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Environmental and economic assessment of service life extending repairs for a concrete silo

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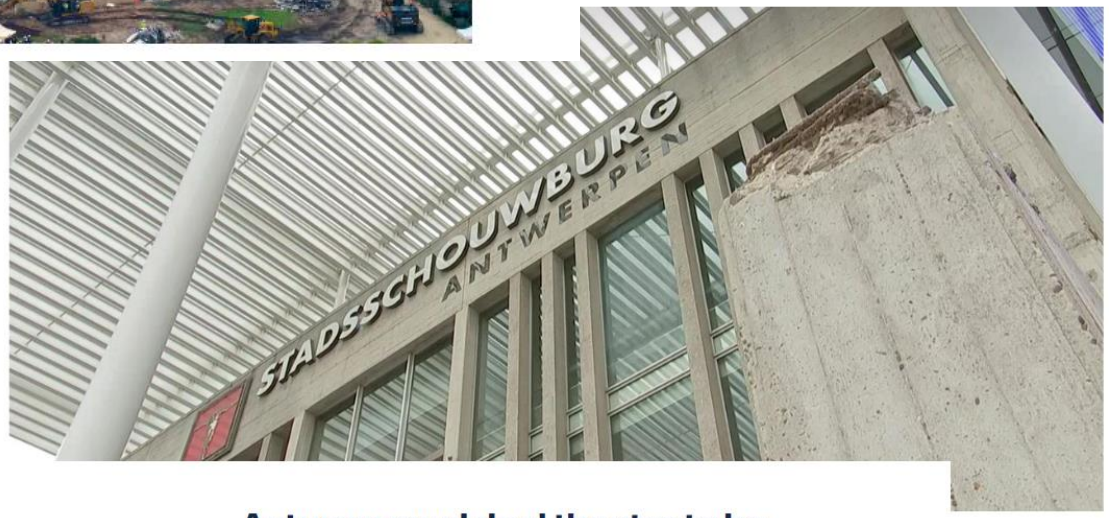
The corrosion of the Morandi Bridge: the story of a predictable collapse?

The New York Times

Engineer Warned of 'Major Structural Damage' at Florida Condo Complex

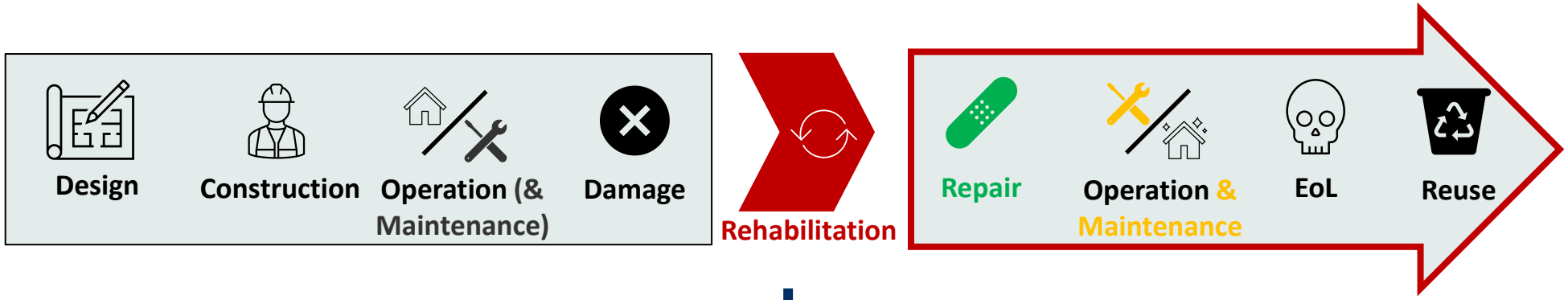


Mon 16 May 13:59

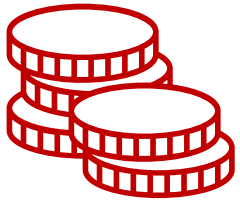
Antwerp municipal theatre to be demolished

