A Circular Life Cycle Cost Model

Quantifying the financial implications of projected level of circularity in real estate development projects

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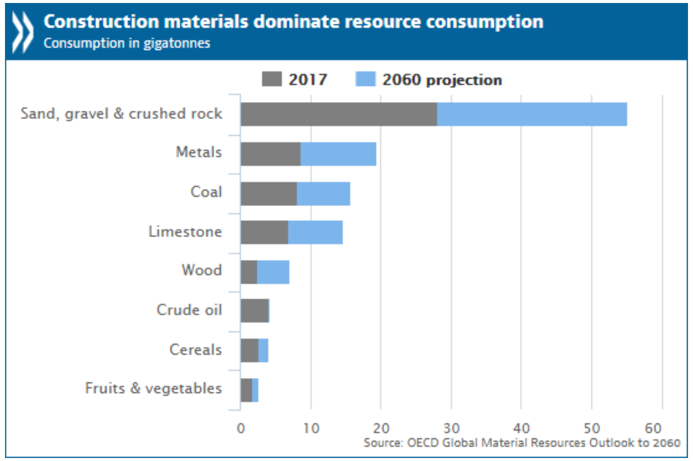
01 | Introduction

Context



(OECD,2017)

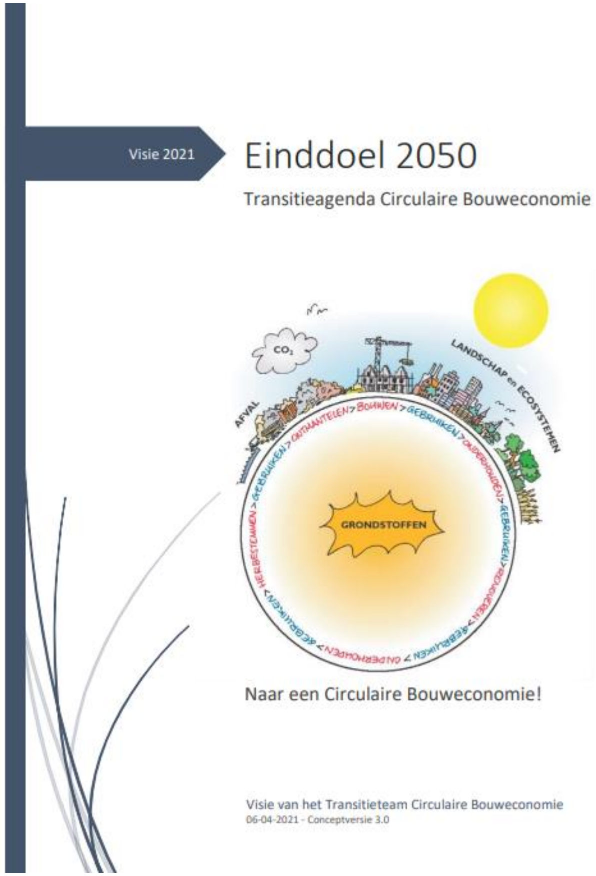
≡ Menu | nrc›

EU akkoord over 55 procent minder CO2-uitstoot in 2030

Klimaatwet Hoe de doelstelling precies gehaald moet worden, wordt later uitgewerkt. Het is voor het eerst dat wettelijk wordt vastgelegd dat de EU in 2050 klimaatneutraal moet zijn.

Ester Meerman · 21 april 2021 · Leestijd 1 minuut

(NRC, 2021)



Circulaire Bouweconomie, 2021)

Environment

Sea level rise could hit 2 metres by 2100 - much worse than feared

New Scientist, 2019)

(University Utrecht, 2022)

Context

LINEAR ECONOMY

CIRCULAR ECONOMY

(COBUILDER, 2018)

Problem statement

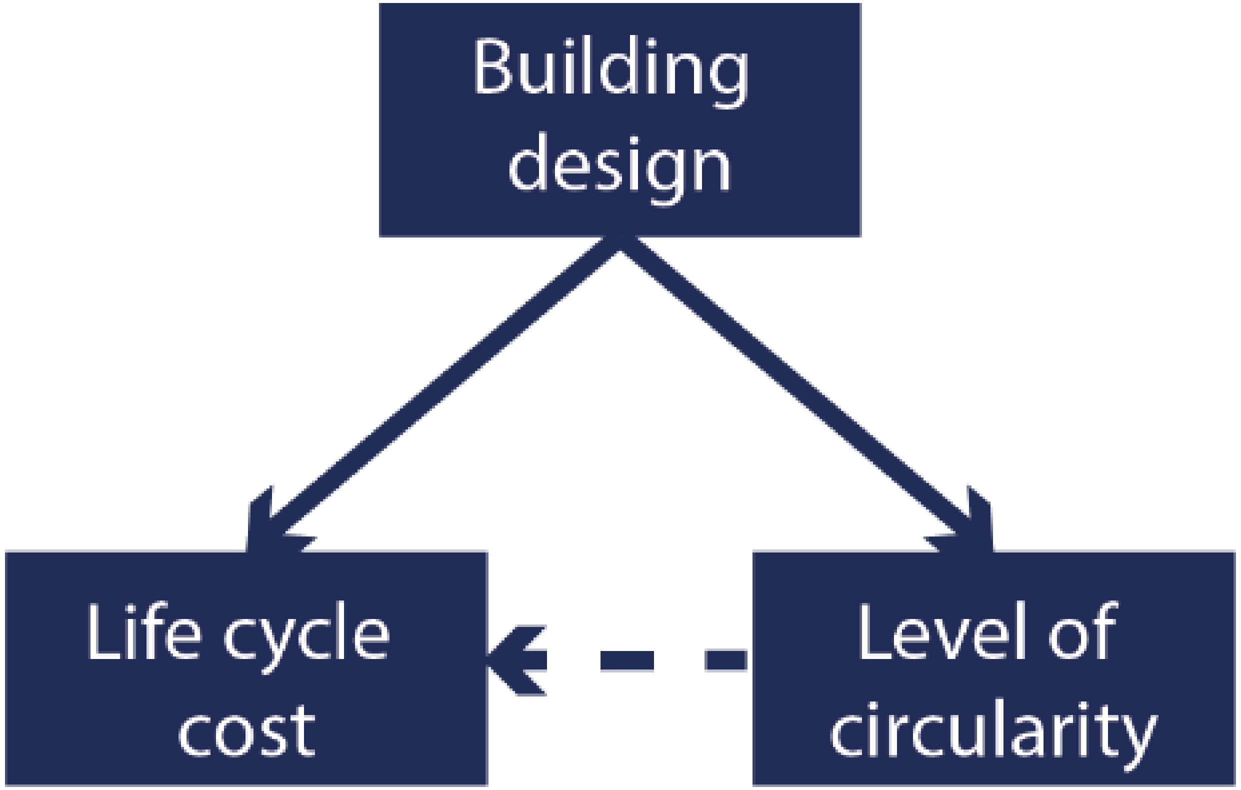
- High environmental impact of the construction industry.
- Limited implementation of circular economy principles in construction.
- Perception of higher costs of circular building.
- There is a lack of circular cost models.

Limited research on the financial implications of applying circular economy principles in the construction sector.

02 | Research design and approach

“How can life cycle cost and circularity metrics be developed and framed for circular real estate development projects?”

Conceptual model of the research



Research design

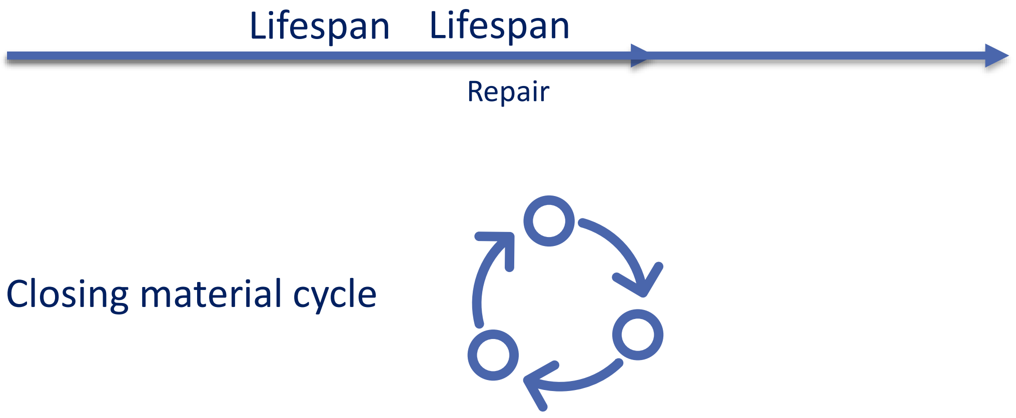
Research design

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Literature study →	Interviews →	Developing C-LCC tool →	Case study modelling →	Conclusion
Circular strategies/ building levels	Barriers & obstacles	Requirements of tool	Case study selection	Validation of tool and data
Circular assessment	Input model/ scenarios	Realizing concept tool	Scenario selection	Circular life cycle cost model
Circular LCC	Measuring uncertainties	Describing every step	Relations between LoC & LCC	
Criteria for model	Semi-structured interviews	Designing of tool	Analysis results	

03 | Theoretical background

What is a circular built environment?

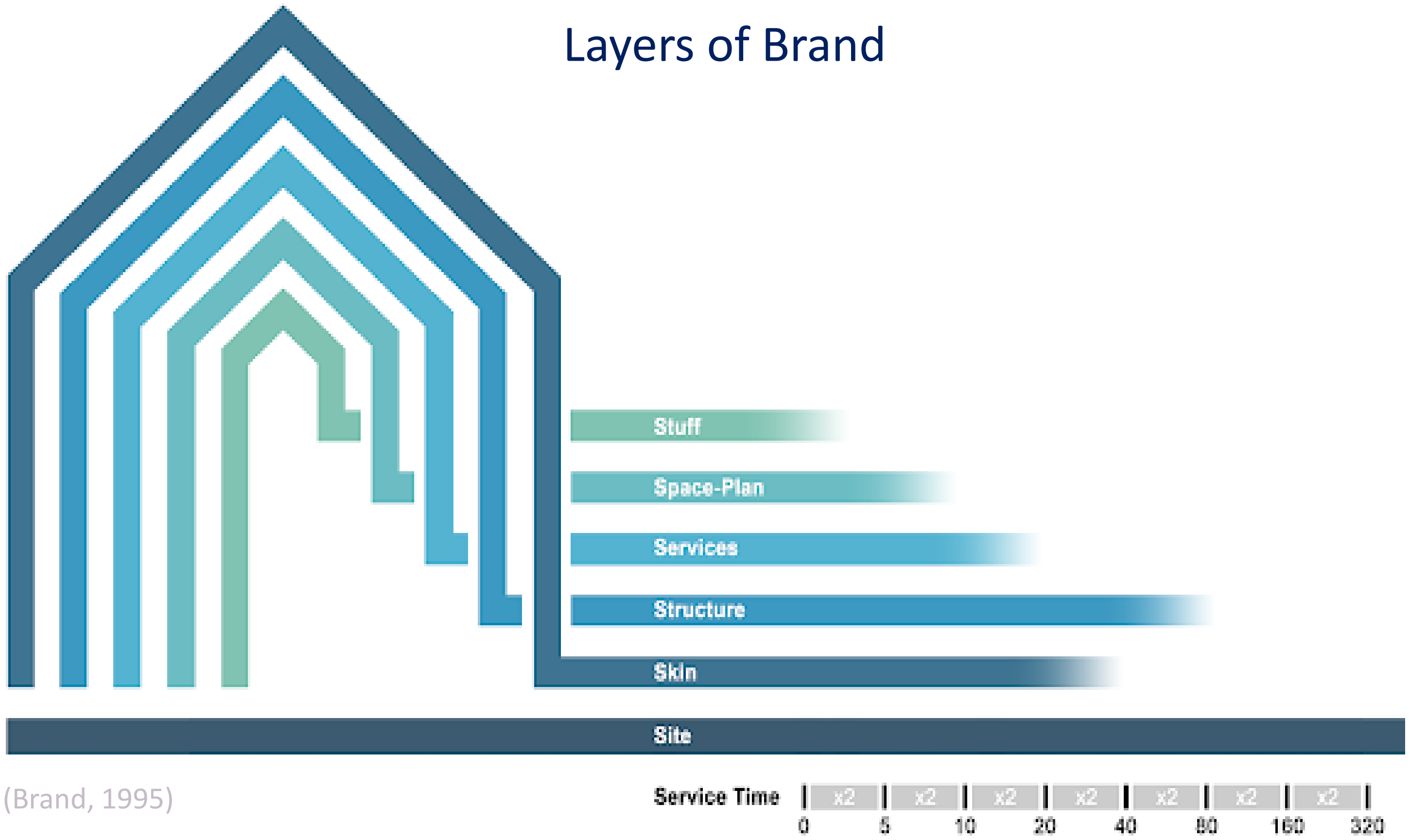
- Compressing cycles
  - Use of renewable resources
- Extending cycles
  - Extending lifetime of component
- Cycling back-cycles
  - Reuse of components



How to design a circular building?

- Selection of circular materials
- Design for disassembly
- Design for adaptability
- Layers of Brand

Layers of Brand



(Brand, 1995)

How to assess circularity?

