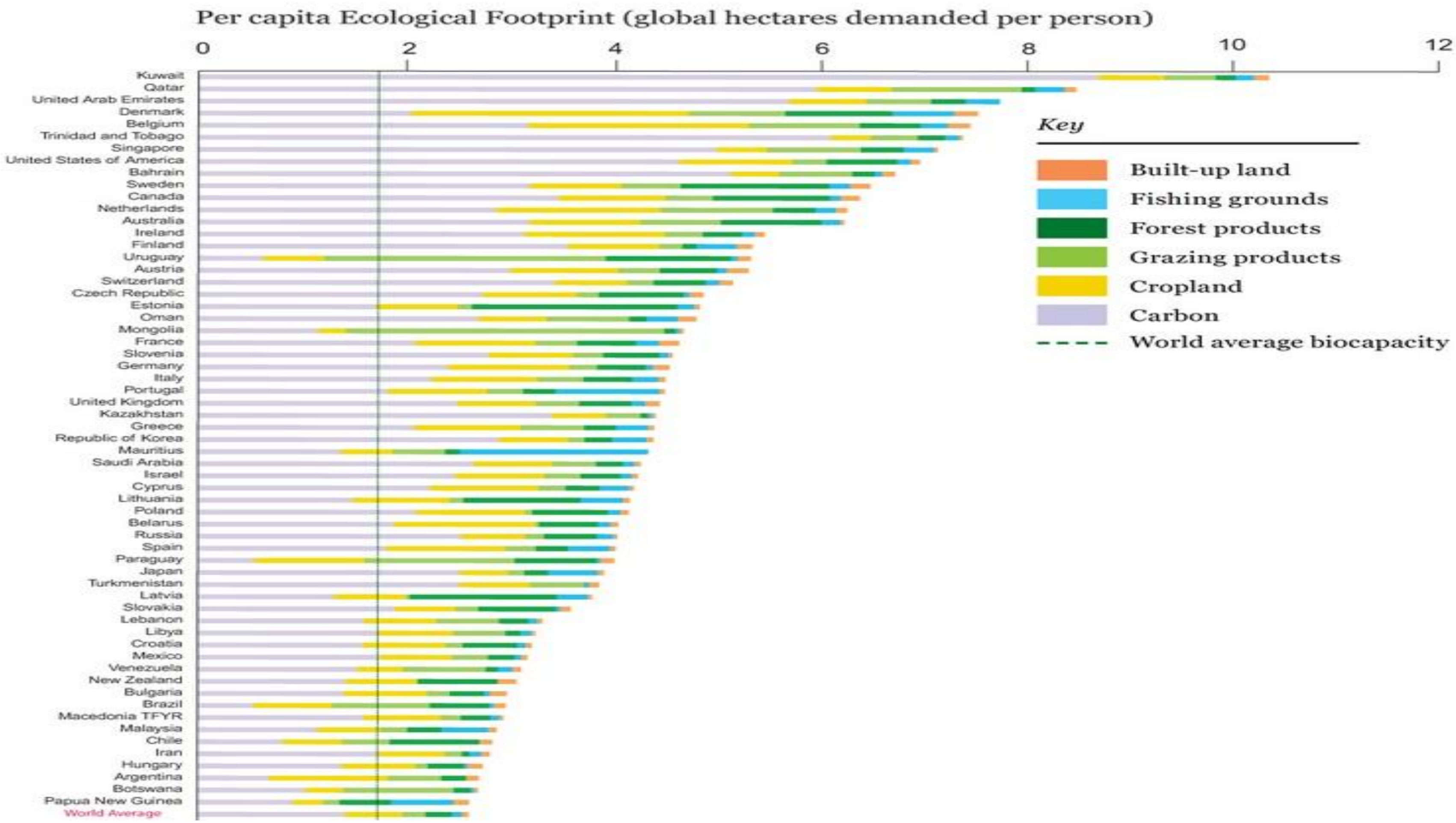
- **CO_2 enters the atmosphere through**
  - Burning fossil fuels (coal, natural gas, and oil)
  - Solid waste
  - Trees and wood products
  - As a result of certain chemical reactions (e.g., manufacture of cement)

- **CO_2 is removed from the atmosphere when it is absorbed by plants as part of the biological carbon cycle**

INFOGRAPHIC

FOOTPRINT BY COUNTRY

This comparison includes all countries with a populations greater than 1 million for which complete data is available (Global Footprint Network, 2014)



Carbon footprint contributed by buildings

- **Purpose is to find out how much carbon dioxide emissions building produces during it's lifespan**

- **Buildings alone are responsible for 38% of all human Greenhouse Gas emissions (20% residential, 18% commercial)**

- **Important to identify the sources of these emissions and understand their relations to the construction phase and essential in climate change mitigation**

Environmental certificates for buildings in Finland

	LEED	BREEAM	RTS	JOUTSENMERKKI
Location and connections				
Transportation	x	x		
Lot selection	x	x		
Green areas	x	x	x	
Process				
Lifecycle costs		x		
Maintenance			x	x
Moisture risk management			x	x
Energy and environment				
Energy efficiency	x	x	x	x
Water use	x	x	x	x
Functional assurance	x	x	x	x

	LEED	BREEAM	RTS	JOUTSENMERKKI
Materials				
CO2 measurement	x	x	x	
Material efficiency	x	x	x	x
Resp. procurements		x		x
Waste management	x	x		x
Indoor air				
Indoor air quality	x	x	x	x
Natural light	x	x	x	x
Material emissions	x	x	x	x
Chemical risks			x	x
Acoustics	x	x	x	x
Site management				
Site environment	x	x	x	x
Cleanliness	x		x	
Waste management	x		x	x

Source: Rakennushankkeiden ympäristöluokitukset Suomessa

Purpose of carbon footprint assessment of buildings

- Can be used as a design goal or criteria
- Helps reduce the emissions of buildings by quantifying it
- Makes the choice easy for ideal structures
- Helps to improve the lifecycle efficiency, design goals and setting the lifecycle requirement for the structures

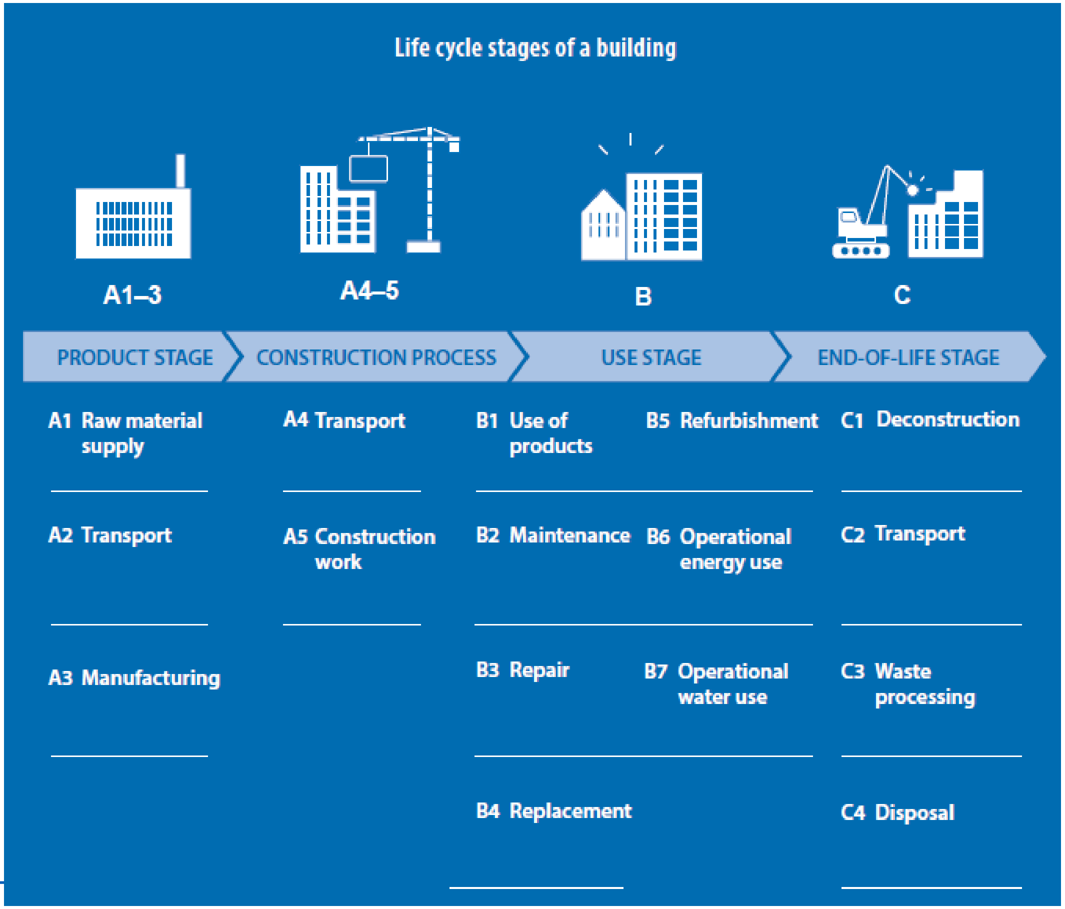
Methods, processes, tools

Life cycle assessment (LCA) methods

1. Process LCA
2. Input-output LCA (IO LCA)

Four stages:

