Asset Level Modelling of RISKs In the Face of Climate Induced Extreme Events and ADAPTation (RISKADAPT)

Climate change adaptation options

23/10/2024

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Modeling of Risks and Adaptation

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Agenda

1. Introduction
    a) Relation between Adaptation options and climate change
    b) Evaluation of corrective actions
2. Replacement
    a) Low carbon drivers
    b) Infrastructure and building options
3. Refurbishment
    a) Concrete structure
    b) Steel structure

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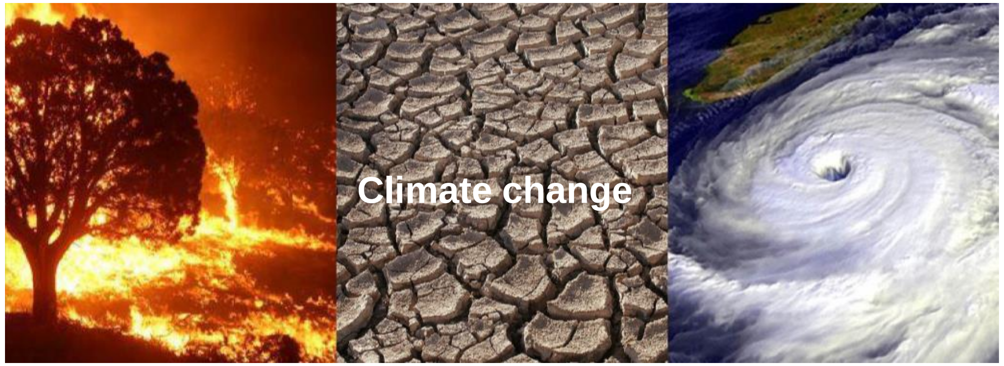
1a. Relation between adaptation options and climate change



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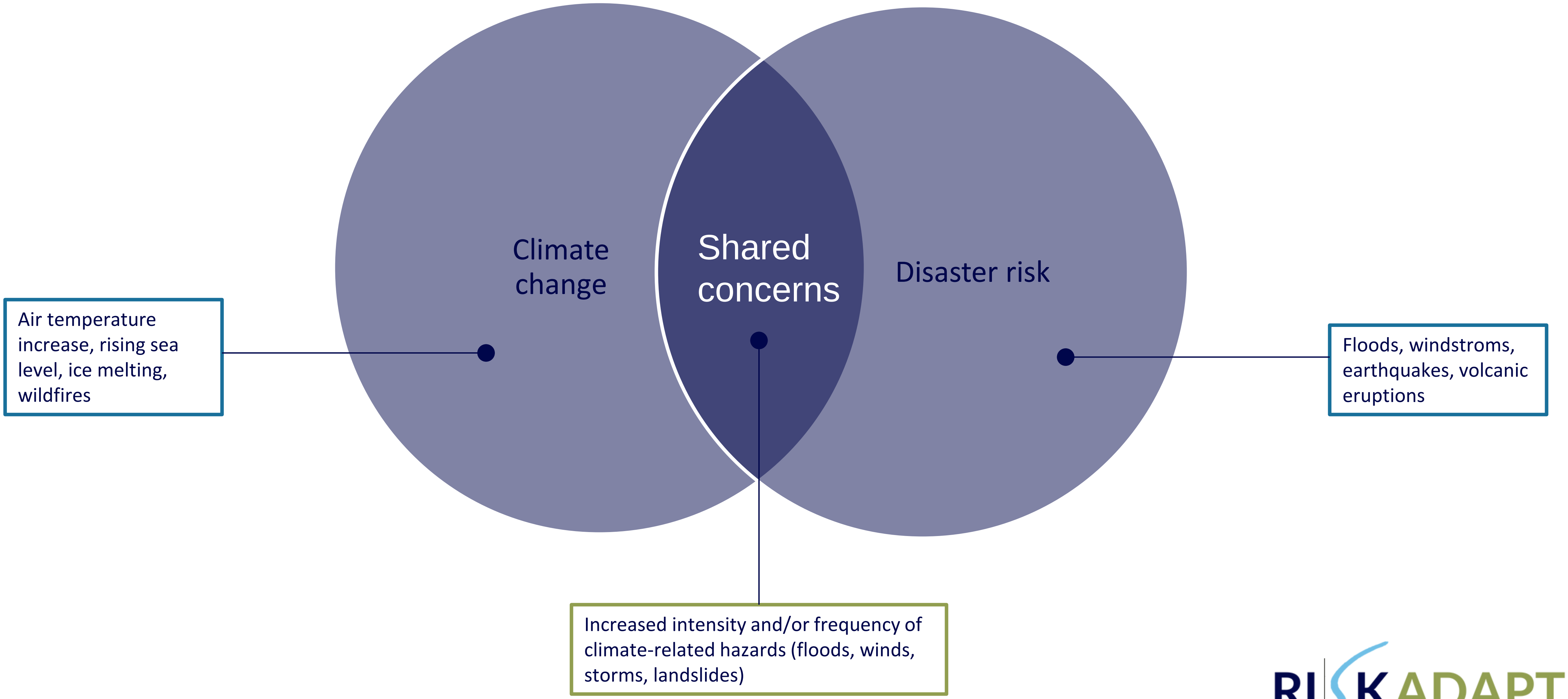
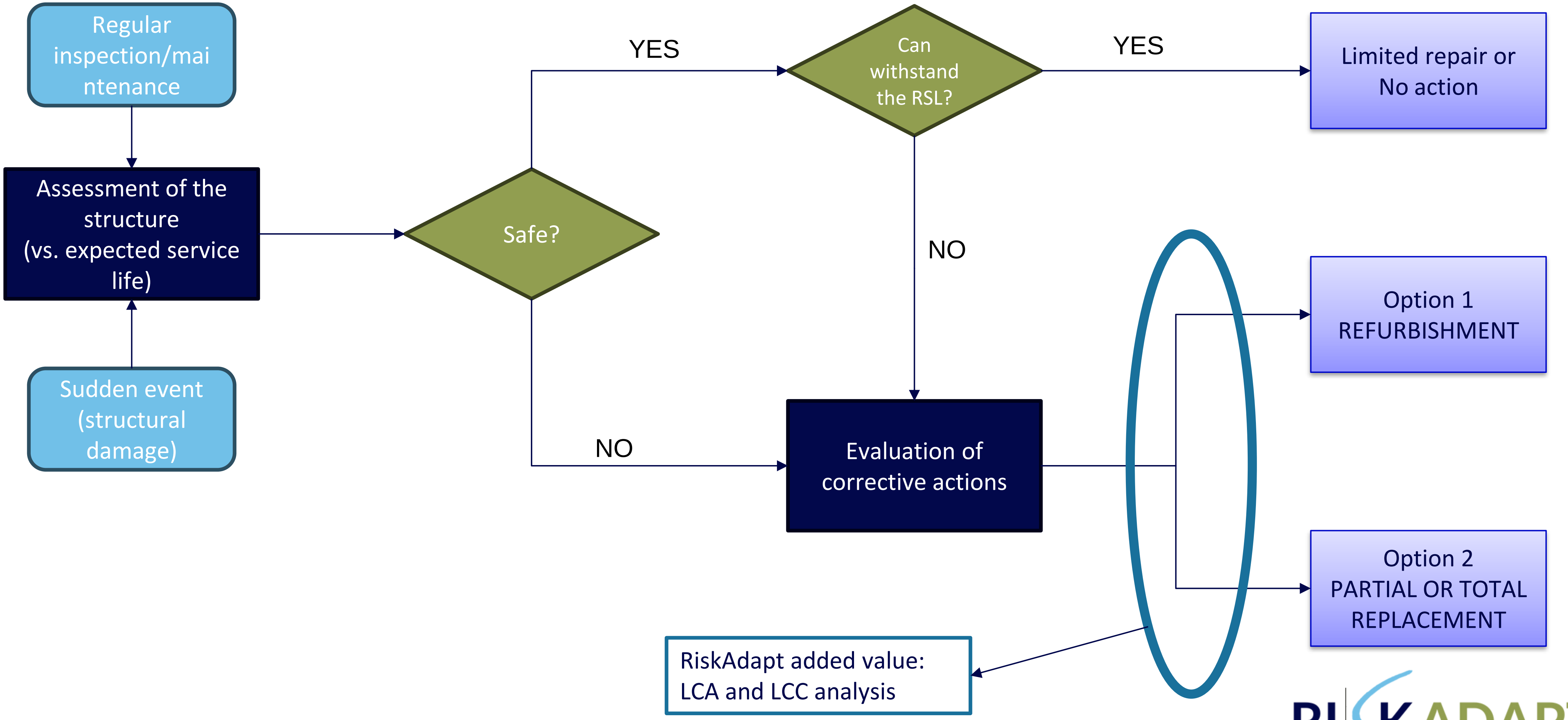
1a. Relation between adaptation options and climate change



