SZÉCHENYI ISTVÁN EGYETEM
SZE - GYŐR

DESIGN OF STRUCTURES 2.

10. Economy, durability and environmental questions of structural design

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2019. 11. 29.

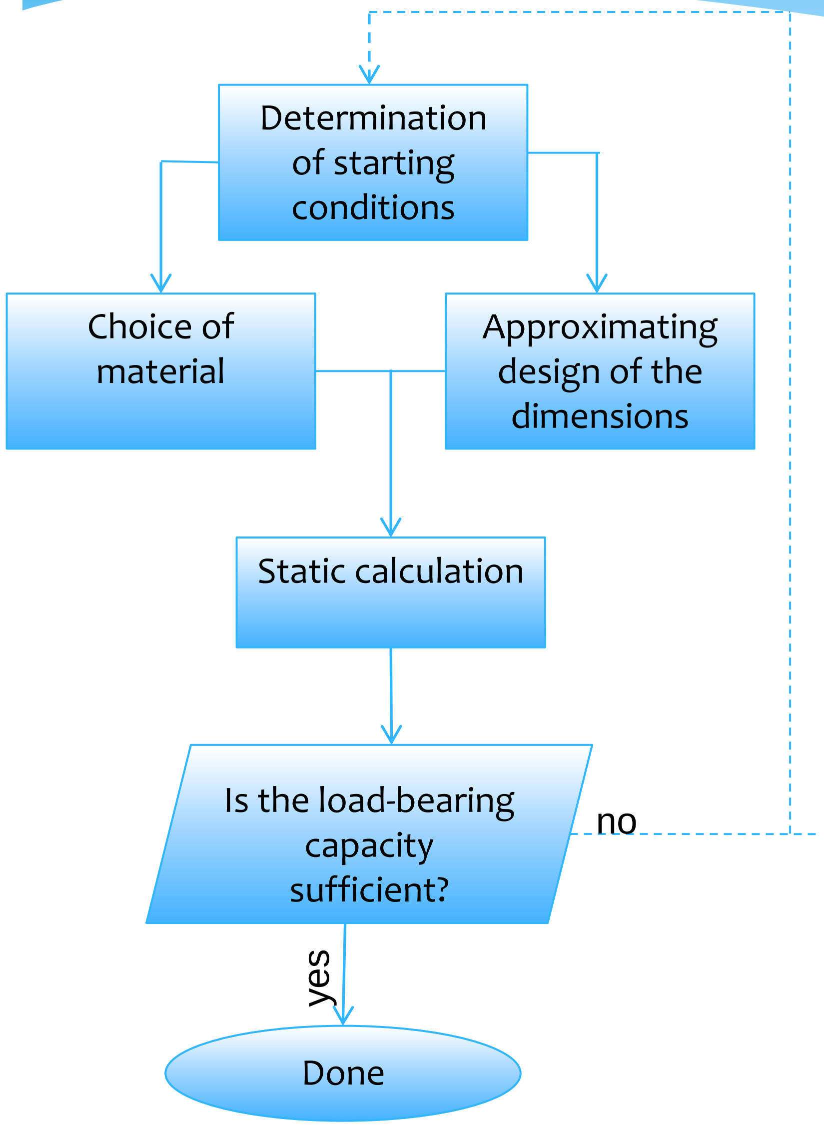
Content

* Aspects of structural design
* Requirements of ultimate and serviceability limit states
* Safety level
* Economy
* Durability
* Sustainability

Structural design

* Client→ Design need→ Engineer
  * **Requirements**
    * functional
    * aesthetical
    * technical
    * economical
  * Choice of the type of the structure – conceptual plan:
    * The choice of the type of the structure depends on:
      * Dimensions and properties of the available site
      * The applicable construction technology
      * Construction and operation costs
  * Detailed plan – including disciplines

Structural design



The result of the conceptual design:

* Structural material
* Geometry of the structure
* Determination of the loads
* Completion of static calculation:
  * Is the load-bearing capacity sufficient?
  * Do the structure fulfil the serviceability requriements?

Checking

* Examination its effect on conceptual and detailed design

Requirements

I. Structural requirements
II. Safety requirements
III. Serviceability requirements

The structure fulfils the safety requirements, if the collapse or any significant damage has a sufficient low probability of occurence during its entire working life.