1. Product
2. Construction
3. Use
4. End-of-life



Source: https://julkaisut.valtioneuvosto.fi/handle/10024/161796

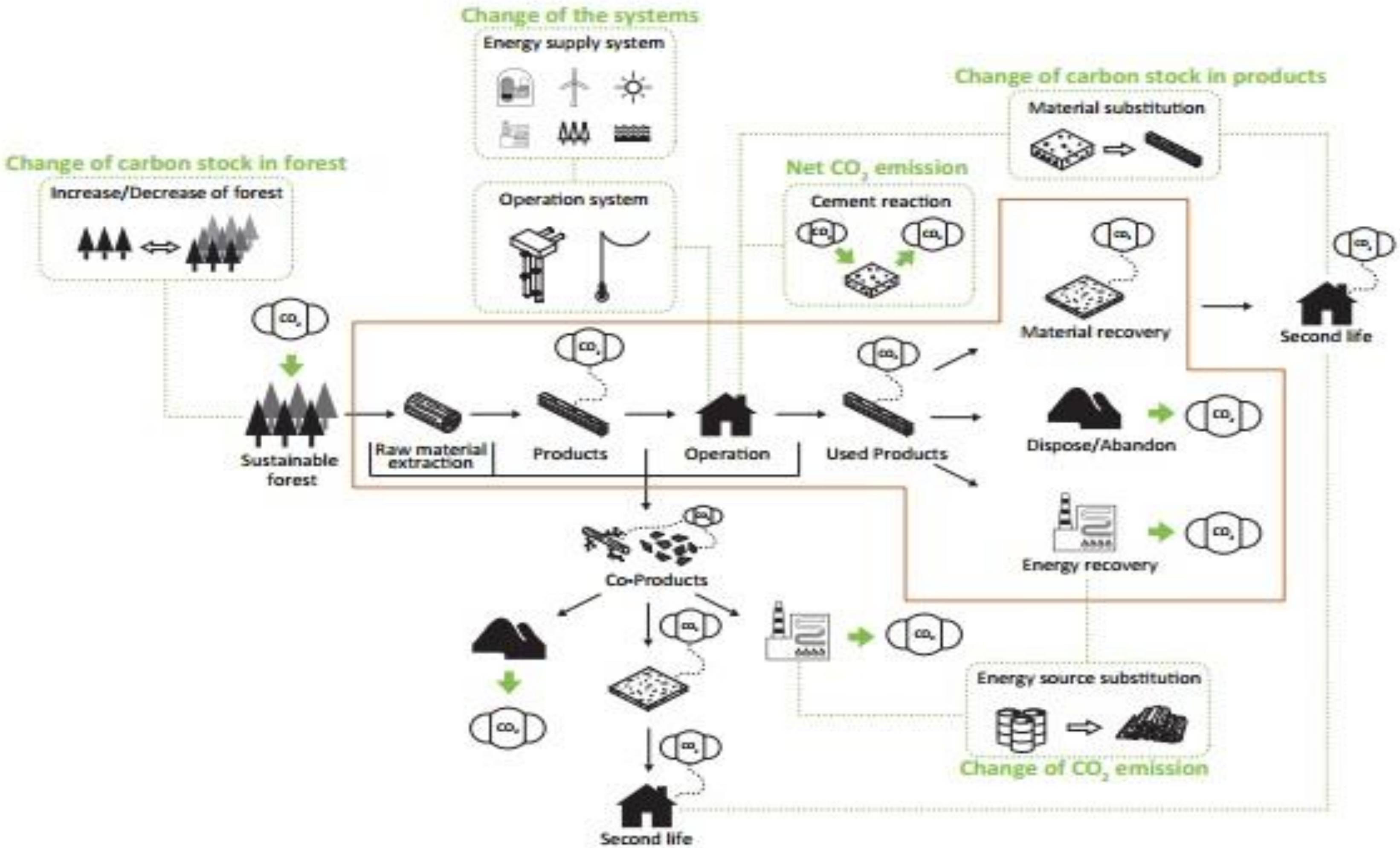
Process method to analyze carbon footprint

- **A bottom-up approach**

- **Takes into account all processes in the product life cycle, from production to disposal of the product → accuracy**

- **Requires detailed information on the entire life cycle of the product → expensive in terms of time and computation**
  - Data required is often not available
  - Supplier not wanting to unveil information on their production processes
  - Manual process and can take days per product

Process method: How to define system boundaries in the assessments?



F.4.5-1 Holistic picture of carbon footprint related to a wood-based building system and simplified system boundary (red line) for the system building including only direct environmental effects.

Croissant example – 1/5

Step I – Building a process map

1. **Define the functional unit**
   - the appropriate functional unit is driven by how the product is typically consumed (e.g. one 100 g croissant or tonne of croissants)

2. **List the ingredients and proportions**
   - Flour (wheat) – 60%
   - Water – 20%
   - Butter – 15%
   - Other (e.g. yeast) – 5%
   - Packaging material (film and secondary packaging)

Guide to PAS 2050 How to assess the carbon footprint of goods and services. Available at: http://aggie-horticulture.tamu.edu/faculty/hall/publications/PAS2050_Guide.pdf

Croissant example – 2/5

3. List the activities involved in producing and consuming croissants

- Produce and transport raw materials
  - *Grow and transport wheat; mill into flour*
  - *Supply water*
  - *Produce milk; manufacture butter*
  - *Produce other ingredients*
  - *Produce film packaging*
- Manufacture and package croissants
- Distribute finished product
- Retail
- Use (eat)
- Dispose of waste

4. Reflect on what might have been missed

Croissant example – 3/5

Step II – Checking boundaries and prioritisation

- **Which life cycle stages, inputs and outputs should be included in the assessment**

- **What not to include:**
  - Immaterial emissions sources (less than 1% of total footprint)
    - *water supply, storage and retail*
  - Human inputs to processes
  - Transport of consumers to retail outlets
  - Animals providing transport

Croissant example – 4/5

Step III – Collecting data

- **Two types of data are necessary to calculate a carbon footprint:**
  - Activity data
  - Emission factors

- **Activity data refers to all the material and energy amounts involved in the product's life cycle (material inputs and outputs, energy used, transport, etc.)**
- **Emission factors provide the link that converts these quantities into the resulting GHG emissions: the amount of greenhouse gases emitted per 'unit' of activity data (e.g. kg GHGs per kg input or per kWh energy used).**

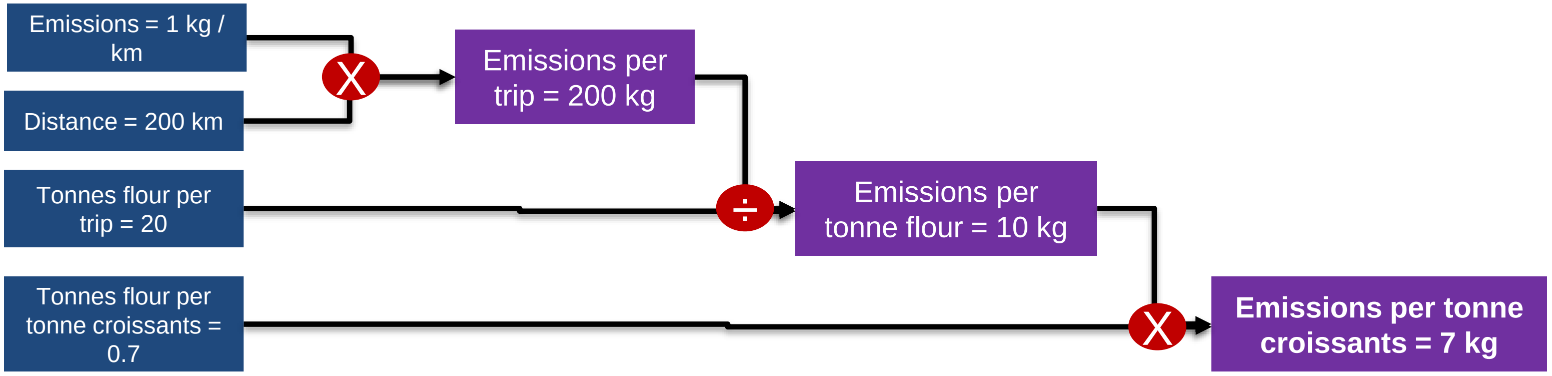
Croissant example – 5/5

Step IV –Calculating the footprint

- **Carbon footprint of a given activity =**

Activity data (mass/volume/kWh/km) × Emission factor (CO_2e per unit)

- **Simple Flour transport example:**

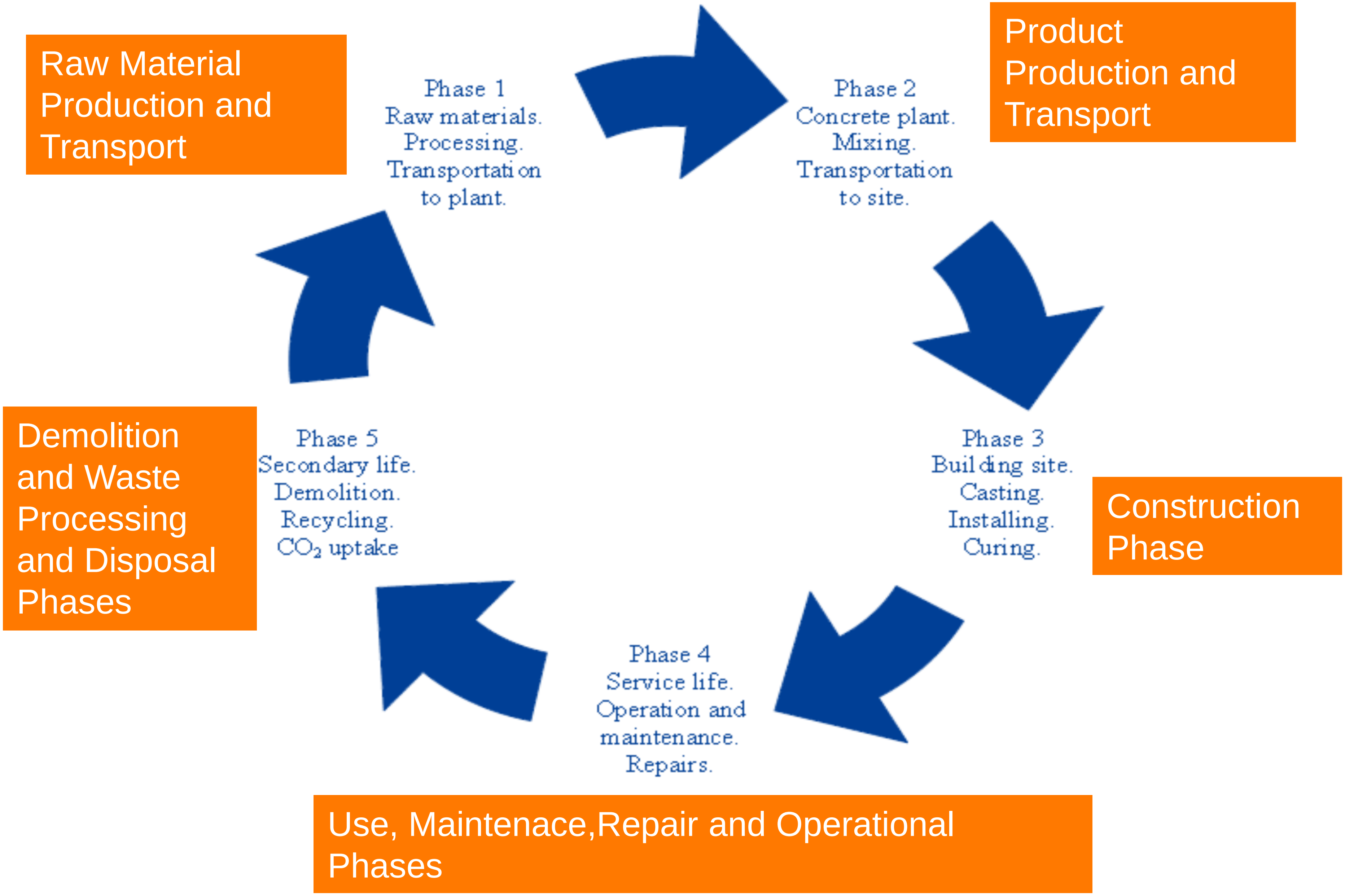


Croissant example – Results

Raw materials (including transport)			Manufacturing			Distribution/retail			Consumer use			Disposal/recycling			Total
Wheat agriculture	500	44 %	Plant A	200	17 %	Transport	30	3 %	Freezing	50	4 %	Transport	50	4 %	
Flour milling	50	4 %				Storage	0	0 %	Toasting	40	4 %	Decay	100	9 %	
Water supply	0	0 %				Retail	0	0 %							
Other ingredients	100	9 %													
Film packaging	20	2 %													
Total	670	59 %		200	17 %		30	3 %		90	8 %		150	13 %	1140

Figures are in grams CO2e per tonne croissants, and are for illustration purposes only.
Percentages are per cent of total.