1b – Evaluation of corrective actions



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2. REPLACEMENT
(focus on precast solutions for buildings and infrastructures)

2a - CERIB Report – 5 main opportunities regarding low-carbon adaptation of precast concrete products

1. Low-carbon binders
2. Industrial by-products as part of concrete composition
3. Recycled aggregates driven from Construction and Demolition Waste (CDW)
4. Reuse of concrete elements
5. Structural design

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Purpose of service provision:
RiskADAPT Project – Task 4.1 – Low Carbon Structural Adaptation Options regarding precast concrete products – Main opportunities and technical data

At the request of: **BIBM**
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2a - CERIB Report – 5 main opportunities regarding low-carbon adaptation of precast concrete products

1. Low-carbon binders

a. Energy efficiency improvements

- Cement production is reducing energy consumption by modernising kilns, improving fuel efficiency, and lowering electricity use. Alternative fuels such as biomass and kiln upgrades further reduce CO_2 emissions.

b. Clinker reduction through alternative materials

- The use of alternative binders like geopolymer cements and SCMs (e.g., fly ash, silica fume, slag) reduces Portland cement content and CO_2 emissions.
- Replacing clinker with pozzolanas and limestone further cuts emissions and improves cement properties, while new technologies lower production temperatures and absorb CO_2.

c. CCS technologies

- CO_2 capture methods, including post-combustion and oxyfuel technology, are being developed, along with innovative approaches like algae-based CO_2 capture.

Cements	GHG emissions (kg CO_2 eq / t)	% of clinker (in this EPD)	% of other secondary constituents	Main secondary constituents
CEM I	827	98.2%	1.8%	
CEM II/A-L or CEM II/LL	714	85.7%	14.3%	Limestone
CEM II/A-S or CEM II/A-M or CEM II/A-V	696	84.5%	15.5%	Blast furnace slag or Fly ash or Calcareous and pozzolana compounds
CEM II/B-L	602	70.9%	29.1%	Limestone
CEM III/A	565	54.8%	45.2%	Blast furnace slag
CEM III/A-PM or CEM III/A-ES	389	35.3%	64.7%	Blast furnace slag
CEM III/B	339	29.8%	70.2%	Blast furnace slag
CEM III/C	225	15.4%	84.6%	Blast furnace slag
CEM V/A (S-V)	518	55.3%	44.7%	Blast furnace slag and Fly ash

Table 1. Greenhouse gas emissions and main composition of the main current cements in France

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2. Industrial by-products in concrete composition

- **Granulated Blast Furnace Slag (GBFS)**
  - By-product of pig-iron production.
  - Reduces CO_2 by up to 390 kg per tonne of cement.
  - Enhances long-term strength and chemical resistance but reduces early strength and heat of hydration.
- **Fly Ash (FA)**
  - By-product of coal-fired furnaces.
  - Reduces CO_2 by up to 90 kg per tonne of cement.
  - Improves workability, long-term strength, and durability, with enhanced resistance to sulphate attack.
- **Silica Fume**
  - By-product from the production of silicon and ferro-silicon.
  - Reduces CO_2 by up to 47.5 kg per tonne.
  - High pozzolanic activity but limited availability.
- **Non-standardised by-products**
  - Identified or under research.
  - Conversion steelworks slag,
  - Cupola slag, foundry fine particles, paper mill sludge ashes, biomass boiler ashes and crushed glass.

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3. Recycled aggregates from Construction and Demolition Waste (CDW)

Current Use

Concrete waste is primarily used in backfill, roadworks, and quarry filling. Standards are increasing recycled content in structural concrete (e.g., up to 60% in France).

Types of Aggregates

- Plant-based: Hemp, flax, cork, bamboo.
- Industrial waste: Slag, foundry sands, rubber, textiles.
- Other sources: Agricultural land, bottom ash, marine sediment.

Research is ongoing to increase the use of recycled aggregates in concrete

- VEEP Project: Developed technologies (ADR, HAS) for on-site recycling and CO_2 reduction.
- RE4: Created prefabricated concrete products with high recycled content.
- SeRaMCo: Explored using recycled aggregates in concrete production, revealing environmental challenges.

Recycled aggregates reduce environmental impact and costs, particularly when transport is kept within 50 km and renewable energy is used in the recycling processes. However, the reduction in CO_2 emissions is limited.

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4. Reuse of concrete elements

Reusing construction elements at the end of a structure's life is more sustainable in terms of material recovery, primarily for non-structural items.

Recent projects have explored the reuse of structural concrete elements:

- ReCreate – reusing precast concrete for a circular economy.

A Swedish pilot showed a 92% lower carbon footprint using prefabricated concrete elements for a demountable building.

- Re:Crete (Switzerland)

Reused concrete blocks from demolition to build a footbridge.

- Super Circular Estate (Netherlands)

Experimented with deconstructing and reassembling housing units using 3D modules and recycled concrete.

Research findings (France):

- Reusing concrete elements showed a 30% reduction in carbon emissions compared to virgin materials.
- French regulations (2022) now consider reused components to have a "null" carbon footprint (to encourage the use of 2nd hand products).

Challenges:

Reuse is limited by non-standardised specifications, design rules and local regulations.