Damage -> Concrete repair

Service life extension

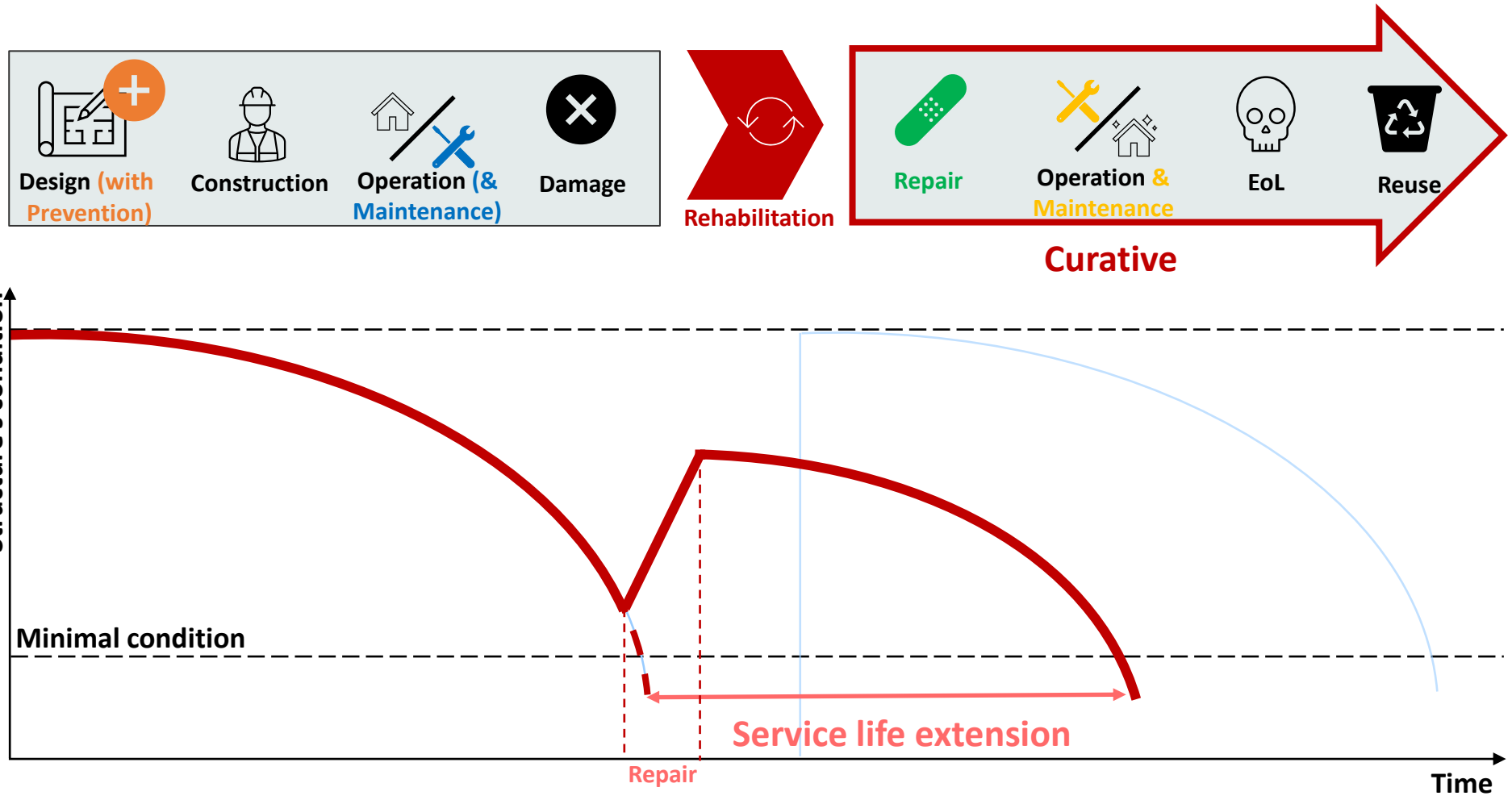


Environmental cost?



Economic cost?