Estimation Phases in Buildings



STANDARD MATERIAL EMISSIONS

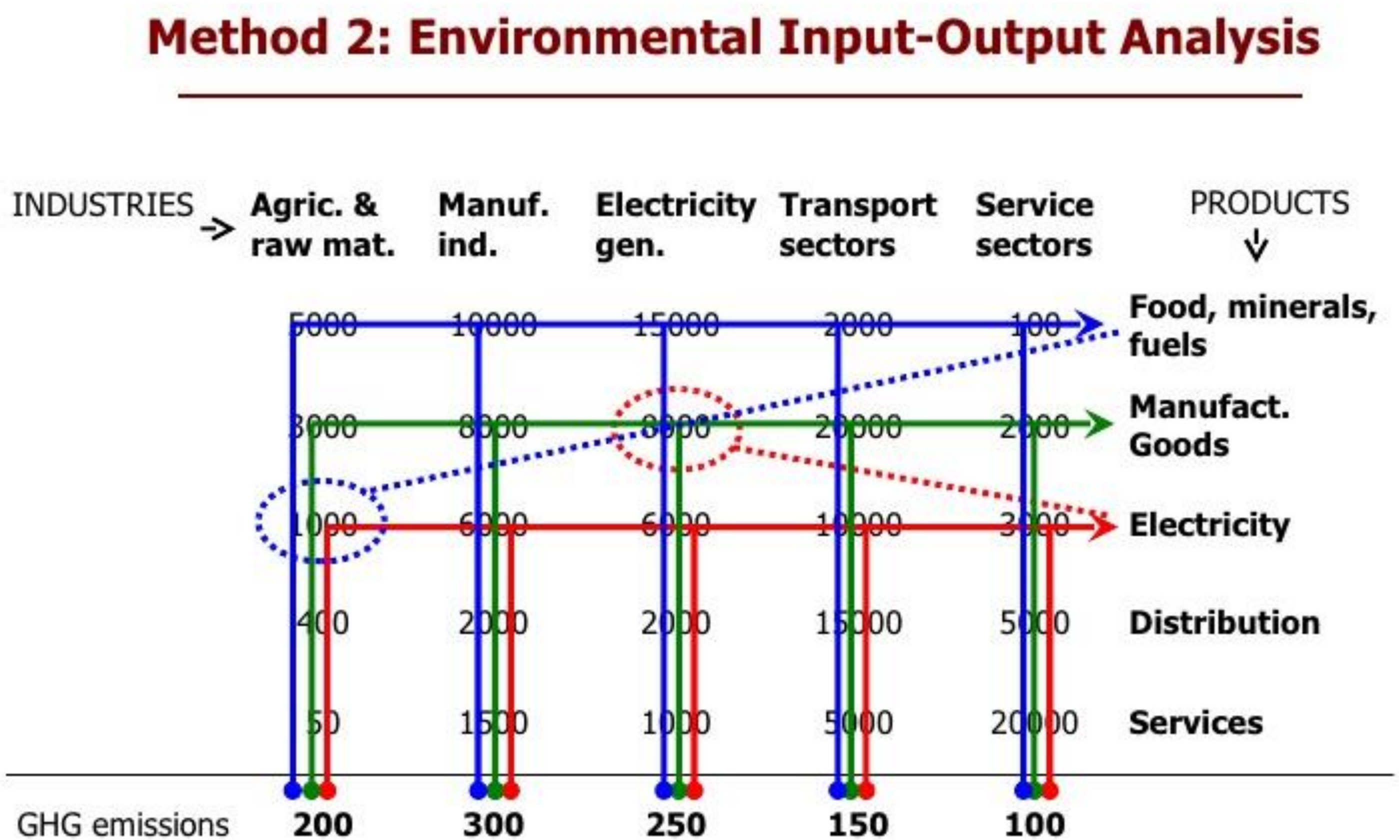
Table 1. Embodied carbon balance for production of ready mixed concrete based on Danish figures. Phases 1-3, cradle to building site. Total embodied CO_2: ECO2 = 402 kg/m^3 = 0.17 kg/kg based on a density of 2400 kg/m^3 (4046 lb/yd^3).

Functional unit: FU = one m^3 (0.765 yd^3)	Production			Transportation		
	A	B ECO2	A·B ECO2	D	E ECO2	A·D·E ECO2
Item	$\frac{kg}{FU}$ (lb/yd^3)	-	$\frac{kg}{FU}$	km	$\frac{kg}{kg \cdot km}$	$\frac{kg}{FU}$
Cement OPC	300 (506)	0.8-0.9	255	100	$100 \cdot 10^{-6}$	3
SCM	29 (49)	0	0	100	$100 \cdot 10^{-6}$	~0
Sand	660 (1113)	0.003	2.0	20	$100 \cdot 10^{-6}$	1.3
Coarse	1170 (1976)	0.003	3.5	20	$100 \cdot 10^{-6}$	2.3
Water	145 (244)	-	-	-	-	-
Steel	30 (51)	1.0	30	500	$100 \cdot 10^{-6}$	1.5
Concrete	2400 (4046)	0,04	96	30	$100 \cdot 10^{-6}$	7.2
		Sum =	**387**		**Sum =**	**15**
-	-			-	**Total =**	**402**

Input-Output method to analyze carbon footprint

- **A top-down approach**
- **Use of carbon intensities, measured in kilograms of carbon dioxide per money spent, to assign footprint to a product based on the price of the product**
- **The method uses information about industry transactions**
  - Purchases of materials by one industry from other industries
  - Information about direct environmental emissions of industries
- **The model is based on sector averages**
  - Cannot handle any product specific data

Allocation of emissions to products through financial transactions between industries