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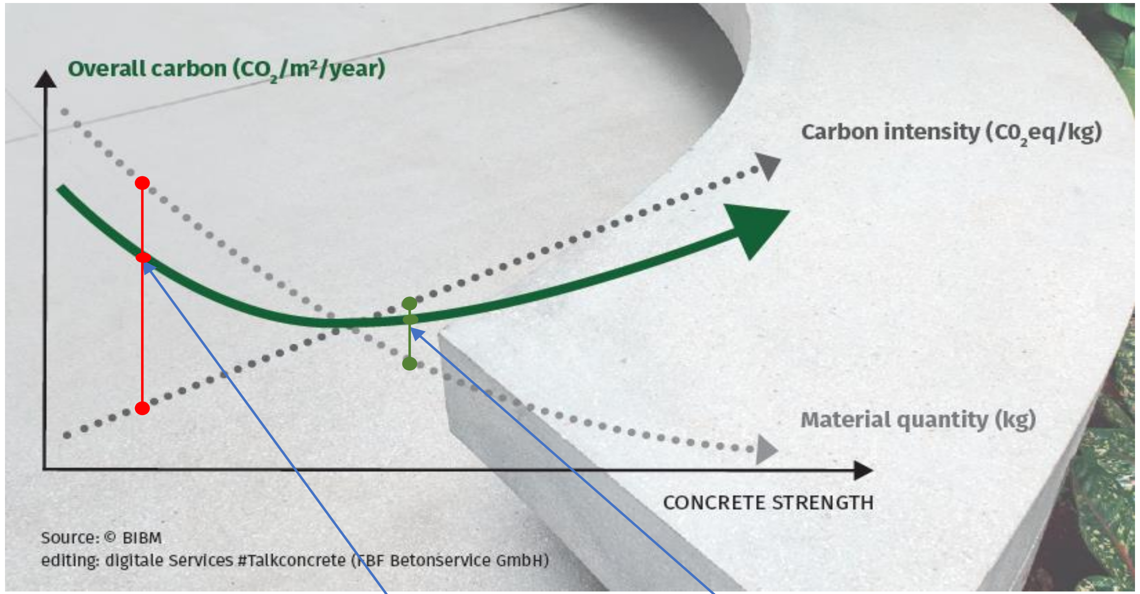
5. Structural design

Optimising concrete strength and using innovative materials can greatly reduce the environmental impact of concrete structures.

The total carbon profile of a concrete work (building or civil engineering) depends on two factors that need to be considered together to find the optimum solution:

- Carbon intensity of the concrete used (mainly linked to the carbon intensity of the cement).
- Quantity of material (concrete) used for a given function.



The best solution can therefore be found using a concrete (cement) with higher specific carbon intensity.

Numerical example

	Traditional prestressed concrete deck (C35/45)		High performance prestressed concrete deck (C80/95)	
	"Low-carbon" concrete 270 $kgCO_2eq/m^3$		"High-carbon" concrete 340 $kgCO_2eq/m^3$	
	quantity	*GWP ($kgCO_2eq$)*	*quantity*	*GWP ($kgCO_2eq$)*
Average thickness (m)	0.75	/	0.37	/
Concrete volume (m³)	390	105 300	188	63 920
Rebars (t)	39	44 460	39	44 460
Prestressed steel (t)	12	13 680	8	9 120
Weight (deck) (t)	975	/	520	/
GWP subtotal	/	**163 440**	/	**117 500**

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5. Structural design

High/Ultra-High-Performance Concrete (UHPC)
UHPC reduces CO_2 emissions by using less concrete in structural elements like bridges, despite higher cement content. Its longer lifespan makes it more CO_2 efficient over time, especially when combined with clinker-efficient cements.

French Project "BHP 2000“
Case studies showed that high-performance concrete, with alternative binders or upgraded classes, offers significant environmental benefits and cost savings.

Bridge design
A 21.5m bridge using high-performance concrete reduced material use and CO_2 emissions by 28% compared to traditional concrete. A 189m bridge with B40 vs B80 (silica fume) solutions showed improved performance and a 16% lower carbon footprint.

Picture of the 21.5 m long bridge

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2b - Infrastructure and building options

- Infrastructure
  - 5 cases
  - 100 years RSL

- Building
  - 5 cases
  - 50 years RSL

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2b - Infrastructure and building options

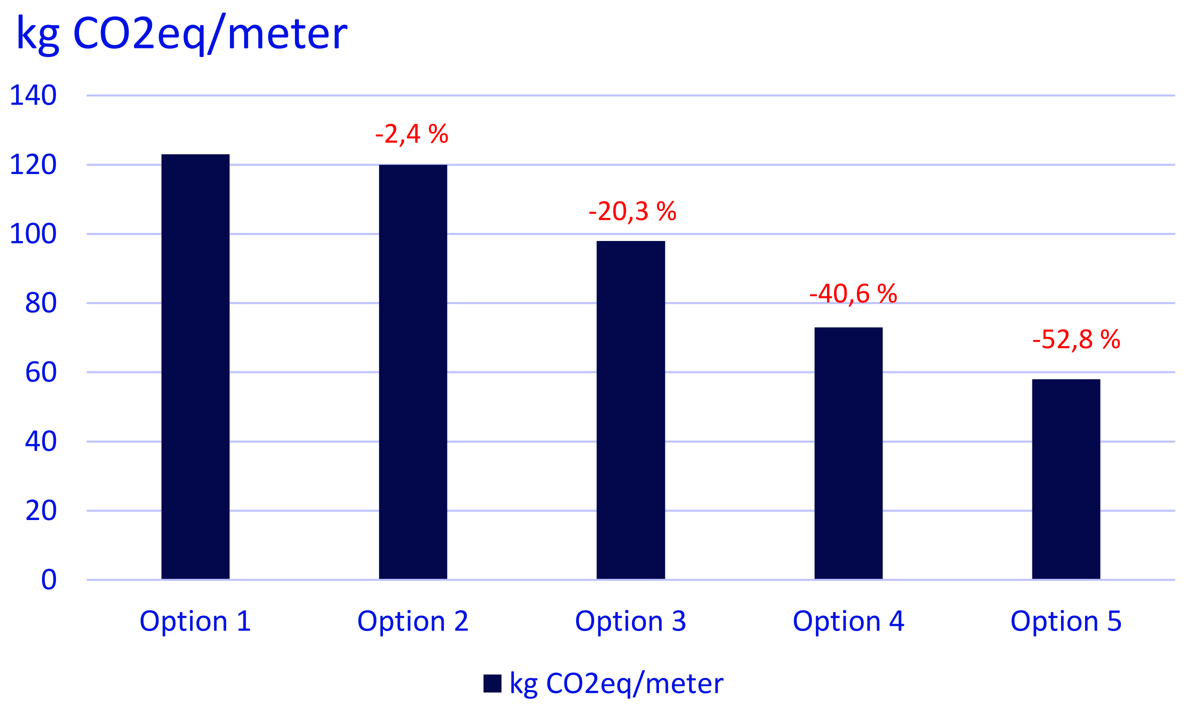
- Parameters
  - Compressive strength (conventional and high)

  - Binder (cement and mineral additions)