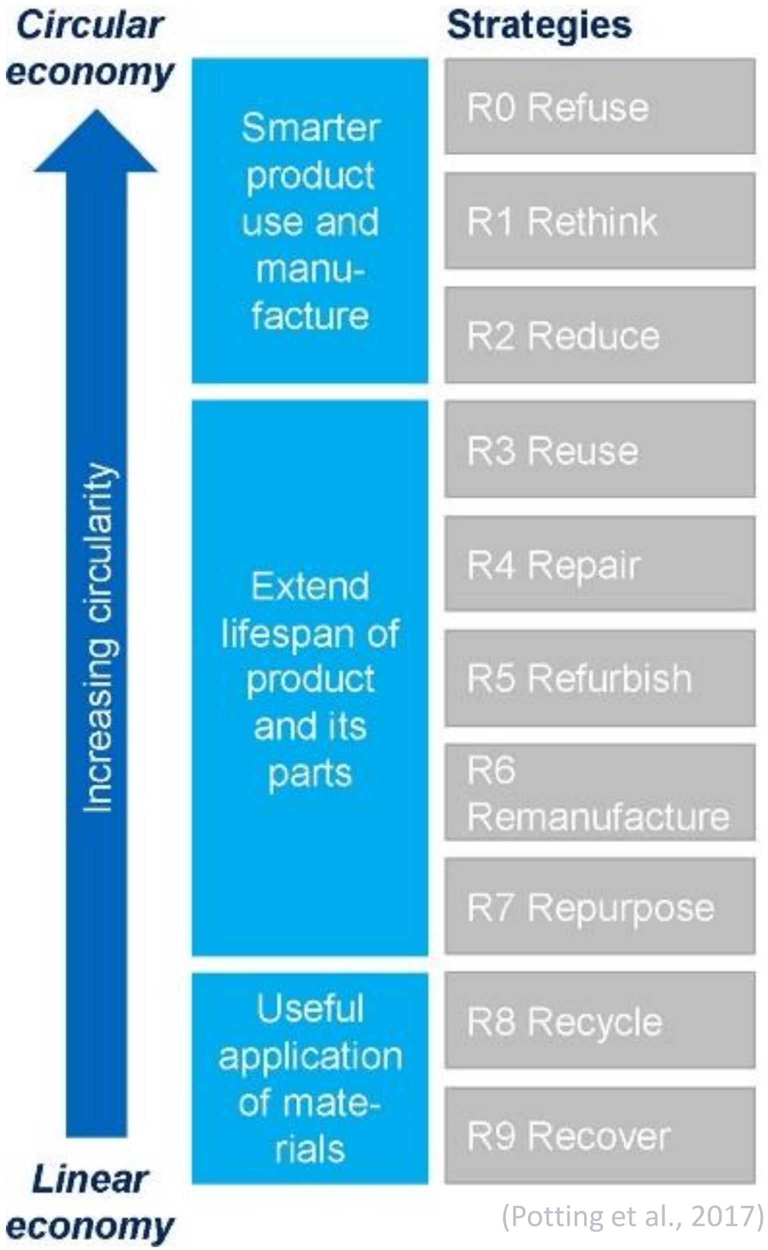
Assessment values:

- Functionality
- Technical
- Economic
- Social

Assessment methods:

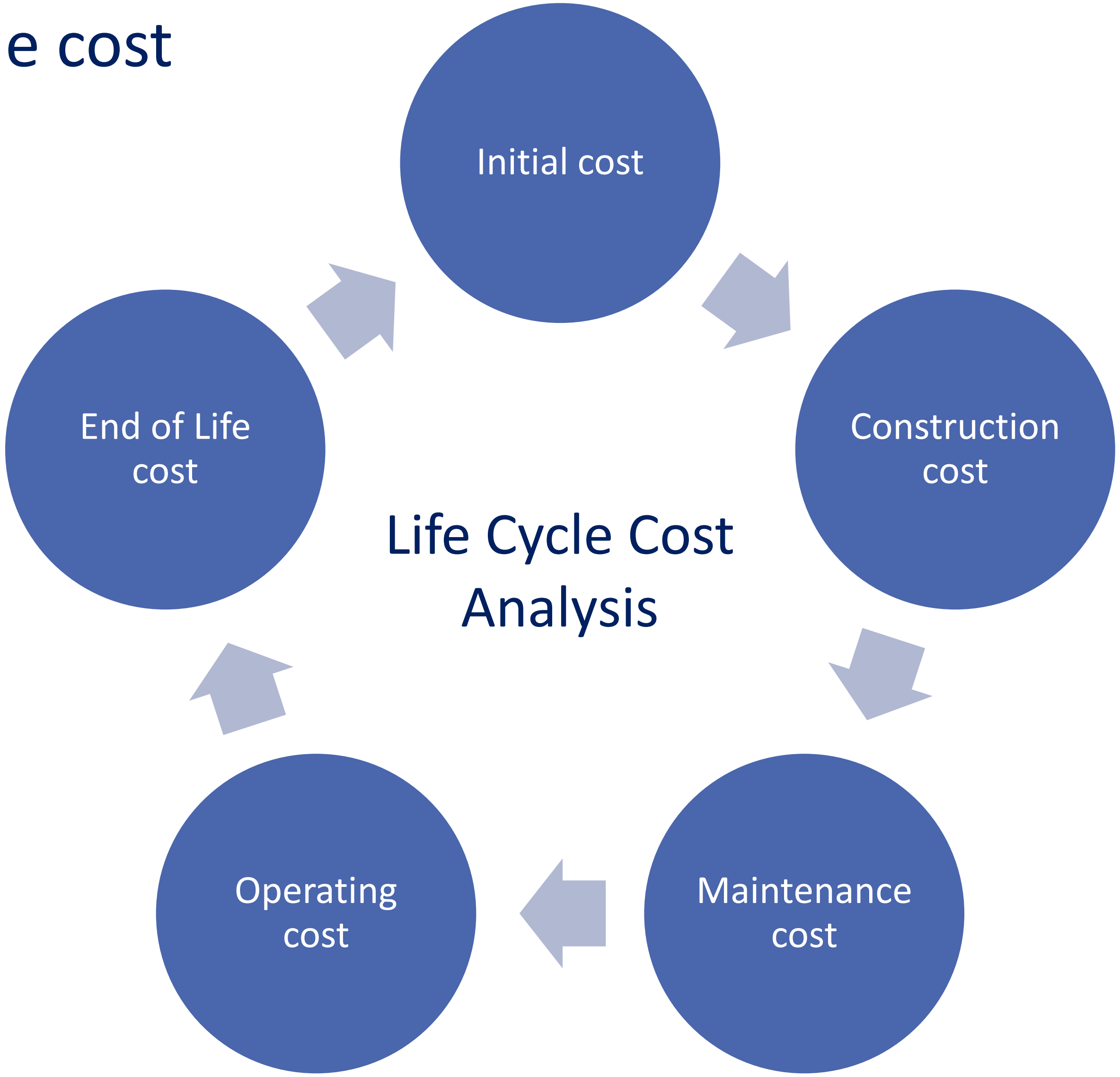
There is still no holistic assessment model for circularity

Circular strategies



(Potting et al., 2017)

Life cycle cost



Time value of money

- Discount rate
- Inflation rate

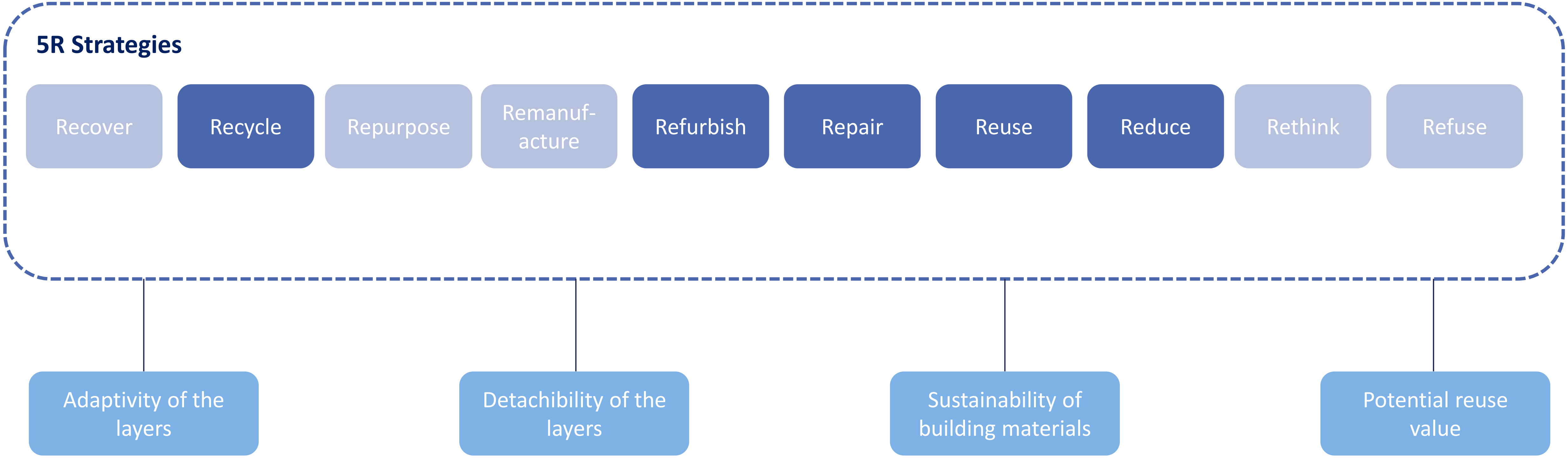
04 | Development of the tool

Synthesis of literature and interviews

10R Strategies

- Recover
- Recycle
- Repurpose
- Remanuf-acture
- Refurbish
- Repair
- Reuse
- Reduce
- Rethink
- Refuse

Synthesis of literature and interviews

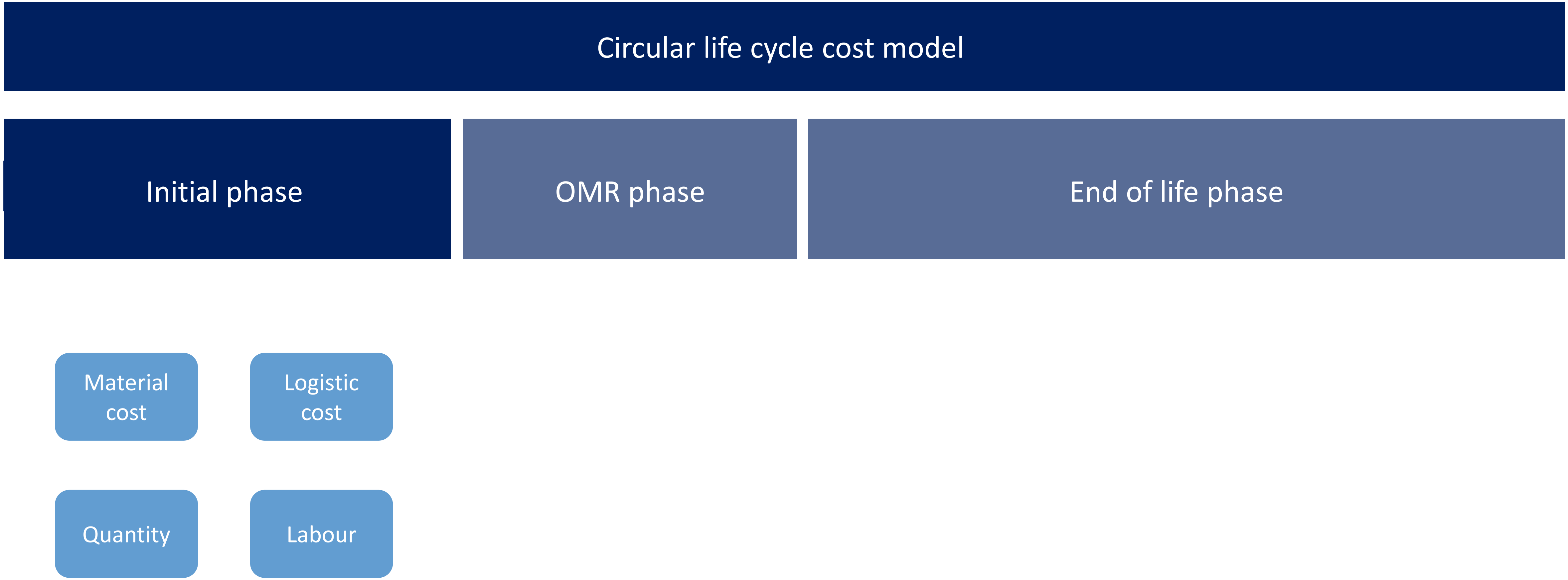


Design of the tool:

Circular life cycle cost model

Initial phase	OMR phase	End of life phase

Design of the tool:



Design of the tool:

Circular life cycle cost model

Initial phase

OMR phase

End of life phase

OMR cost

Reuse value

Recycle value

Design of the tool:

Circular life cycle cost model

Initial phase	OMR phase	End of life phase

- Loss product
- Quality reduction
- Dismantling cost
- Revision cost
- Transport cost
- Storage cost

