# Life Cycle Cost Assessment of Civil Infrastructure Reinforced with Non-Corrosive Materials


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# Outline

- Sustainability assessment and life cycle perspective
- Life Cycle Cost Assessment (LCCA) or Life Cycle Costing (LCC)
- Case study: Halls River Bridge
- LCC of Halls River Bridge
- Comparative LCC of Halls River Bridge
- Conclusions

# Sustainability assessment and life cycle perspective

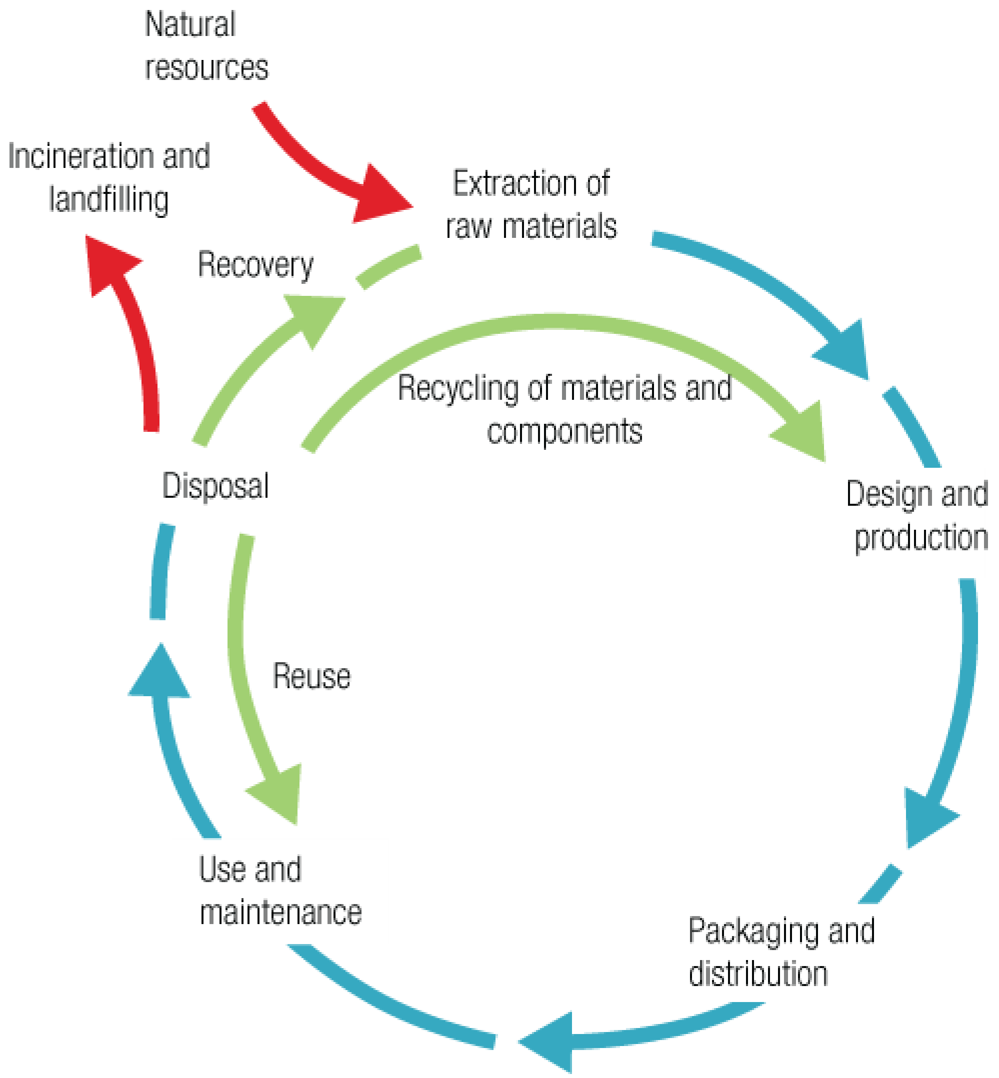
# Life Cycle Thinking (LCT)

"Life Cycle Thinking (LCT) is about going beyond the traditional focus on production site and manufacturing processes to include environmental, social and economic impacts of a product over its entire life cycle."