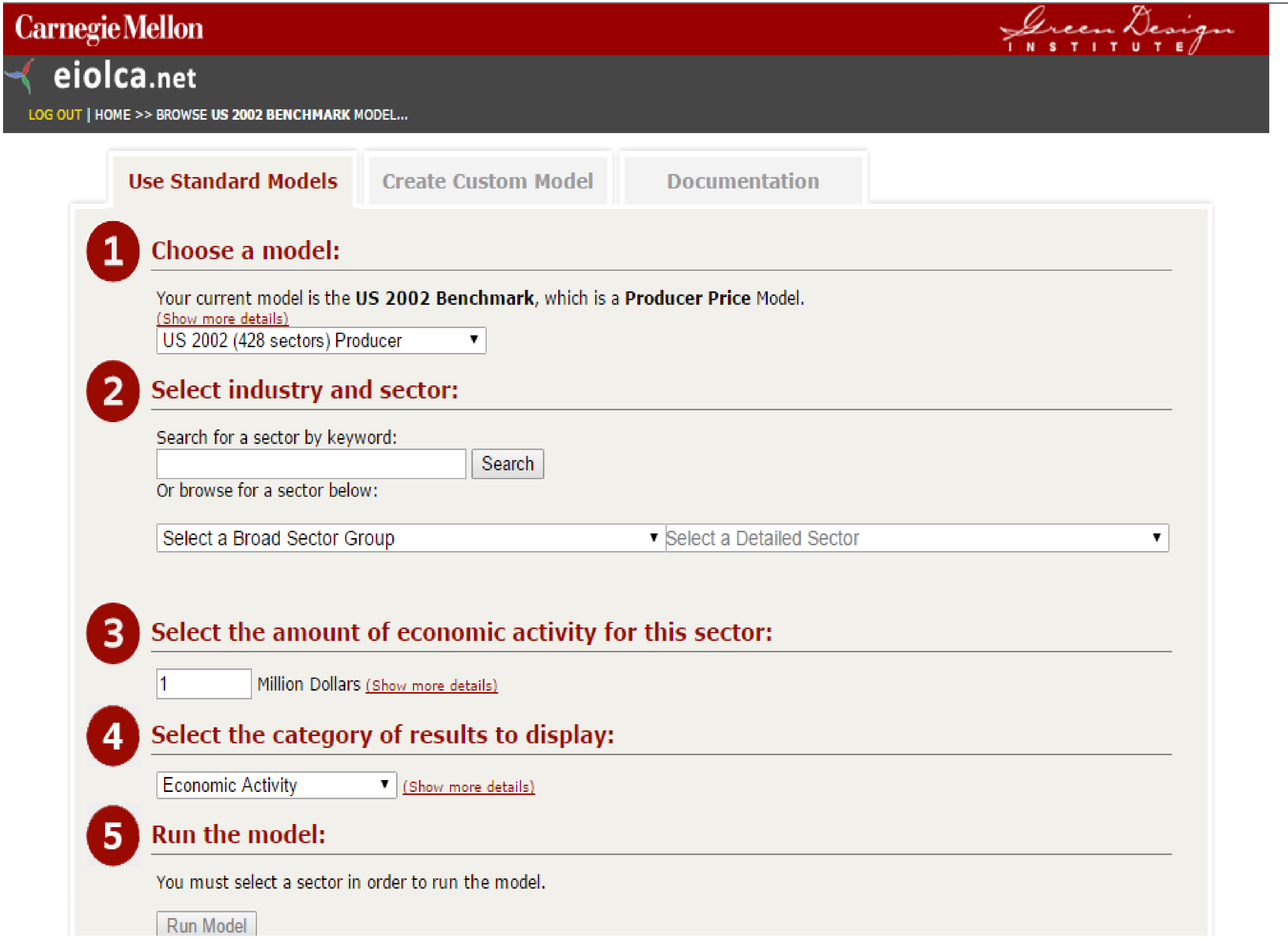


The Economic Input-Output Life Cycle Assessment (EIO-LCA) method

Buildings

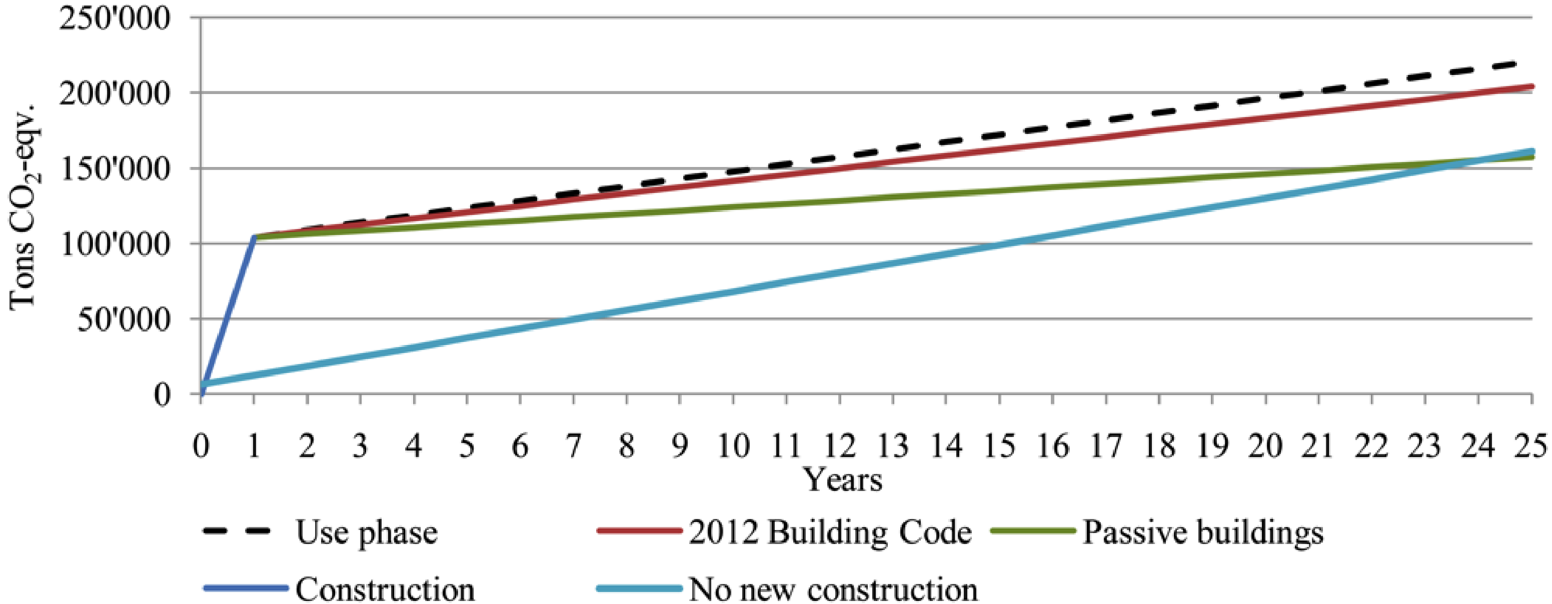
Material or function	EIO-LCA sector	M€	Total t CO_2e
Timber	Sawmills and Wood Preservation	4,96	3650
Concrete	**Concrete pipe, brick and block manufacturing**	**3,68**	**7060**
Steel	**Iron, steel pipe and tube manufacturing from purchased steel**	**3,16**	**6420**
HEVAC-material	Iron and Steel Mills	2,72	1580
Brickwork (bricks + plaster)	Brick and Structural Clay Tile Manufacturing	2,22	4460
Electric material	Miscellaneous electrical equipment manufacturing	1,92	729
Windows and doors	Wood Window and Door Manufacturing	1,88	1120
Energy	**Power generation and supply**	**1,2**	**11200**
Furniture	Nonupholstered Wood Household Furniture Manufacturing	0,97	475
Water insulation	Paint and Coating Manufacturing	0,71	763
Domestic appliance	Household Refrigerator and Home Freezer Manufacturing	0,59	460
Plastic pipes and basins	Plastics Pipe and Pipe Fitting Manufacturing	0,51	716
Heat insulation	Industrial Process Furnace and Oven Manufacturing	0,47	237
Subcontractors	Other nonresidential structures	26,40	16200
Others	Residential permanent site single- and multi-family structures	18,00	11900
Total		**69,39**	**66970**

Estimation Tool



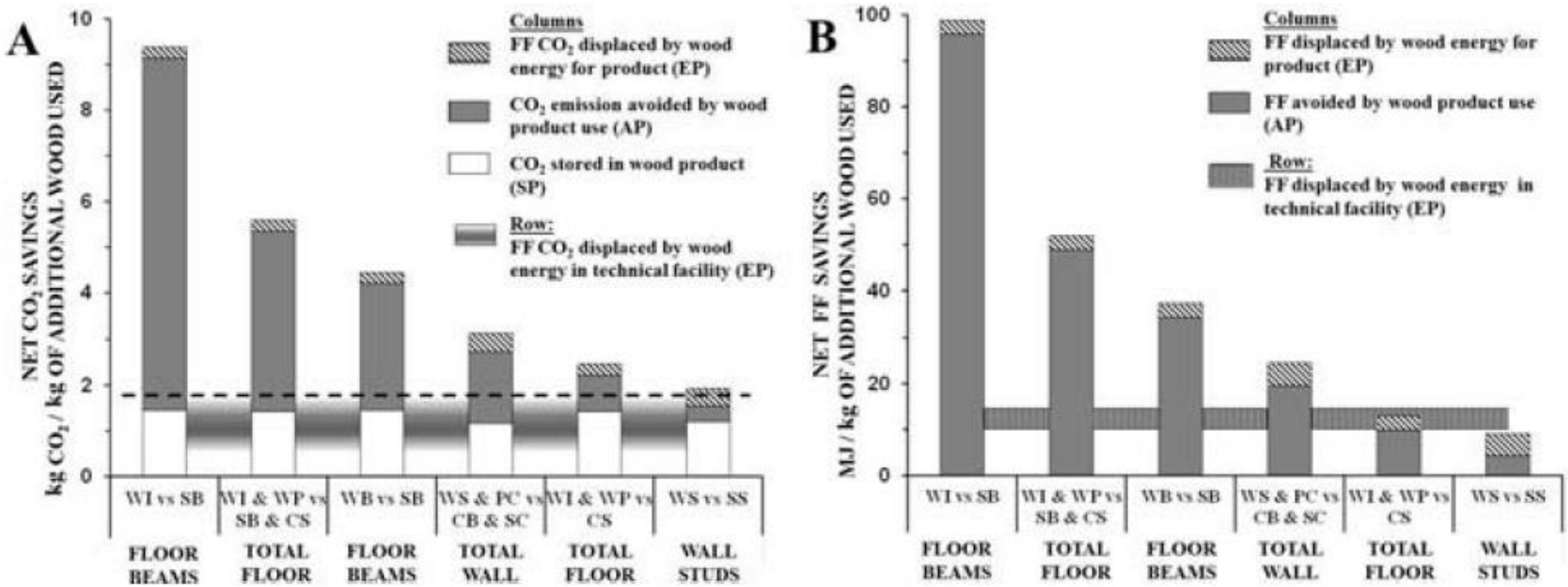
Source: http://www.eiolca.net/cgi-bin/dft/use.pl

Example: 70,000 m2 residential development area



Heinonen et al. (2011) A Longitudinal Study on the Carbon Emissions of a New Residential Development, Sustainability 2011, 3(8), 1170-1189; doi:10.3390/su3081170

CO2 and fossil fuel savings of wood products compared to steel and concrete building components



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Chadwick Dearing Oliver, Nedal T. Nassar, Bruce R. Lippke & James B. McCarter (2014) Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests, Journal of Sustainable Forestry, 33:3, 248-275, DOI: 10.1080/10549811.2013.839386

Methods to reduce carbon footprint

Green Feature		
Manufacturing Process	**Building operations**	**Waste Management**
Waste reduction	Energy Efficiency	Biodegradable
Pollution Prevention	Water Treatment & Conservation	Recyclable
Recycled materials	Nontoxic	Reusable
Embodied Energy Reduction	Renewable Energy Source	Others
Natural Materials	Longer Life	

Strategies adopted to reduce GHG emissions during construction

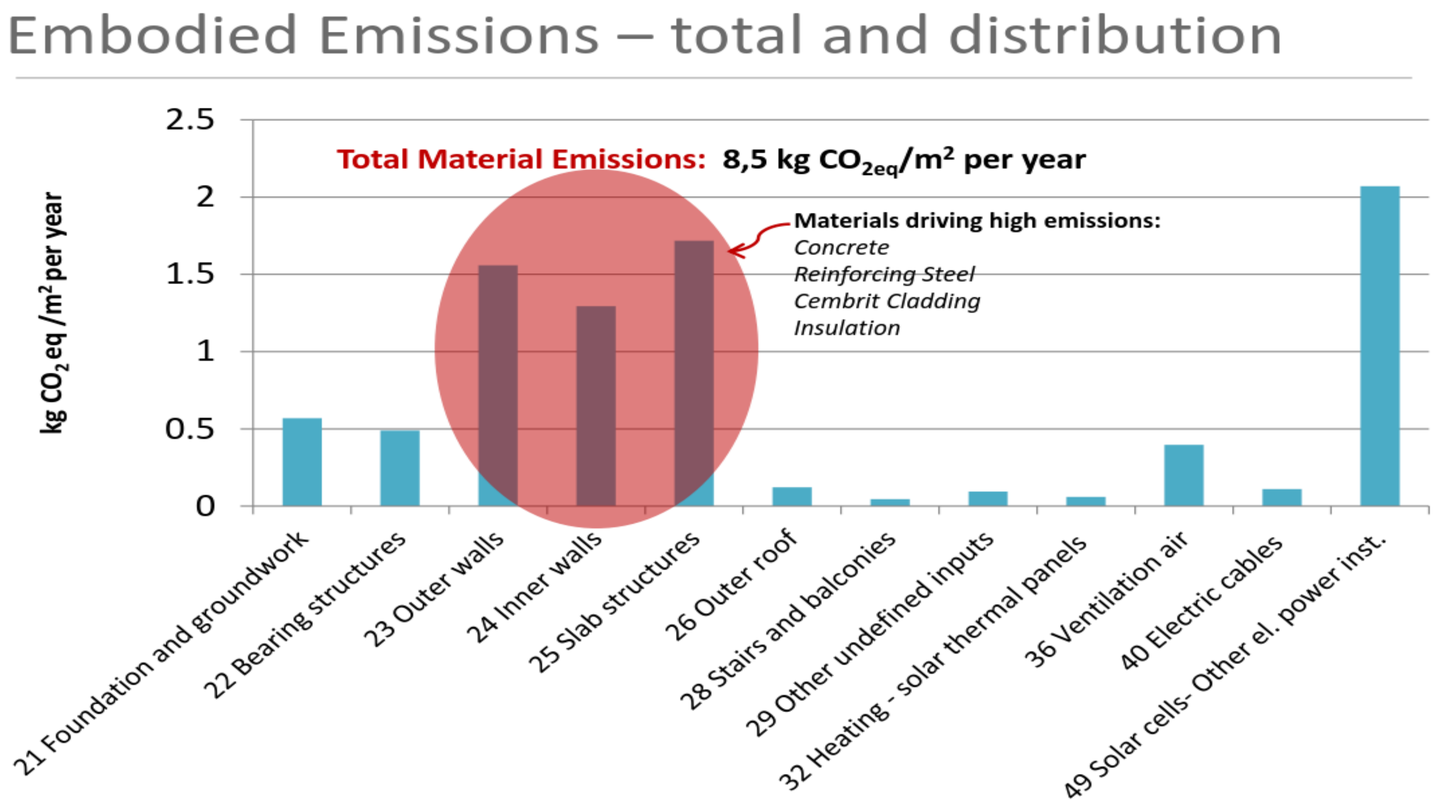
- **Reduce quantity of materials used**

- **Select materials with low emissions factors associated**
  - e.g. recycled materials