Example

Initial phase

Linear window frame

Material cost

Logistic cost

Quantity

Labour cost

€570,-

Circular window frame

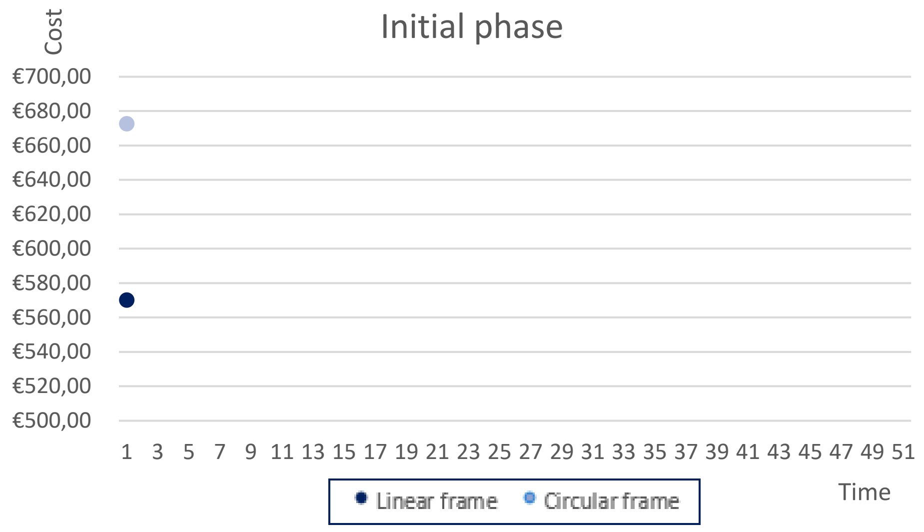
Material cost

Logistic cost

Quantity

Labour cost

€672,-



Initial phase

Linear window frame

Material cost

Logistic cost

Quantity

Labour cost

€570,-

Circular window frame

Material cost +20%

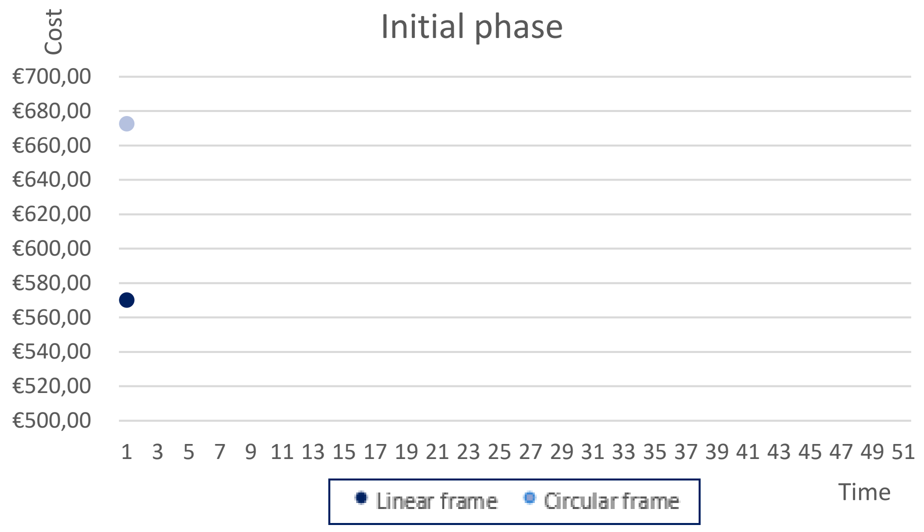
Logistic cost

Quantity

Labour cost -10%

€672,-

+ 18%



OMR phase

Linear window frame

OMR cost

Reuse value

Recycle value

€252,- / 10y

€570,- / 30y

Circular window frame

OMR cost

Reuse value

Recycle value

€230,- / 10y

€455,- / 30y

OMR phase

Lineair window frame

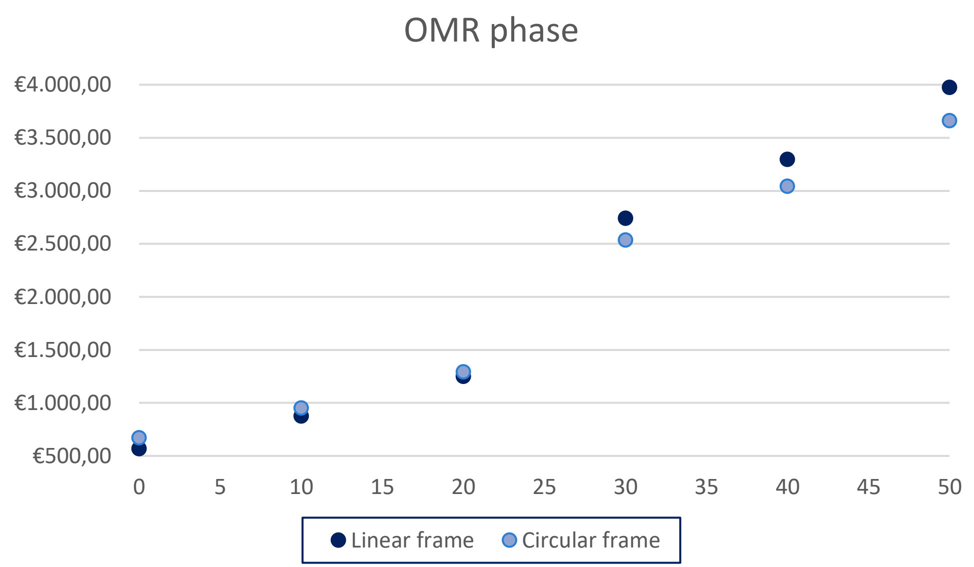
OMR cost

Reuse value

Recycle value

€252,- / 10y

€570,- / 30y



Circular window frame

OMR cost: - 9%

Reuse value: +€216,-

Recycle value

€230,- / 10y   - 9%

€455,- / 30y   - 20%

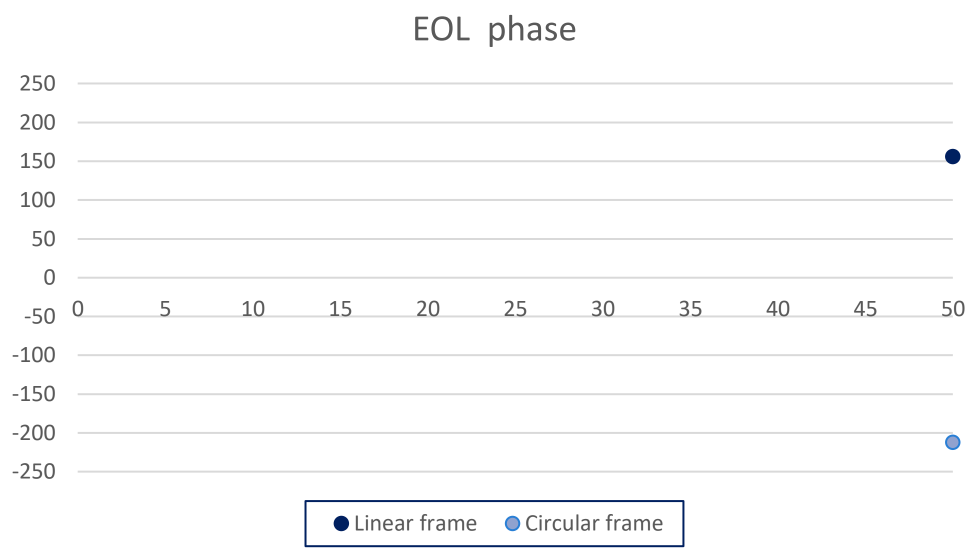
EOL phase

Lineair window frame

Dismantling cost

Transport cost

€156,-



Circular window frame

Dismantling cost

Quality reduction

Loss cost

Transport cost

Revision cost

Storage cost

- €181,-

- 216%

Life cycle cost

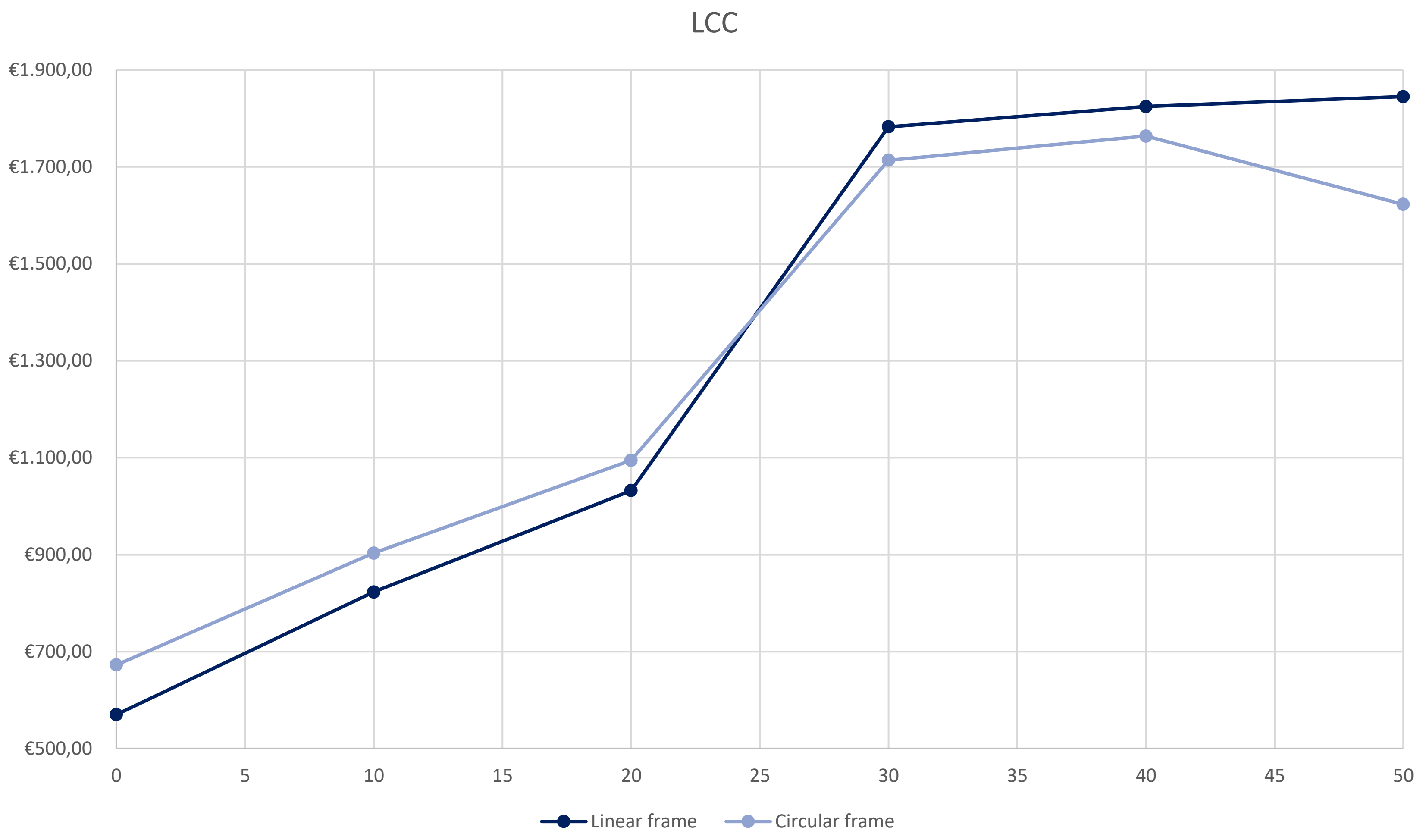
Lineair window frame

€1.844,-

Circular window frame

€1.622,-

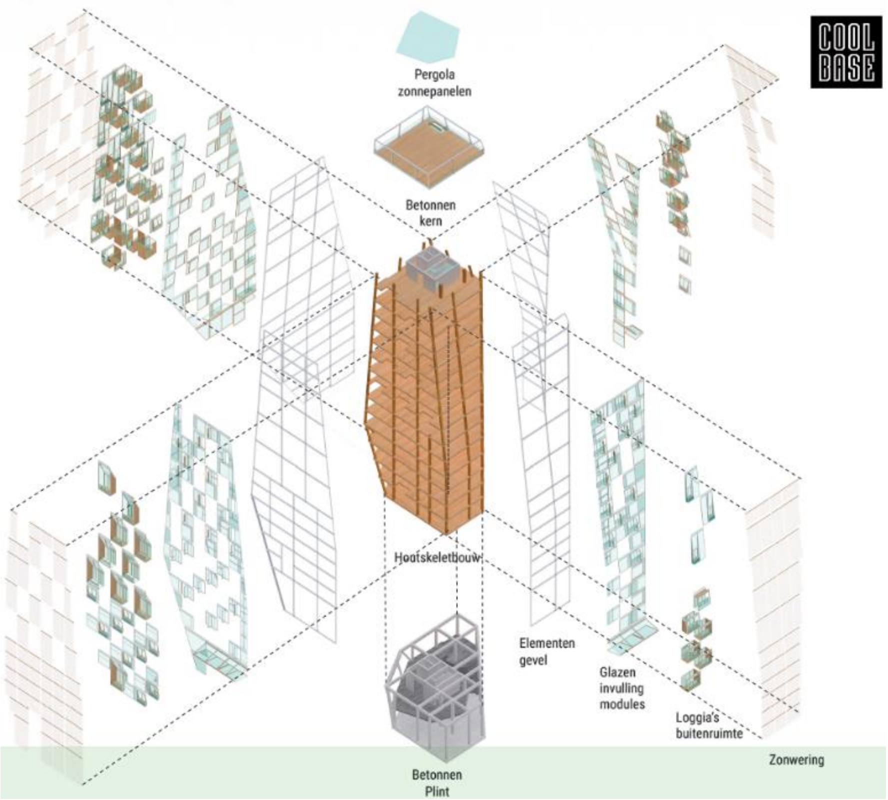
- 12 %



05 | Case study Coolbase

Case selection

(FSD, 2022)



(FSD, 2021)

