KU LEUVEN

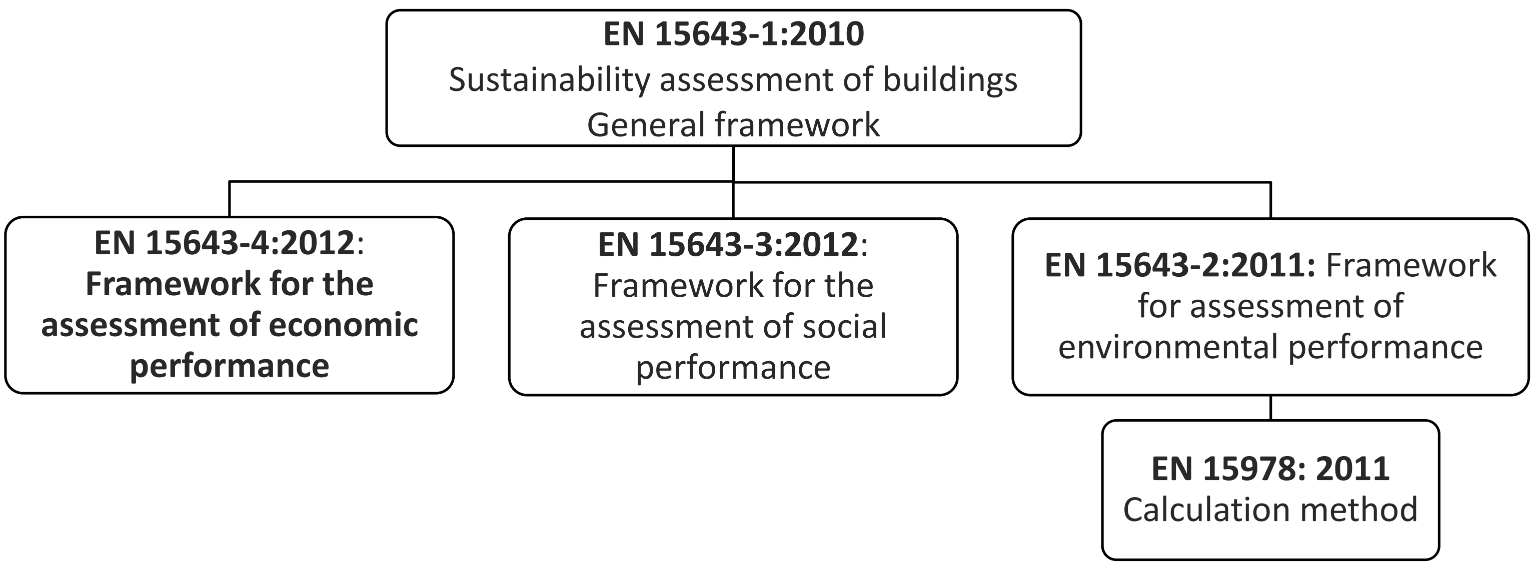
Life-cycle cost of steel bridges

A study to estimate the maintenance costs of steel bridges

Authors: Prof. Dr. Ir. B. Rossi, J. Rossi, S. Marquart

General principles of life-cycle assessment

- The life cycle **cost** is the cost calculated **throughout its life cycle** while fulfilling technical and functional requirements.
- Used to identify the **economic impacts** of the construction works and to enable the client, user and designer to **make decisions** and choices that will help to address the need for sustainability.
- Sustainability assessment of buildings – European suite of **standards**:



Coated steel bridges – Painting system

- Commonly:
  - A **zinc-rich primer** onto the prepared surface (in shop) ⇨ adhesion and corrosion protection
  - Followed by one or more **undercoat(s)** (in shop) ⇨ barrier function
  - And the **finish** (on site) ⇨ UV-radiation protection and aesthetic

- Typical high performance layer composition (supposed to be used in very high corrosive environment)

Layer	Binder / Pigment	Thickness (μm)	Total thickness (μm)
Topcoat (Finish)	Aliphatic polyurethane	1 x 50	275 measured (mean): 268
Intermediate Coat	Epoxy polyamide	1 x 150	
Primer	Ethyl silicate / Zinc powder	1 x 75	