- **Select materials suppliers as close as possible from the construction site**

- **Divert demolition wastes to recycling instead of landfills or incineration**

Examples: Material emissions



Summary of the topic

- **Role of buildings in producing and reducing GHG emissions**
- **Role of operation / use phase as source for emissions in built environment**
- **Calculation methods:**
  1. Process method
  2. Input-output method

Further readings

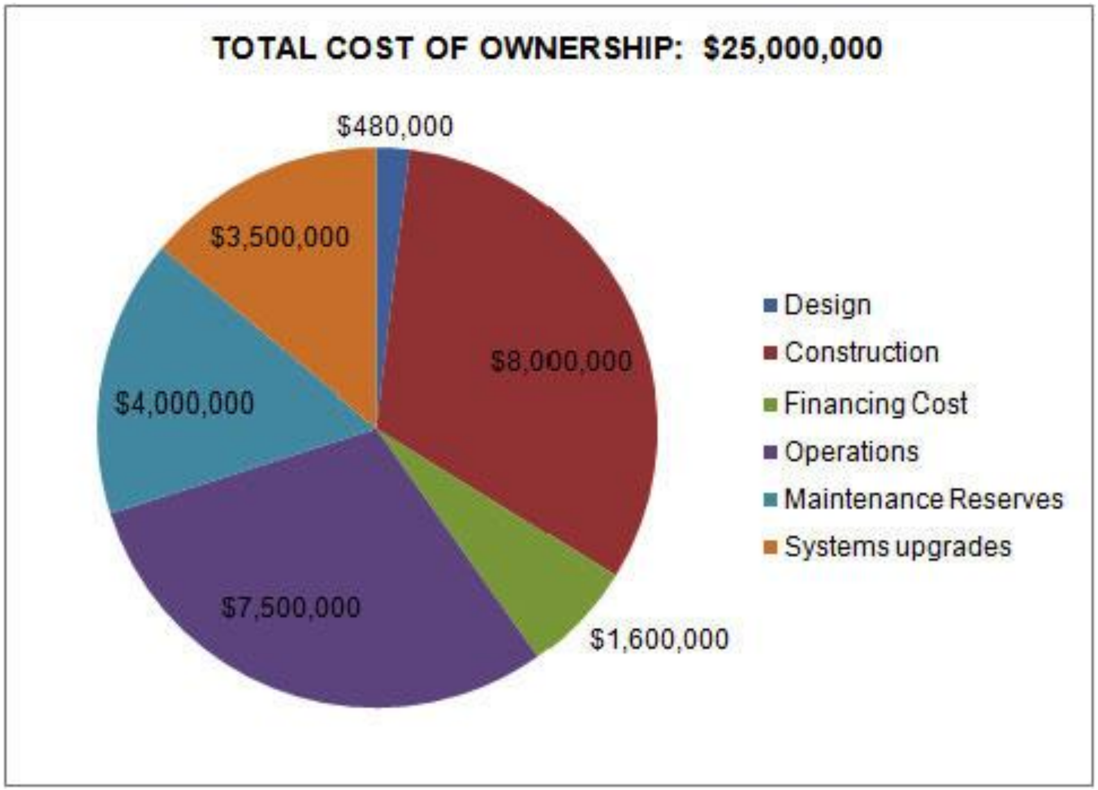
Säynäjoki, A. (2014) How Does the Construction of a Residential Area Contribute to Climate Change? Doctoral diessertation, Aalto University publication series.

Barnett, R. W. Barraclough, V. Becerra, S. Nasuto. A comparison of methods for calculating the carbon footprint of a product. Available at: https://www.reading.ac.uk/web/FILES/tsbe/Barnett_TSBE_Conference_Paper_2012.pdf

Guide to PAS 2050 How to assess the carbon footprint of goods and services. Available at: http://aggie-horticulture.tamu.edu/faculty/hall/publications/PAS2050_Guide.pdf

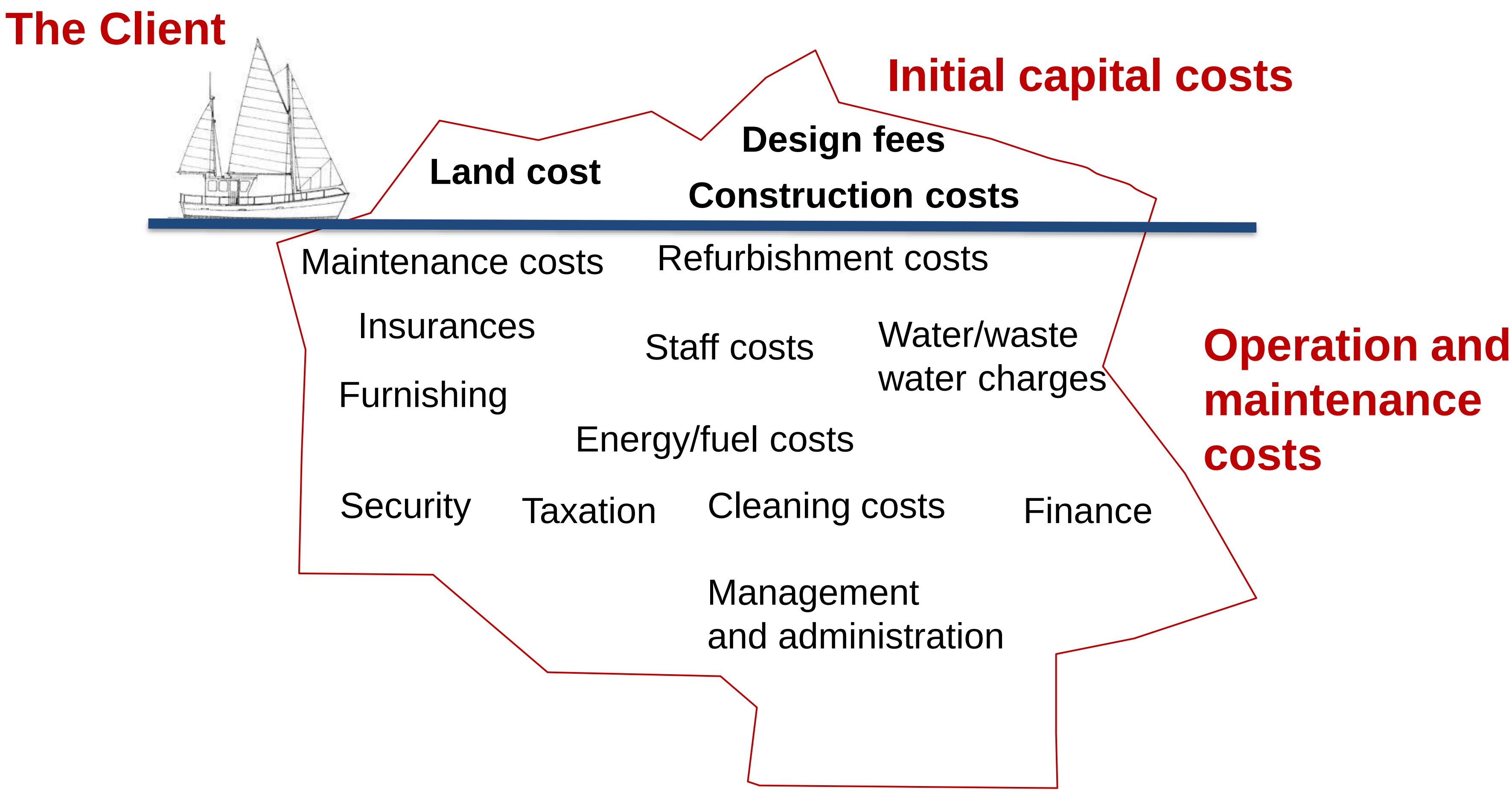
Lifecycle cost analysis

What does ownership really cost? 30-year life of classroom



Source: http://valuesinarchitecture.blogspot.fi/2011/03/what-does-your-building-really-cost.html

The hidden costs of buildings



Life cycle cost analysis (LCC)

- **Life cycle costing (LCC) is the process of economic analysis**
  - to assess the total cost of ownership of a product,
  - including its cost of production, installation, operations, maintenance, conversion, and/or decommission.