  - Recycled aggregates content

2b - Infrastructure and building options

Linear beam for Infrastructure – Mainly applicable to Pilot 1



1. C30 concrete with mineral filler (30x90, 100 kg/m³ steel)

2. 20% recycled aggregates

3. Use of CEM III (GGBS)

4. C60 High compressive strength (20x60, 180 kg/m³ steel)

5. C60, CEM III and mineral additions

Costs of the different solutions are comparable

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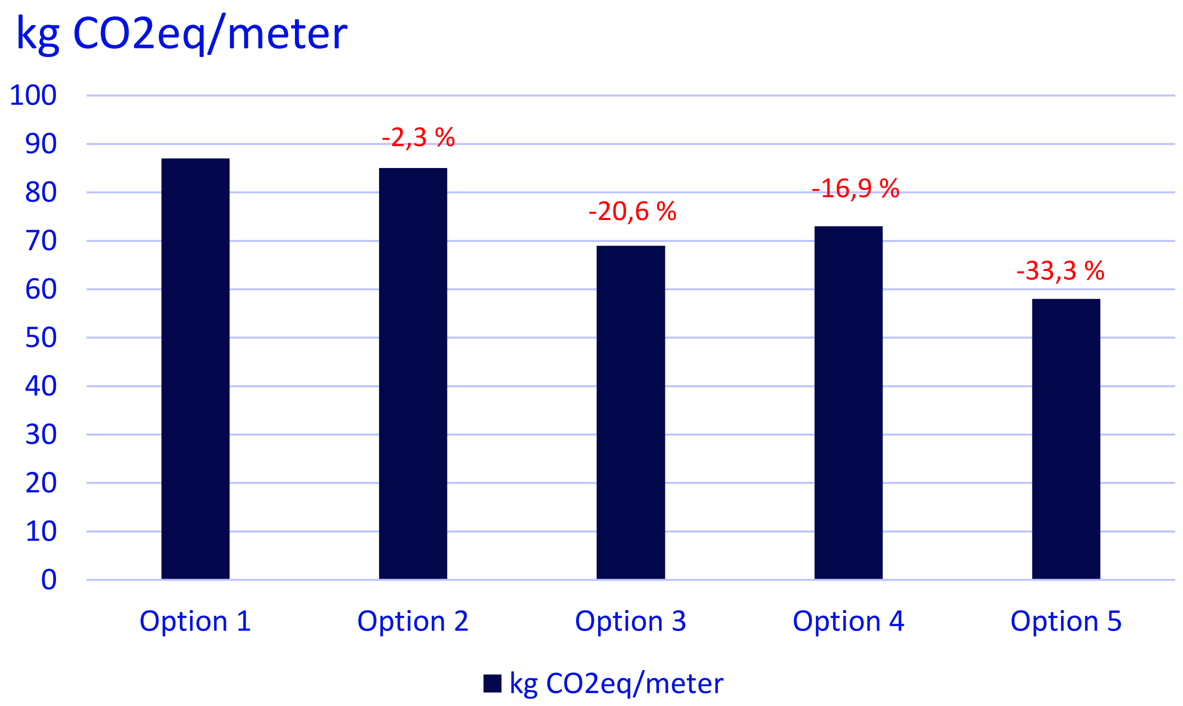
2b - Infrastructure and building options

Linear beam for building



1. **C30 concrete with mineral filler (50x50, 50 kg/m³ steel)**
2. **20% recycled aggregates**
3. **Use of CEM III (GGBS)**
4. **C60 High compressive strength (40x40, 100 kg/m³ steel)**
5. **C60, CEM III and mineral additions**

Costs of the different solutions are comparable

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3. REFURBISHMENT

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3a - Strengthening of Reinforced Concrete Structures – Pilot 3

Aim of Strengthening

- ➢ Upgrading the performance of an existing concrete element (and the overall structure) in terms of strength, stiffness or ductility

Strengthening Methods (jacketing)