Environment definition

- Environment definition according to ISO 12944-2

Categories		Typical exposure
C1	negligible	-
C2	low	Low pollution, mostly rural areas
C3	medium	Moderate pollution, urban/industrial areas, coastal areas with low salinity
C4	**severe**	**Industrial areas, coastal areas with moderate salinity**
C5-I	industrial	Industrial areas with high humidity and aggressive atmospheres
C5-M	maritime	Coastal and offshore regions with high salinity

Coated steel bridges – « Assumed » maintenance activities

- **E0**: Initial coating
  - Surface preparation (solvent cleaning, hand & tool cleaning, abrasive blast cleaning, water jetting)
  - Application of coating – presently : paint or metallic coating
- **E1**: 'Patch-up' (or 'touch-up') i.e. Preparation on localized areas + application of a compatible new coat
- **E2**: Overcoating i.e. removal of small deteriorated areas or of a whole layer of coating + new coating of the whole surface
- **E3**: Remove & Replace i.e. All rusted areas and existing coatings are removed + new coating of the whole surface

Coated steel bridges – « Assumed » maintenance activities

- Maintenance of paints
  - “Compatible” with the substrate and the environment
  - DFT ranges from 150 to 300 microns
  - Required surface : Sa 2 ½ (commonly used for long term protection)

- Maintenance of metallic coatings

Option	Coating Type	Dry Film Thickness (microns)	Required Surface
1	Organic zinc-rich primer	50 at affected areas	SSPC-SP 11
2	Inorganic zinc silicate paint	30 greater than the local zinc coating	Sa 2½
3	Zinc metal spray	30 greater than the local zinc coating	Sa 2½

Painting system – Determination of the maintenance factors

- Cost data based on Literature review & Interview with experts:

Reference	Cost range for different painting operations ($/m²)											
	Initial Coating			Patch Up			Overcoating			Remove & Replace		
(Mark Yunovich)	17.12	-	53.70	17.12	-	53.70	11.00	-	86.00	43.00	-	215.25
(Jayson L. Helsel, 2008)	11.05	-	44.67	23.96	-	220.34	13.25	-	116.93	27.94	-	258.83
(bauforumstahl, et al., 2013)	17.70	-	36.97	n.a.	-	n.a.	35.79	-	74.97	n.a.	-	n.a.
(Raed El Sarraf)	37.50	-	57.45	82.70	-	122.95	n.a.	-	n.a.	50.50	-	n.a.
(Kwang-Min Lee, 2006)	n.a.	-	n.a.	n.a.	-	n.a.	n.a.	-	n.a.	n.a.	-	236.00
(American Iron and Steel Institute, 2007)	n.a.	-	n.a.	n.a.	-	n.a.	43.06	-	64.58	129.20	-	150.69
Experts (3)	n.a.	-	n.a.	56.95	-	68.34	n.a.	-	n.a.	113.90	-	170.85
Average	**20.8**	**-**	**48.2**	**45.1**	**-**	**116.3**	**25.7**	**-**	**85.6**	**72.9**	**-**	**206.3**
StdDev.	**11.5**		**9.2**	**30.5**		**75.5**	**16.1**		**22.5**	**45.5**		**44.9**

HDG – Determination of the maintenance factors

- Cost data based on Literature review & Interview with experts:

Reference	Cost range for painting operations ($/m²)						
	Initial Coating (in shop)	Patch Up*			Overcoating**		
Literature	39.39	n.a.	-	n.a.	n.a.	-	n.a.
Expert (1)	34.12	n.a.	-	n.a.	n.a.	-	n.a.
Average	**36.75**	**46.82**	**-**	**112.80**	**n.a.**	**-**	**116.9**
StdDev.	**3.73**	n.a.	**-**	n.a.	n.a.	**-**	n.a.

*'Patch Up' costs based on the coating types described on slide 4 ⇨ relatively "weak" hypothesis seen the costs of *metalizing* (metalizing costs based on (Jayson L. Helsel, 2008) ranges from 364.7 to 384.5)

** Overcoating costs assumed to be the maximum stated in (Jayson L. Helsel, 2008) ⇨ "strong" hypothesis

Determination of the maintenance factors

- Includes:
  - Surface Preparation,
  - Coating Material & Application (labour part)
  - Other costs such as:
    - Preliminary field painting cost considering the structure's complexity according to data in (Jayson L. Helsel, 2008)
    - Multiplier for 'Existing Coating Condition' according to Helsel (Jayson L. Helsel, 2008)
    - Weighting of the containment factors given in (Jayson L. Helsel, 2008)