Safety level

- A building should be desinged to avoid the collapse or any similuar forms of structural failure
- Absolute safety does not exist:
  - Design errors
  - Higher than normal meteorological actions
  - Imprecision of construction
  - Material defects
  - Inbuilt materials with lower quality
- Increasing safety → increasing costs
- Furthermore, increasing the safety level of the structure is unnecessary beyond a given limit

Safety level

* Who is responsible for determination of the safety level of buildings?
* Standards:
  * MSZ
  * EC
* Quantification of safety:
  * **Safety factor**

$$\gamma = \frac{loading\ that\ causes\ failure\ in\ the\ structure}{expected\ loading}$$

Eurocode

Based on the Eurocode:

- The working life of a residence is 50 years
- The probability of significant damage during this working life is 10^{-4}–10^{-5} , which means that failure can be occured in every 10000-100000 cases
- The safety is taking into account by the standards at two levels:
  - In determination of the actions
  - In determination of the properties of materials

Serviceability requirements

The structure fulfils the serviceability requirements, if the limitation of the functioning of the structure has sufficient low probability of occurence during the entire working life

Serviceability requirements

The verification of serviceability limit states should be based on criteria concerning the following aspects:

* Deformations that affect
  * The appearance
  * The comfort of users
  * The functioning of the structure under normal use (including the functioning of machines or services)
* Or that cause damage to finishes or non-structural members

Examinations:

* Deflections, deformations
* Vibrations
* Cracks

The propability of limitation of functioning is 10^{-2}–10^{-3} during the working life, which means that limitation in functioning can be occured in every 100-1000 cases.

Economy

- The building have to fulfill the structural, safety and serviceability requirements – structural designer is responsible for
-
- Additional requirements:
  - Technical
  - Aesthetical
  - **Economical**

Economy

* **Optimization process - fulfilling the minimal technical requirements with low cost**
* The cost of the structure:
  * Construction cost
  * Construction time
  * Operation costs

* Sometimes the safety level of the structure can be increased with minimal expense
* For example:
  * Strengthening the sensitive joints
  * Increasing the reinforcement in the column-plate connections (punching analysis)

Economy

Decreasing the costs of the structure:

* **If the form and material is given,** the costs of the structure can be decreased with the precision of the calculation
* The extent of decrease is about **~5-10%**
* **Changing the design concept**
  * Using three hinged arch or shell instead of the traditional column-beam structure
  * Optimization between the function and the structure (column over column)
  * Example: Sydney opera house
* Usually the correct choose of the structure is more important than the precision of the calculation

Durability

* Lifetime of our buildings: **50 years**

* Beside the comformity under ultimate and serviceability limit states the durability design is important as well
* The durability design means mostly the use of **construction rules** and the correct choice of material properties

Durability

Design aspects:

* Condition of use
* Expected environmental conditions
* The ingreditens, the properties and performance of the different materials
* The soil properties
* The structural system
* The form of the structural elements and structural details
* The quality of construction and the level of control
* The used protection measures
* The operation during the lifetime

Factors affecting durability

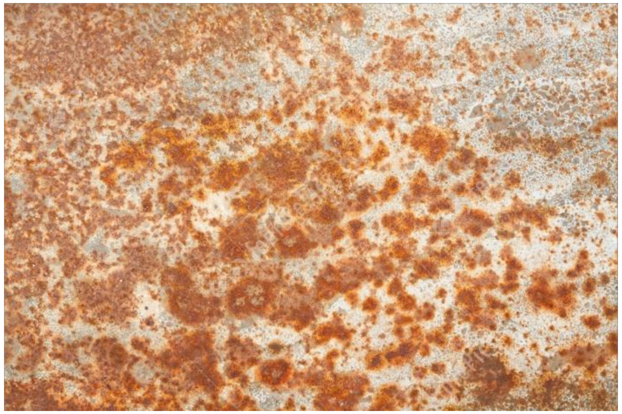
* The extent of the lifetime
* **Environmental effects**
* Material properties
* Quality of the construction
* Change in the function
* Change in the structural system
* Protection of the structural elements (covering, painting, etc.)

Corrosion protection of steel

In the case of steel → the corrosion protection is very important

Coating is the most common used method

* Metallic coatings (zinc, aluminium, tin etc.)
* Paintings
  * Its lifetime depends on the thickness of the layer
* Combined coatings
  * Galvanic protection + painting
* Stainless steel



Corrosion protection of steel

The quality of the coating should be chosen based on the environmental effects

BS EN ISO 14713:1999

Table 1 - Environmental categories, corrosion risk and corrosion rate.