✓ Reinforced Concrete Jacketing

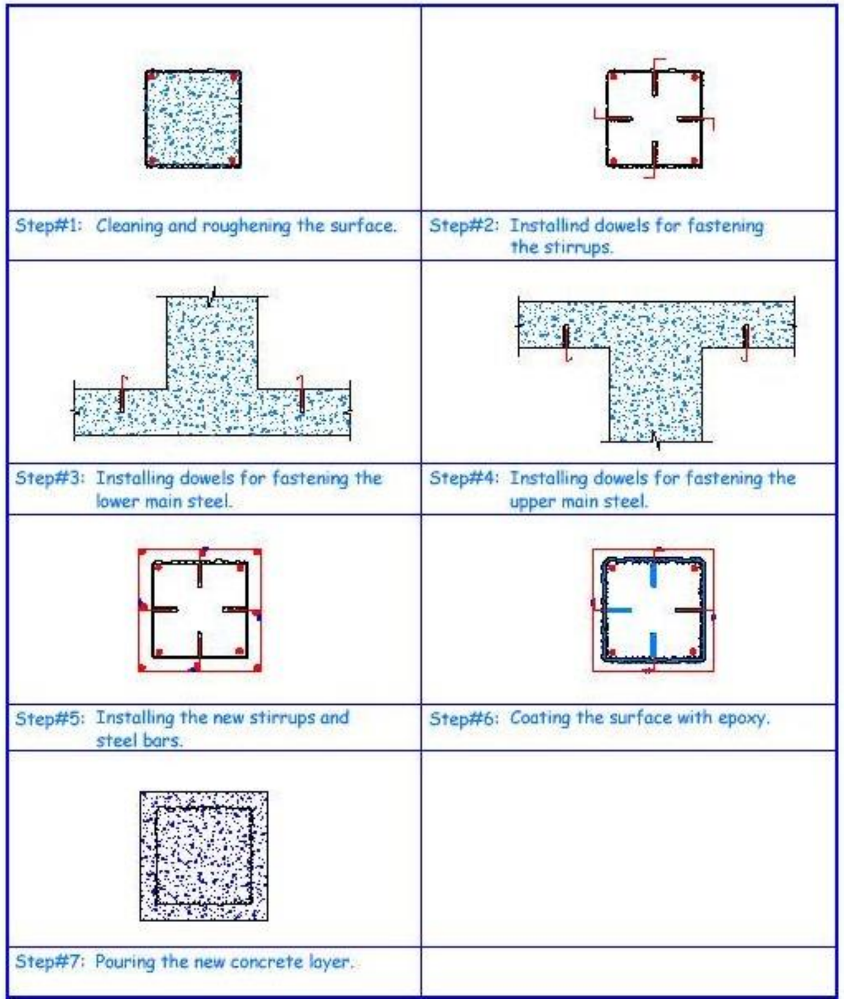
✓ Steel Jacketing

✓ Fibre-Reinforced Polymer (FRP) Jacketing

3a - Reinforced Concrete Jacketing

Process

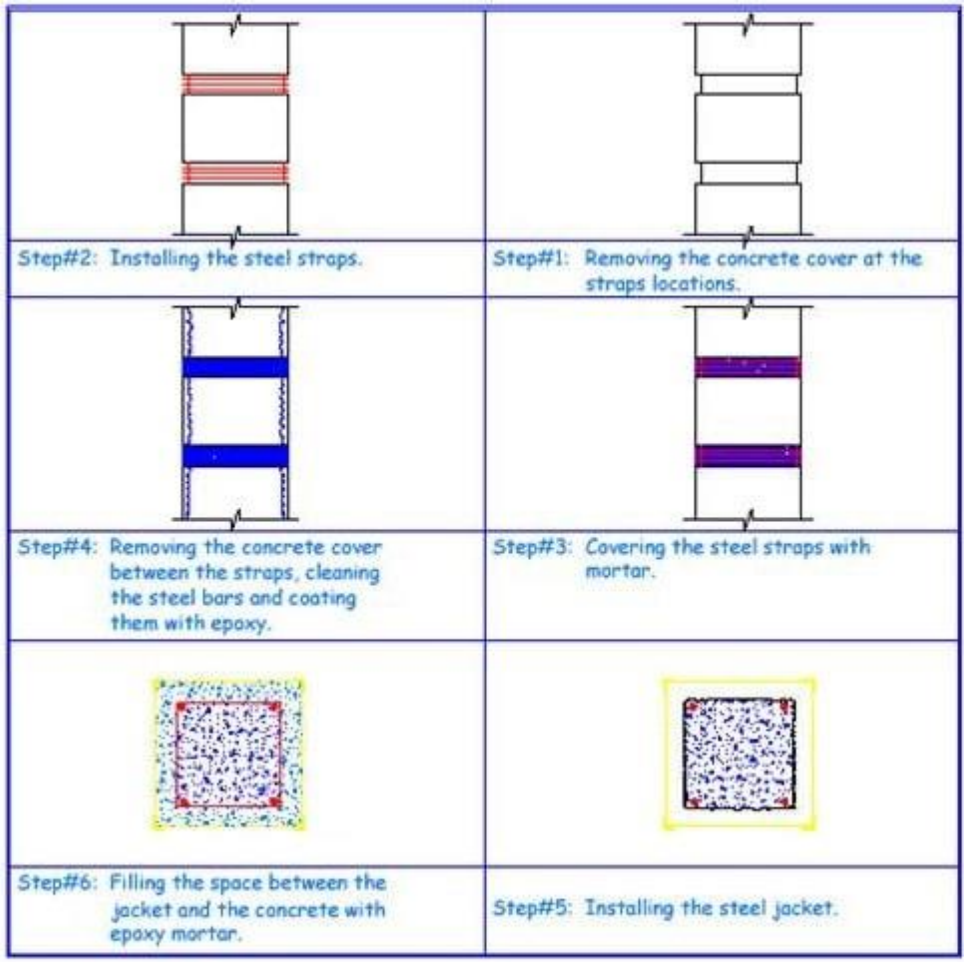
- **Cleaning** and **roughening** the surface of the element
- Adding **steel connectors** into the existing member to connect the new stirrups
- Adding new steel **bars** and **stirrups**
- Coating the surface of the existing member with an **epoxy material** to ensure **bonding** between old and new concrete
- Pouring a **new concrete** layer before the epoxy material dries



Steel Jacketing

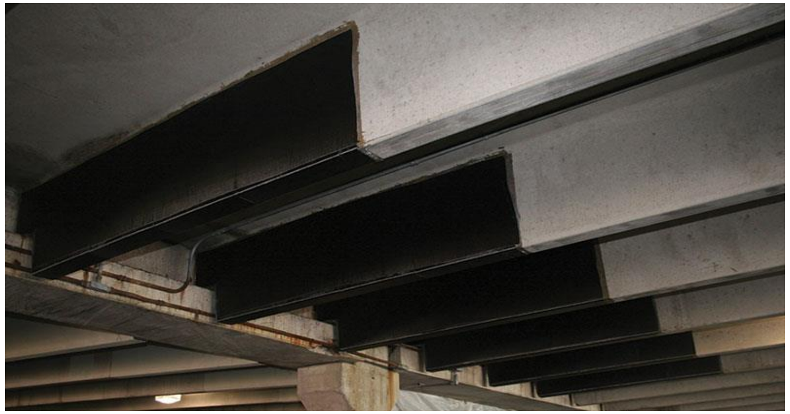
Process

- Remove the concrete cover and **clean** the reinforcing steel bars
- Coating the steel bars with an **epoxy material** that prevents **corrosion**
- Installing of the new **steel jacket**
- Pouring an **epoxy material** that ensures **bonding** between concrete members and the new steel jacket
- **Filling the space** between the concrete member and the steel jacket with an **epoxy material**



3a - Fibre-Reinforced Polymer (FRP) Jacketing

- FRPs are composite materials comprised of **high strength fibers** such as glass, carbon or steel wires embedded in a polymer matrix
- FRPs can be fabricated on site or prefabricated in a manufacturing facility
- Once cured, the FRP becomes an **integral part of the structural element**, acting as an externally bonded reinforcing system
- Most common FRPs for strengthening concrete members are **carbon** based FRPs (CFRP) - they have superior mechanical properties (high tensile strength, stiffness, durability) as compared to glass FRPs (GFRPs)
- Different shapes of FRPs can be used for strengthening applications, such as rods, bars and plates



- **Advantages of FRP strengthening**
  - ✓ No increase in the cross-sectional area
  - ✓ Minimal extra weight

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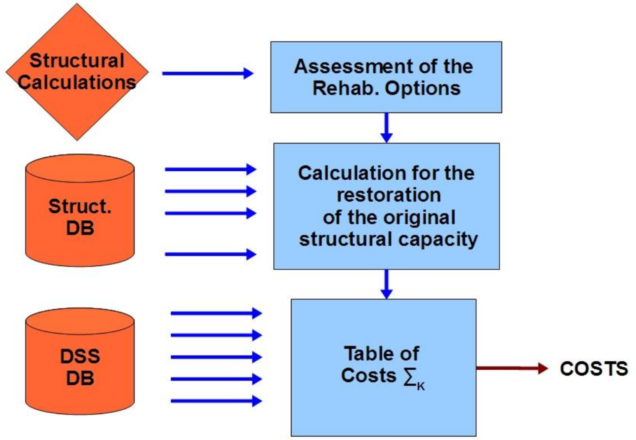
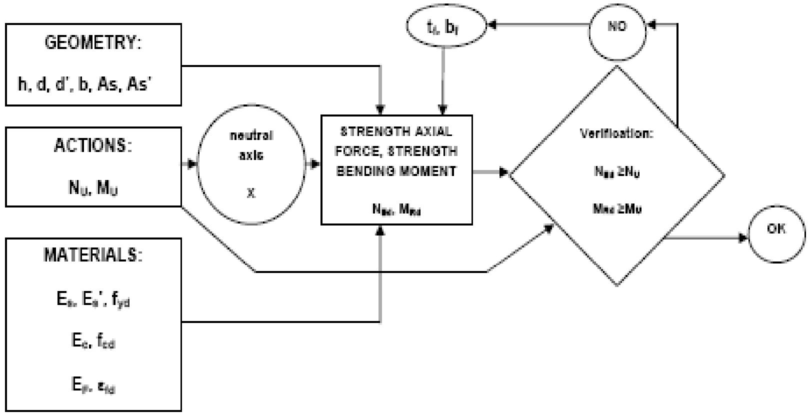
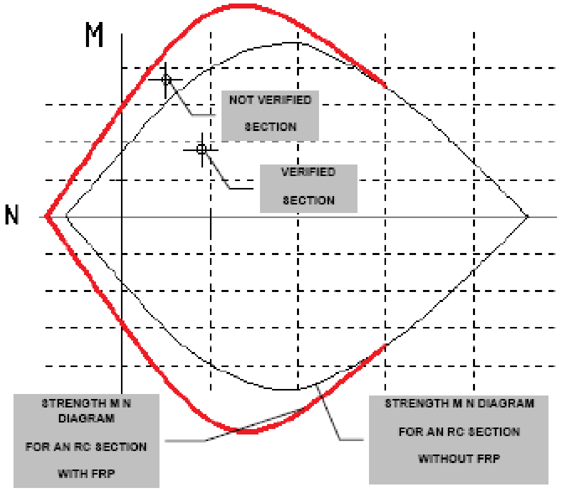
3a - Strengthening Methodology