Service life extension



State-of-the-art

- Very limited research: sustainability assessment of concrete
- Lack of LCA and LCCA results of service life-extending concrete maintenance and repair
- Only one study comparing repair strategies through LCA and LCCA of the ones considered

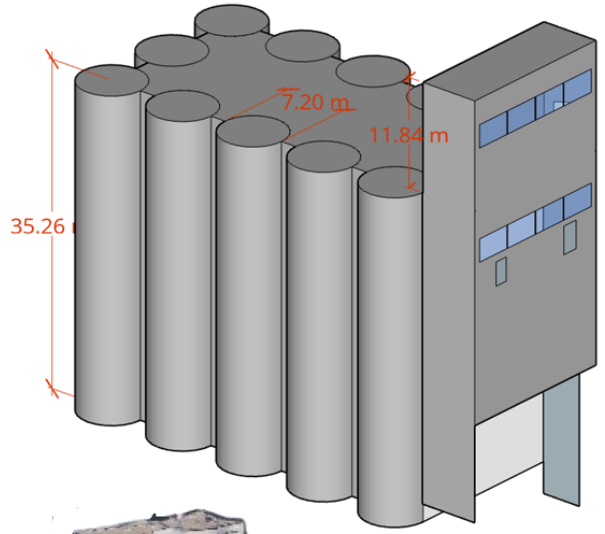
Reference	Type of structure	Goal
Wittocx et al. **2022** **Revamping corrosion damaged reinforced concrete balconies: Life cycle assessment and life cycle cost of life-extending repair methods**	Balconies	**Analysing five frequently used repair strategies:** 1) Patch repair 2) Conventional repair (CR) 3) Galvanic cathodic protection (GCP) 4) Impressed current cathodic protection (ICCP) 5) New: demolishing and rebuilding

Goal

- **Environmental impact -> Life cycle assessment (LCA)**
- **Economic impact -> Life cycle cost analysis (LCCA)**
- **Corrosion damaged concrete silo**
- **Frequently used repair techniques:**
  - Conventional repair (CR)
  - Conventional repair with surface protection (CR-SP)
  - Galvanic cathodic protection with zinc foil (GCP-F)
  - Galvanic cathodic protection with zinc gauze (GCP-G)
  - Impressed current cathodic protection with titanium gauze (ICCP-G)
  - Impressed current cathodic protection with a conductive coating (ICCP-C)

Methodology: case

- **Corrosion:** bad and dangerous condition of the construction
- **Silo ‘block’:**
  - Residual life span: 0
  - 11 cylinders (Ø 7,2 m x 35 m) connected 1,8 m wall
  - Horizontal reinforcement: ribbed, Ø 14 mm with 200 mm spacing
  - Vertical reinforcement: ribbed, Ø 10 mm with 300 mm spacing
- **Rectangular silo ‘tower’:**
  - Residual life span: 66 y.
  - 47 m x 18 m x 6.6 m
  - Horizontal reinforcement: non-ribbed, Ø 14 mm with 250 mm spacing
  - Vertical reinforcement: non-ribbed, Ø 10 mm with 250 mm spacing
- **Total area:** 6690 m^2, 50.4 tons of steel rebars
- **3 Functional units (FU):** service life extension for 20, 40 and 50 years



Methodology: LCA

- **Consequential approach:**
  - Identification of marginal suppliers
  - Substitution of dependent co-products
- **Cradle-to-cradle approach:**
  - Demolishing of the damaged or contaminated parts
  - Reconstruction
  - Operation phase
  - End-of-life: recycling potential
- **Ecoinvent database v3.8**
- **ReCiPe 2016 v1.07 method:** midpoints & endpoints

Methodology: LCCA

- **Same processes as LCA**
- **Net Present Value (NPV):** costs and revenues at different stages in time are compared=discounting