https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

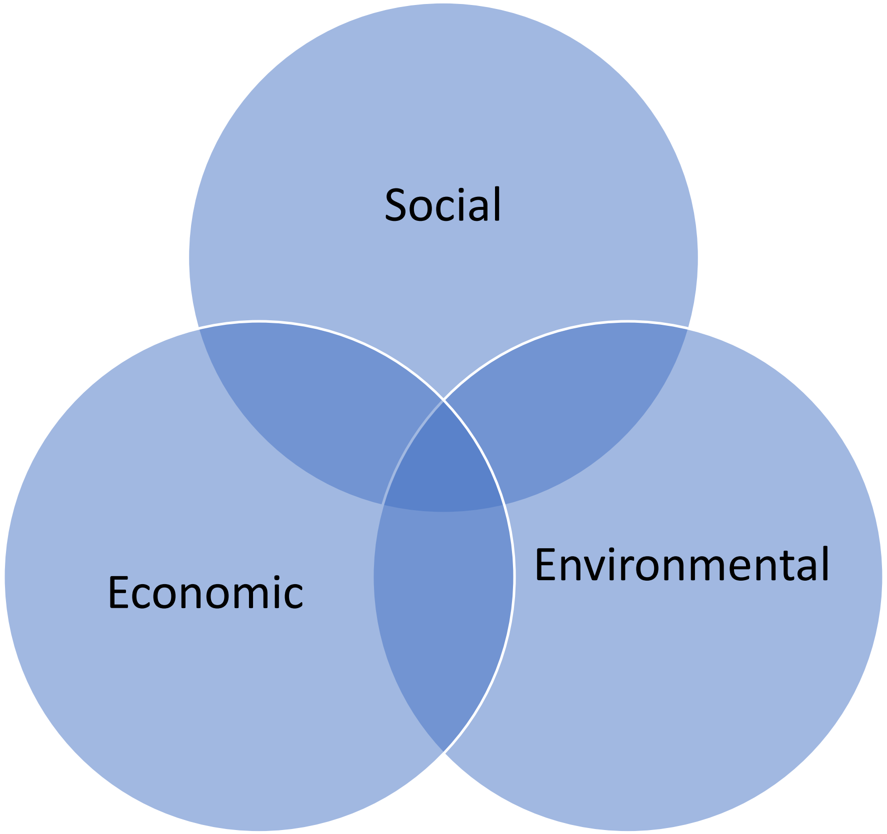
# Life Cycle Thinking (LCT)

Life stages of the product




https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

# Key sustainability pillars

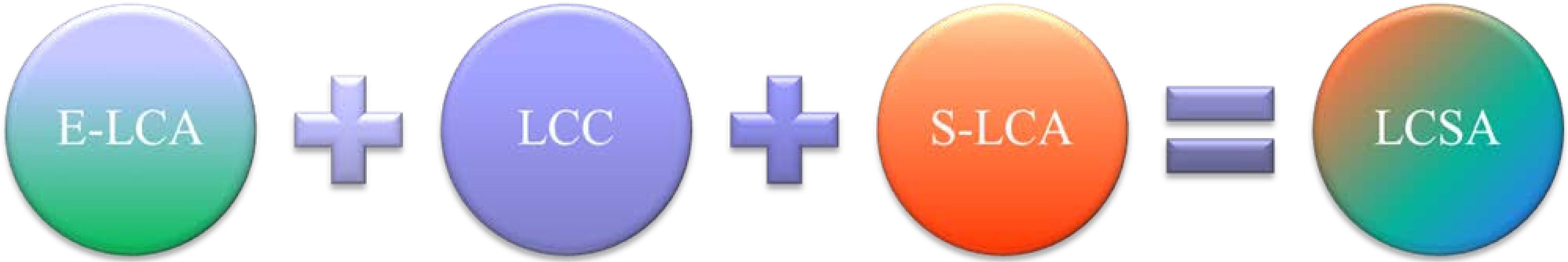


# Life Cycle Management (LCM)

Life Cycle Management is the way to make operational LCT.