Development of circularity scenario’s

5R Strategies

Reduce

Reuse

Repair

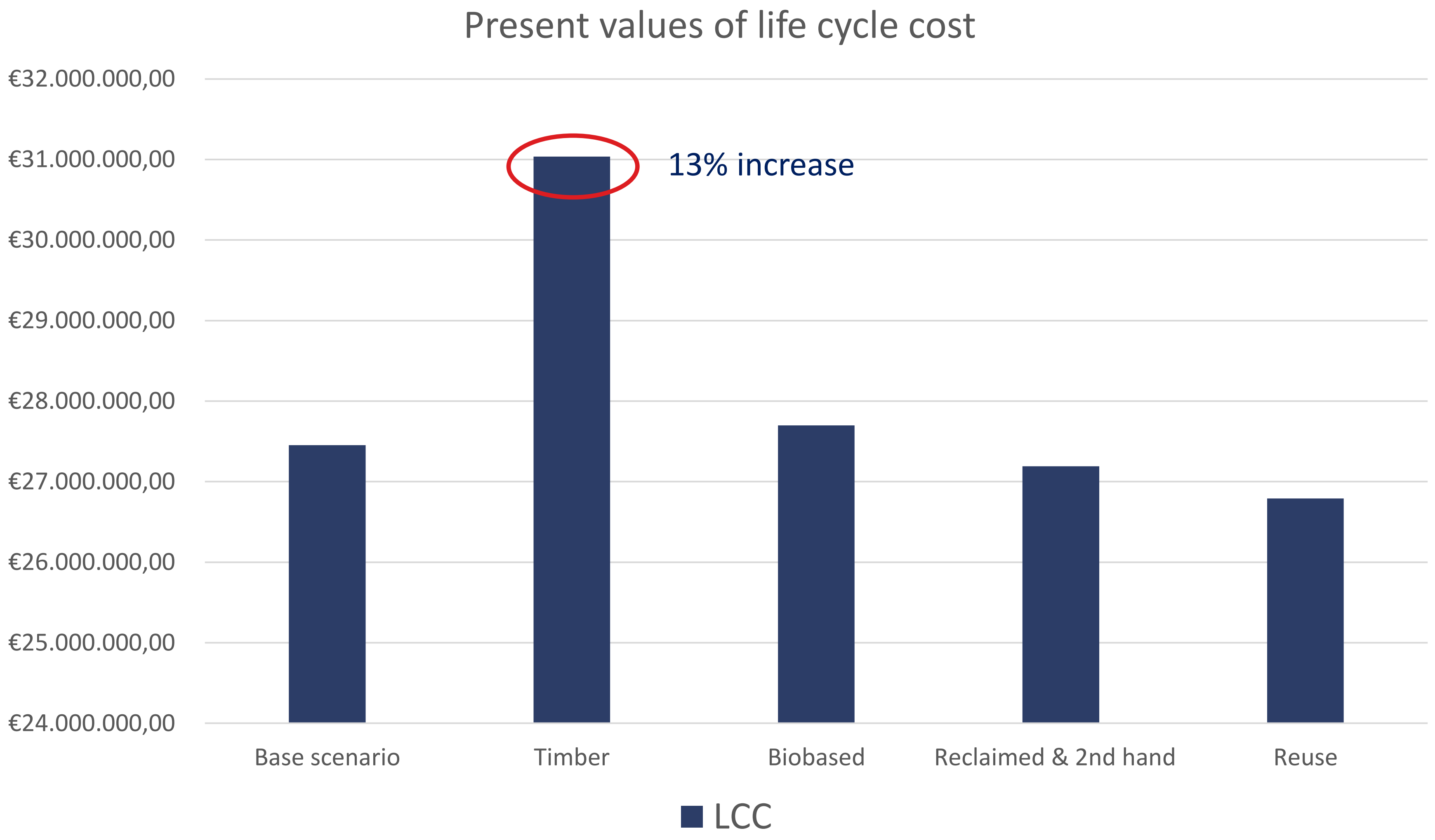
Refurbish

Recycle

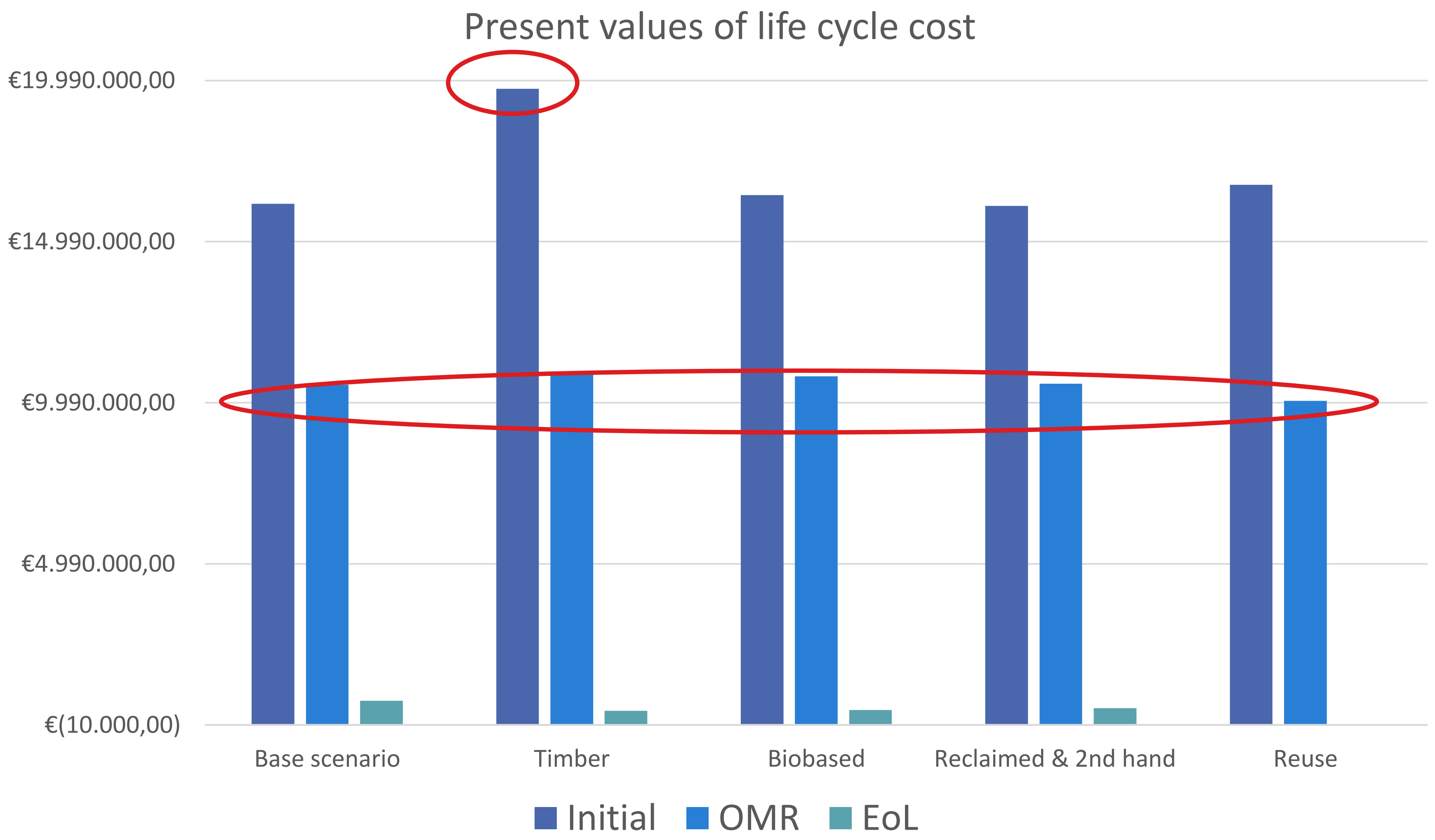
Scenario	Interventions	Layer of Brand
Base	None	-
Timber	Reduce use of concrete and steel and replace by wood	Structure
Biobased	Use of biobased products	Skin and space plan
Reclaimed & 2nd hand	Implement reclaimed and 2nd hand products	Skin and space plan
Reuse	Implement products with a high probability of reuse	Structure, skin and space plan

06 | Results

Analysis

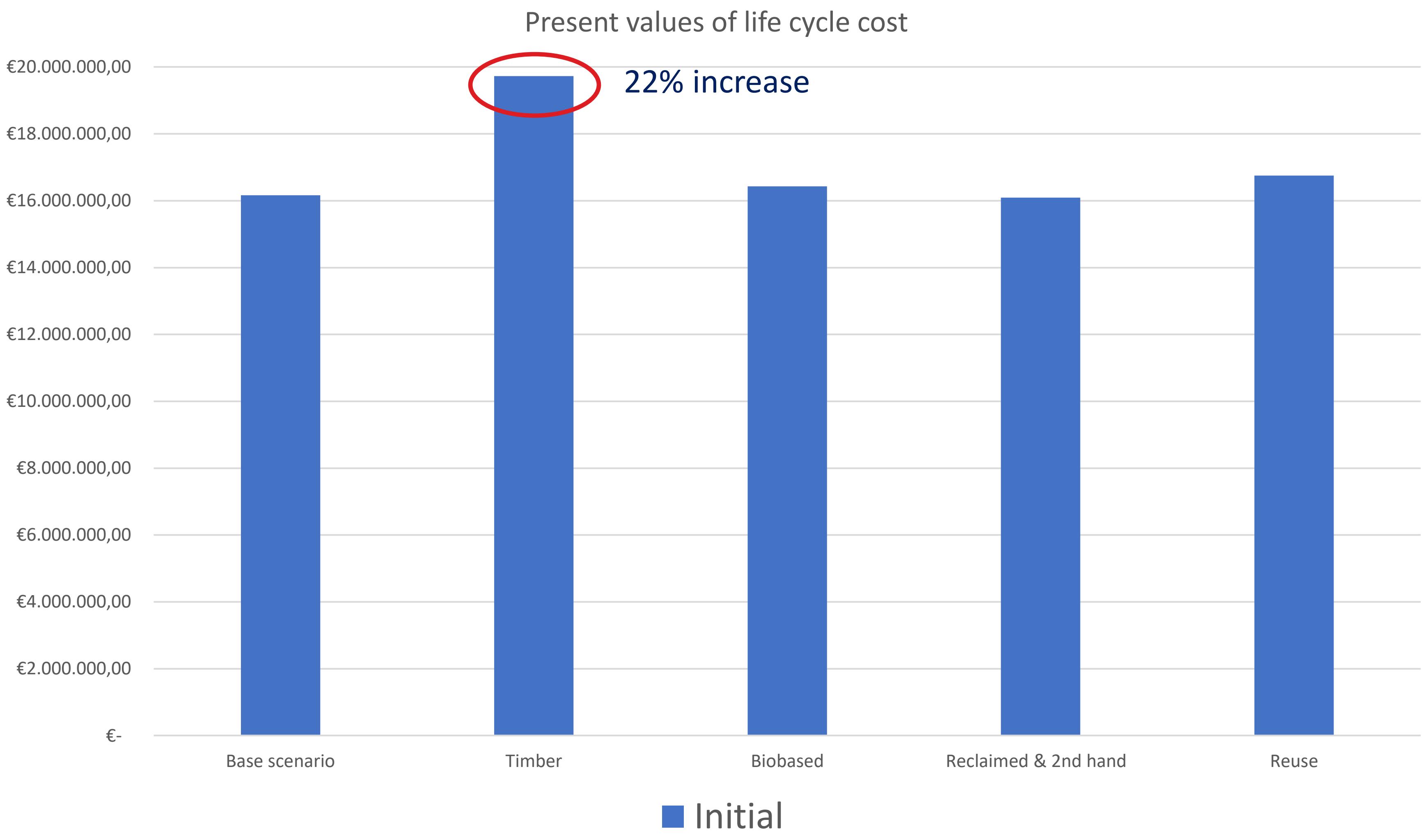

Present values of life cycle cost
€32.000.000,00
€31.000.000,00
€30.000.000,00
€29.000.000,00
€28.000.000,00
€27.000.000,00
€26.000.000,00
€25.000.000,00
€24.000.000,00
13% increase
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
LCC

Analysis

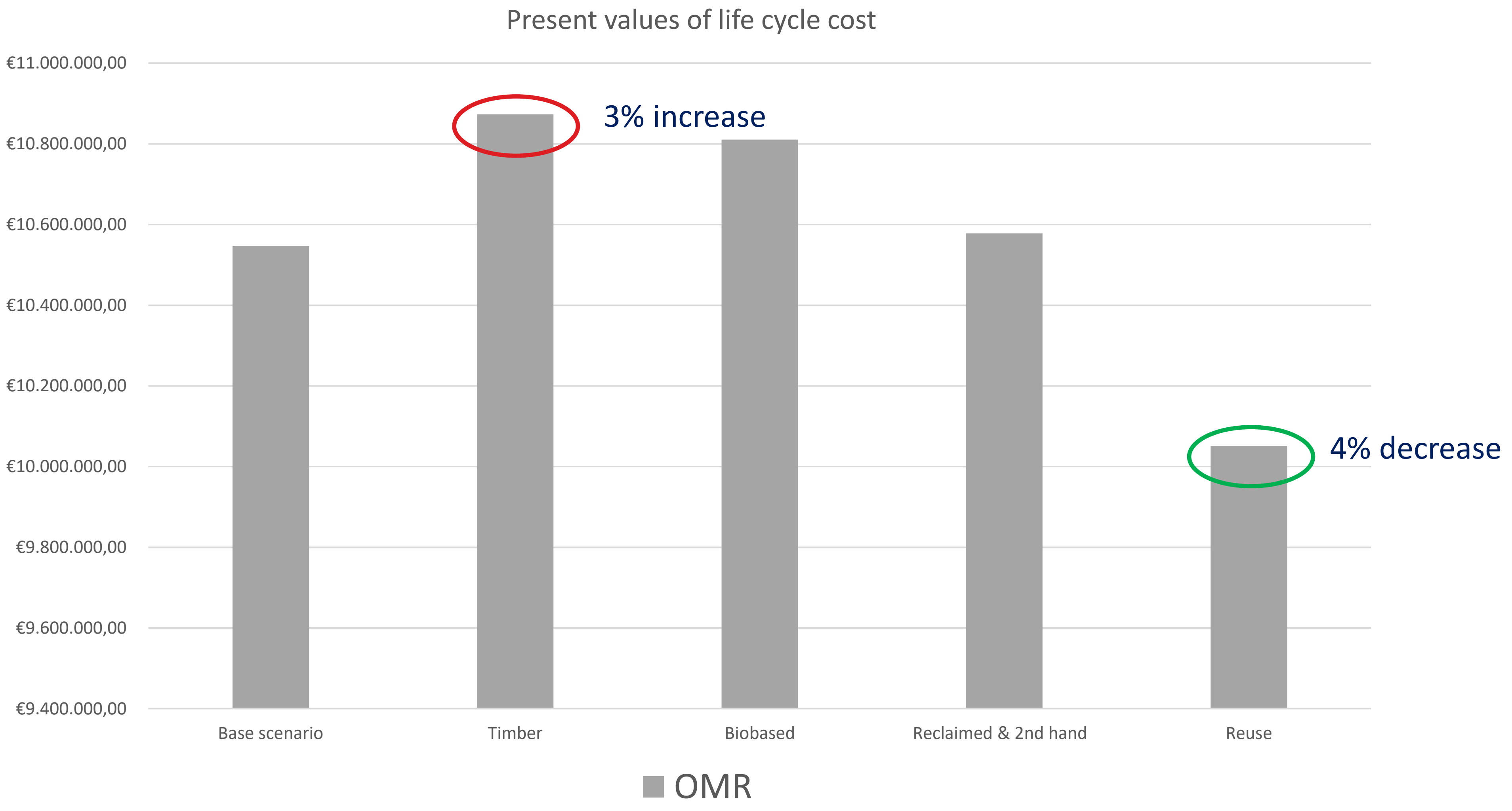


Present values of life cycle cost
€19.990.000,00
€14.990.000,00
€9.990.000,00
€4.990.000,00
€(10.000,00)
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
Initial
OMR
EoL