Code	Corrosivity Category	Corrosion Risk	Corrosion Rate (average loss of zinc µm/year)
C1	Interior: dry	Very low	≤ 0.1
C2	Interior: occasional condensation Exterior: Exposed rural inland	Low	0.1 – 0.7
C3	Interior: High humidity, some air pollution Exterior: Urban inland or mild coastal	Medium	0.7 – 2
C4	Interior: Swimming pools, chemical plants etc Exterior: Industrial inland or urban coastal	High	2 – 4
C5	Exterior: Industrial with high humidity or high salinity coastal	Very High	4 - 8
Im2	Sea water in temperate regions	Very High	10 - 20

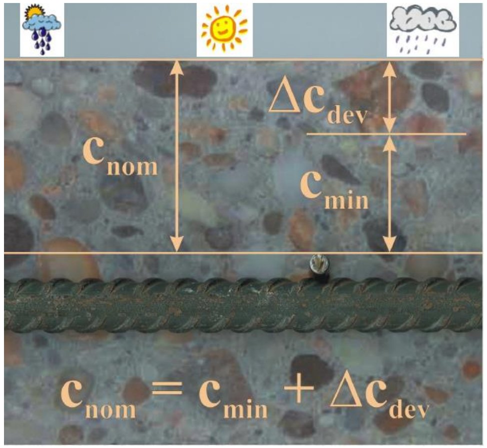
Corrosion protection of steel

Structural design aspect related to corrosion protection

* Every part of the structure should be reachable (**maintainance**)
* **Hollow sections** should be closed hermetically
* In the case of **thin and utilized cross section** the corrosion protection is more significant
* Use of cross sections with **few corners** is favourable
* **Do not use discontionous welded joints** on outdoor structures
* Take care about the **connection** between steel and concrete
* Take care about the **protection of joints, bolts,** etc.

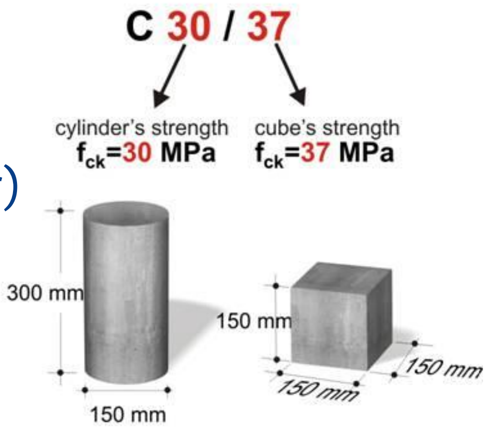
Durability of concrete structures

Reinforced concrete: → **Construction rules based on the exposure classes**



- Every class defines
  - The minimal concrete covering (c_{min})
  - The maximal water-to-cement ratio (v)
  - The minimal compressive strength (f_{ck})
  - The minimal cement content