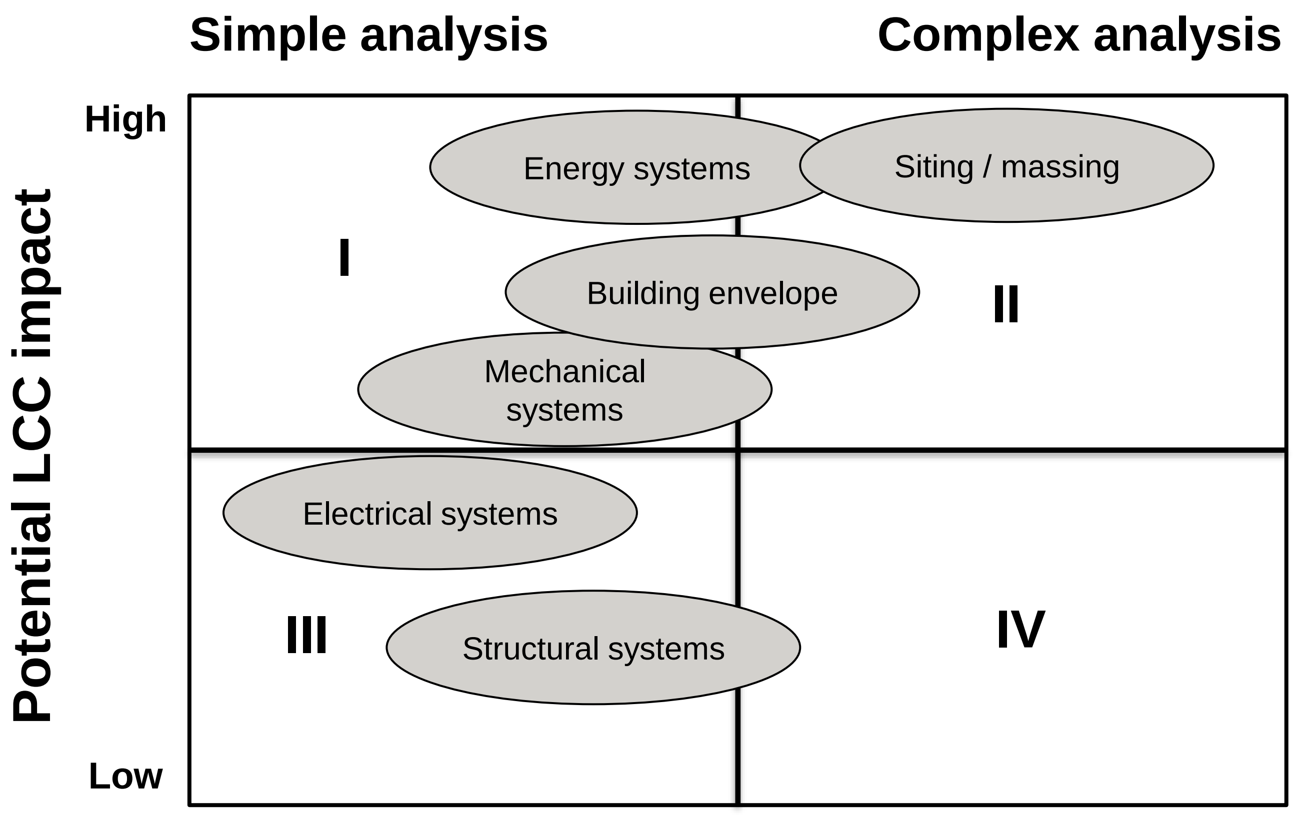
Cost elements in LCC

- **For a building, there are several cost elements:**

  1. Initial Cost
  2. Energy & Water Costs
  3. Operation, Maintenance & Repair Cost
  4. Replacement Cost
  5. Other Costs (e.g. taxes)
  6. Residual Value

- **The identification of cost elements and their sub-divisions are based on the purpose and scope of the LCCA**

LCC impact and analysis of different building sub-systems



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Source: https://lbre.stanford.edu/sites/all/lbre-shared/files/docs_public/LCCA121405.pdf

Steps for calculating LCC

1. Identify alternatives
2. Define cost element categories
3. Determine time for each cost element
4. Estimate value of each cost element
5. Calculate net present value (NPV) of each cost element, for every year (over its time period)
6. Calculate LCC by adding all cost elements, at every year
7. Analyze the results

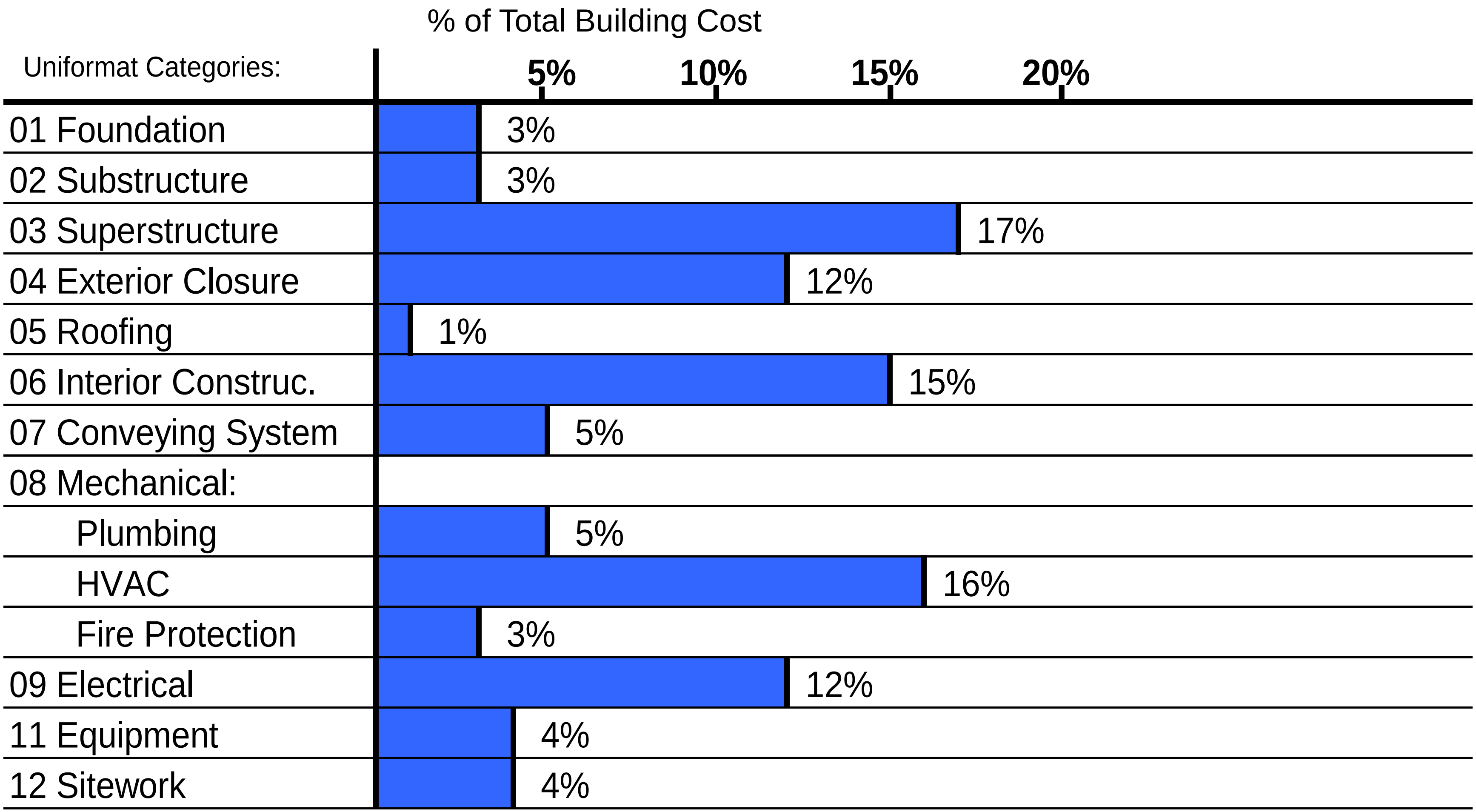
Net Present Value (NPV)

- **NPV analysis takes into account the time value of money**
- **Future cash flows are discounted to a base date to enable better decision making**
  - Cash flows can be negative (costs) or positive (revenues)
- **Discount rate (r) represents the rate by which ‘future money’ becomes less valuable for owner**
  - Investor’s opportunity cost (investments with similar risks)
  - Discount rate typically higher than inflation

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}$$

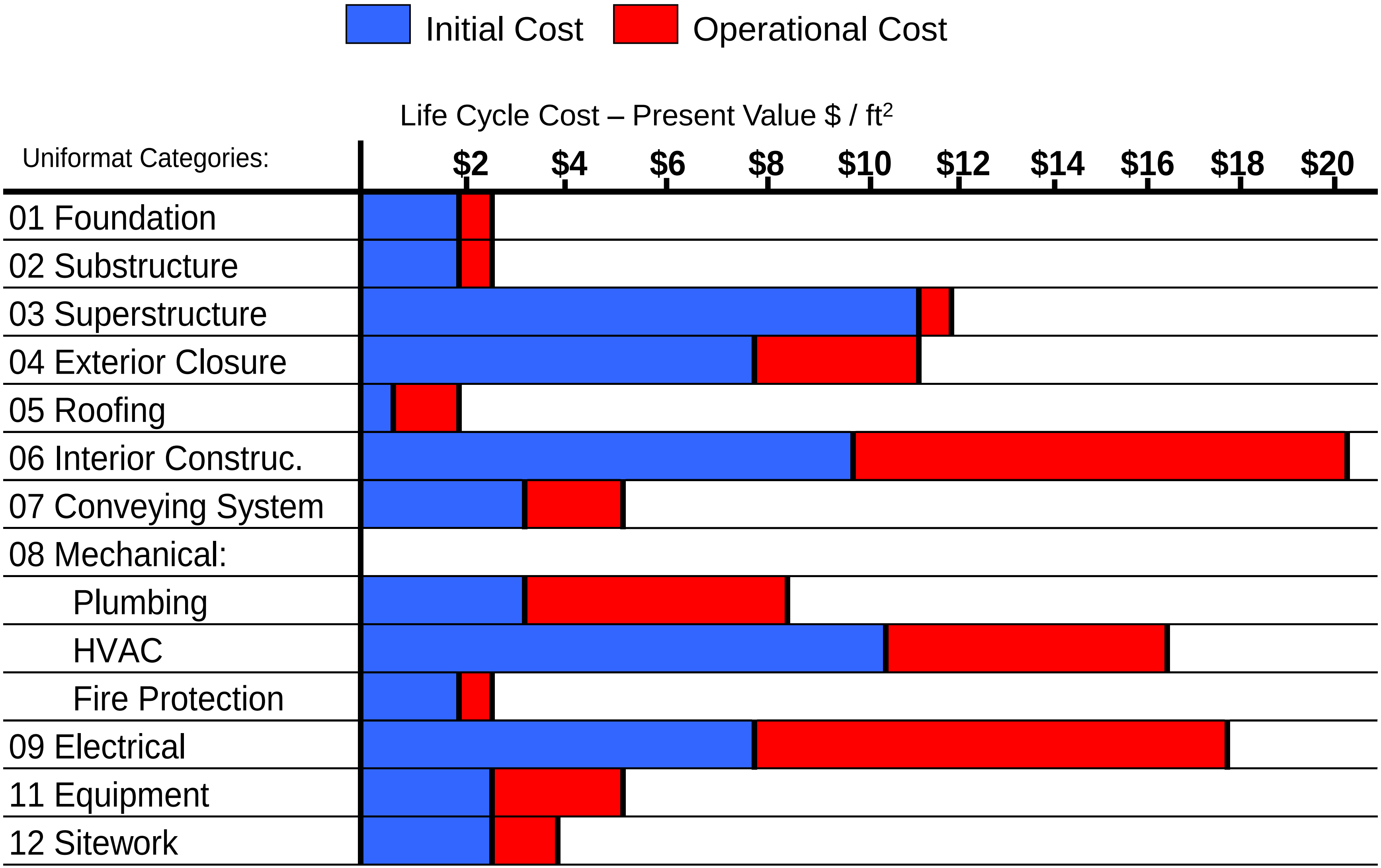
$$-C_0 = Initial\ Investment$$
$$C = Cash\ Flow$$
$$r = Discount\ Rate$$
$$T = Time$$