Analysis

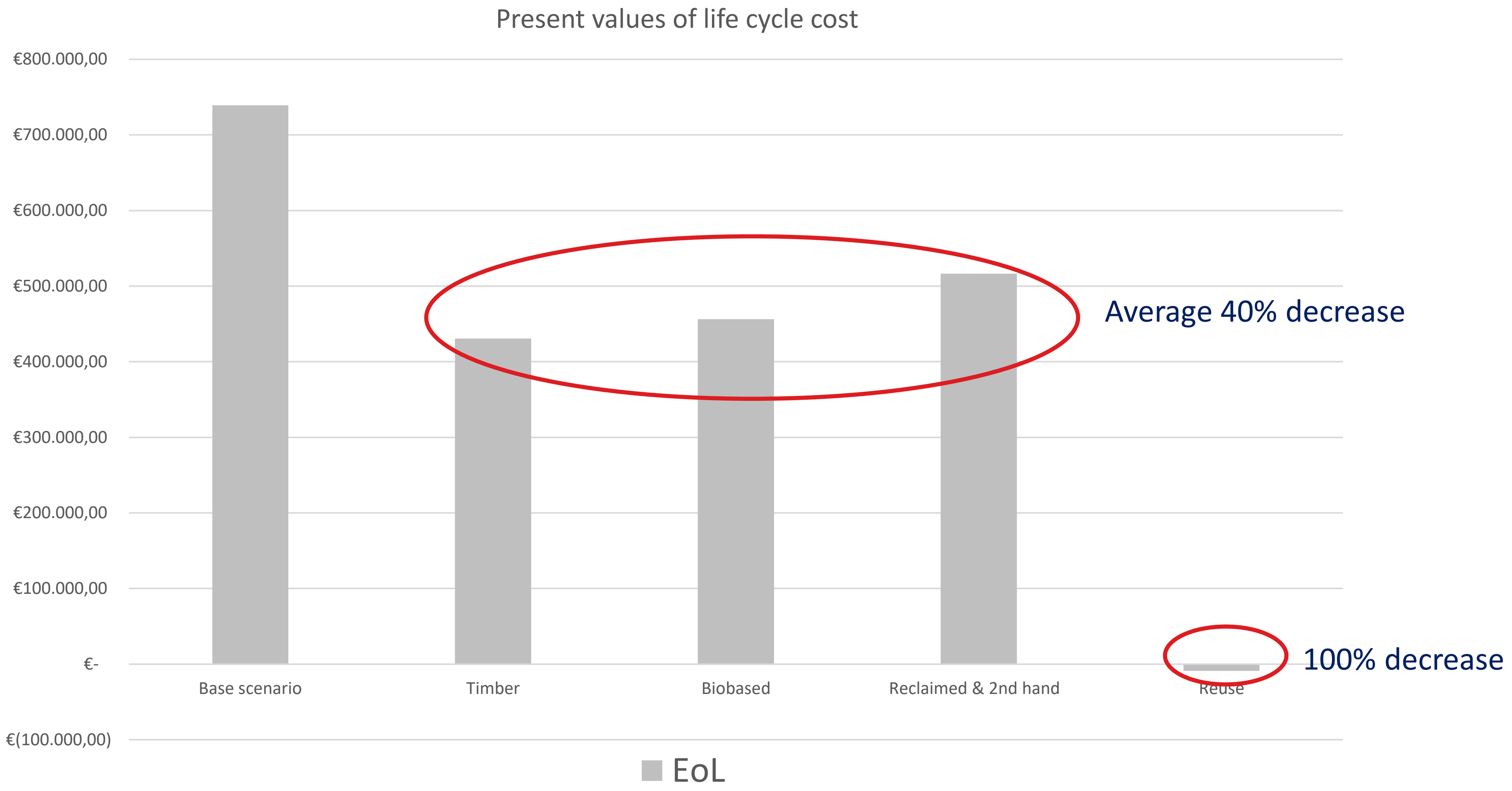

Present values of life cycle cost
22% increase
€20.000.000,00
€18.000.000,00
€16.000.000,00
€14.000.000,00
€12.000.000,00
€10.000.000,00
€8.000.000,00
€6.000.000,00
€4.000.000,00
€2.000.000,00
€-
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
Initial

Analysis



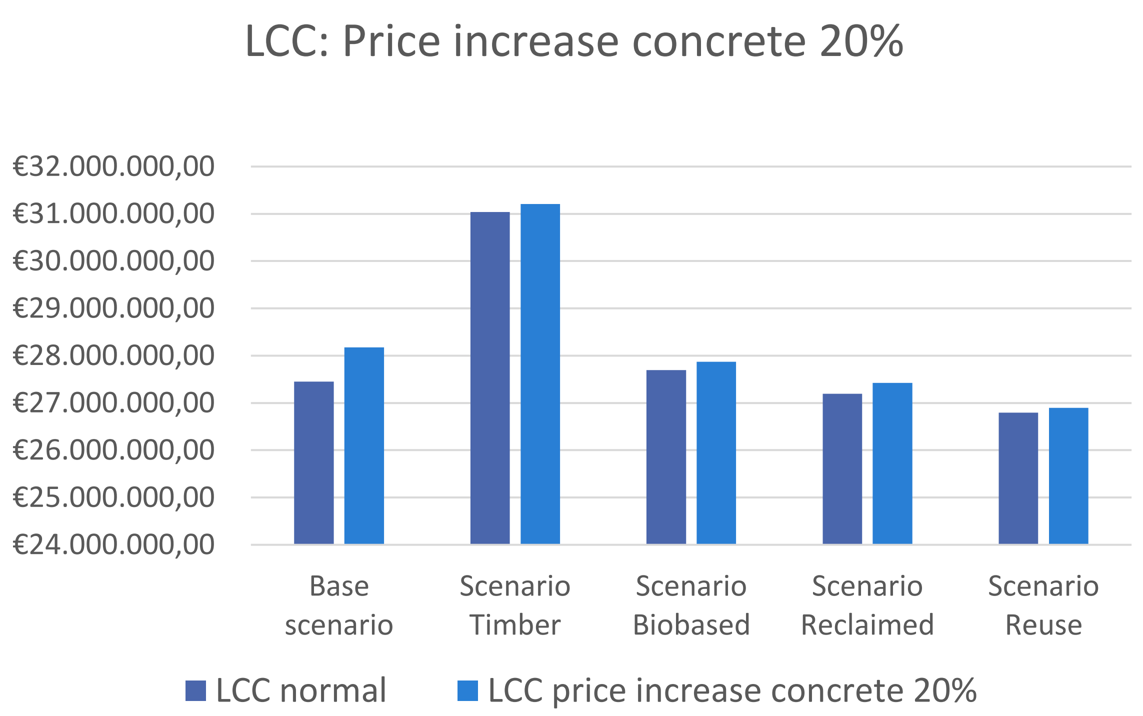
Present values of life cycle cost
€11.000.000,00
€10.800.000,00
€10.600.000,00
€10.400.000,00
€10.200.000,00
€10.000.000,00
€9.800.000,00
€9.600.000,00
€9.400.000,00
3% increase
4% decrease
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
OMR

Analysis



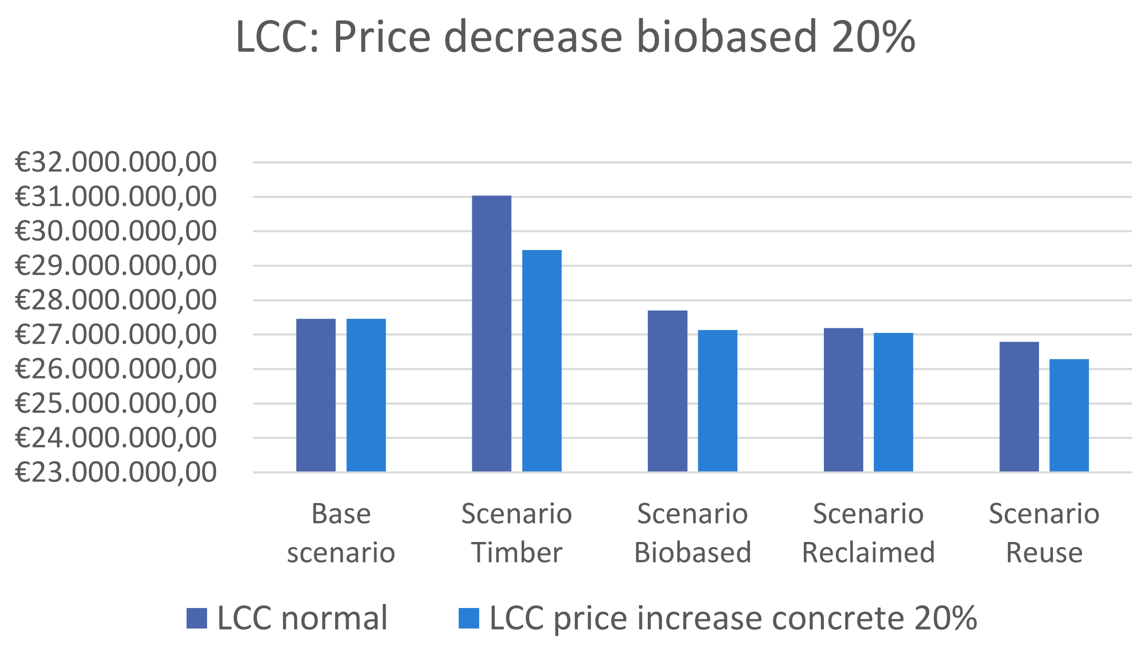
Present values of life cycle cost
€800.000,00
€700.000,00
€600.000,00
€500.000,00
€400.000,00
€300.000,00
€200.000,00
€100.000,00
€-
€(100.000,00)
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
EoL
Average 40% decrease
100% decrease

Sensitivity analysis: price increase concrete



Scenario	Δ LCC %
Base Scenario	+2,6 %
Scenario Timber	+0,6 %
Scenario Biobased	+0,6 %
Scenario Reclaimed	+0,9 %
Scenario Reuse	+0,3 %

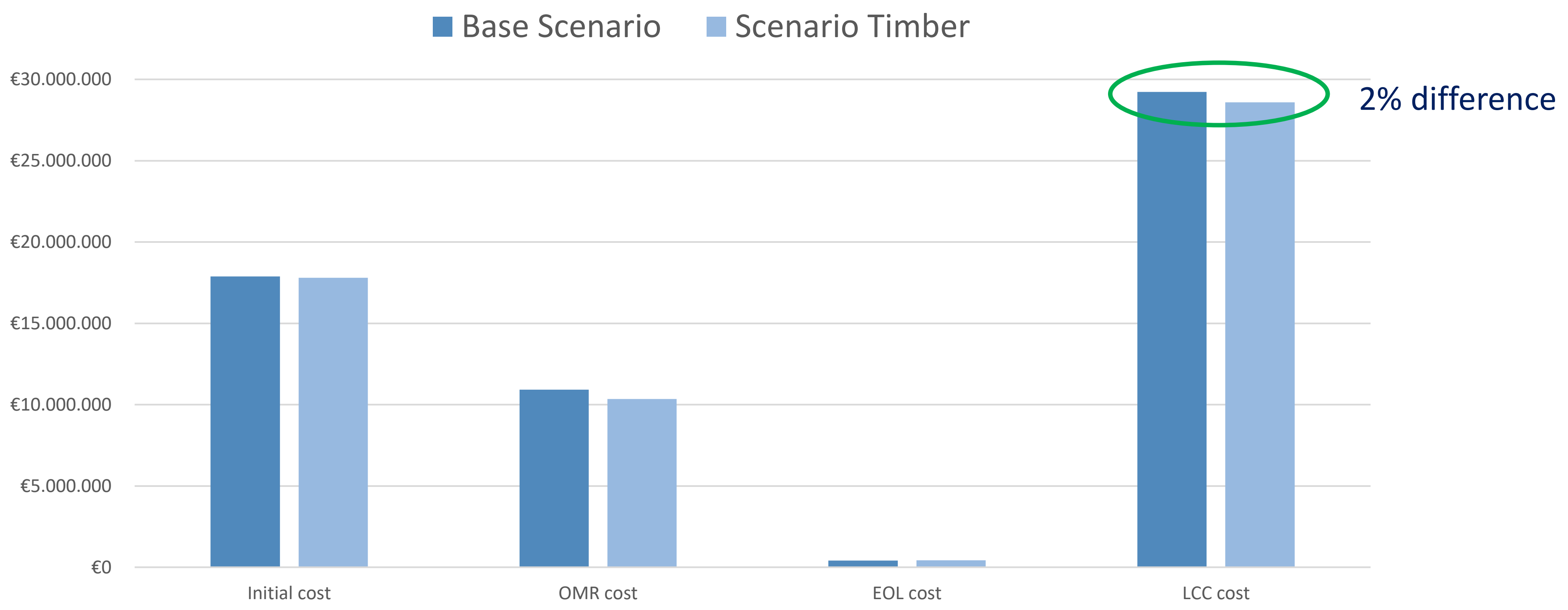
Sensitivity analysis: price decrease biobased



