Life Cycle Assessment in Concrete Mix Design: Lessons from the Eco Concrete Competition

Hessam Azarijafari, Ph.D.
Deputy Director, Concrete Sustainability Hub
Massachusetts Institute of Technology (MIT)

ACI San Francisco Convention *04/03/2023*

Concrete is the most commonly used building material … for good reason

- Global cement production ~ 4 billion tons per year.
- Concrete production is about 30 billion tons per year

Versatile

Durable

Constructable

Available

Economical

How should we evaluate the sustainability aspect of the of concrete?

How can we mitigate the environmental impacts?

ACI Eco concrete Competition was developed to promote the environmental performance in concrete mix design as an important aspect of sustainability

Objective of the competition:

How can you improve the durability and environmental impacts?

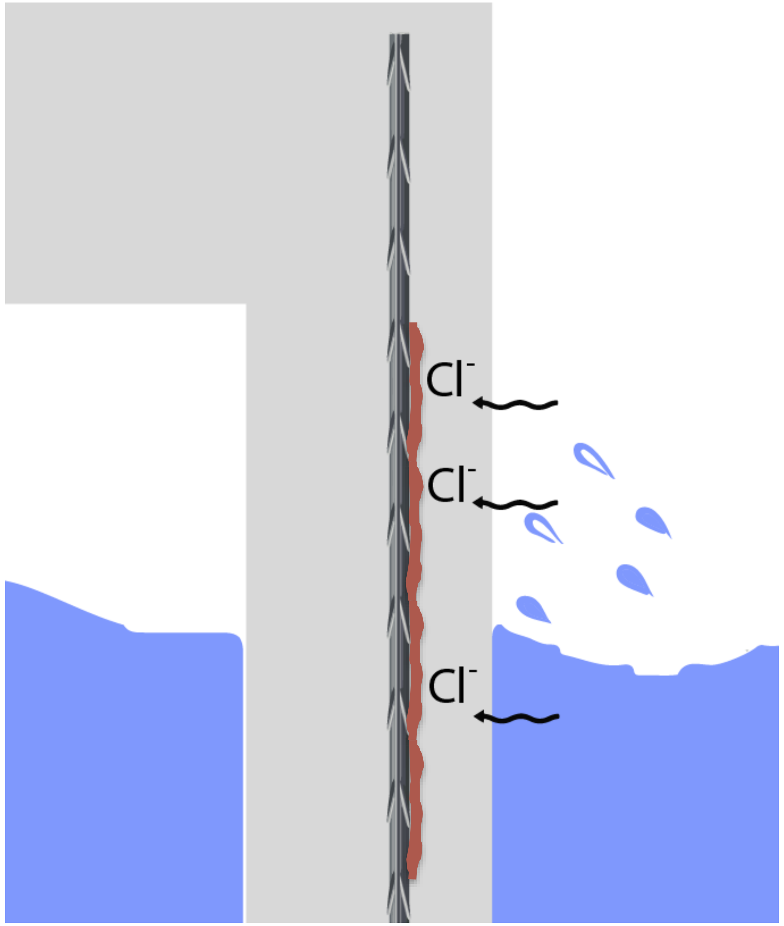
- durability → Service life estimation
- environmental impacts → Life cycle assessment (LCA)

How do we estimate the service life of concrete mixtures?

- Long-term chloride penetration resistance of concrete mixtures is simulated based on their critical chloride content in time.