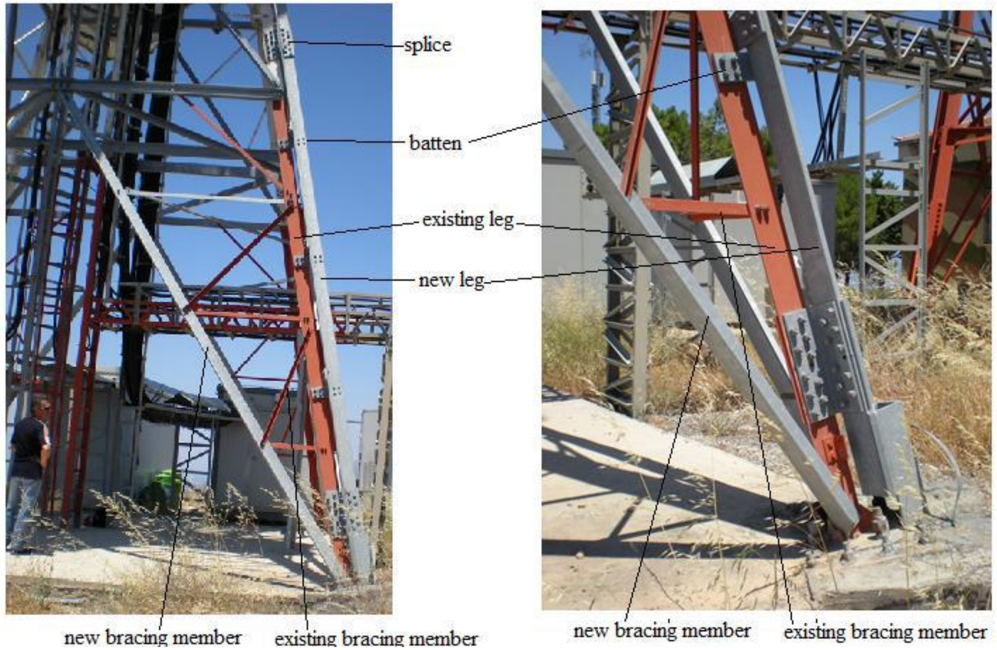
Process

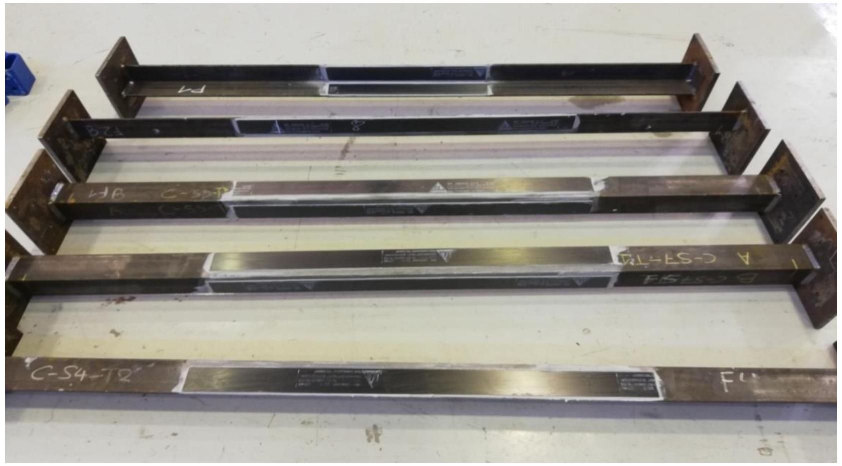
- Specify the **strengthening option(s)**
- Perform the structural assessment – Estimate the **new structural capacity**
- Estimate the **costs** and **environmental impacts** of each alternative (in case there are multiple options)
- **Select the optimum** alternative



3b - Strengthening of Steel Elements/Structures

Strengthening Methods





1. Add **extra members** from conventional or High Strength Steel (HSS)

2. **Replace existing members** with lighter members of HSS

3. Apply **Fiber-Reinforced Polymer (FRP) plates** on the steel members

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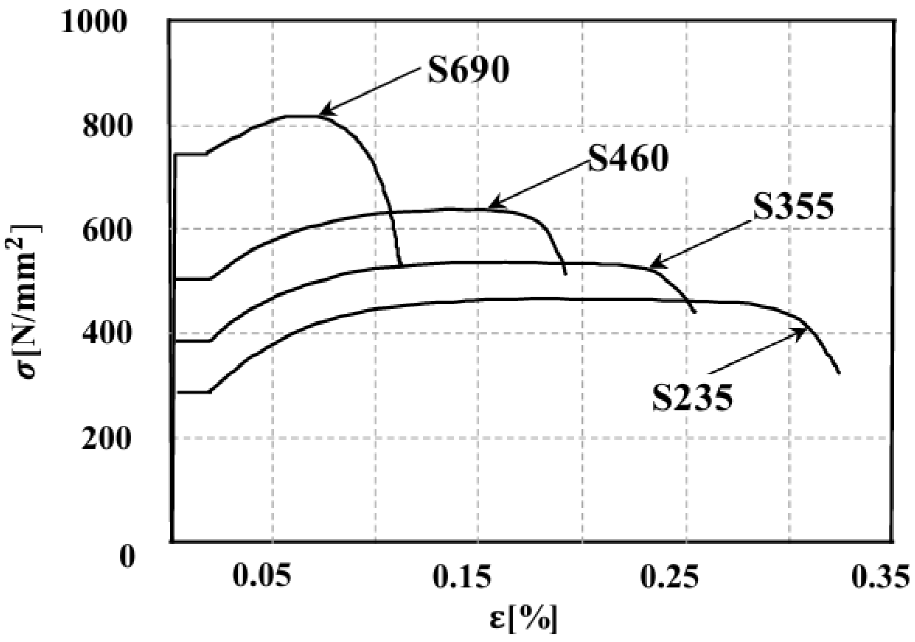
3b - High Strength Steel (HSS)

- Conventional Steel: yielding point up to 355 MPa
- High Strength Steel (HSS): **yielding point** from 460 MPa or larger
- HSS can be used for the **extra strengthening members** or for the **replacement** of the whole structure (e.g. a lattice tower)



- **Advantages of HSS**

✓ Less material required – lighter structure

✓ Lower transportation and construction costs

✓ Lower CO_2 emissions

- **Disadvantages of HSS**

✓ More prone to buckling, fatigue and deflection

✓ Higher unit cost - counterweighted by less material required

3b - Fibre-Reinforced Polymers (FRP)