- Environmental Life Cycle Assessment (E-LCA)
- Life Cycle Cost Assessment (LCCA) or Life Cycle Costing (LCC)
- Social Life Cycle Assessment (S-LCA)

# Life Cycle Sustainability assessment




https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/life-cycle-sustainability-assessment/

# Standardization framework

ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services

| | | | |
|---|---|---|---|
| **Methodological basics** | ISO 15392 Sustainability in buildings and civil engineering works — General principles<br>ISO/TS 12720 Sustainability in buildings and civil engineering works — Guidelines on the application of the general principles in ISO 15392<br>ISO/TR 21932 Sustainability in buildings and civil engineering works — A review of terminology<br>ISO 20887 Sustainability in buildings and civil engineering works — Design for disassembly and adaptability of buildings | | |
| | ISO 21929-1 Sustainability in building construction — Sustainability indicators — Part 1: Framework for the development of indicators and a core set of indicators for buildings<br>ISO/TS 21929-2 Sustainability in building construction — Sustainability indicators — Part 2: Framework for the development of indicators for civil engineering works | | |
| **Construction works** | ISO 16745-1Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage — Part 1: Calculation, reporting and communication | | |
| | ISO 16745-2 Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage— Part 2: Verification | | |
| | ISO 21931-1 Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 1: Buildings | | |
| | ISO 21931-2 Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment —Part 2: Civil engineering works | | |
| **Construction products and services** | ISO 21930 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services | | |
| | **Environmental aspects** | **Economic aspects** | **Social aspects** |

# Sustainability in the construction sector

- ISO 21931-1:2021. Sustainability in buildings and civil engineering works. Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment. Part 1. Buildings | Status: Current, Draft for public comment | Published 17/05/2021
- ISO 21931-2:2019 Sustainability in buildings and civil engineering works. Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment. Civil engineering works

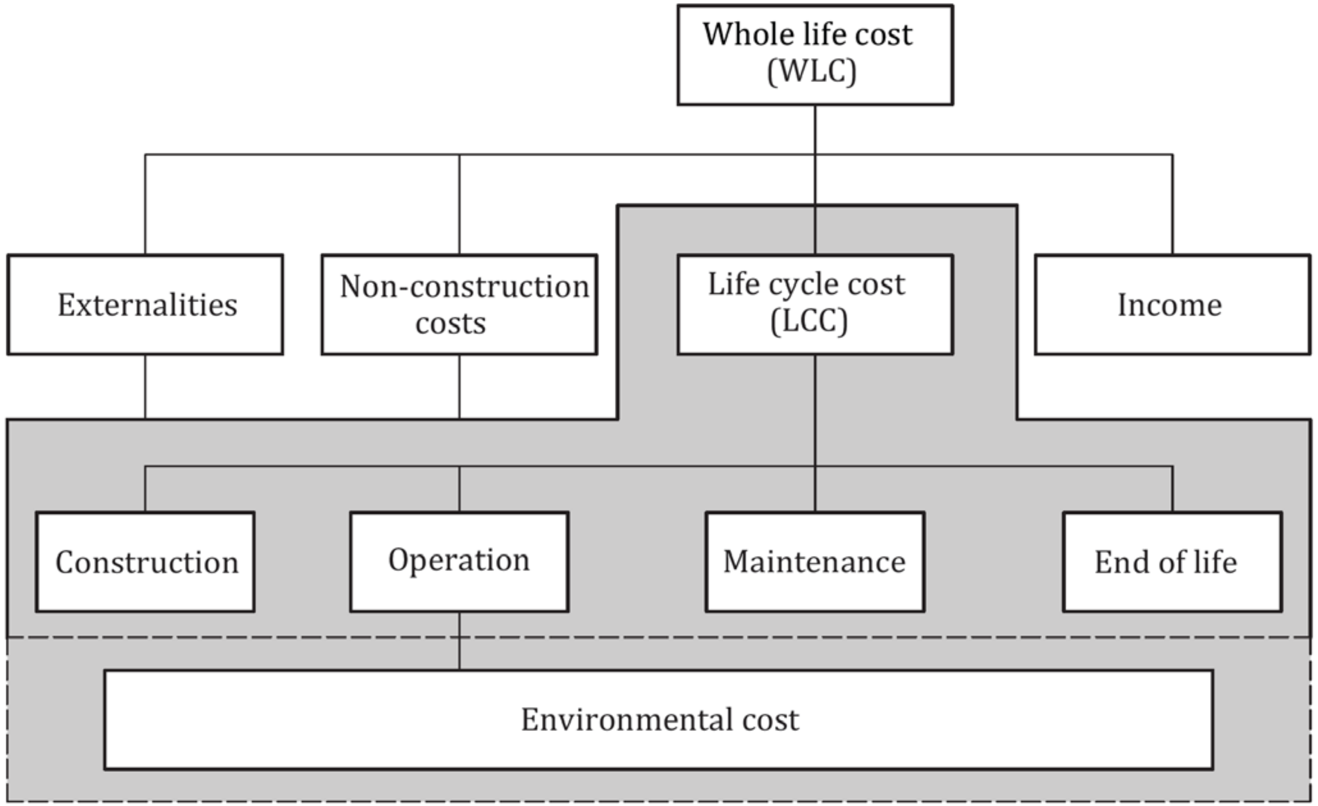
# Life Cycle Cost Assessment (LCCA)
# or
# Life Cycle Costing (LCC)