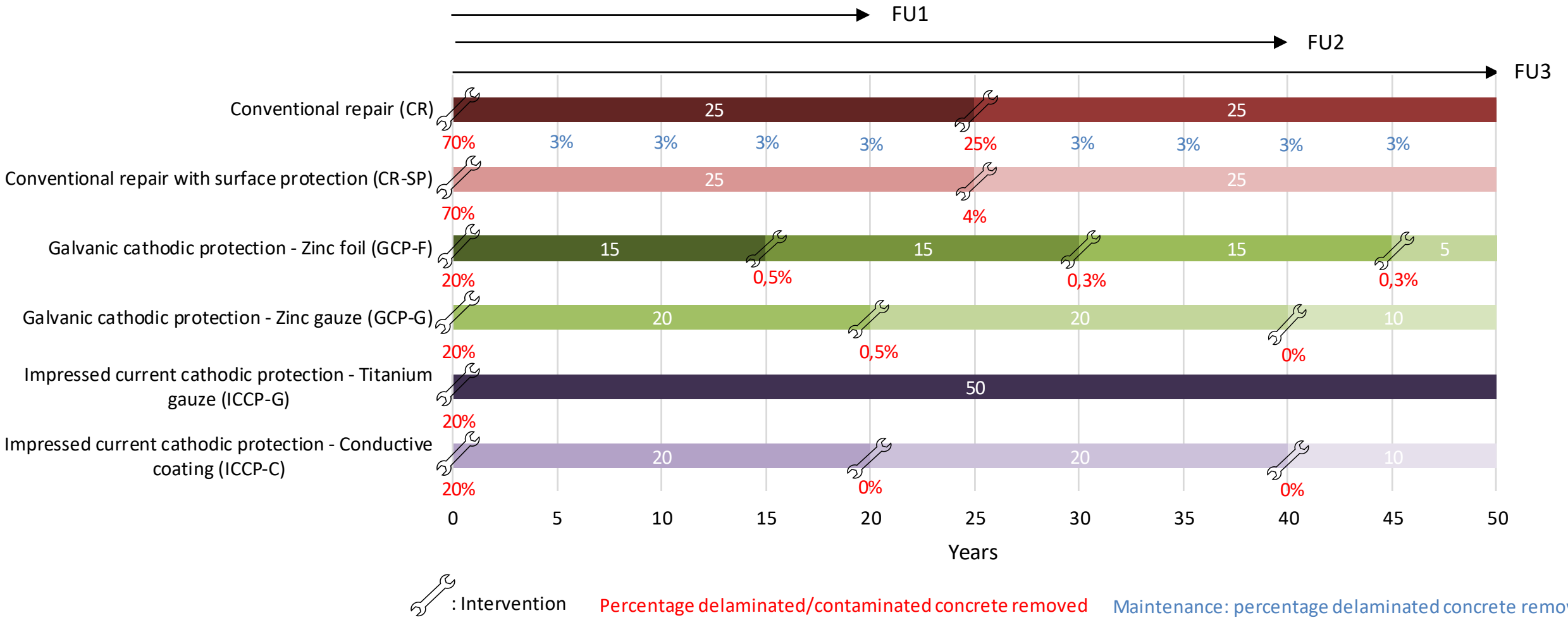
$$NPV = I_0 + \sum_{i=1}^{N} \frac{CF_i}{(1+d)^i}$$

where I_0 = Initial investment; N = study period; i = year; CF_i = cashflow in year i; d = real dis-count rate