Determination of the maintenance factors

- Service life data based on Literature review & Interview with experts:

Painting system	Maintenance Event	System age in environment C4 (years)				Average Service Life Extension (years)
		Literature	Experts	Average	StdDev.	
	'Touch Up'	15.2	10.5	12.8	3.0	5.7
	'Overcoating'	17.1	19.3	18.5	2.2	12.5
	'Remove & Replace'	31.6	30	31.0	8.6	12.8

HDG	Maintenance Event	System age in environment C4 (years)
		Experts (only)
	'Touch Up'	**40**

The studied bridge

- Size, weight and surface chosen according to Bridge Inventory data:

Bridge Overall Dimensions			Steelwork Data				
Length (m)	Width (m)	Area (m^2)	Specific Weight (t/m^2)	Steel Weight (t)	Specific Surface (m^2/t)	Steel Surface (m^2)	Coated Area (m^2)
36.9	15.8	583	0.18	104.94	14.25	1495	1346

- Material option:
  - Option 1: Carbon steel with initial coating and regular maintenance
    >> variable maintenance scenario
  - Option 2: Galvanized including regular maintenance

The boundary of the assessment

- Following the principles described in EN 15643-4:2012 for buildings, the system boundary includes costs related to:
  - Module A i.e. the *Cost of products supplied at factory gate ready for construction,* all other costs (i.e. purchase of land, professional fees, taxes…) being disregarded ;
  - Module B2 i.e. the *Cost of repairs and replacement of minor components/small areas* and the cost of *Replacement or refurbishment of major systems and components.*
  - No Economic impacts and aspects at the *End of Life* (Modules C1-C4) are presently taken into account
  - *Traffic congestion costs* are not included in this analysis (as in the sense of EN 15643-4:2012)

Net future values and Net present values

- Net future value (NFV) is the inflated cost at the end of the planning horizon.
- The Net present value of the estimated cost over the planning horizon is the discounted value of the NFV to the present.