- **Advantages**

✓ High tensile strength

✓ High corrosion resistance

✓ Lower weight – lower transportation cost and emissions

✓ Easy application

✓ Minimal extra weight added on the existing structure

✓ No significant change is the member dimensions (e.g. cross-section area)

✓ Steel lattice towers: no change in the wind forces attracted

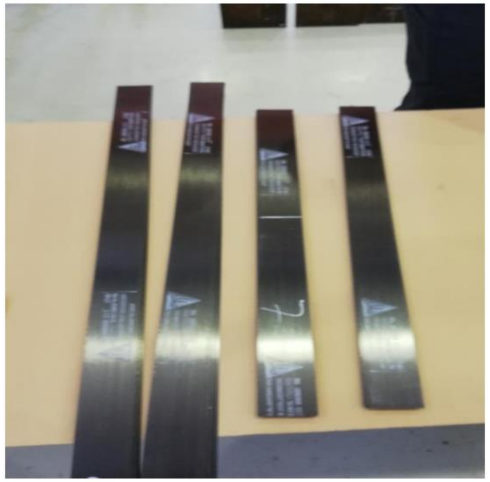
- **Disadvantages**

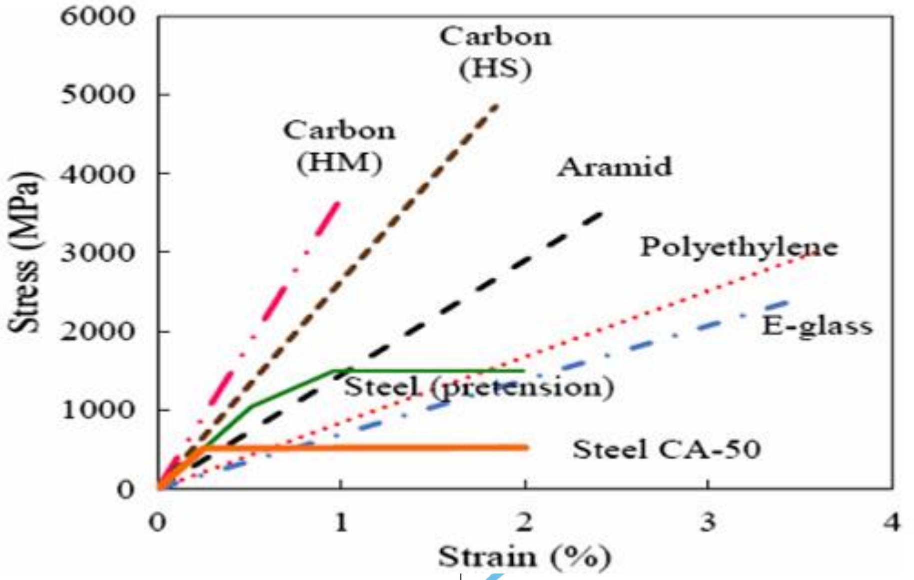
✓ Linear elastic response in tension – brittle failure

✓ Low shear strength

✓ Poor resistance to fire and high temperature

✓ Higher unit cost – can be balanced by its higher performance





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3b - Adaptation Options for RISKADAPT Pilot 2 (Transmission Tower)

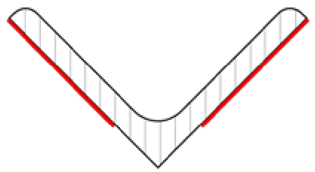
I. Rebuild the tower with HSS (S460)

- **Scenario 1 (mass reduction: 11.28%):**
  - i. Replace all members of L70x7 with L65x6
  - ii. Replace all members of L60x6 with L50x5

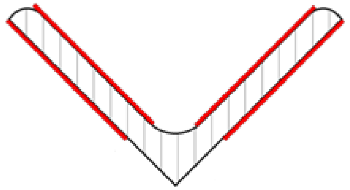
- **Scenario 2 (mass reduction: 16.30%):**
  - i. Replace all members of L70x7 with L60x6
  - ii. Replace all members of L60x6 with L50x5
  - iii. Replace all members of L50x5 with L40x4

- **Scenario 3 (mass reduction: 22.75%):**
  - i. Same as Scenario 2 except for replacing all members of L70x7 with L55x5

II. Strengthen L70x7 sections of both legs with CFRP plates (S512: 50mm x 1.2mm)



- **<u>Scenario 1 (single strengthening)</u>:**
  - ✓ Apply CFRP plate only externally
  - ✓ CFRP quantity: 256 m of plates that correspond to 24.58 Kg



- **<u>Scenario 2 (double strengthening)</u>:**
  - ✓ Apply CFRP plate both externally and internally
  - ✓ CFRP quantity: 512 m of plates that correspond to 49.15 Kg

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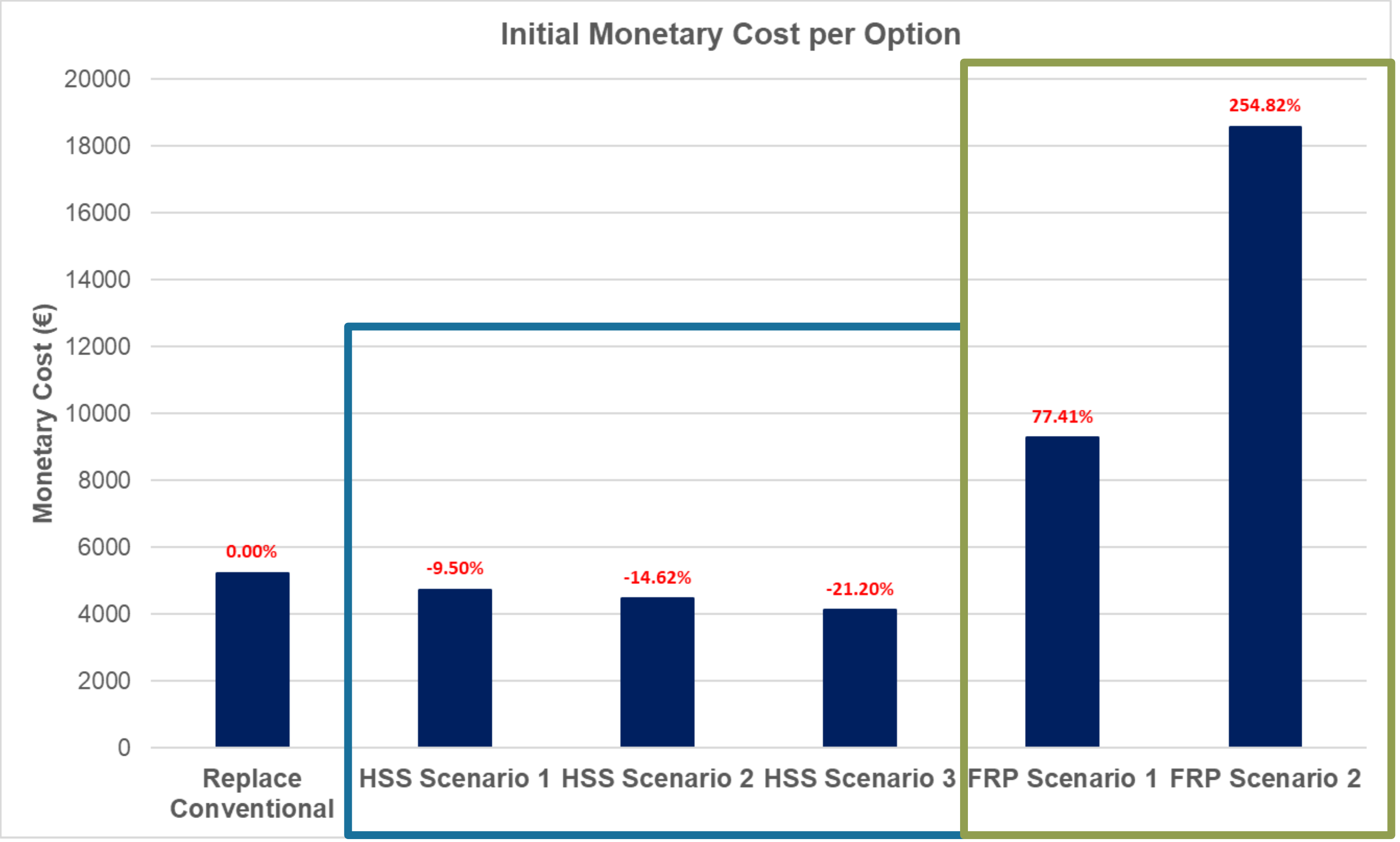
3b - Monetary Cost of Material per Option