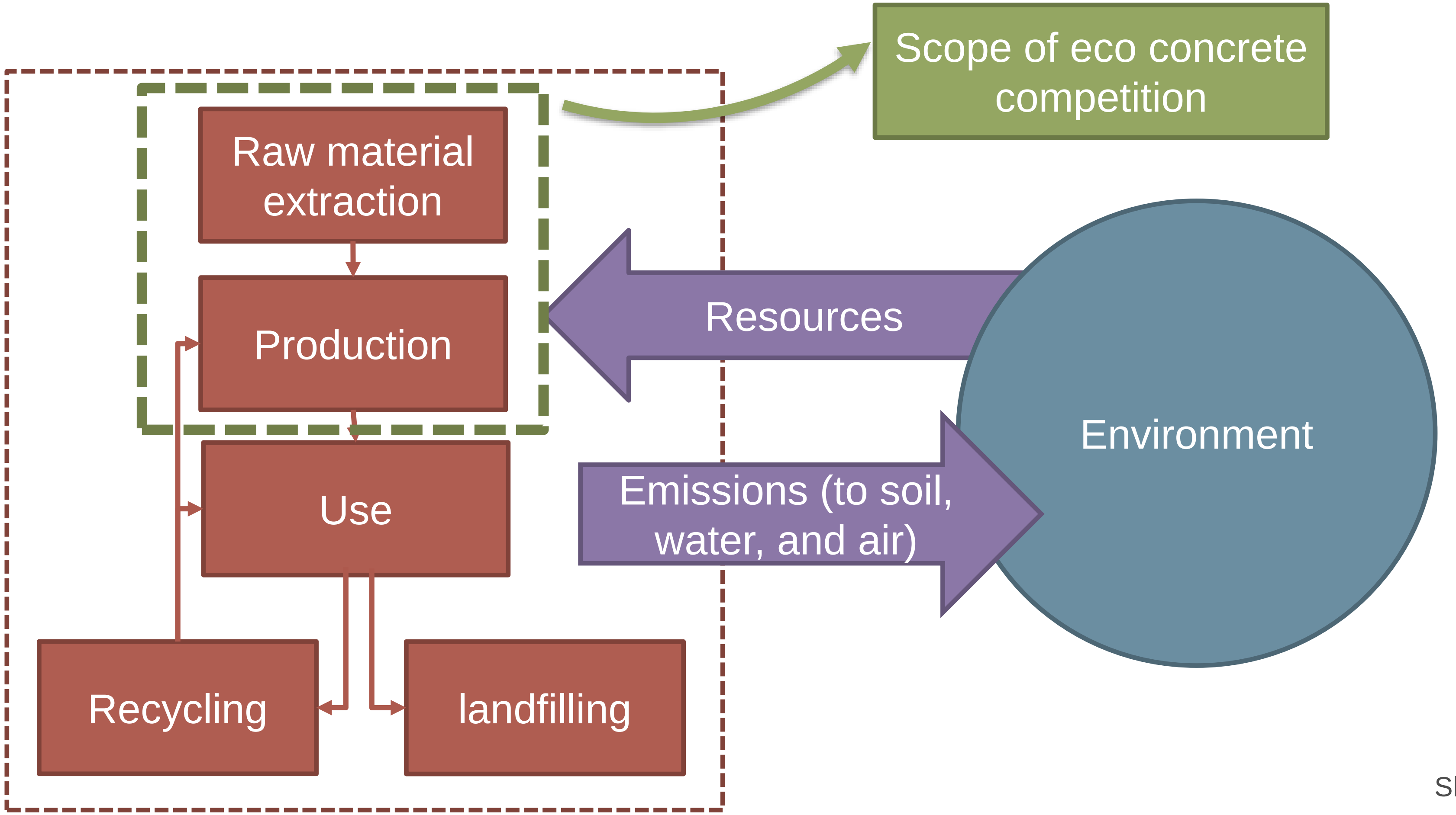
- Life-365™ software is considered to estimated the service life of concrete mixtures based on the corrosion initiation time.

Software download: http://www.life-365.org/



How do we calculate the environmental impacts of concrete?

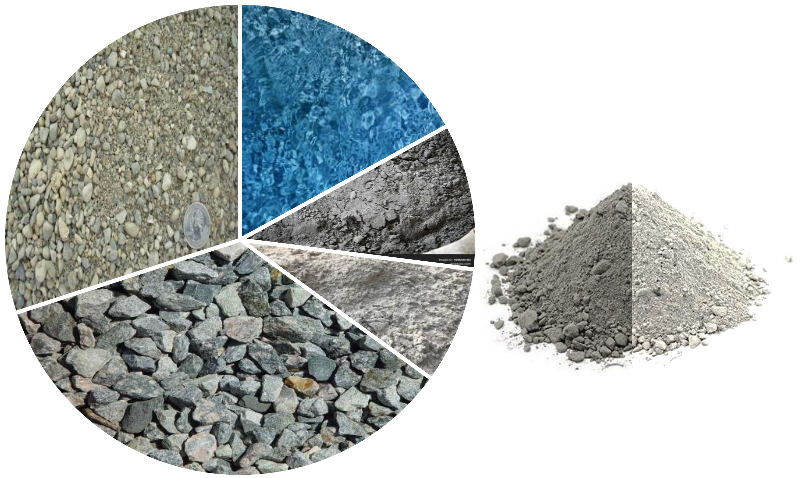
Life cycle assessment (LCA) is a quantitative method for assessing of the potential environmental impacts of any products (e.g., concrete) during its life cycle.



What should we design and evaluate in the eco concrete competition?