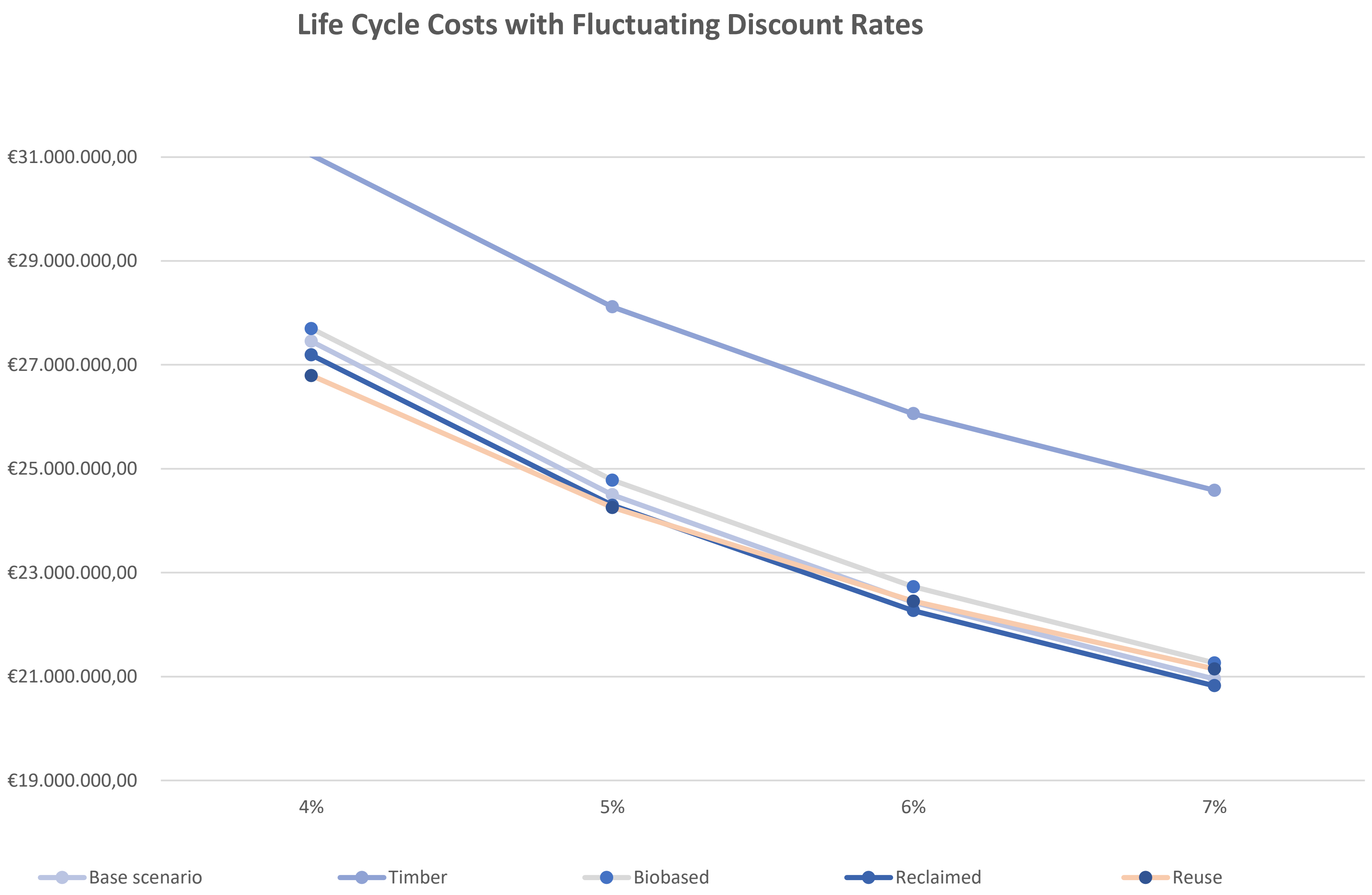
Scenario	Δ LCC %
Base Scenario	+0,0 %
Scenario Timber	-5,1 %
Scenario Biobased	-2,1 %
Scenario Reclaimed	-0,5 %
Scenario Reuse	-1,9 %

Analysis: Price increase traditional buildings materials & decrease timber

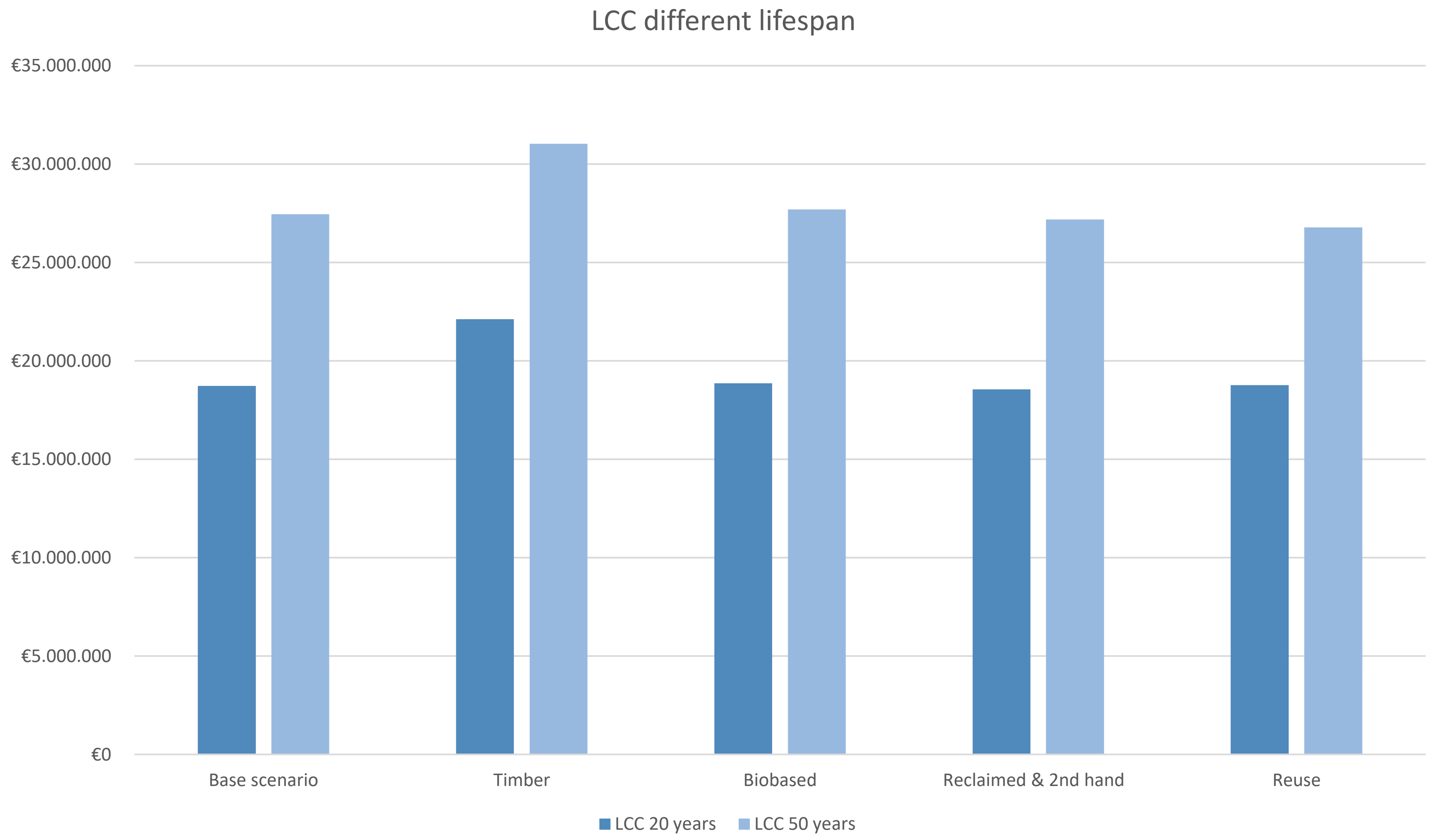
- +30 % increase concrete, brick, steel etc.
- -30 % decrease timber



Analysis: Fluctuating discount rate



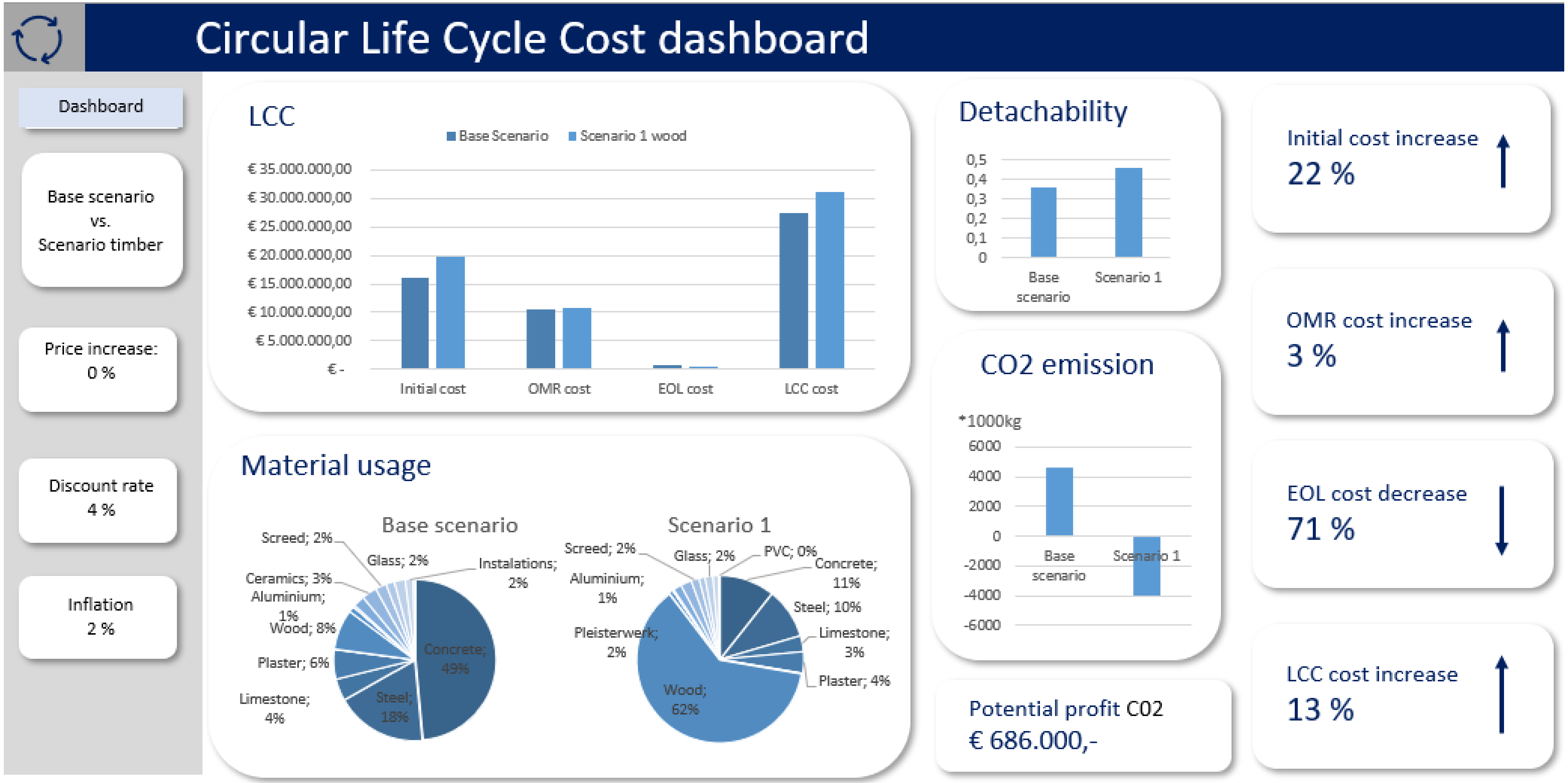
Analysis: LCC different lifespan

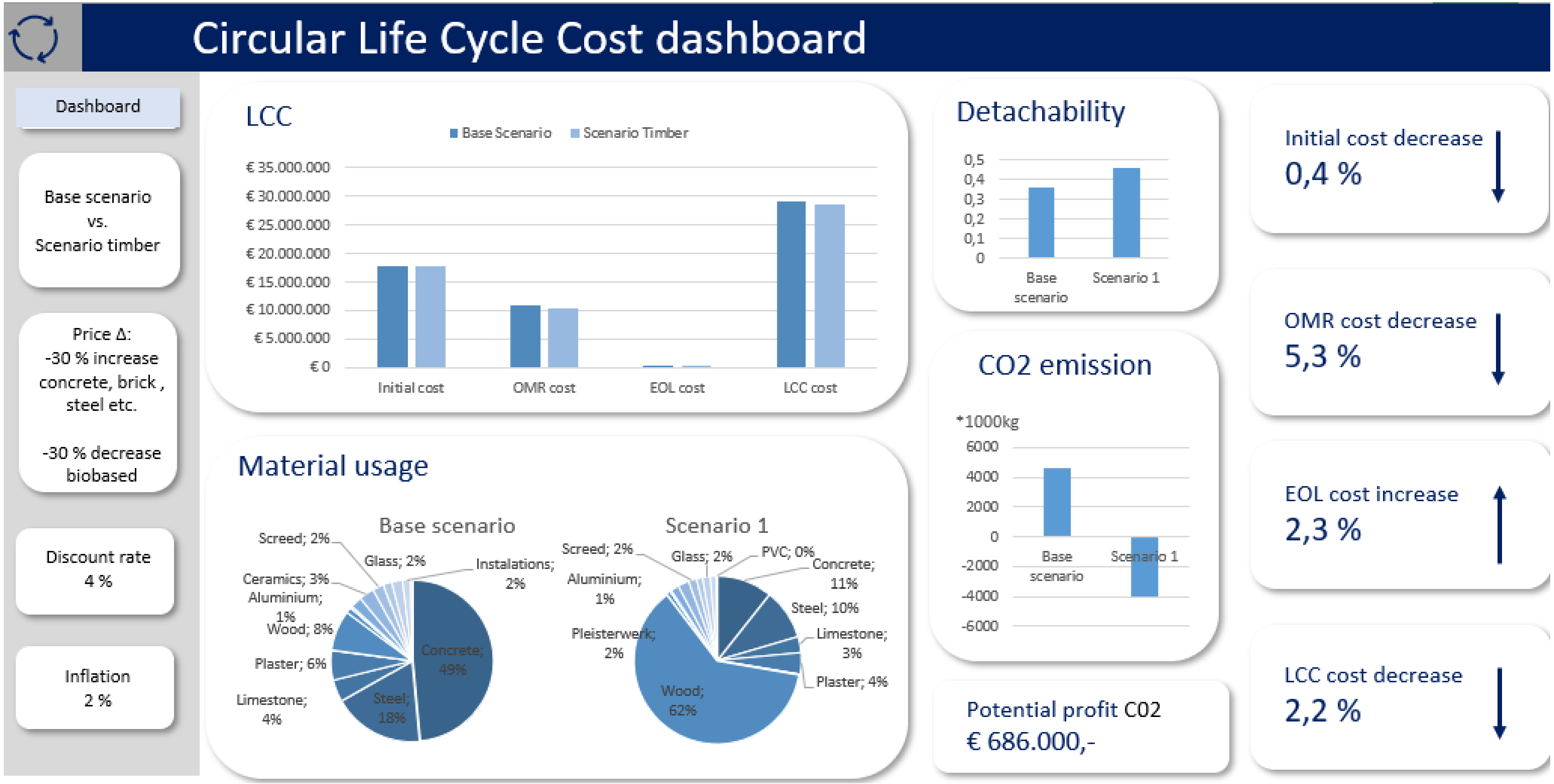


07 | Discussion

Discussion

- Level of circularity has a big impact on financial implications
- Detachability of product impacts OMR and EOL cost
- Circular construction buildings are promising
- Tool can help transition to a more circular building environment
- Still in development → uncertainties