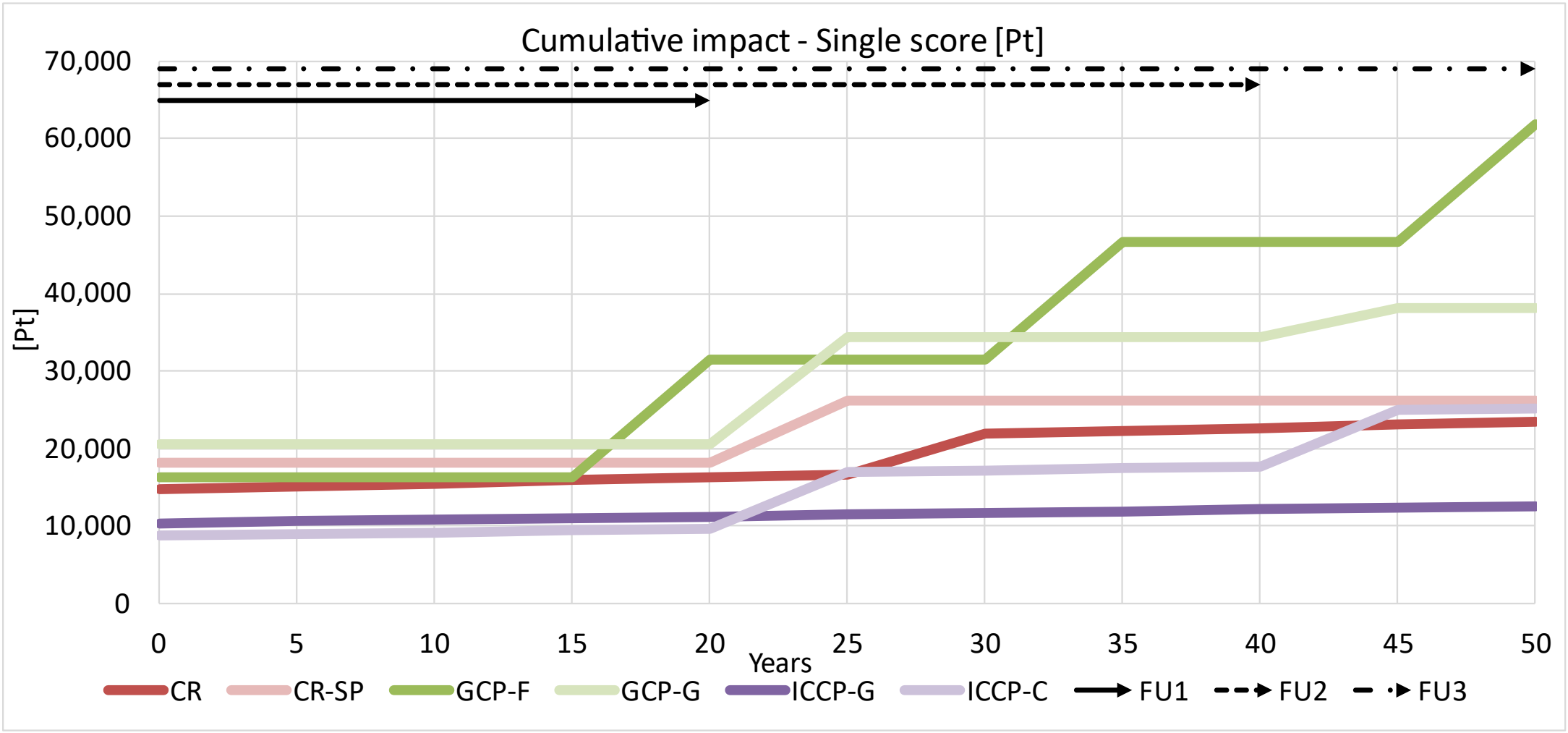
$$d = \frac{d_n - r_{inf}}{1 + r_{inf}}$$