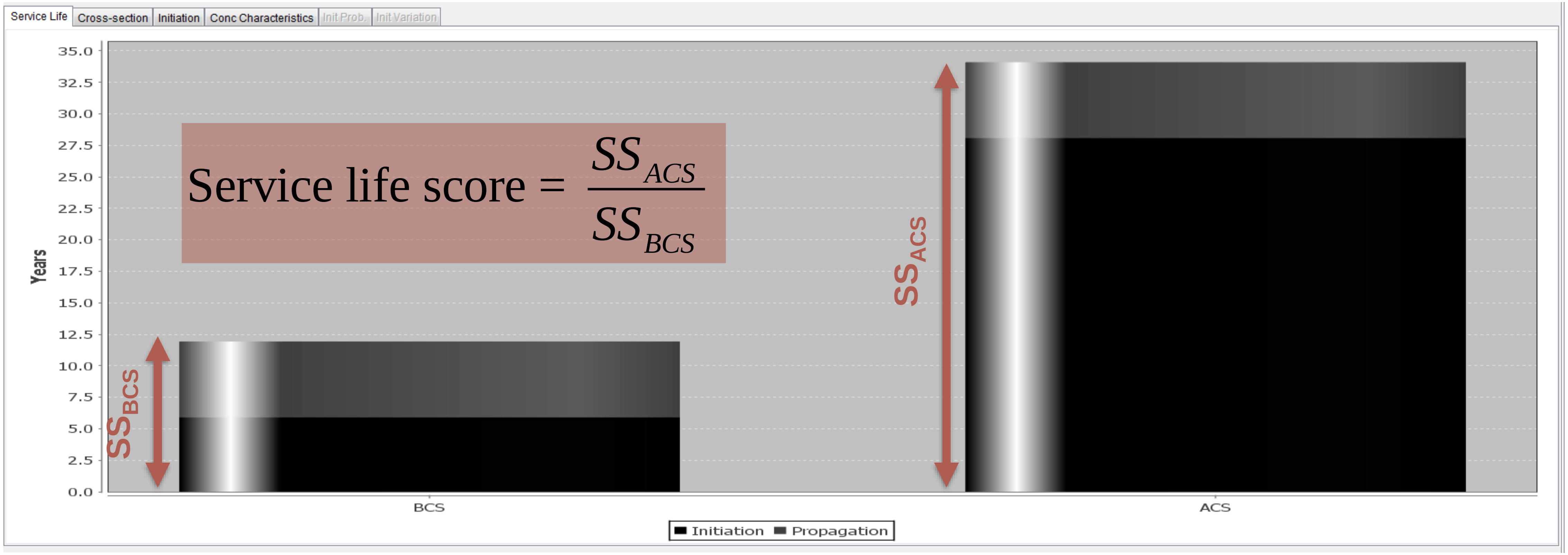
Base-case scenario (BCS)

Alternative-case scenario (ACS)



Service life prediction shall be conducted for the BCS and ACS mixtures

Service life simulation and Ratio calculation



$$\text{Service life score} = \frac{SS_{ACS}}{SS_{BCS}}$$

Section 2.5 of the ECOCONCRETE STUDENT COMPETITION 2021 rules:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf

How do we do LCA in the eco concrete competition?

Streamlined LCA tool was developed in 2017 for this competition

Eco Concrete Student Competition

Designing Base-Case Scenario concrete

Developped by ACI Sherbrooke Student Chapter

Run calculations Go!

Last calculation update: 2017-03-13

1) Input insertion

Base-Case concrete mix design

Components	Category	Subcategory	Amount kg/m³
Cementitious Materials and fillers			
Type 1 (GU) Portland Cement	Cement	Main-Product	400
+ **Aggregates**			
Sand	Fine aggregates	Crushed	900
- 5-10mm aggregate	Coarse aggregates	Crushed	1000
+ **Water**			
Water#1		Tap water	170
+ **Admixtures**			
Admixtures #1			
		Total amount	**2470**
		Total binder content	400
		Water-to-binder ratio	0.40
		Cement substitution rate	0%

[1]Amount required for the production of 1 kg of material

[2]Distance between the origin of the material and the batching plant (your university)

EcoConcrete Student Competition

Summary

Developped by ACI Sherbrooke Student Chapter

2) results

Table 1 : Base- and Alternative-Case

Mix characteristics	Unit	Base-Case Scenario	Scenario	Note
Density	kg/m³	2470	2470	
Total binder content (b)	kg/m³	400	400	$b_{BCS} = b_{ACS}$
Water-to-binder ratio (w/b)		0.40	0.40	$w/b_{BCS} = w/b_{ACS} = 0.43$
Cement substitution rate	%	0%	40%	Maximum 40%

Table 2 : Details of the potential environmental impact scores and variation

Impacts categories	Units	Base-Case Scenario	Alternative-Case Scenario	Potential environmental impact reduction
Global warming	kg $CO_{2\,eq}$	366.973	231.749	36.8%
Carcinogenic	CTUh	0.000	0.000	33.3%
Ozone depletion	kg CFC-11 $_{eq}$	1.55E-05	9.10E-06	41.5%
Ecotoxicity	CTUe	596.460	392.430	34.2%
Fossil fuel depletion	MJ	142.815	83.578	41.5%
			Average:	**37.5%**