Circular Life Cycle Cost dashboard
Dashboard
Base scenario
vs.
Scenario timber
Price increase:
0 %
Discount rate
4 %
Inflation
2 %
LCC
Base Scenario
Scenario 1 wood
€ 35.000.000,00
€ 30.000.000,00
€ 25.000.000,00
€ 20.000.000,00
€ 15.000.000,00
€ 10.000.000,00
€ 5.000.000,00
€ -
Initial cost
OMR cost
EOL cost
LCC cost
Material usage
Base scenario
Screed; 2%
Glass; 2%
Instalations; 2%
Ceramics; 3%
Aluminium; 1%
Wood; 8%
Plaster; 6%
Limestone; 4%
Steel; 18%
Concrete; 49%
Scenario 1
Screed; 2%
Glass; 2%
PVC; 0%
Concrete; 11%
Aluminium; 1%
Steel; 10%
Pleisterwerk; 2%
Limestone; 3%
Plaster; 4%
Wood; 62%
Detachability
0,5
0,4
0,3
0,2
0,1
0
Base scenario
Scenario 1
CO2 emission
*1000kg
6000
4000
2000
0
-2000
-4000
-6000
Base scenario
Scenario 1
Potential profit C02
€ 686.000,-
Initial cost increase
22 %
OMR cost increase
3 %
EOL cost decrease
71 %
LCC cost increase
13 %


Circular Life Cycle Cost dashboard
Dashboard
Base scenario
vs.
Scenario timber
Price Δ:
-30 % increase
concrete, brick ,
steel etc.
-30 % decrease
biobased
Discount rate
4 %
Inflation
2 %
LCC
Base Scenario
Scenario Timber
€ 35.000.000
€ 30.000.000
€ 25.000.000
€ 20.000.000
€ 15.000.000
€ 10.000.000
€ 5.000.000
€ 0
Initial cost
OMR cost
EOL cost
LCC cost
Material usage
Base scenario
Screed; 2%
Glass; 2%
Instalations; 2%
Ceramics; 3%
Aluminium; 1%
Wood; 8%
Plaster; 6%
Limestone; 4%
Steel; 18%
Concrete; 49%
Scenario 1
Screed; 2%
Glass; 2%
PVC; 0%
Concrete; 11%
Aluminium; 1%
Steel; 10%
Pleisterwerk; 2%
Limestone; 3%
Plaster; 4%
Wood; 62%
Detachability
0,5
0,4
0,3
0,2
0,1
0
Base scenario
Scenario 1
CO2 emission
*1000kg
6000
4000
2000
0
-2000
-4000
-6000
Base scenario
Scenario 1
Potential profit C02
€ 686.000,-
Initial cost decrease
0,4 %
OMR cost decrease
5,3 %
EOL cost increase
2,3 %
LCC cost decrease
2,2 %

08 | Conclusion

Conclusion

"How can life cycle cost and circularity metrics be developed and framed for circular real estate development projects?"

- Circular life cycle cost tool can properly assess a building's costs and degree of circularity
- Costs and benefits should be split across all life phases of a building
- R-strategies used in measuring the degree of circularity in different scenarios
- Tool used to define costs, factoring in multiple variables to minimize uncertainties
- Promising results for mapping level of circularity and financial implications

09 | Limitations and recommendations

Limitations

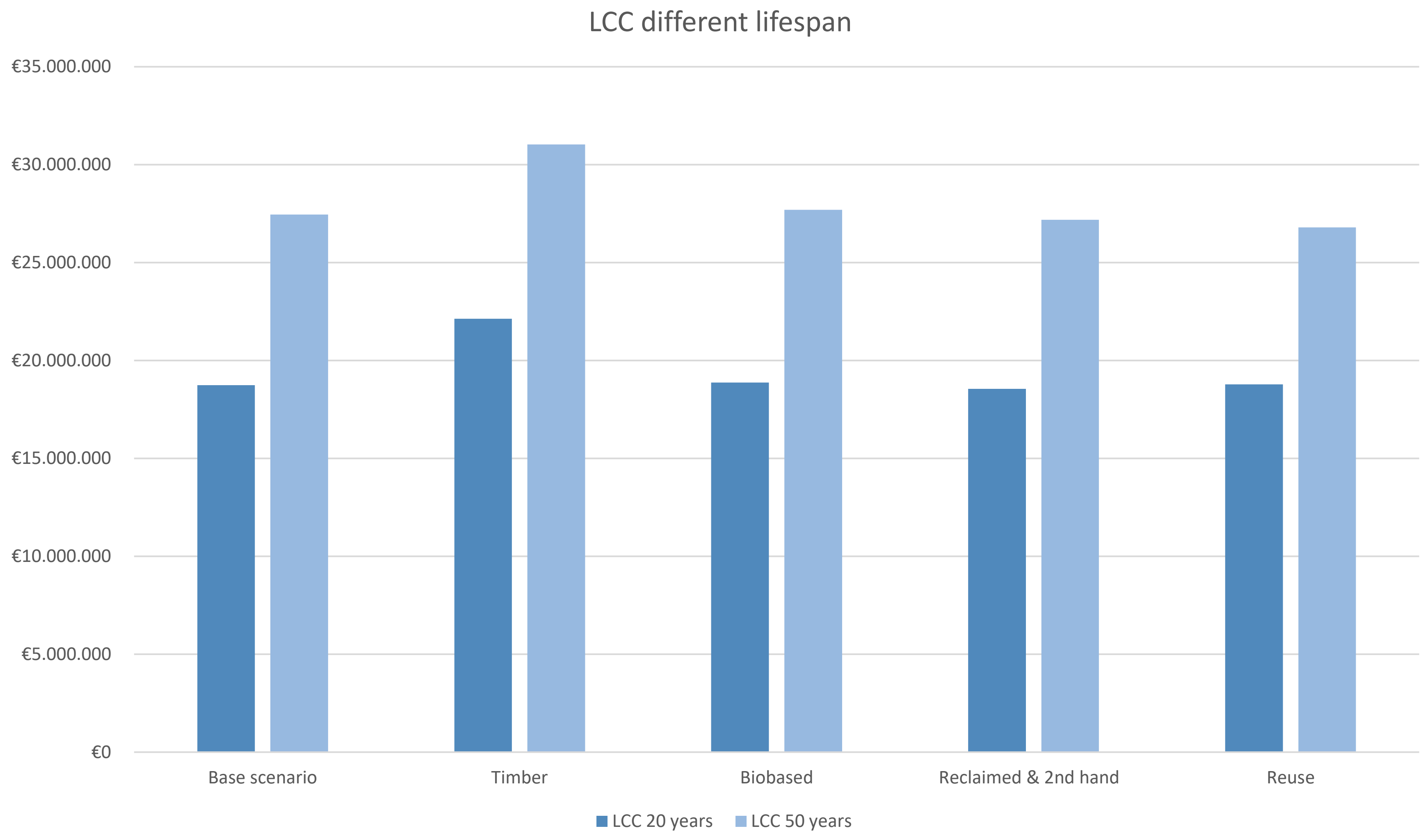
- Data collection from multiple sources
- The scope of this study is restricted to the analysis of a single case study
- The estimation of costs carries a level of uncertainty
- The measurement of circularity degree is not quantified in this research

Further research

- The integration of a quantitative circularity assessment
- A study that targets multiple case studies could generate more data
- The inclusion of an environmental cost indicator in a cost analysis
- Creation of a uniform dataset of construction products
- A study focusing specifically on defining the financial residual value of products

? | Questions?

? | appendix?

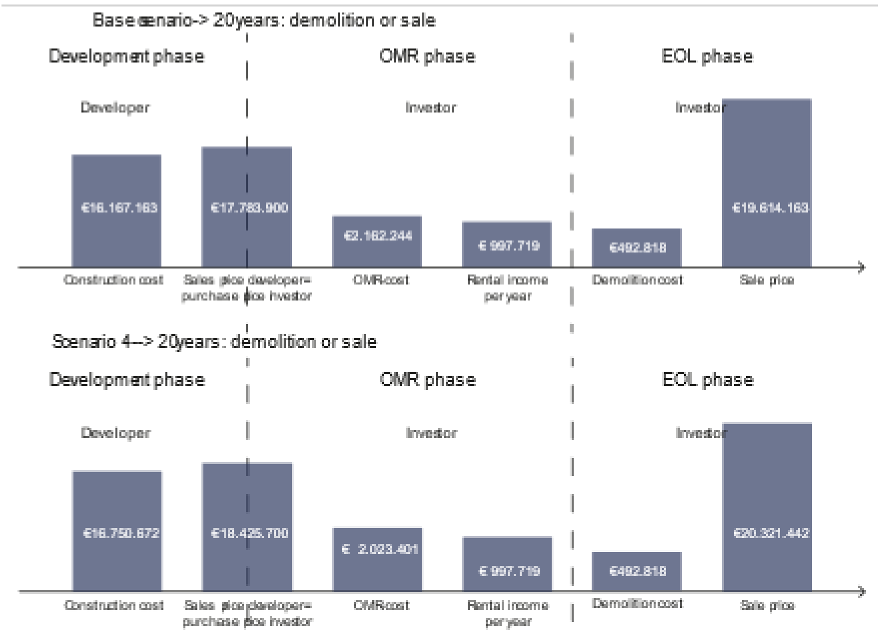


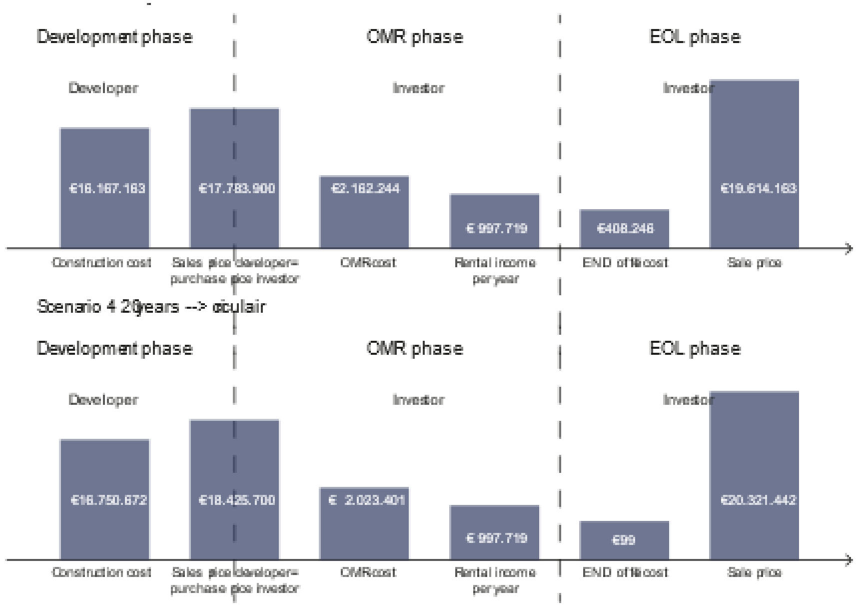
LCC different lifespan
€35.000.000
€30.000.000
€25.000.000
€20.000.000
€15.000.000
€10.000.000
€5.000.000
€0
Base scenario
Timber
Biobased
Reclaimed & 2nd hand
Reuse
LCC 20 years
LCC 50 years

Traditional vs circular model

	Development phase	OMR phase	End-of-life phase
Real estate developer	Foundation costs Sales proceeds		
Investor		OMR costs Rental income	Demolition costs Redevelopment costs Residual value (circular)

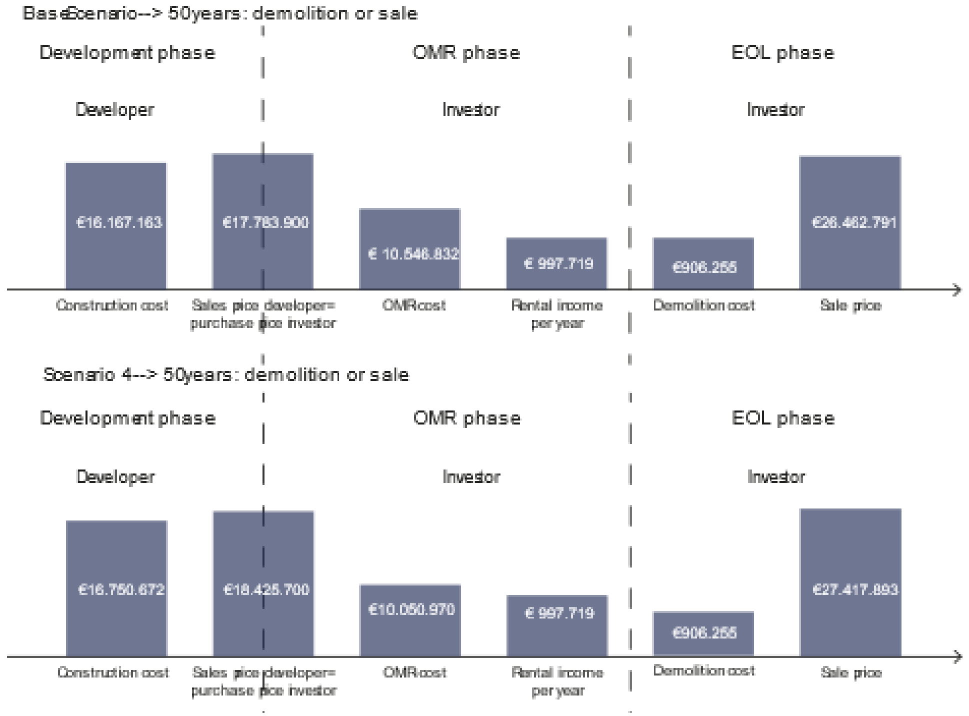
Traditional vs circular

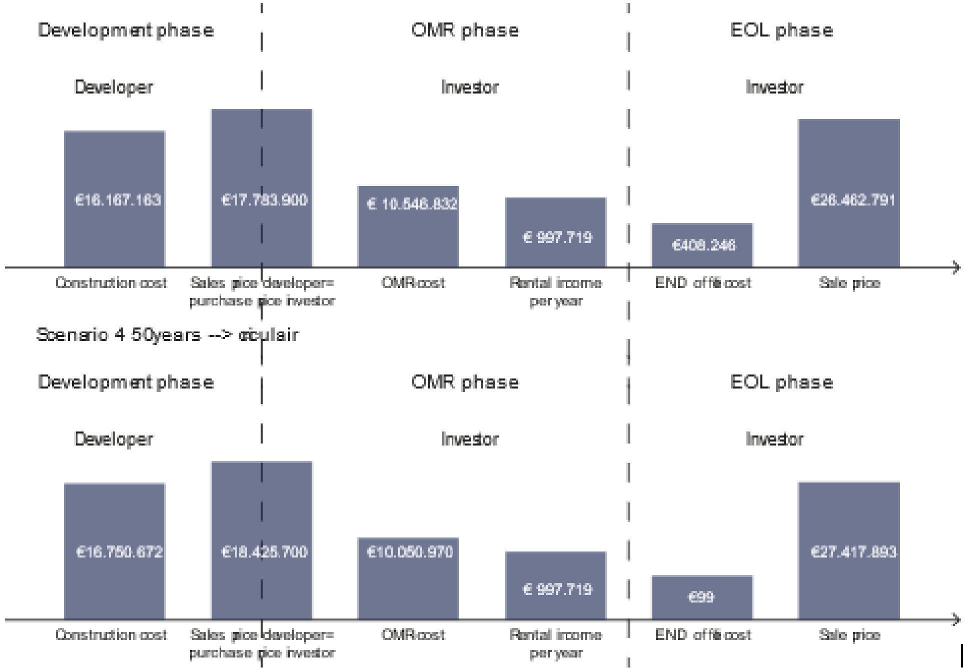




- Base Scenario - 20 years: demolition or sale: 0.0%
- Scenario 4 - 20 years: demolition or sale: 0.1%
- Base Scenario - 20 years: circular: 0.6%
- Scenario 4 - 20 years: circular: 3.1%