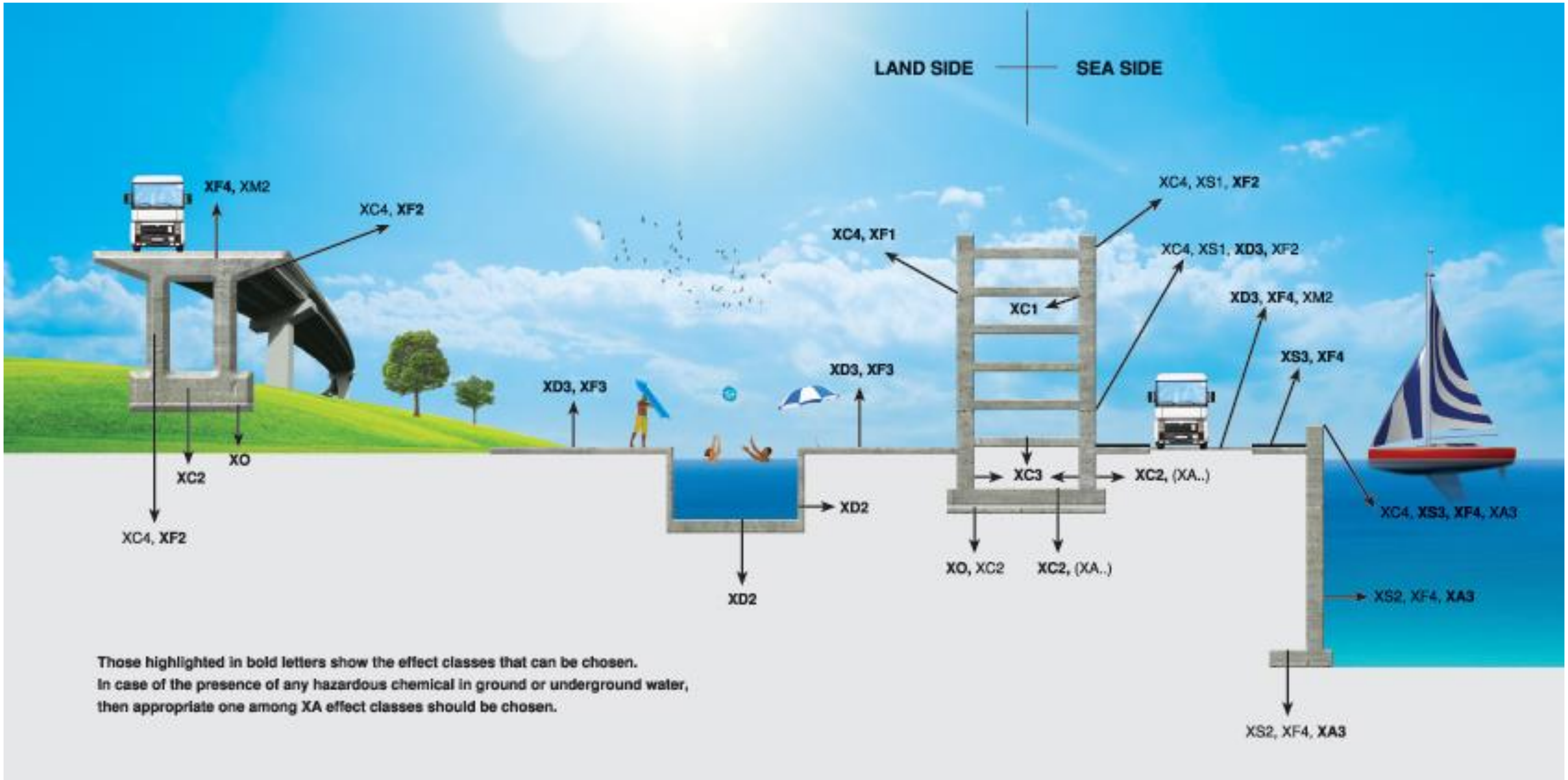
The exposure classes are defined in EN206-1:2000
The main classes are:
XO – no risk of corrosion or attack
XC – risk of carbonation induced corrosion
XD – risk of chloride-induced corrosion (other than sea water)
XS – risk of chloride induced corrosion (sea water)
XF – risk of freeze thaw attack
XA – chemical attack



Durability of concrete structures

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs

Durability of concrete structures



Durability of concrete structures

Determination of cover thickness based on the structural class and the exposure class:

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Durability of wood structures

- Physical protection
  - Technical solutions (restraining water, ventilation, etc.)
- Chemical protection
  - Treatment against fungal and insect attack
  - Fire protection
- Use of the preservatives:
  - Coating
  - Dipping
  - Pressure treatment

- The durability depends also on the quality of the connecting elements and glue

Durability of wood structures

- The protection requirements are determined based on exposure classes

Class	Hazard Type	Situation	Typical Uses	Typical Treatments
H1	Insect borer hazard (other than termites)	Inside above ground. Dry.	Framing, flooring, furniture, interior joinery (architraves, skirting boards etc).	ACQ, CCA, Liquid Boron, LOSP.
H2	Insect borer and termite hazard	Inside, above ground.	Framing: roof trusses, beams, interior battens, flooring.	ACQ, CCA, LOSP.
H2F	Insect borer and termite hazard	Inside, above ground, South of Tropic of Capricorn only.	Framing: roof trusses, beams, interior battens, flooring.	Bifenthrin, Permethrin.
H3	Moderate fungal decay and termite hazard	Outside, above ground.	Weatherboard, fascia, pergolas, (above ground), window joinery, framing and decking boards, bearers and joists.	ACQ, CCA, LOSP.
H4	Severe decay, borers and termites.	Outside, in-ground.	Fence posts, greenhouses,. Pergolas (in-ground) and landscaping timbers.	ACQ, CCA.
H5	Very severe decay, borers and termites.	Outside, in-ground. Contact with or in fresh water.	Retaining walls, piling, house stumps, building poles, cooling tower fill.	ACQ, CCA
H6	Marine wood borers and decay.	Northern/southern marine waters.	Boat hulls, marine piles, jetty cross-bracing, landing steps etc.	CCA

Note: The Hazard Class numbering system is the opposite to the durability of natural timbers where 1 is the most durable and 4 the least durable.