Figure 1: Your improvements in a glance

Table 3 : Sensivity analysis and estimation of your final score

Performances	Units	Weigthing factor	Results
Written report	%	**0.30**	**100.0%**
Poster presentation	%	**0.10**	**100.0%**
Compressive strength	MPa	**0.15**	**50.0**
Electrical resistivity	kΩ*cm	**0.20**	**254.0**
Environmental impact reduction	%	**0.25**	**37.5%**
	Final score	**/100**	**84.4%**

Cover page | Base-Case Scenario | Alternative-Case Scenario | Summary | Database

Download: https://www.concrete.org/Portals/0/Files/Excel/EcoConcrete-CalculationTool.xlsm

Life cycle assessment shall be conducted by the streamlined LCA tool designed for this competition

Step 1) After mixtures definition:

A. Materials suppliers shall be identified in your city.

B. Transportation distances shall be presented on a map.

C. Transportation distances from the supplier to university shall be calculated.

Mix design definition

Eco Concrete Student Competition

Designing Base-Case Scenario concrete

Developped by ACI Sherbrooke Student Chapter

Run calculations Go!

Last calculation update: 2017-03-13 00:29

Base-Case concrete mix design

Components	Category	Subcategory	Amount kg/m³
Cementitious Materials and fillers			
Type 1 (GU) Portland Cement	Cement	Main-Product	400
Aggregates			
Sand	Fine aggregates	Crushed	900
5-10mm aggregate	Coarse aggregates	Crushed	1000
Water			
Water#1		Tap water	170
Admixtures			
Admixtures #1			
		Total amount	2470
		Total binder content	400
		Water-to-binder ratio	0.40
		Cement substitution rate	0%

[1]Amount required for the production of 1 kg of material

[2]Distance between the origin of the material and the batching plant (your university)

Transportation definition

Transport[2]			F
Road	Rail	Waterway	G
km	km	km	k
			3
			2
			3
			0
0	0	0	3

Streamlined LCA tool instruction:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-CalculationTool-Instructions.pdf

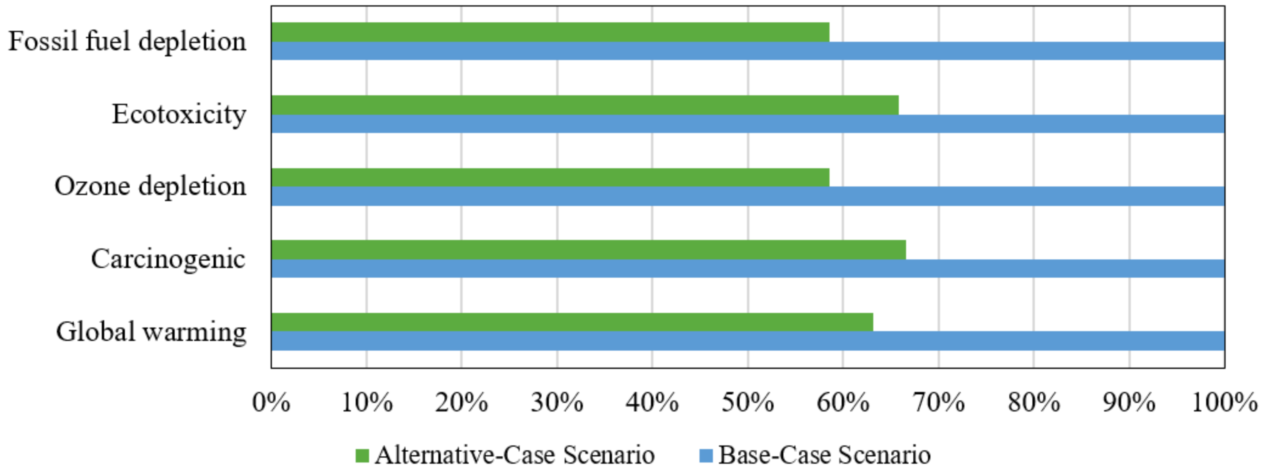
Calculation of relative environmental improvement score

Step 3) Check if all the parameters were inserted correctly (all the boxes are green)

Table 2 : Details of the potential environmental impact scores and variation

Impacts categories	Units	Base-Case Scenario	Alternative-Case Scenario	Potential environmental impact reduction
Global warming	kg $CO_{2\,eq}$	366.973	231.749	36.8%
Carcinogenic	CTUh	0.000	0.000	33.3%
Ozone depletion	kg CFC-11 $_{eq}$	1.55E-05	9.10E-06	41.5%
Ecotoxicity	CTUe	596.460	392.430	34.2%
Fossil fuel depletion	MJ	142.815	83.578	41.5%
			Average:	37.5%