where d = real discount rate; dn = nominal discount rate; rinf = inflation rate

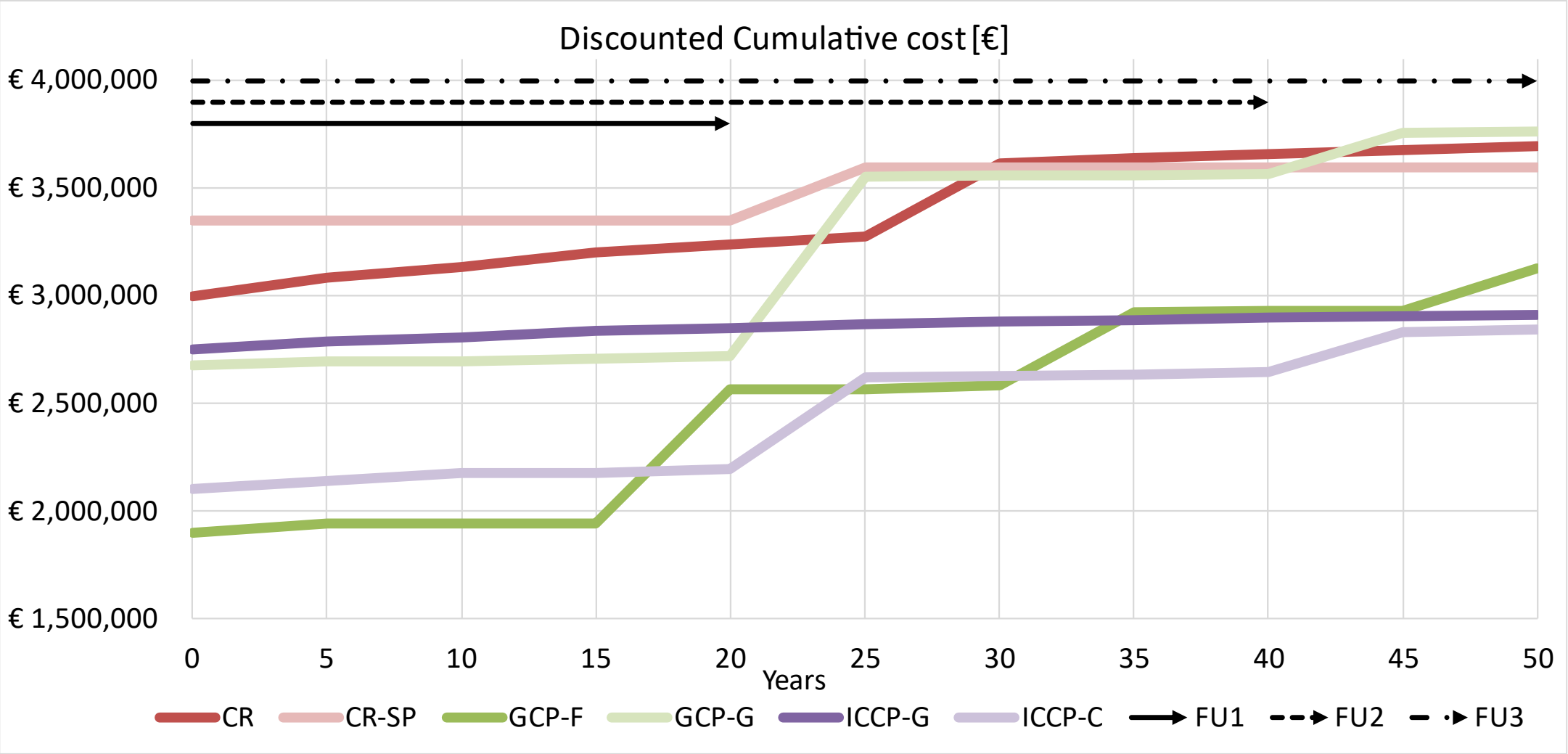
Scenarios


FU1
FU2
FU3
Conventional repair (CR)
25
25
70%
3%
3%
3%
3%
25%
3%
3%
3%
3%
Conventional repair with surface protection (CR-SP)
25
25
70%
4%
Galvanic cathodic protection - Zinc foil (GCP-F)
15
15
15
5
20%
0,5%
0,3%
0,3%
Galvanic cathodic protection - Zinc gauze (GCP-G)
20
20
10
20%
0,5%
0%
Impressed current cathodic protection - Titanium gauze (ICCP-G)
50
20%
Impressed current cathodic protection - Conductive coating (ICCP-C)
20
20
10
20%
0%
0%
0
5
10
15
20
25
30
35
40
45
50
Years
: Intervention
Percentage delaminated/contaminated concrete removed
Maintenance: percentage delaminated concrete removed