Durability of masonry structures

* The type of the brick and mortar is choosen based on the exposure classes

Class	Micro condition of the masonry	Examples of masonry in this condition
MX1	**In a dry environment**	Interior of buildings for normal habitation and for offices, including the inner leaf of external cavity walls not likely to become damp. Rendered masonry in exterior walls, not exposed to moderate or severe driving rain, and isolated from damp in adjacent masonry or materials.
MX2	**Exposed to moisture or wetting**	
MX2.1	Exposed to moisture but not exposed to freeze/thaw cycling or external sources of significant levels of sulfates or aggressive chemicals	Internal masonry exposed to high levels of water vapour, such as in a laundry. Masonry exterior walls sheltered by overhanging eaves or coping, not exposed to severe driving rain or frost. Masonry below frost zone in well drained non-aggressive soil.
MX2.2	Exposed to severe wetting but not exposed to freeze/thaw cycling or external sources of significant levels of sulfates or aggressive chemicals	Masonry not exposed to frost or aggressive chemicals, located: in exterior walls with cappings or flush eaves; in parapets; in freestanding walls; in the ground; under water.
MX3	**Exposed to wetting plus freeze/thaw cycling**	
MX3.1	Exposed to moisture or wetting and freeze/thaw cycling but not exposed to external sources of significant levels of sulfates or aggressive chemicals	Masonry as class MX2.1 exposed to freeze/thaw cycling.
MX3.2	Exposed to severe wetting and freeze/thaw cycling but not exposed to external sources of significant levels of sulfates or aggressive chemicals	Masonry as class MX2.2 exposed to freeze/thaw cycling.
MX4	**Exposed to saturated salt air, seawater or de-icing salts**	Masonry in a coastal area. Masonry adjacent to roads that are salted during the winter
MX5	**In an aggressive chemical environment**	Masonry in contact with natural soils or filled ground or groundwater, where moisture and significant levels of sulfates are present. Masonry in contact with highly acidic soils, contaminated ground or groundwater. Masonry near industrial areas where aggressive chemicals are airborne.
NOTE In deciding the exposure of masonry the effect of applied finishes and protective claddings should be taken into account.		

Durability of masonry structures

Example:

- MX3.1: exposed to wetting and freeze

Type of the brick: **S1** or **S2**, where S1 and S2 is related to the soluble salt content

TELJESÍTMÉNYNYILATKOZAT

DoP száma: 17028W3169

Termék:

Porotherm 44 K Profi

A termék típusának egyedi azonosító kódja a teljesítménynyilatkozat száma.

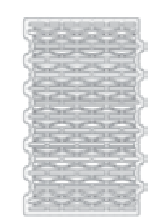
Wienerberger

Wienerberger Téglaipari zRt.
Bártfai u. 34. - 1119 Budapest
Magyarország

Rendeltetése falazott falakban, pillérekben, válaszfalakban:	védett falazott szerkezethez
A teljesítmény állandóságának értékelésére és ellenőrzésére szolgáló rendszer:	System 2+
Harmonizált szabvány:	EN 771-1:2011+A1:2015
Bejelentett szerv(ek):	1415

A(z) P - falazóelem nyilatkozat szerinti teljesítménye(i)