Figure 1: Your improvements in a glance



Score calculation and Question and answer interview

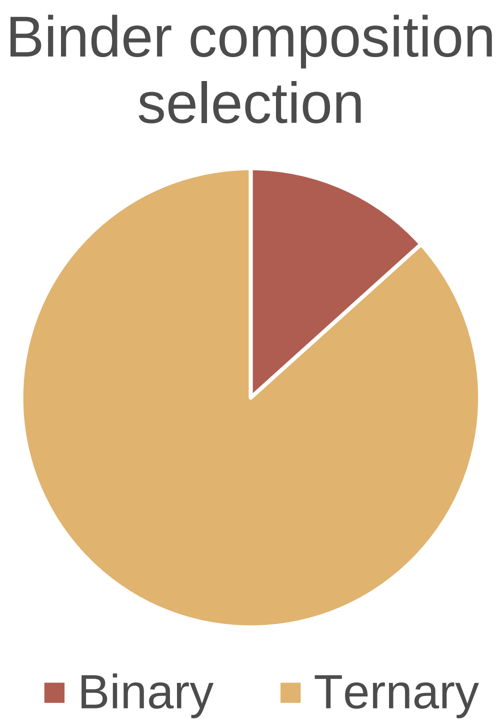
$$Score = 20\%\ report + 30\%\ presentation + 25\%\ durability + 25\%\ LCA$$

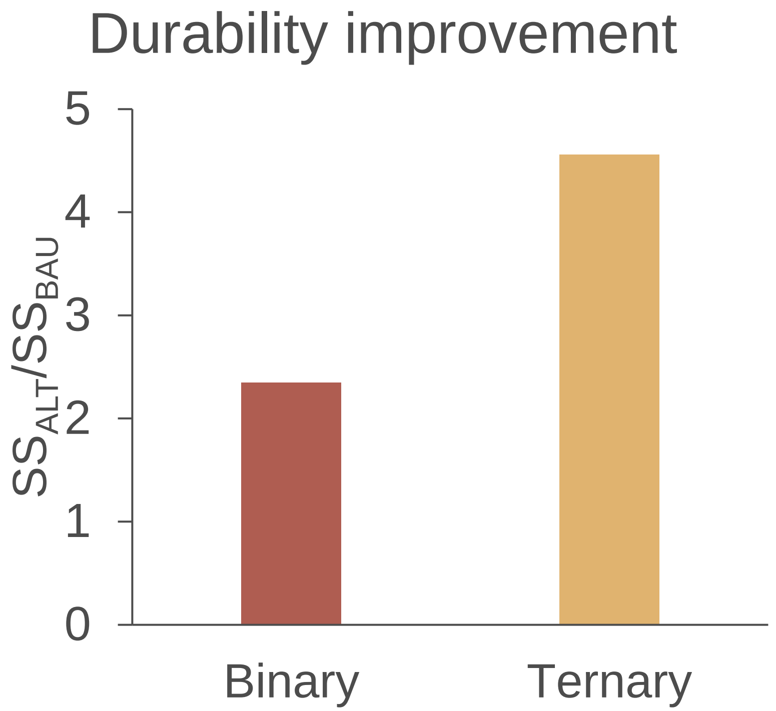
Submission requirement by the deadline:

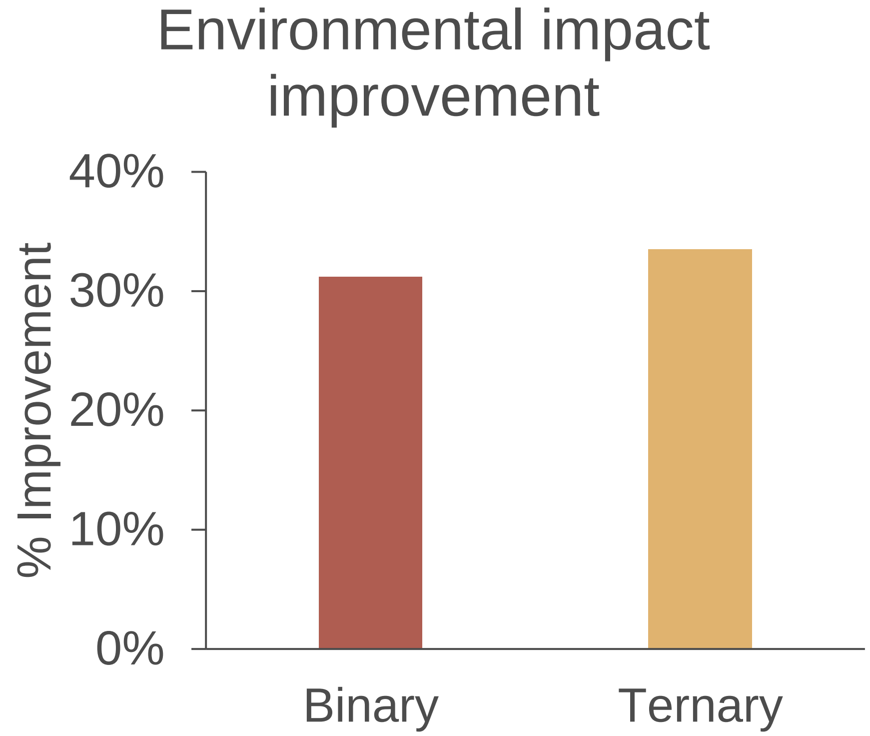
- PDF report
- YouTube link of the recorded video
- Excel tool (including the calculated LCA results)
- Saved file of the Life-365 results (JSON format)