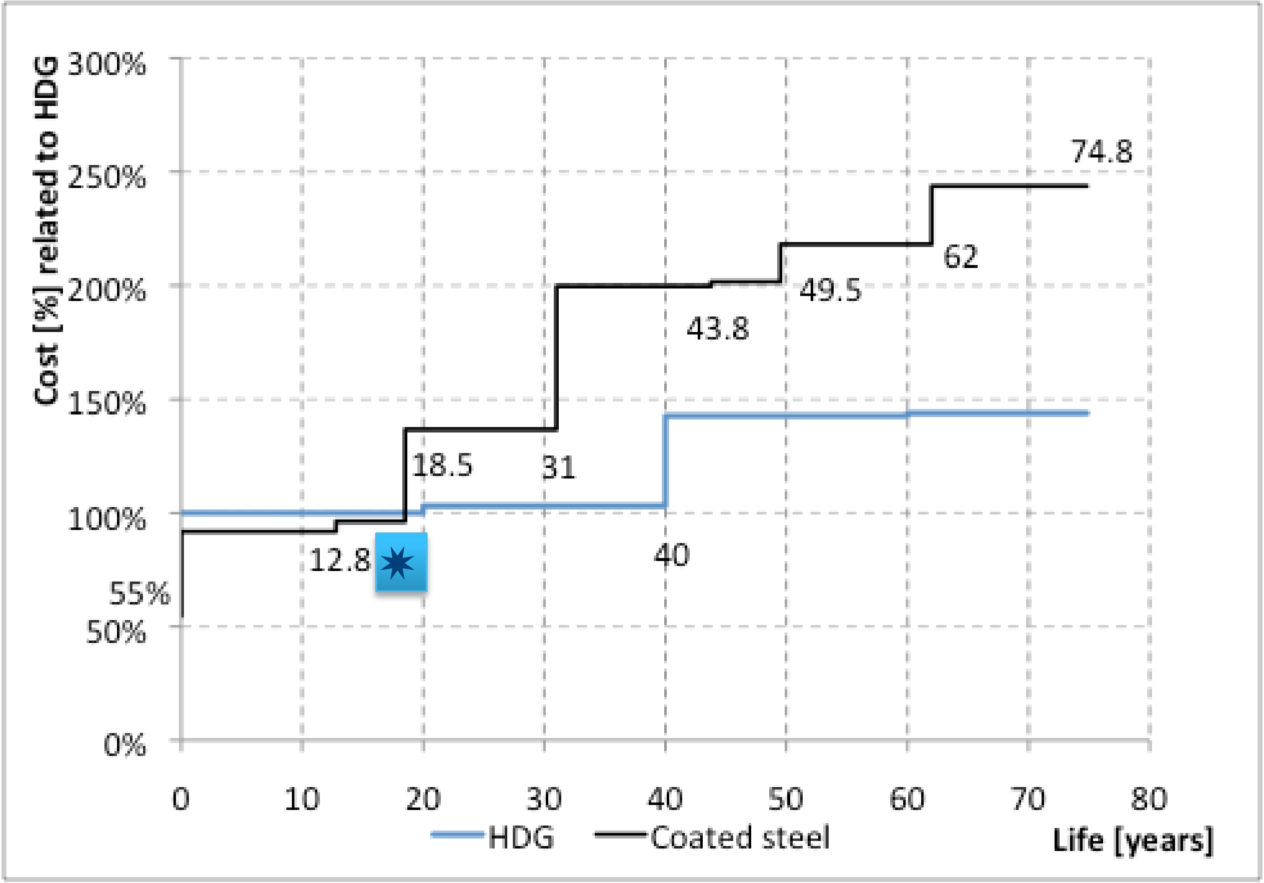
Net Future Value: $$NFV = C(1+i)^n$$

Net Present Value: $$NPV = C\left[(1+i) / (1+d)\right]^n$$

- C is the current cost,
- i is the escalation rate,
- d is the discount rate,
- n as year of occurrence of the cost (study period).

Case study 1 – Hypotheses and results

- Scenario Coated steel :
  E1/E2/E3-E1/E2/E3
- Scenario HDG:
  'Touch Up' after 20 y.
  'Overcoating' after 40 y.
  'Touch Up' again after 20 y.
- Touch Up: 5% of the surface
- Overcoating: Preparation of 10% and coating of 100% *(already included in the previous costs)*



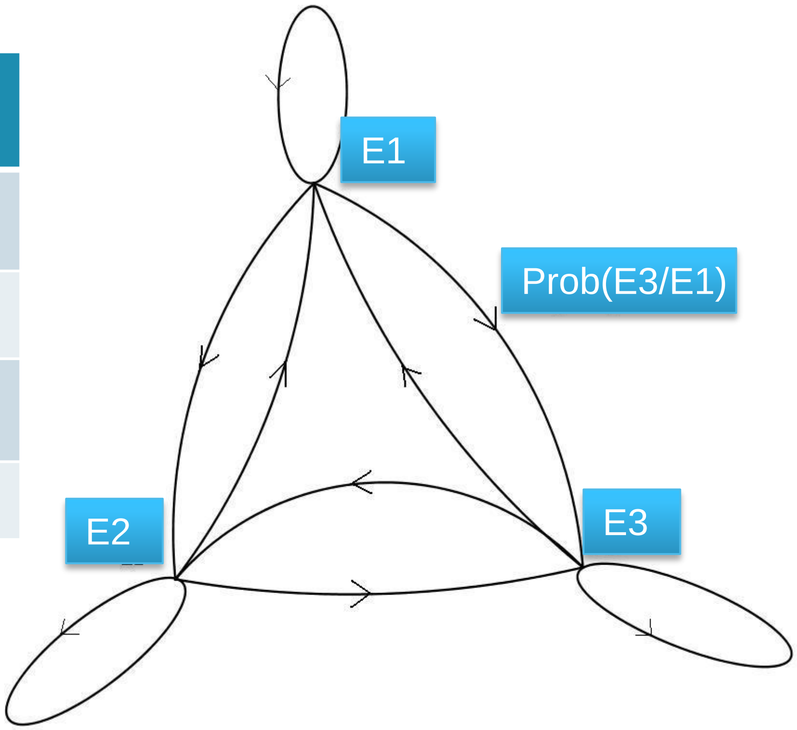
Case study 2 – Sensitivity analysis

- Sensitive to:
  - Inflation rate ↗☐ (resp. discount rate ↙) obviously influences ↗ the total cost ☐ (end of lifespan) rather than point ✷
  - Service life and cost data obviously influences the total cost as well as the point ✷ (intersection between both NPV i.e. starting of *investment return*)
  - Above all: the *Maintenance Scenario*…