Traditional vs circular





Research method

Literature review

Semi structures-interviews

Total of ten interviews (3/10)

- 5 developers
- 3 investors
- 2 contractors

Goal of interviews:

- Focus on which strategy
- Focus on which layers
- Better defining uncertainties such as EOL and OMR
- Circular construction operations
- Additions for a better working model

Interview review

- 3 interviews conducted
- Strategy focus: refuse, rethink, reduce, reuse, recycle and recover
- Focus on layers structure, skin, space plan
- Better defining of OMR costs and EOL costs
  - EOL→ Calculation model for determining financial residual value (Alba Concepts)

- Calculation model for determining financial residual value:

1. Disposal value:

- Dismountable costs, Transport costs

2. Residual value:

- Initial cost (material) – Loss

3. EOL:

- Overhaul costs, Quality reduction, Recycling value

Interview review

Limitations

-too little real input for model

-uncertainties remain difficult to define (OMR , EOL)

-too less construction data

Development of scenario’s + Interventions from interviews

Strategy	Site	Structure	Skin	Services	Space plan
Reduce	Minimize intensive construction material usage	Reducing the amount of material used in the structure	reduce the demand for virgin resources→ wood for example	Smart systems that reduce energy usage	reducing the overall space needed.
Reuse	Making the structure demountable	designing structural components such that they can be easily disassembled and reused in the future.	Reuse of old window frames and façade systems	Reusable of Electrical Components	Using demountable partitions for interior walls allows for easy reconfiguration of spaces.
Repair	Site Infrastructure Repair	strengthening existing structural components instead of replacing them entirely.	Window and Door Repair	Equipment and System Maintenance	Flooring Restoration
Refurbish	Site	Repair damaged sections of the structure	Refurbish exterior cladding	Upgrade electrical systems with more sustainable options	Space plan
Recycle	Use of recycled concrete	Use of recycles concrete and reclaimed steel	Recycled aluminium and steel for frames	recycling copper piping from plumbing systems or recycling steel components	Focus on renewable/ biobased materials

- Tekst weg, uitleggen hoe de r strategien vertaald zijn in de scenario’s
- En waarom die 4 de er is

→

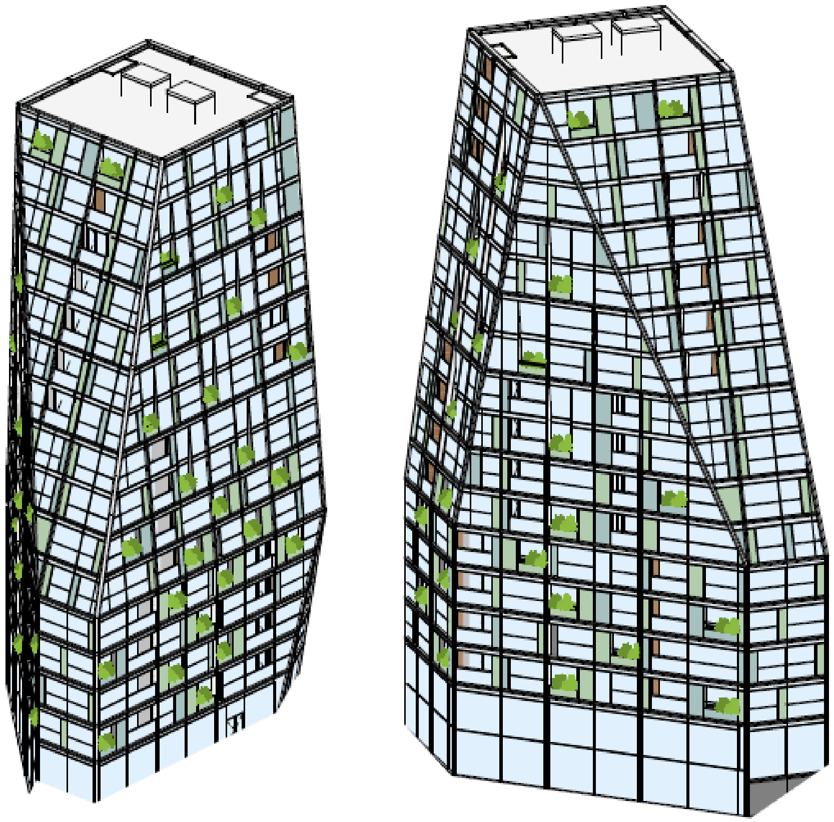
Scenario	Interventions
Scenario 1 (Reduce)	Reduce use of products such as concrete and steel (structure)
Scenario 2 (Reduce)	Substitution of primary raw materials with biobased products
Scenario 3 (Recycle)	Substitution of new materials with reclaimed materials
Scenario 4 (Reuse)	Keep working with traditional materials, but with a high probability of reuse in the end

Scenario’s

Base Scenario

- Kort uitleggen per scenario waarui deze scenario’s dan bestaan en verschillen ten opzichte van base scenario’s

Structure	Skin	Space plan
Foundation: concrete (cast-in-place) Foundation piles: concrete Floors: Concrete wide slab floor (cast-in-place) + concrete Columns: precast concrete columns Beams: concrete beams Walls: sand-lime brick elements Stairs: concrete stairs Metal structural work: Roof: part metalwork and a concrete roof	Window frames: steel frames Door: steel Windows/doorframes: aluminium and wood Window/door glass: HR ++ Gutter: aluminium Window sill: aluminium Roofcovering: bituminous roofing Facade: Glass curtain wall Wall cladding: wood finishing	Floor finish: PVC floor Interior wall finish: traditional plaster and paint Internal walls: sand-lime brick, gibo and metal stud walls Interior door frames: wooden frames Interior doors: steel casing Interior fencing: steel balustrade Inner sills: natural support Window sill: wood Wall tiles (toilet + bathroom): ceramic tiles Floor tiles (toilet + bathroom): ceramic tiles Stairs: Steel spiral staircase

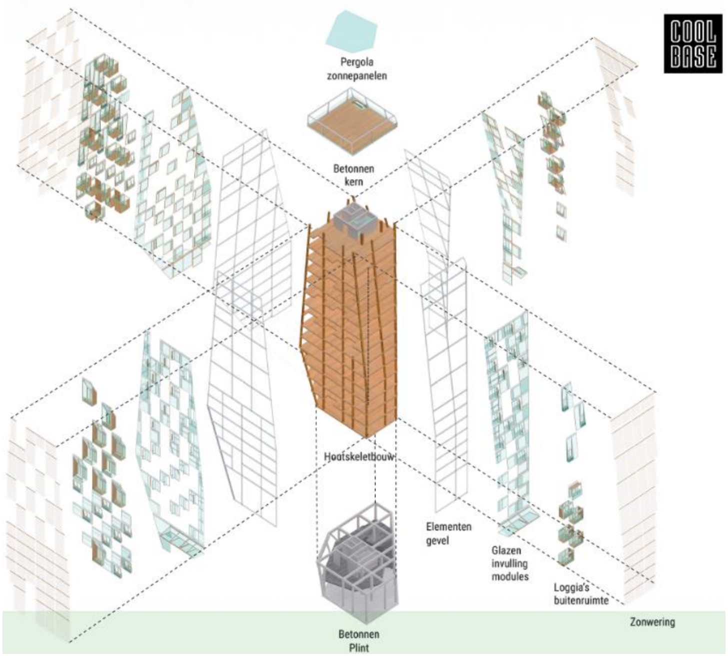


- Kort uitleggen per scenario waarui deze scenario's dan bestaan en verschillen ten opzichte van base scenario's

Scenario's

Reduce use of products such as concrete and steel (structure)

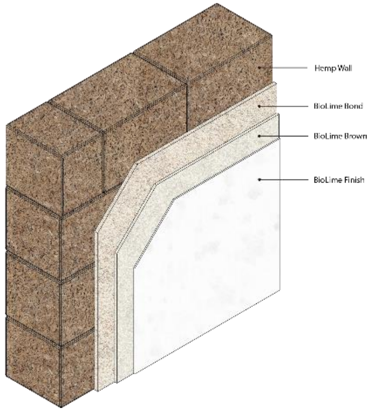
Structure	Skin	Space plan
Foundation: concrete (cast-in-place) Foundation piles: concrete **Floors**: CLT-timber **Columns**: CLT-column if possible, otherwise concrete **Beams**: CLT-timber beams if possible otherwise steel beams **Walls**: CLT - timber **Stairs**: concrete stairs Metal structural work: Roof: part metalwork and a concrete roof	Window frames: steel frames Door: steel Windows/doorframes: aluminium and wood Window/door glass: HR ++ Gutter: aluminium Window sill: aluminium Roofcovering: bituminous roofing Facade: Glass curtain wall Wall cladding: wood finishing	Floor finish: PVC floor Interior wall finish: traditional plaster and paint Internal walls: sand-lime brick, gibo and metal stud walls Interior door frames: wooden frames Interior doors: steel casing Interior fencing: steel balustrade Inner sills: natural support Window sill: wood Wall tiles (toilet + bathroom): ceramic tiles Floor tiles (toilet + bathroom): ceramic tiles Stairs: Steel spiral staircase



Scenario’s

Substitution of primary raw materials with biobased renewables

Structure	Skin	Space plan
Foundation: concrete (cast-in-place) Foundation piles: concrete **Floors**: Concrete wide slab floor (cast-in-place) + concrete Columns: precast concrete columns Beams: concrete beams **Walls**: Hemp building blocks **Stairs**: wooden stairs Metal structural work: Roof: part metalwork and a concrete roof	**Window frames**: wood (Platoowood) **Door**: Wood **Windows/doorframes**: Wood (platoowood) Window/door glass: HR ++ Gutter: aluminium Window sill: aluminium **Roofcovering**: Biobased (Derbigu) Facade: Glass curtain wall Wall cladding: wood finishing	**Floor finish**: Marmoleum floor **Interior wall finish**: Loam, cork and bio-based paint **Internal walls**: Hemp building blocks **Interior door frames**: wooden frames **Interior doors**: wood **Interior fencing**: wooden balustrade Inner sills: natural support **Window sill**: wood **Wall tiles (toilet + bathroom)**: natural hydrated lime (tadel paint) **Floor tiles** (toilet + bathroom): wooden and bamboo tiles **Stairs**: Wooden spiral staircase



Scenario’s

Substitution of new materials with reclaimed materials

Structure	Skin	Space plan
Foundation: Circular/recycled concrete Foundation piles: concrete **Floors**: VBI hollow-core slab floor ‘’green’’ Columns: precast concrete columns **Beams**: used steel beams **Walls**: 2nd hand sand-lime brick elements + Xella sand-lime brick **Stairs**: c2c stairs Metal structural work: Roof: part metalwork and a concrete roof	**Window frames**: Bohaco system **Door**: Úsed doors **Windows/doorframes:** used frames Window/door glass: HR ++ Gutter: aluminium Window sill: aluminium **Roofcovering**: citumen roofing Facade: Glass curtain wall **Wall cladding**: Fireclay bricks + ‘’Armstrong’’ ceilingsystem	**Floor finish:** ‘’Drowa’’ floor **Interior wall finish**: traditional plaster and ‘’rigo’’paint **Internal walls:** Knauf system **Interior door frames**: used frames **Interior doors**: used doors **Interior fencing:** used fencing (sparq) Inner sills: natural support Window sill: wood **Wall tiles (toilet + bathroom):** Mosa tiles **Floor tiles (toilet + bathroom):** Mosa tiles **Stairs**: C2C stairs

Scenario’s

Keep working with traditional materials, but with a high probability of reuse in the end

	Skin	Space plan
Foundation: concrete (cast-in-place) **Foundation piles**: Pekko piles and beams **Floors**: Peikko floors + Cemwoed **Columns**: Peikko columns **Beams**: Peikko beams **Walls**: CLT- walls (Peikko) **Stairs**: wooden stairs **Metal structural work:** Steelframe ConXL and Con XR Roof: part metalwork and a concrete roof	**Window frames:** Profix mechanical connection **Door**: Berkvens zero door **Windows/doorframes:** Profix mechanical connection **Window/door glass**: HR ++ demontable Gutter: aluminium Window sill: aluminium **Roofcovering**: EPDM Facade: Glass curtain wall **Wall cladding**: Alkonder cladding (Lease)	**Floor finish:** Studiowea tiles Interior wall finish: traditional plaster and paint **Internal walls**: CLT **Interior door frames:** Profix mechanical connection **Interior doors:** Berkvens zero door **Interior fencing:** Sparq **Inner sills:** natural support dry connection Window sill: wood **Wall tiles (toilet + bathroom)**: solid surface tiles **Floor tiles (toilet + bathroom):** solid surface tiles **Kitchen:** the new makers Stairs: Steel spiral staircase