Lessons learned: Ternary mixtures considerably improve the durability and environmental performance of mixtures

Combination of Fly Ash, Slag, and Silica Fume







Lessons learned: Recycled materials and transportation needs to be

1) Neglecting the energy consumption of recycled materials (crushing, grinding, and sieving the materials)

2) Overlooking the transportation of material from the quarry to the plan

3) Not satisfying the minimum content of aggregates in both mix designs

Rule: Similar aggregate volume shall be considered

Part of the last winners' video recording

Three version of this competitions has happened so far because of the following

- ACI Staff:
  - Student, Faculty & Young Professional Activities Coordinator
- ACI Committee Chairs:
  - S801 – Student Competition
  - 130 – Sustainability of Concrete
- Tens of volunteers:
  - Report and Video Reviewers
  - Interview Judges

A contribution from ACI Committee 130, Sustainability of Concrete

The Eco Concrete Competition

Lessons learned by (and from) students

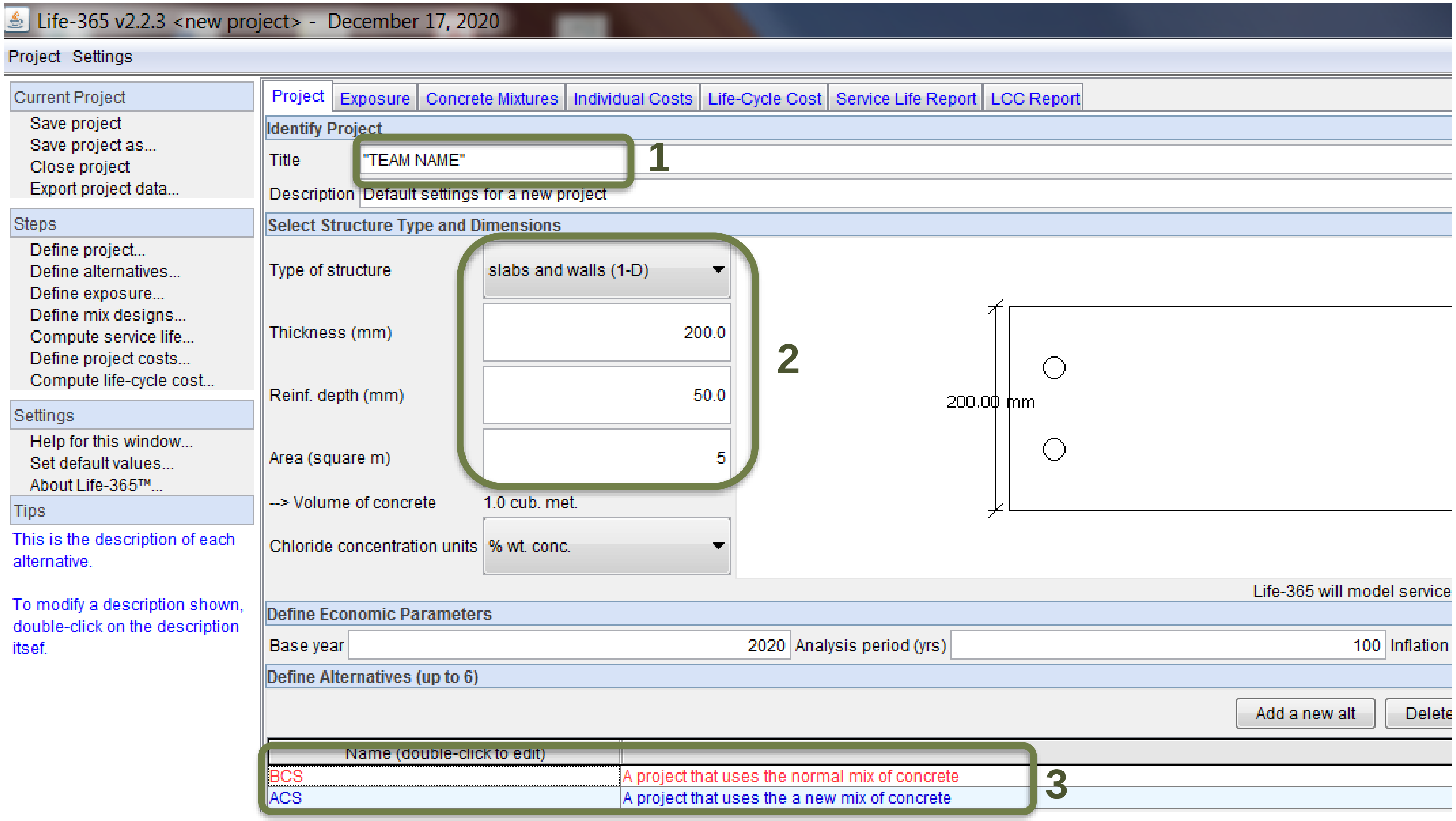
by Hessam Azarijafari, Julie K. Buffenbarger, and Sean Monkman