Case study 2 – Influence of the scenario – The probability of occurrence

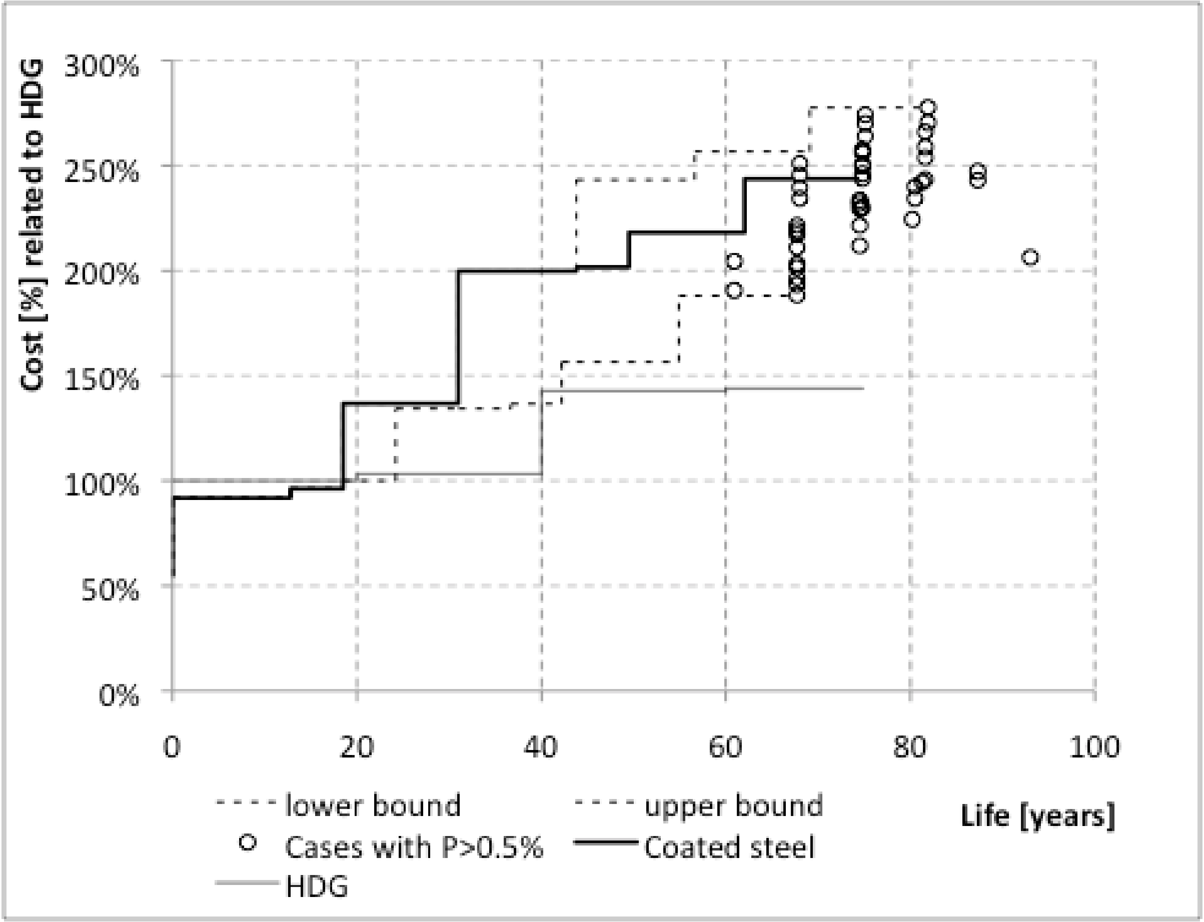
- Maintenance Scenario:
  - Permutation of six « independent events », each characterized by a « probability of occurrence »

Maintenance Event		E1	E2	E3
'Touch Up'	E1	Prob(E1/E1)=0.20	0.15	0.70
'Overcoating'	E2	Prob(E2/E1)=0.70	0.15	0.20
'Remove & Replace'	E3	Prob(E3/E1)=0.10	0.70	0.10
		∑=1	∑=1	∑=1