# LCC Standard

ISO 15686-5:2017 Buildings and constructed assets — Service life planning Part 5: Life-cycle costing

**Life Cycle Costing** is a methodology for systematic economic evaluation of *life-cycle costs* over a period of analysis that covers the entire life cycle or (a) selected stage(s) or periods of interest thereof.

# Whole life cost vs Life cycle cost

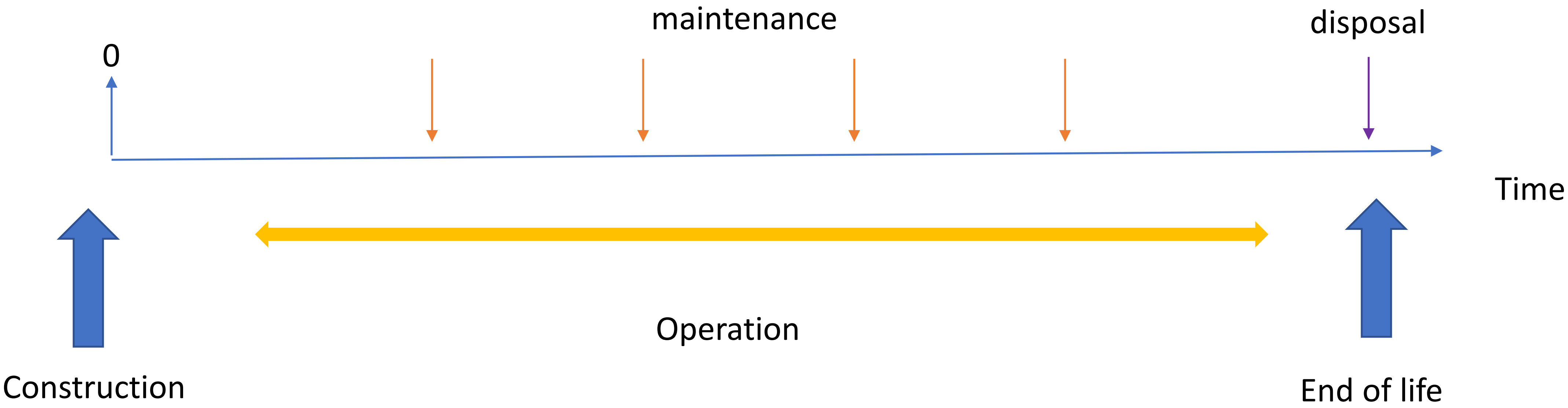



ISO 15686-5:2017 Buildings and constructed assets — Service life planning Part 5: Life-cycle costing

# Cost type in LCC

- Acquisition costs
- Capital costs
- Maintenance costs
- Operation costs
- End-of-life costs
- Environmental costs
- External costs

# Life cycle of construction assets



# Real and nominal costs

- Real costs ensure accuracy, but they might not be the best choice for preparing financial budgets
- Nominal costs are calculated by multiplying the real cost by the inflation/deflation factor

$$q_{i,d} = (1 + a)^n$$

n is the number of years between the base date and the occurrence of the cost;

$a$ is the expected percentage increase in prices per annum

# Discounted costs

Discounted costs are costs that occur in future years reduced by a factor derived from the discount rate.

Different discount rates may apply depending on whether nominal costs or real costs are being discounted.

If nominal costs are used, the nominal discount rate includes an inflation/deflation factor.

If real costs are used, the real discount rate does not include an inflation/deflation factor.