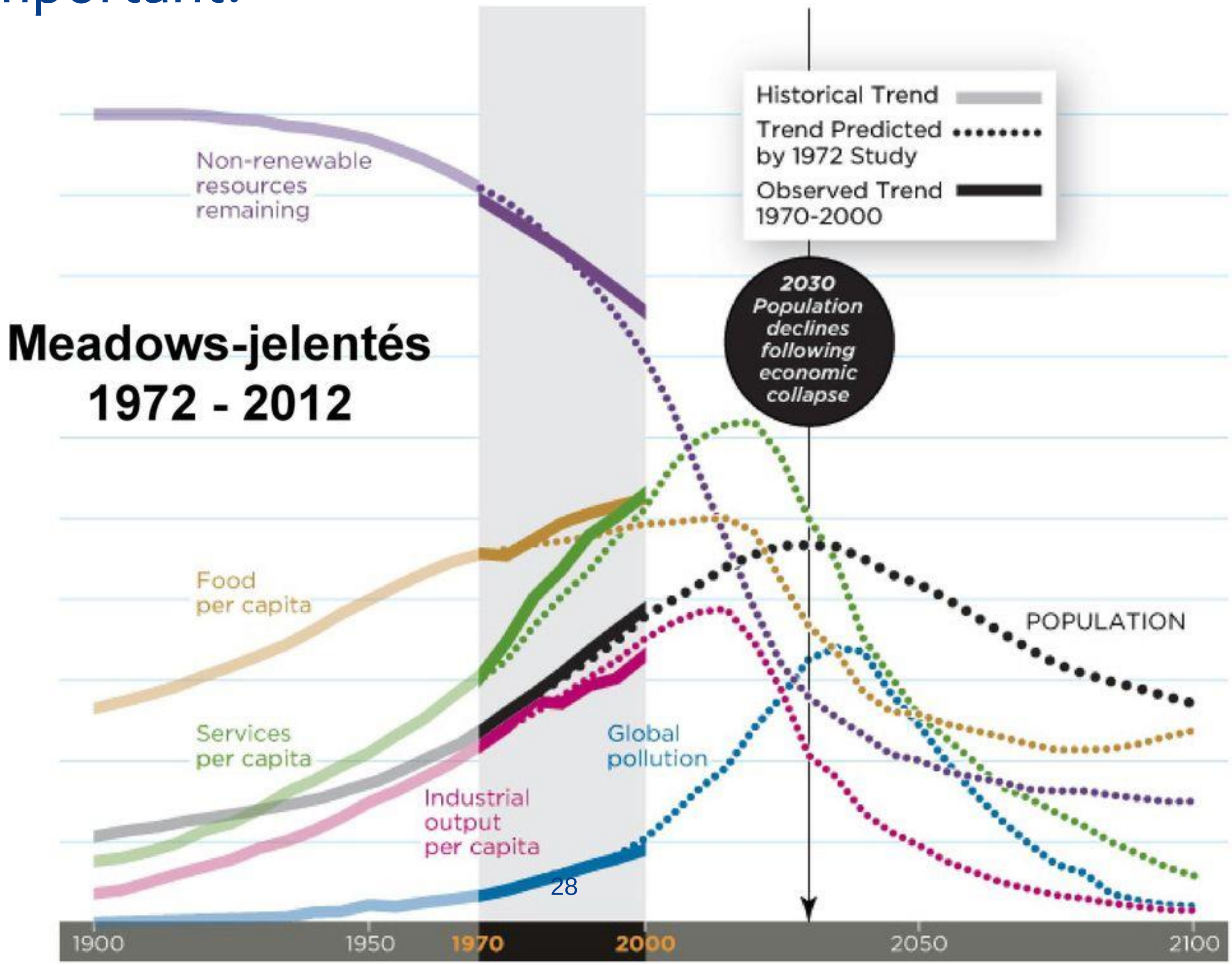
Méretek és mérettűrések			Tm	R2+	
Hosszúság:	mm	250	± 6	5	
Szélesség:	mm	440	± 5	6	
Magasság:	mm	249	± 0.5	1	
Középérték tűrése:	kategória	Tm			
Mérettartomány:	kategória	R2+			
Fekvő felületek síktól való eltérése:	mm	0.3			
Fekvő felületek párhuzamossága:	mm	0.3			
Alak					
Falazóelem csoport:	-	3			
Üregek százalékos aránya:	%	NPD			
Bemélyedések aránya:	%	NPD			
Testsűrűség					
Brutto száraz testsűrűség:	kg/m³	740			
Netto száraz testsűrűség:	kg/m³	NPD			
Tűrés:	kategória / %	Dm / 11			
I kategóriájú falazóelem nyomószilárdsága					
Fekvőfelületre merőleges:	N/mm²	10			
Oldalirányú, falsíkban:	N/mm²	2			
Oldalirányú, falsíkban 2:	N/mm²	NPD			
Tapadószilárdság:	N/mm²	0,3			
Hővezetési tényező, λ10,száraz,elem:	W/(m·K)	0.104			*Meghatározási mód EN 1745:2012 sz.: P5*
Páraáteresztő képesség:	-	μ = 5/10			
Tartósság, fagyhatással szemben:	kategória	F0			
Vízfelvétel:	%	NPD			
Kezdeti vízfelvétel:	kg/(m²·min)	NPD			
Aktív oldható sótartalom:	kategória	S0			
Nedvesség okozta alakváltozás:	mm/m	NPD			
Tűzveszélyesség:	osztály	A1			*tűzvédelmi osztály*
Veszélyes anyagok:	-	NPD			



A valós üregelrendezés kis mértékben eltérhet

Sustainability

Why is it important?