Previous experiences of eco concrete competition
https://www.concrete.org/students/studentcompetitions/ecoconcretecompetition.aspx

Thank you!
Hessam@mit.edu

Service life prediction shall be conducted for the BCS and ACS mixtures

Step 1) Definition of concrete element geometry in the “Project” tab in Life-365™

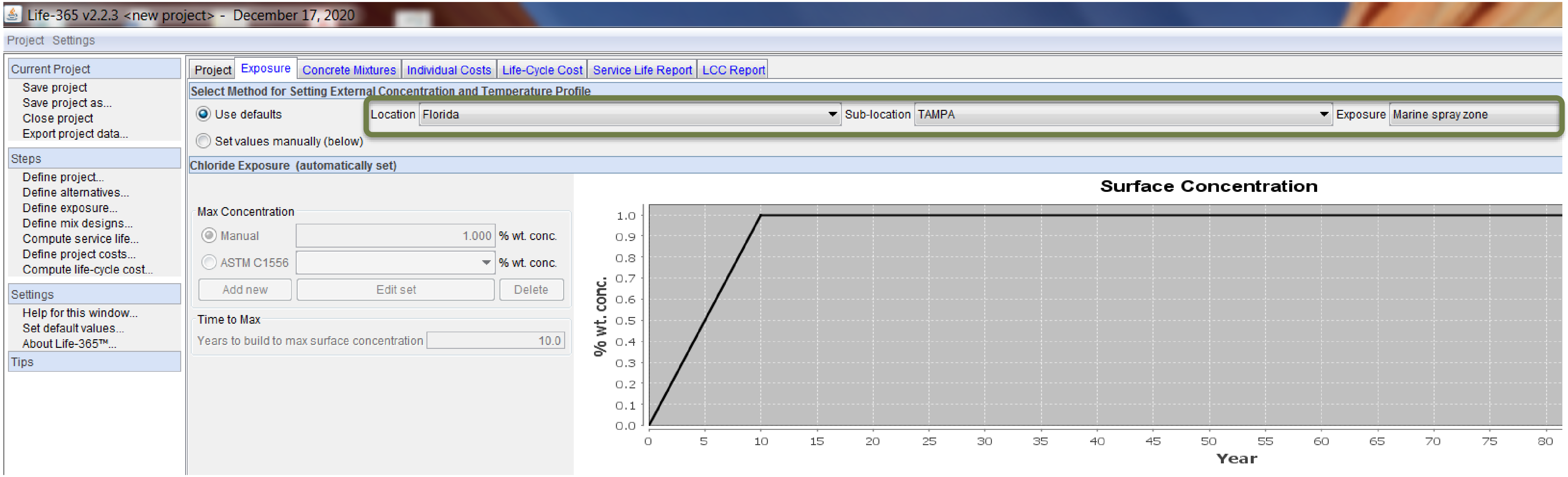


Software download: http://www.life-365.org/

Section 2.5 of the ECOCONCRETE STUDENT COMPETITION 2021 rules: https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf

Service life prediction shall be conducted for the BCS and ACS mixtures

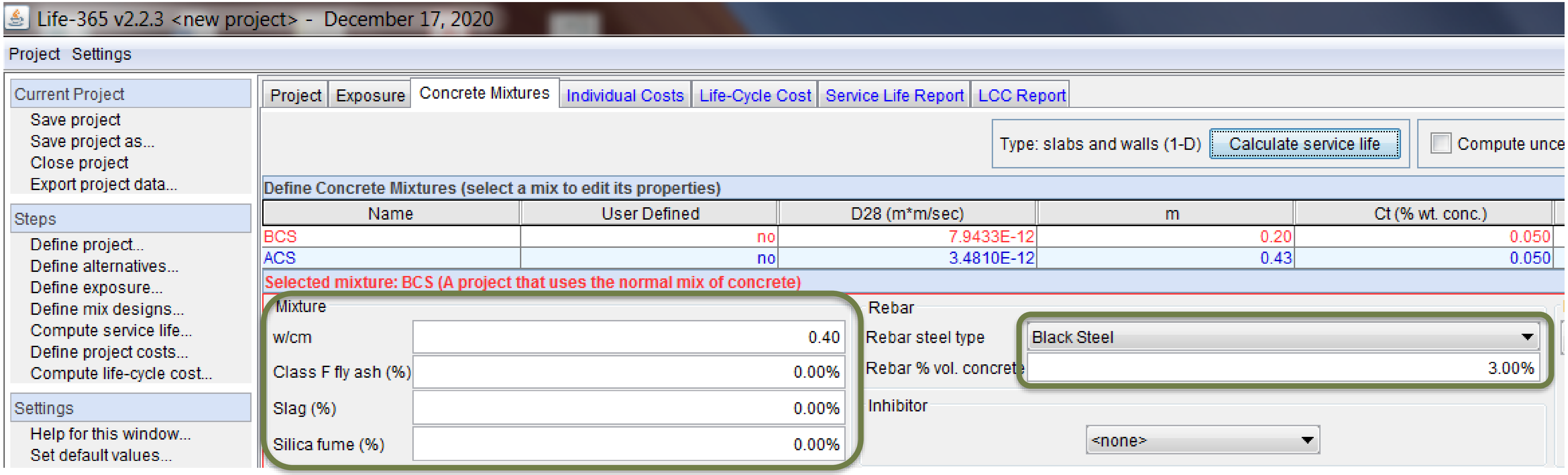
Step 2) Definition of local condition in the “Exposure” tab in Life-365™