# Net Present Value (NPV)

The net present value is the sum of discounted benefits less the sum of discounted costs.

$$NPV = \sum_{n=1}^{p} \frac{C_n}{(1+d)^n}$$

$C_n$ is the cost in year $n$;

$d$ is the expected real discount rate per annum;

$n$ is the number of years between the base date and the occurrence of the cost;

$p$ is the period of analysis (reference life time)

# Case study
# Halls River Bridge

# Halls River Bridge (HRB), Homosassa, Florida

- Short-spanned vehicular bridge
- Five spans
- Total length of 56.7 m
- Width of 17.6 m
- FRP-RC/PC bridge
- Designed for a service life of 100 years

# HRB design features

- 36 CFRP-PC bearing piles
- 235 CFRP-PC/GFRP-RC sheet piles
- 6 GFRP-RC bent caps and bulkhead caps
- 998 m2 GFRP-RC bridge deck
- 150 m long GFRP-RC traffic railings
- two 161 m2 GFRP-RC approach slabs
- 20 m long GFRP-RC gravity wall


# HRB materials

- Concrete mixed with seawater for the bulkhead cap
- Concrete with Recycled Concrete Aggregates (RCA) and concrete with Recycled Asphalt Pavement (RAP) aggregates for the GFRP-RC gravity walls
- White cement concrete and another mixture of high-content slag and fly ash are used in the GFRP-RC traffic railings (for enhanced night-time and wet weather visibility.

# LCC

# Halls River Bridge

# Halls River Bridge: life cycle stages

- **Materials manufacturing**
  - Structural elements
  - Non structural elements
- **Construction**
  - Transportation to site
  - Site equipment
  - Construction waste management
- **Use**
  - Operation
  - Maintenance
  - Rehabilitation / Reconstruction
- **End-of-Life**
  - Demolition / Dismantling
  - Recycling / Reuse
  - Final disposal (Landfilling or Incineration)

# Halls River Bridge: scope

Activities non considered:

- Common to any version of the bridge (street lighting, road markings)
- Minor relevance (formworks, temporary buildings for workers)
- Traffic related emissions
- Accidental or unforeseen repairs (car crashing)

# Halls River Bridge: data collection

Materials manufacturing:

- Concrete mix design ✓
- Concrete amounts ✓
- Reinforcing amounts ✓
- Materials transport
  - Location & distance ✓
  - Means of transport ✓

Construction:

- Materials transport to site:
  - Location & distance ✓
  - Means of transport ✓
- Site vehicles and equipment:
  - Type, power and fuel
  - Working time