Terms

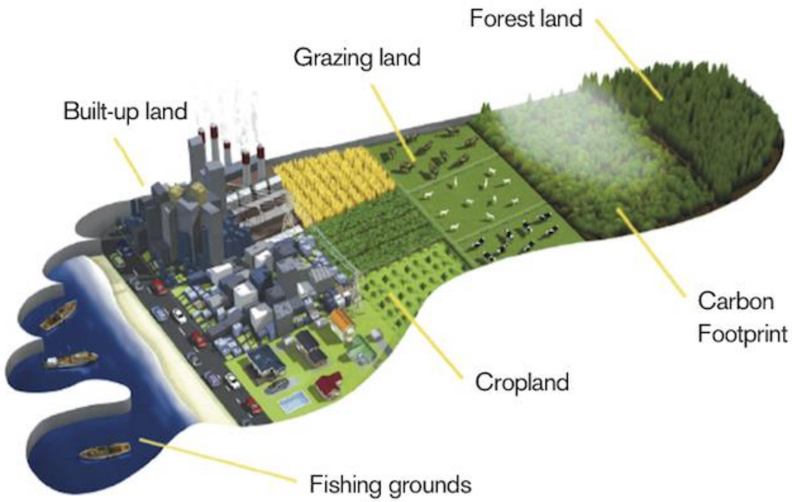
Ecological footprint:

The **ecological footprint measures human demand on nature** - the quantity of nature it takes to support people or an economy

The accounts contrast the biologically productive area people use for their consumption to the biologically productive area available within a region or the world (**biocapacity**, the productive area that can regenerate what people demand from nature)

Carbon footprint:

A carbon footprint is defined as **the total emissions caused by an individual, event, organization, or product**, expressed as carbon dioxide equivalent.



Sustainable architecture

Sustainable architecture is architecture that seeks to **minimize the negative environmental impact** of buildings **by efficiency and moderation in the use of materials, energy, and development space** and the ecosystem at large. Sustainable architecture uses a conscious approach to energy and ecological conservation in the design of the built environment.

Sustainable architecture

The decrease of CO_2 emission can be reached with three methods:

1. Sparing consumption inside the range of ecological footprint
2. Increasing the energy efficiency
3. Conversion to renewable energy resources

Sustainable architecture includes:

* Energy-efficient buildings operated by renewable energy resources
* Low in-built energy content and carbon footprint
* Proper heating and passive cooling system
* Large extent of green area
* Protection of the soil
* Sustainable water usage, water saving solutions

Sustainable architecture

Sustainability requirements of the building materials:

* Optimization of energy usage
* Near **zero CO_2-emission** during the production and application of the material
* Long lifetime, advantageous operation and renewable construction
* Construction and function safety, health maintanance, well-being
* Preferring local and renewable materials
* Avoiding hardly degradable materials
* Reuse of building materials
* Recycle construction waste
* Clarifying the requirements, decreasing the needs

Evaluation of building materials

- In-built energy content (not renewable), and carbon footprint
- Energy need for operation during the lifetime
- CO_2emission during production and transport
- Building physical properties – heat and sound insulation, heat storage, etc.
- Recycling possibilites
- CO_2 emission during and after demolishing

Energy demand classes

* Very low	0 – 100 kWh/m^3
* Low	100 – 400 kWh/m^3
* Medium	400 – 1000 kWh/m^3
* High	1000 – 10 000 kWh/m^3
* Very high	10 000 – 200 000 kWh/m^3

<u>Examples</u>

Aluminium: 100 000 – 200 000 kWh/m^3
Reinforcement: 20 000 kWh/m^3
Polyurethane: 18 000 kWh/m^3
Clay block: 600 kWh/m^3
Aerated concrete blocks: 300-400 kWh/m^3
Mineral wool: 100-400 kWh/m^3
Polystirene foam: 500-1000 kWh/m^3

Life-cycle Cost Analysis (LCCA)

- The purpose of an LCCA **is to estimate the overall costs of project alternatives** and to select the design that ensures the facility will provide the **lowest overall cost** of ownership consistent with its quality and function.
- The LCCA should be performed early in the design process while there is still a chance to refine the design to ensure a reduction in life-cycle costs (LCC)
- The first and most challenging task of an LCCA, or any **economic evaluation** method, is to determine the economic effects of alternative designs of buildings and building systems and to quantify these effects and express them in dollar amounts.