Initial Cost – Office Building - **$100** / SF



Source: Means Life Cycle Costing For Facilities

Life Cycle Cost – Office Building - **$200** / SF



Source: Means Life Cycle Costing For Facilities

Example: Life-cycle costs of wooden windows (40 years)

Initial / Construction costs

- Cost per unit (390€/m²)
- Proportion for operating and joint costs (15%)
- Reserve of rise of the costs (2%)
- Profit and contractor's costs (10+10%)

$$390\,€/m^2 * 1{,}15 * 1{,}02 * 1{,}1 * 1{,}1 = 553{,}54\,€/m^2$$

Maintenance costs

- Painting every 8 years (137 €/m²)
- Reconditioning every 16 years (350 €/m²)
- Renovating every 40 years
- Current value with 40-year time period and 10% discount rate:

$$(0{,}467 + 0{,}218 + 0{,}102 + 0{,}047) * 137\,€/m^2 + (0{,}218 + 0{,}047) * 350\,€/m^2 = 207{,}01\,€/m^2$$

1/(1,1^8) 1/(1,1^16)

Example: Life-cycle costs of wooden windows (40 years)

Operation costs

- Heat transfer through the windows (U-value 1,4 W/m2K):

$$Q_r = 120Kh/a * 1{,}4\, W/m^2K = 168\, kWh/m^2/a$$

- Cost of heating energy (0,077€/kWh):

$$168\, kWh/m^2/a * 0{,}077\, €/kWh = 12{,}936\, €/m^2/a$$

- Current value with 40-year time period and 10% discount rate:

$$9{,}779 * 12{,}936\, €/m^2/a = 126{,}5\, €/m^2$$

Total costs

- Life-cycle costs of wooden windows are:

$$553{,}54\, €/m^2 + 207{,}01\, €/m^2 + 126{,}5\, €/m^2 = 887{,}05\, €/m^2$$

Quality management

Quality is not only luxury goods

Quality ~

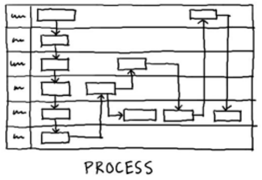
”fitness of the product or service to the customers’ requirements”

”sum of attributes for a product or service that enables it to meet the requirements or specified need of the customer”

What do we mean by quality?

1. Product represents its ”type”

2. Conformity with production process



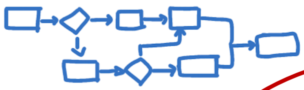
Site manager, superintendent

Supervisors 3. Fulfillment of product requirements

User, operator, designer 4. Fit for purpose of use

Investor, owner 5. Readiness of customer to pay

Implications from quality in manufacturing and services



Manufacturing
typically better control of processes and product characteristics than in services

Services
Typically better customer value and satisfaction than in manufacturing

- **Construction is not purely any of those, options:**

  → Moving toward more **customer-focused service business:** understand better the use of building and of which customers are ready to pay

  → Moving toward more **process-centered and standardized production:** decrease variation and waste in processes

Quality management in transition

1. Quality control and inspections

"Reacting to the outcomes of site activities"

This is minimum activity from client!

2. Quality assurance

"Preventing defects in products and avoiding problems", standard processes

This should be minimum activity from contractor!

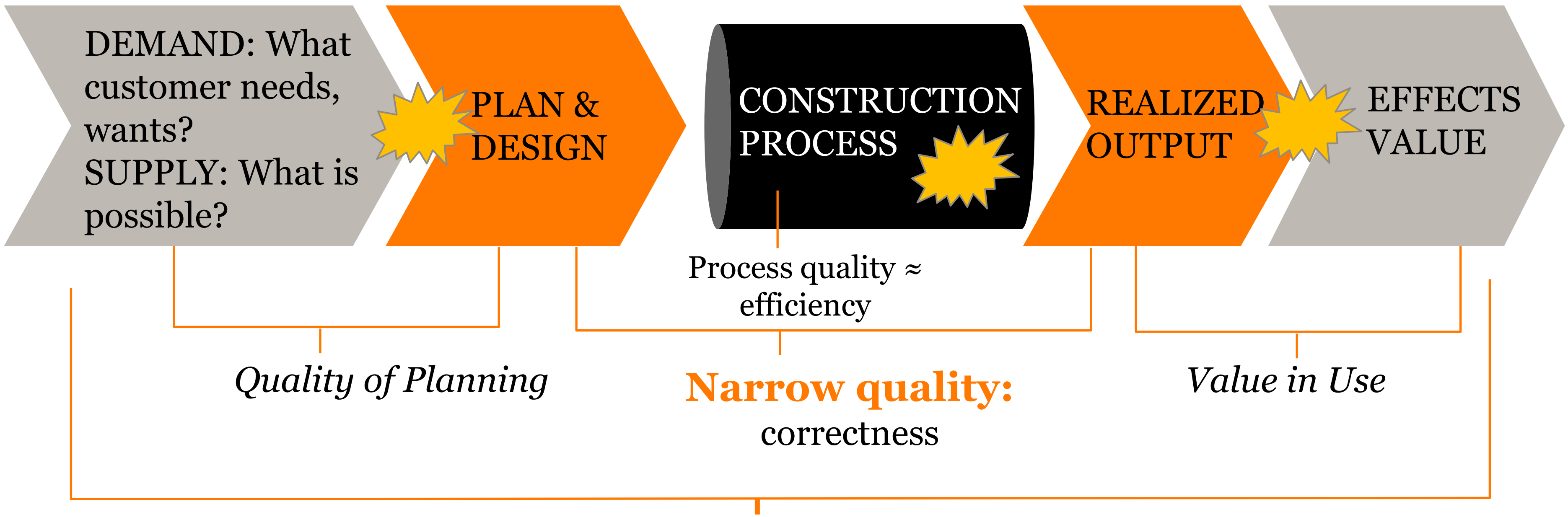
3. Total quality management (TQM)

"Effort toward a permanent climate in which an organization continuously improves its ability to deliver high-quality products and services"

4. Quality management systems

"Strategic business function of companies"

Understanding Wide Quality in Construction Industry



Wide quality: realization of desired effects

Tools and practices:

Communication platforms *Checklists* *Six Sigma Tools* *After sale operations*

Visualization *Modeling* *Error Reports* *Education* *User communities*

Quality management practices in construction

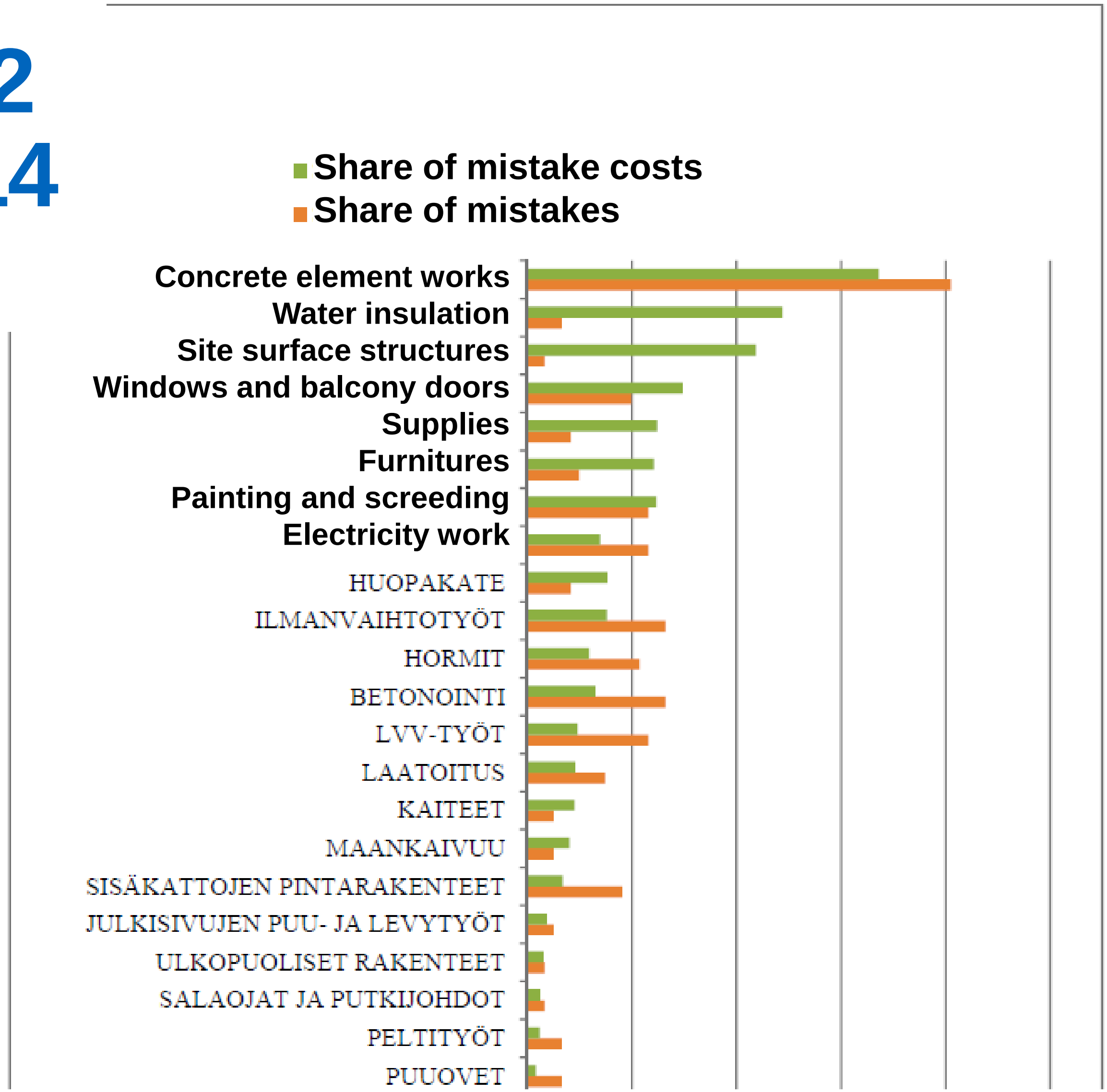
- **Client sets quality requirements for end-product and construction processes**
  - References to general quality requirements, e.g. RYL 2010
- **Authorities set general quality requirements: e.g. personnel qualifications, needed reviews & inspections**
  - Kick-off meeting, inspection book, quality assurance report