# Halls River Bridge: data collection

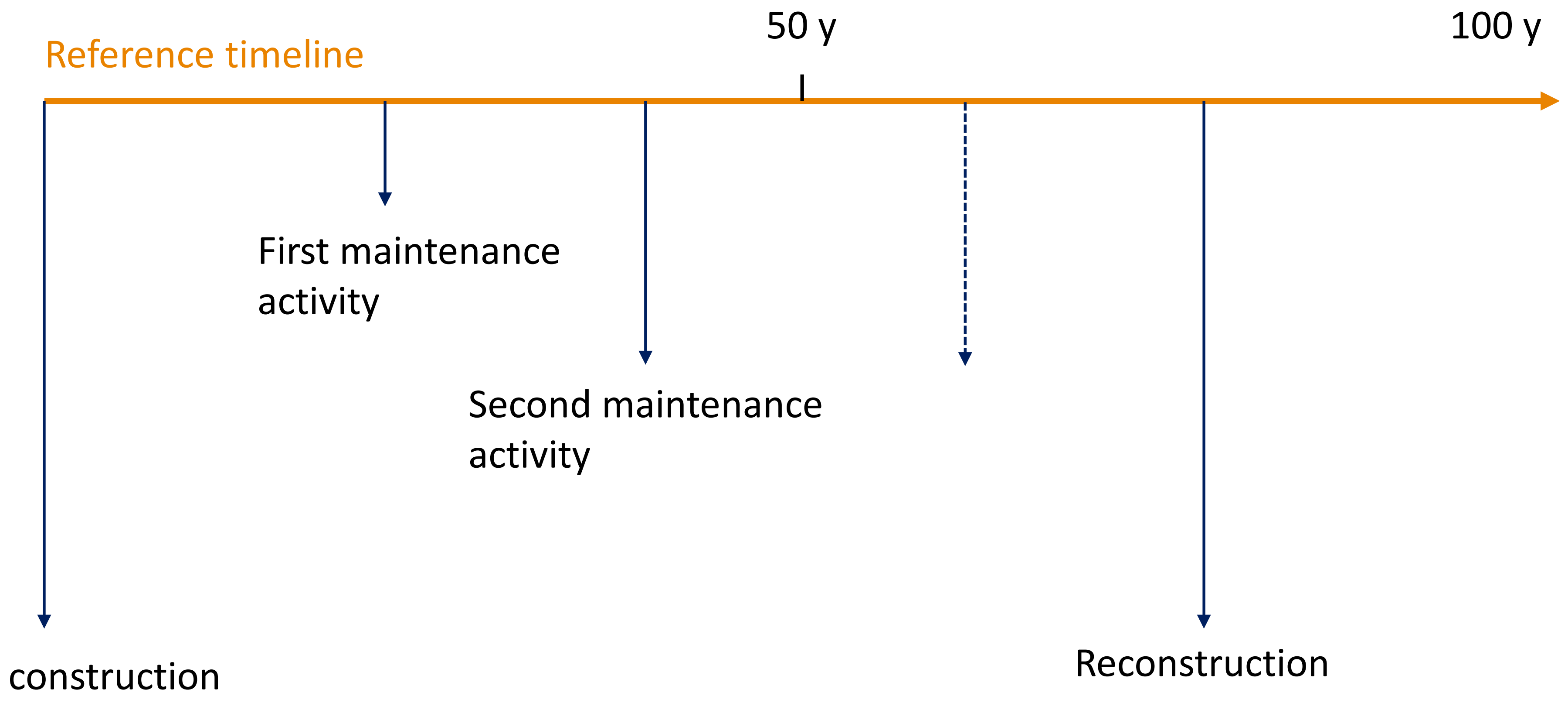
Operation

- Maintenance schedule:
  - Frequency
  - Type (materials substitution, equipment)
- Reconstruction in case life span is shorter that the reference life adopted in FU
  - When

End-of-Life scenarios (present statistics or other sources)

- Demolition (equipment, working time)
- Amount recyclable materials:
  - % of recycled steel
  - % of recycled concrete
  - % of recycled GFRP
- Final fate of non recycled materials
- GFRP: type of recycling

# Timeline




*The Halls River Bridge performing the function as intended by designers for a period of 100 years*

# Comparative LCC
# Halls River Bridge

# Comparative LCC

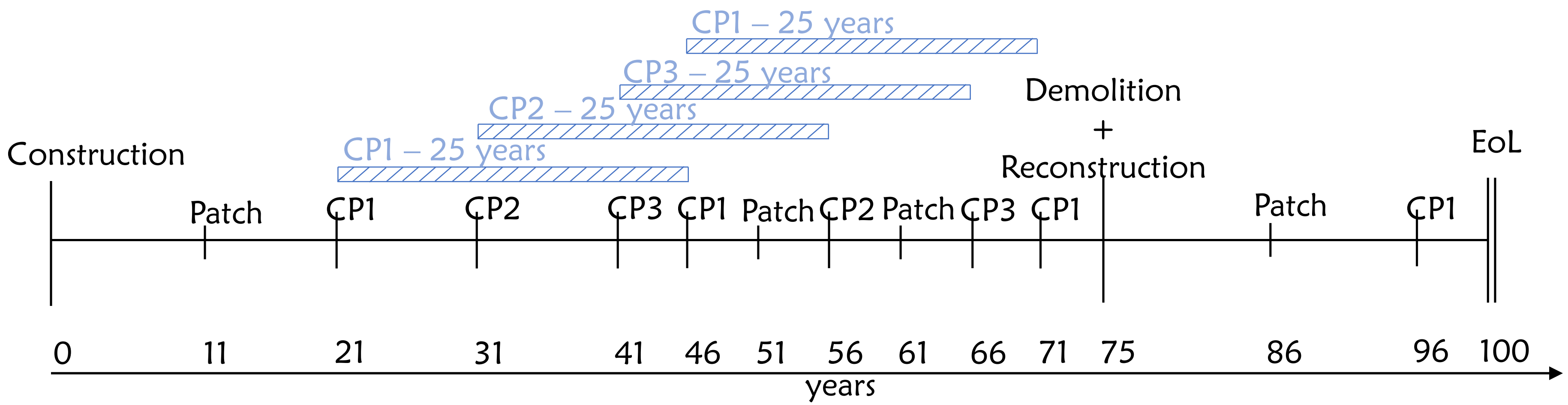
- FRP-RC/PC BRIDGE DESIGN (100 years service life)
- CS-RC/PC BRIDGE DESIGN (75 years service life)

| COMPONENTS | | FRP/STEEL RATIO |
|---|---|---|
| PRECAST | GIRDERS | 2.0 |
| CIP | BENT CAPS | 2.0 |
| | BULKHEAD CAPS | 1.5 |
| | DECK | 1.5 |
| | CONCRETE TRAFFIC RAILING | 1.7 |
| | APPROACH SLAB | 1.3 |
| | GRAVITY WALL | 1.0 |