Section 2.5 of the ECOCONCRETE STUDENT COMPETITION 2021 rules:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf

Service life prediction shall be conducted for the BCS and ACS mixtures

Step 3) Definition of mix design in the “Concrete Mixtures” tab of Life-365™



Binder percentage shall be exactly defined based on constituents of BCS and ACS mixtures

Section 2.5 of the ECOCONCRETE STUDENT COMPETITION 2021 rules:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf

Results should be presented in two format: written report and Video recording

1. Written Report
   - PDF format (check the due date from the competition rule documents)
   - No more than 20 pages
   - Don’t forget the illustration of maps and results!
   - Discussion of results and how they can be applied in large scale

2. Video recording
   - No longer than 7 minutes
   - Presentation of all team members is a plus
   - Slides should innovatively discuss the results and calculation process

Results validation should be done to assure satisfying all the competition criteria

Step 2) Check if all the parameters were inserted correctly (all the boxes are green)

EcoConcrete Student Competition

Summary

Developped by ACI Sherbrooke Student Chapter

Table 1 : Base- and Alternative-Case Scenarios charcateristics

Mix characteristics	Unit	Base-Case Scenario	Alternative-Case Scenario	Note
Density	kg/m³	2470	2470	
Total binder content (b)	kg/m³	400	400	$b_{BCS} = b_{ACS}$
Water-to-binder ratio (w/b)		0.40	0.40	$w/b_{BCS} = w/b_{ACS} = 0.40$
Cement substitution rate	%	0%	40%	Maximum 40%

Streamlined LCA tool instruction:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-CalculationTool-Instructions.pdf

Rules of competition for material selection and mix designs for the Base-case scenario (BCS)

The design should correspond to a local structural concrete practice.

Aggregates = at least 75% of the total concrete mass

Water to binder ratio = 0.40

Binder = 100% portland cement

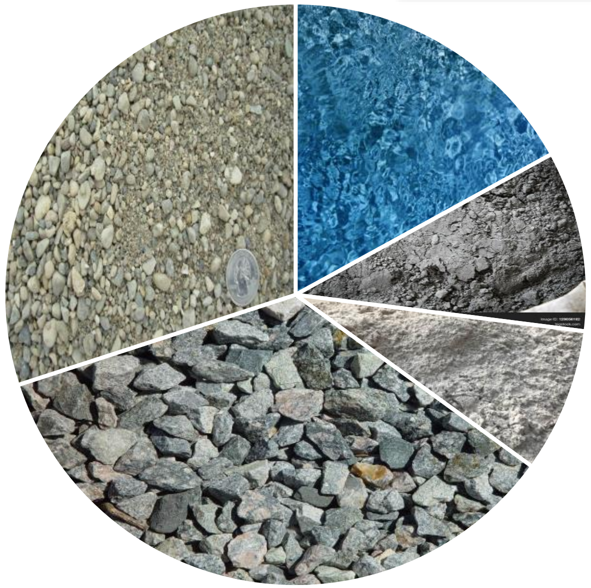
Section 2 of the ECOCONCRETE STUDENT COMPETITION 2021 rules:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf

Rules of competition for material selection and mix designs For the Alternative-case scenario (ACS)

The volume of aggregates and binders shall be equal to those in the BCS mixture

Water to binder ratio = 0.40

Similar aggregate volume shall be considered



Similar binder volume to shall be considered

40% maximum binder replacement by supplementary cementitious materials (SCM)

Only SCMs predefined in Life-365™ software shall be included.

Multiple types of SCMs are allowed.

Section 2 of the ECOCONCRETE STUDENT COMPETITION 2021 rules:
https://www.concrete.org/Portals/0/Files/PDF/EcoConcrete-RulesFinal.pdf