→ **Designers design according to requirements**

→ **Contractor plans practices to ensure that requirements for processes and end-product are fulfilled**

- **Detailed drawings work as ”communication tools” between requirements and contractor:**
  - Locations, measurements, tolerances, materials, visual quality, connections…

Process mistakes (242 mistakes in 14 projects)



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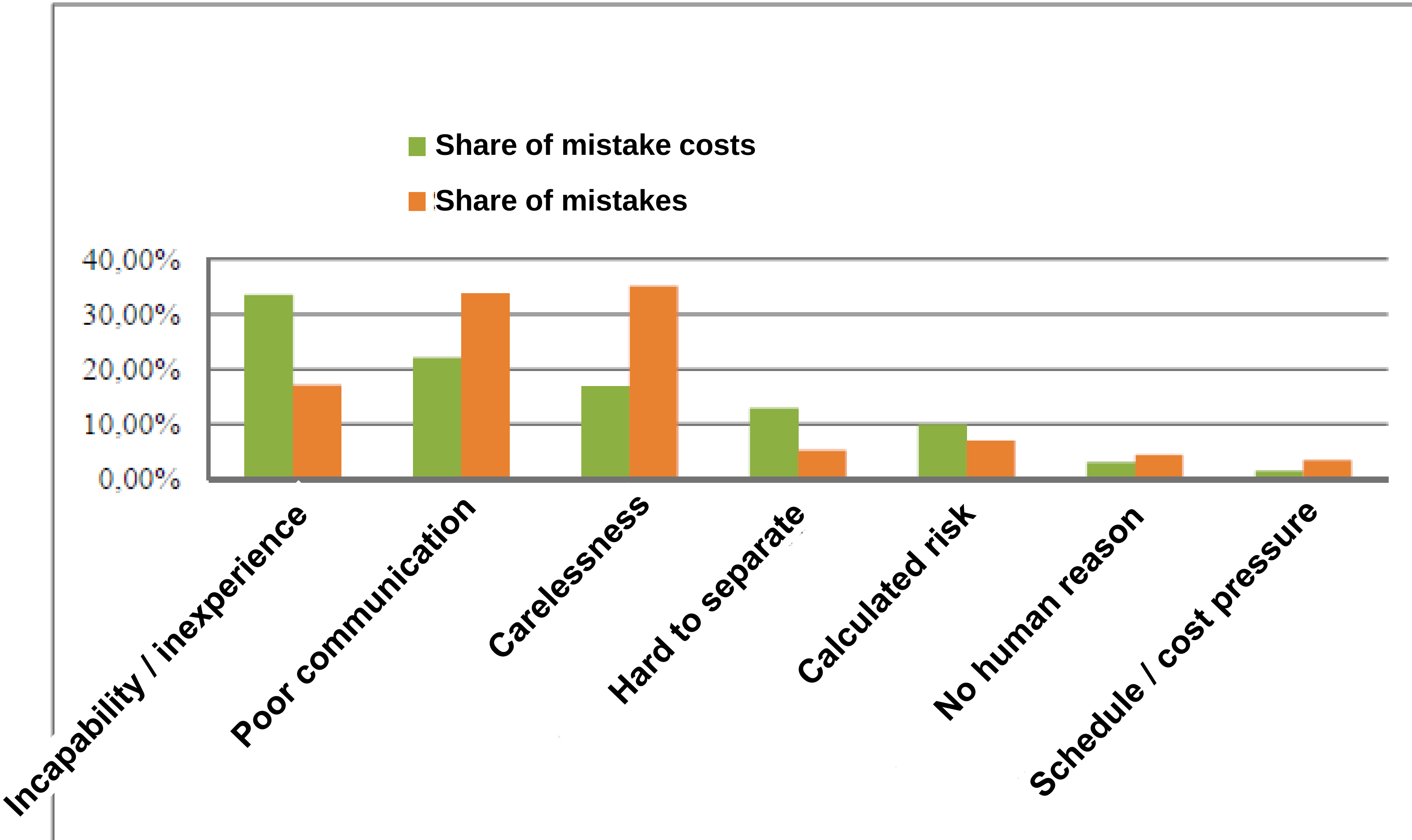
Source: Kirjalainen 2016

Human reasons behind mistakes



Source: Kirjalainen 2016

How customer can ensure good quality?

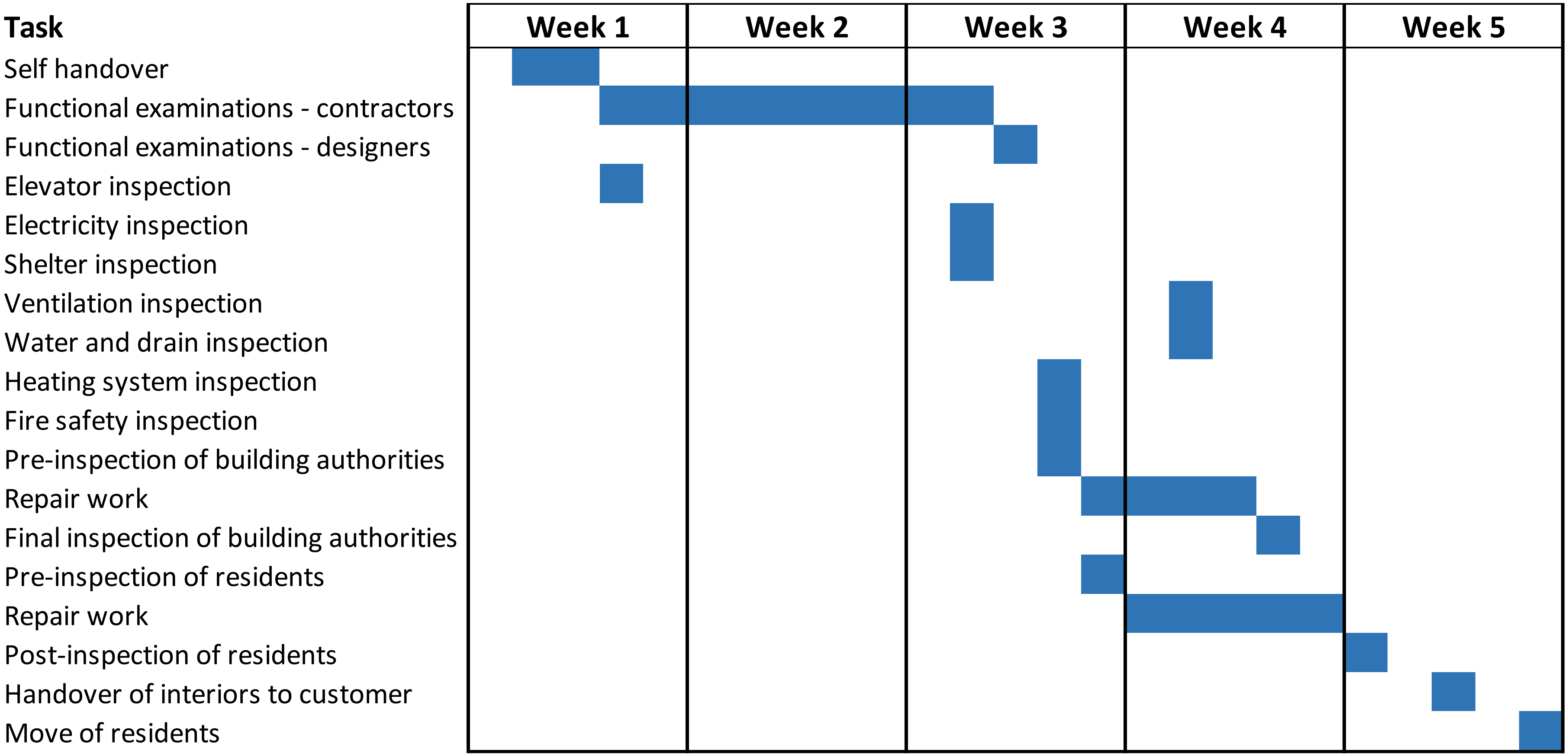
- **Developing <u>trust, continuous collaboration and communication</u> between customer, designers and contractors**
- **Smooth and systematic <u>information flow</u> about quality requirements and project decisions between customer, project manager, designers, contractor, sub-contractors and workers**
  - Problems related to missing or incorrect information are removed effectively
- **<u>Division of responsibilities</u> and duties is clear among actors**
- **Customer and project manager ensure that <u>premises for good quality</u> exist:**
  - Inform about decisions, design documents are timely delivered to contractor, design documents are checked and fit between documents is ensured, materials from customer are delivered timely

→ LEAN CONSTRUCTION!

Quality assurance practices of contractor

- Documented responsibilities and duties
- Documents about quality requirements and analysis of potential quality problems
- Kick-off meeting with sub-contractors and workers
- Workstation handover with previous workers
- Model work
- Inspection after first job
- Spot checks
- Tests and examinations
- Self handover

Handover process – example of a residential building



Health & Safety as part of quality in construction

- **Focus on people on-site instead of product**
- **Customer's / Project manager's liabilities**
  - Safety coordinator, safety documents
    - *Abnormal dangers and harms, safety instructions, person identification system, pass*
- **Contractor's liabilities**
  - Safety control and management on site
  - Evaluation of specific safety risks
    - *Material handling, detonation, excavation, abutments, traffic, fall protection, use of large equipment, large element assembly, power cables…*
  - Orientation, inspections
- **TR metric ® for evaluating safety in construction site**
  - Categories: 1) workers; 2) scaffolds/bridges/ladders; 3) equipment; 4) fall protection; 5) electricity/lightning; 6) ordering/cleanliness/waste/dust
  - Simple **correct – incorrect** evaluation (max 100%), done e.g. weekly
- **Accidents / 1M working hours**

Summary

- **Describe and apply life-cycle analysis methods**
- **Describe and apply life-cycle cost analysis method**
- **Describe different definitions for quality in construction**
- **Describe quality and safety management methods and practices**