Life-cycle Cost Analysis (LCCA)

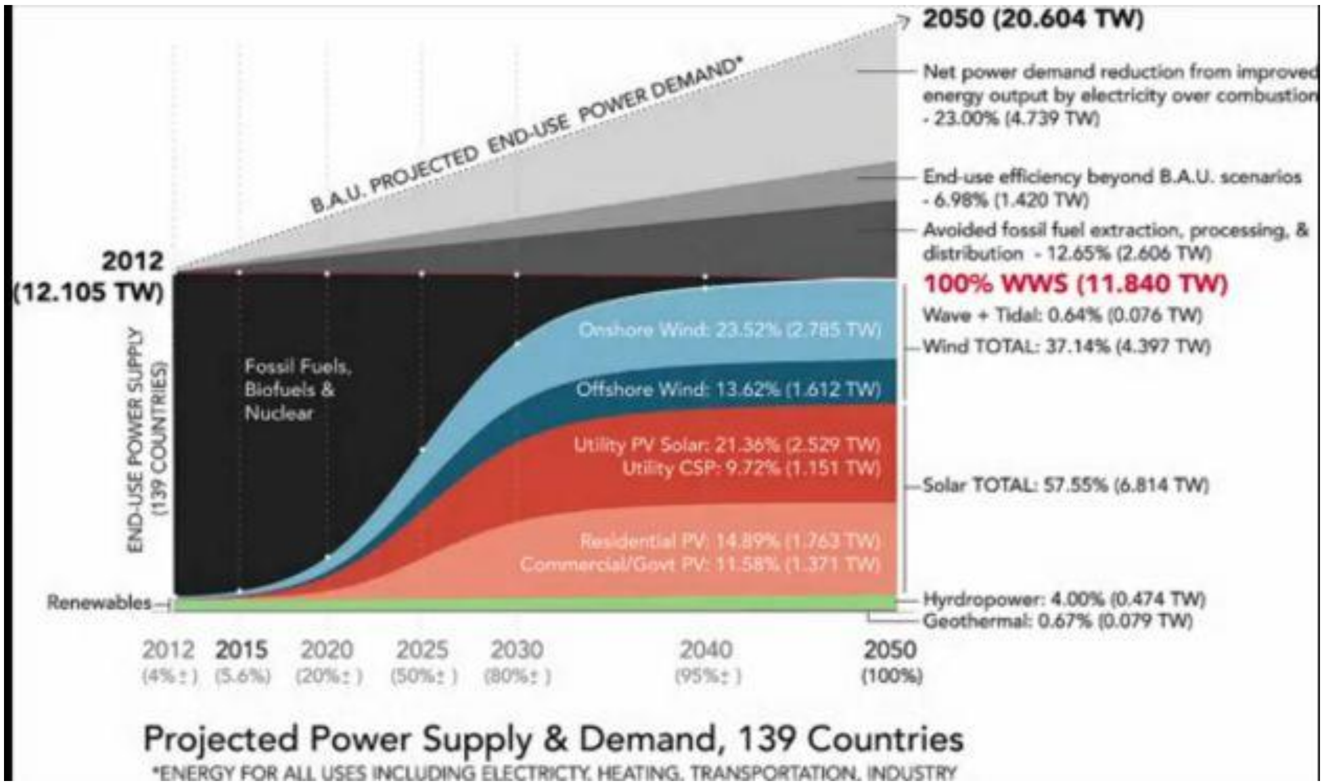
* There are **numerous costs** associated with acquiring, operating, maintaining, and disposing of a building or building system. Building-related costs usually fall into the following categories:

  * Initial Costs—Purchase, Construction Costs
  * Fuel Costs
  * Operation, Maintenance, and Repair Costs
  * Replacement Costs
  * Residual Values—Resale or Salvage Values or Disposal Costs
  * Finance Charges—Loan Interest Payments
  * Non-Monetary Benefits or Costs

* **Only those costs** within each category that are relevant to the decision and **significant in amount** are needed to make a valid investment decision. **Costs are relevant when they are different for one alternative compared with another**; costs are significant when they are large enough to make a credible difference in the LCC of a project alternative

Rules and standards

* 2012/27/EU Directive on energy efficiency of the buildings
* Energy Roadmap 2050: The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95%, when compared to 1990 levels, by 2050.



Thank you for your attention!