Case study 2 – Influence of the scenario – Results & Main conclusions

- Only for the « most probable » cases (P>0.5%):
  - Range of cost: 188% – 277%
  - Range of lifespan: 60 – 93 years

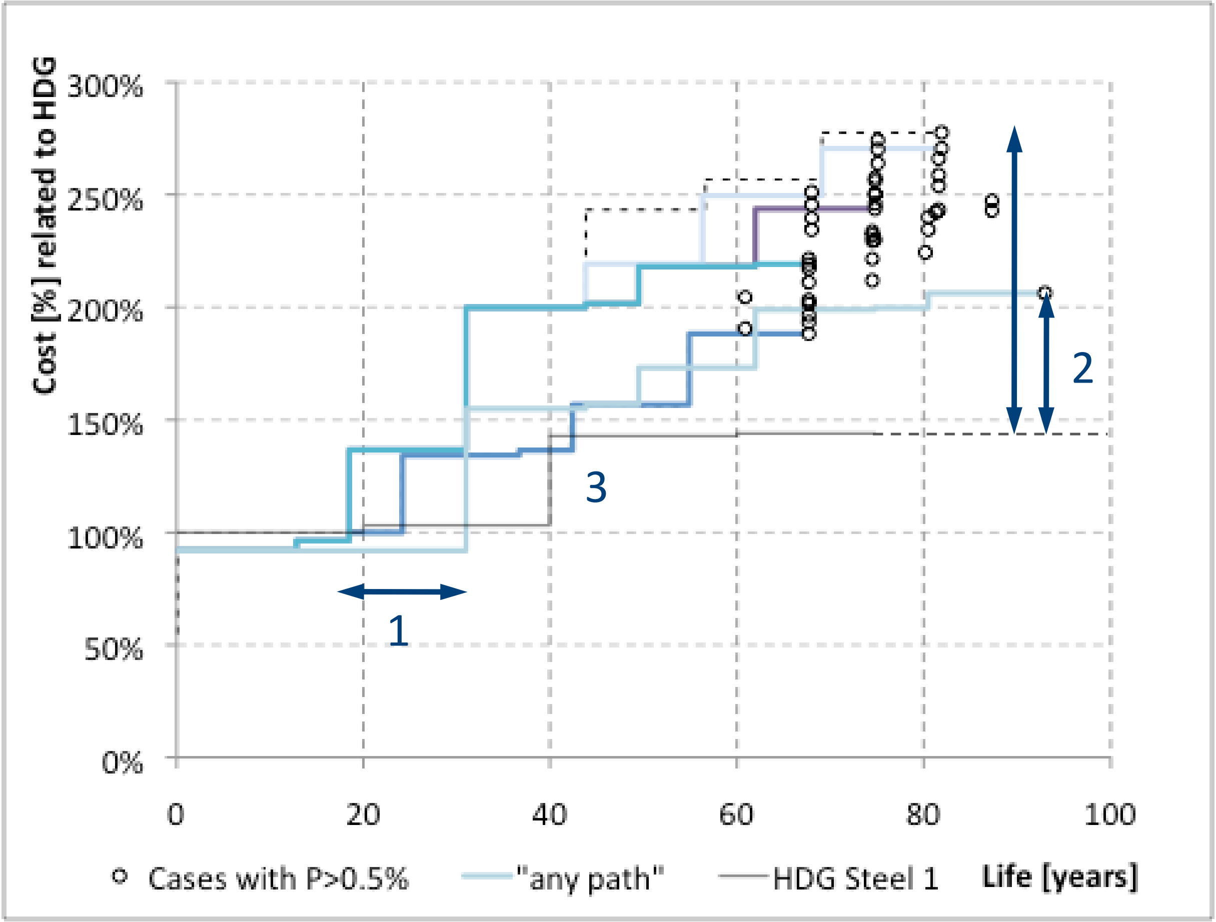


Case study 2 – Influence of the scenario – Results & Main conclusions

- 1) *Intersection range* : depending on the scenario chosen for the steel option, the moment at which the investment return starts ranges from 18.5 to 31 years

- 2*) Difference in total cost*: 44% – 133%

- 3) *Overcoating of HDG option after 40 y.*
  ⇨ short period during which painted steel option is '*better*'



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Barbara Rossi
Barbara.rossi@kuleuven.be