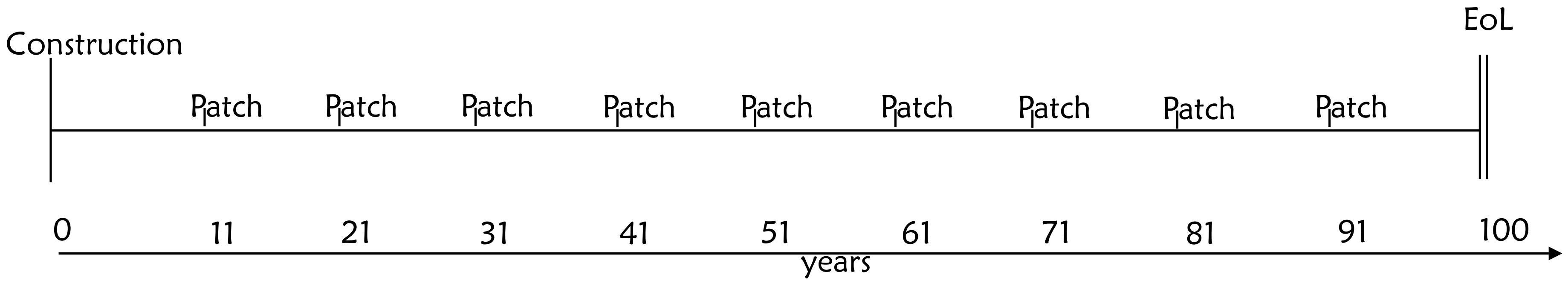
# HRB materials

| | COMPONENTS | QUANTITY | MATERIALS | DESCRIPTION |
|---|---|---|---|---|
| PRECAST | BEARING PILES | 575.77 m | CFRP-PC | Square section 0.46 m x 0.46 m; CFRP strand and spirals from Japan (Tokyo); Piles assembled and cast in Jacksonville (FL). |
| | SHEET PILES | 1,395.68 m | CFRP-PC / GFRP-RC | Rectangular section 0.30 m x0.76 m; CFRP longitudinal strand from Japan (Tokyo); GFRP transversal reinforcement from Canada; Sheet piles manufactured in Jacksonville |
| | GIRDERS | 495.00 m | GFRP-RC | Nine girders per each span (total of five spans); GFRP-RC; |
| CIP | BENT CAPS | 139.38 $m^3$ | GFRP-RC | Six bent caps with six piles per bent |
| | BULKHEAD CAPS | 72.66 $m^3$ | GFRP-RC | |
| | DECK | 998.43 $m^2$ | GFRP-RC | CIP; Concrete: CLASS IV 5500 PSI |
| | ADDITIONAL FRP-RC COMPONENTS | | | |
| | TRAFFIC RAILINGS | 149.96 m | GFRP-RC | |
| | APPROACH SLAB | 322.37 $m^2$ | GFRP-RC | |
| | GRAVITY WALL | 19.51 m | GFRP-RC | RAP (9.75 m)<br>RCA (9.75 m) |

# Periodical maintenance and repair activities




Steel-RC/PC alternative




FRP-RC/PC alternative

# LCC results: discount rate 1%

| RESULTS | | |
|---|---|---|
| | CS-RC/PC BRIDGE | FRP-RC/PC BRIDGE |
| NET PRESENT VALUE (NPV) | $ 7,858,262 | $ 6,287,592 |
| NET SAVING (NS) | | $ 1,570,670 |
| ANNUAL SAVING (AS) | | $ 15,707 |

# Conclusions

- Materials (GFRP and CFRP more expensive than CS)
- Maintenance (more frequent and serious operations in CS-RC/PC)
- Service life (100y for FRP-RC/PC vs. 75y for CS-RC/PC)

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