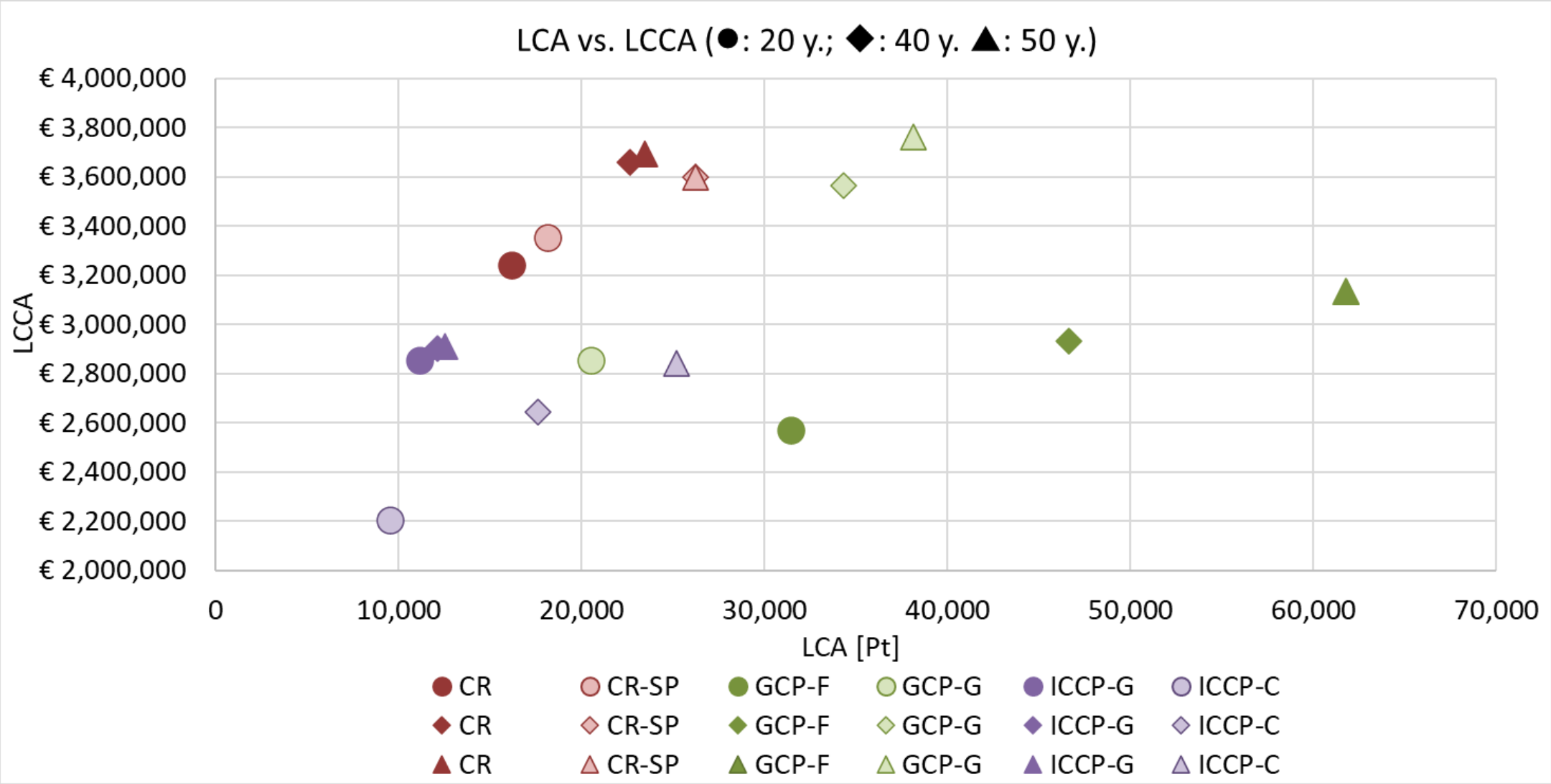
LCA Results


Cumulative impact - Single score [Pt]
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
[Pt]
0
5
10
15
20
25
30
35
40
45
50
Years
CR
CR-SP
GCP-F
GCP-G
ICCP-G
ICCP-C
FU1
FU2
FU3

LCCA Results



LCA vs LCCA


LCA vs. LCCA (●: 20 y.; ◆: 40 y. ▲: 50 y.)
€ 4,000,000
€ 3,800,000
€ 3,600,000
€ 3,400,000
€ 3,200,000
€ 3,000,000
€ 2,800,000
€ 2,600,000
€ 2,400,000
€ 2,200,000
€ 2,000,000
LCCA
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
LCA [Pt]
CR
CR-SP
GCP-F
GCP-G
ICCP-G
ICCP-C

Conclusion

- **LCA and LCCA-> key factor for reducing the environmental and economic impact**
- **Service life extension:**
  - 20 years: ICCP-C for LCA and LCCA
  - 40 years: ICCP-G for LCA and ICCP-C for LCCA
  - 50 years: ICCP-G for LCA and ICCP-C for LCCA
- **Electro-chemical ICCP treatments good options for this case study:** low initial cost/impact + low need for interventions after the first repair
- **Small service life extensions:** ICCP economically less good than GCP-F
- **Further research:**
  - In-depth analysis of the necessary activities and materials
  - Service life extension of repairs

Thank you for listening

Questions?

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