- **Baseline Scenario:** Replace the tower with the same made by conventional steel

- **Assumptions**

✓ Conventional Steel Cost: 2000 €/tn

✓ HSS Cost: 2040 €/tn

✓ CFRP Cost: 36.30 €/m (incl. adhesive product)

Note: only the costs of purchase the raw material have been considered

- **Results**

✓ The initial cost of **all HSS scenarios is lower** than replacing with conventional

✓ **Applying CFRPs** in the existing structure results in **much higher cost** of material **BUT** it **can be balanced** since no demolition is required (lower work/costs)

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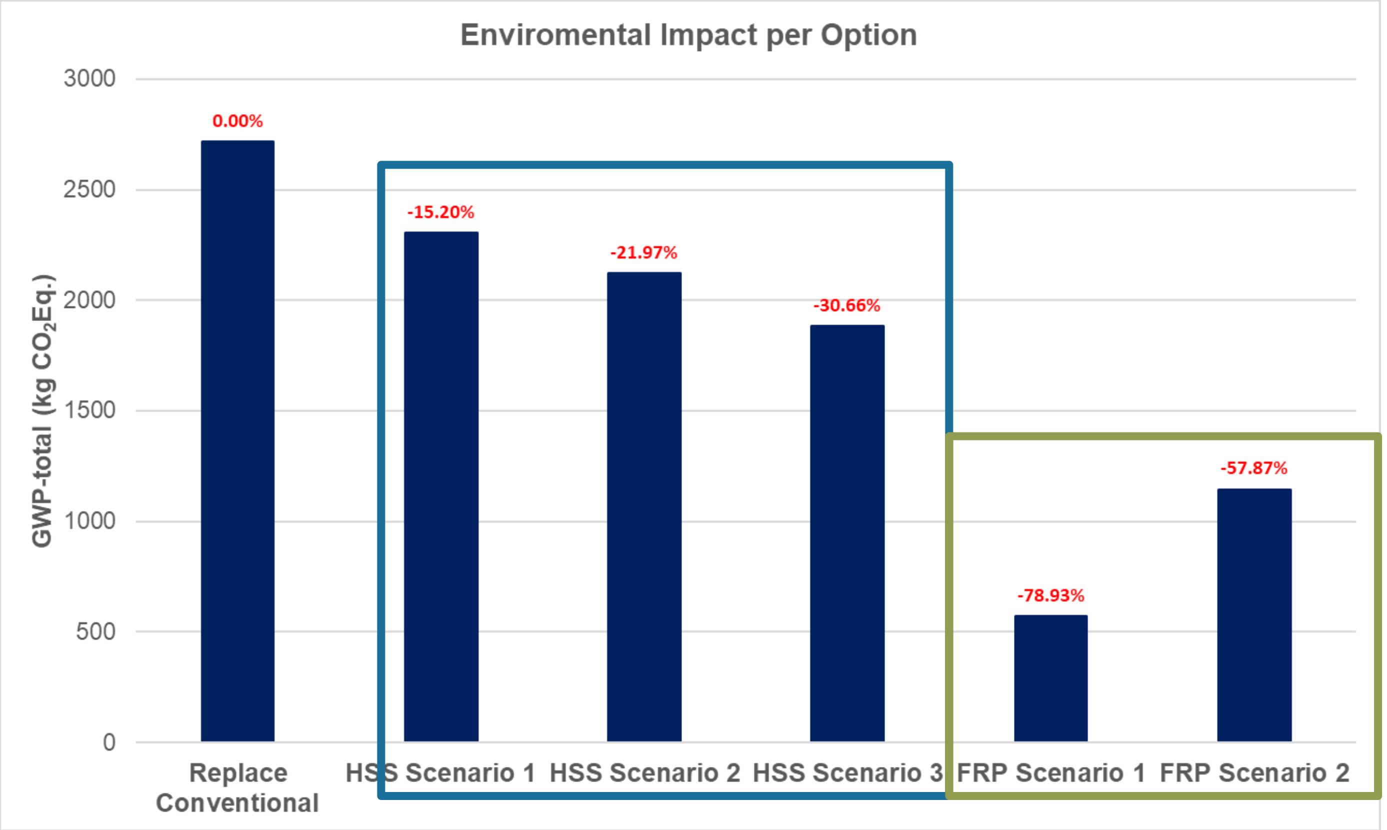
3b - Environmental Impact per Option



- **Baseline Scenario:** Replace the tower with the same made by conventional steel
- **Variable:** total Global Warming Potential (GWP)
- **Assumptions**
  - ✓ The total GWP has been estimated only for the production & installation phases of lifecycle (phases A1-A3 & A5)
  - ✓ In the HSS scenarios, the contribution in GWP from EoL and recycling (phases C1-C4 & D) of the existing tower has been considered

- **Results**
  - ✓ All scenarios result in lower total GWP
  - ✓ **CFRPs** show the greatest GWP reduction: ~79% for single scenario and ~58% for double scenario

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Conclusion

1. Climate change will foster adaptation options based on both costs **AND** environmental impacts
2. The evaluation of corrective actions can bring two main scenarios
   - Replacement (partial or full)
   - Refurbishment
3. In case concrete replacement, low carbon drivers need to be considered
   - It is possible to optimise the structure from a GWP point of view
   - Limited impacts on the costs
4. In case of concrete repair
   - Different methodologies are available
   - Balance between environmental, monetary and technical considerations is needed
5. In case of steel repair
   - Environmental and monetary drivers are opposite
   - Need to balance the two drivers (but taking into account also the different boundary conditions like costs, speed, etc...)

THANK YOU!

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http://riskadapt.eu/

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