Canada Chairholder on Sustainable Multifunctional Construction Materials

Planning Sustainable Bio-inspired Printed Infrastructure for Erosion Control

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Coastal erosion: American context

- Coastal erosion intensifies the effects of sea-level rises, king tides and storm surges.
- "roughly $500 million per year in coastal property loss, including damage to structures and loss of land," according to the U.S. Climate Resilience Toolkit.

Example of the St. Lawrence River

Pictures courtesey of Conservation de la Nature Canada

Erosion control: key facts

Sediments in number: 2020

Countries/Regions	Sediments ($M.m^3$)
Québec	0,45
France	56
Chine	343
USA	357

Ports au Québec

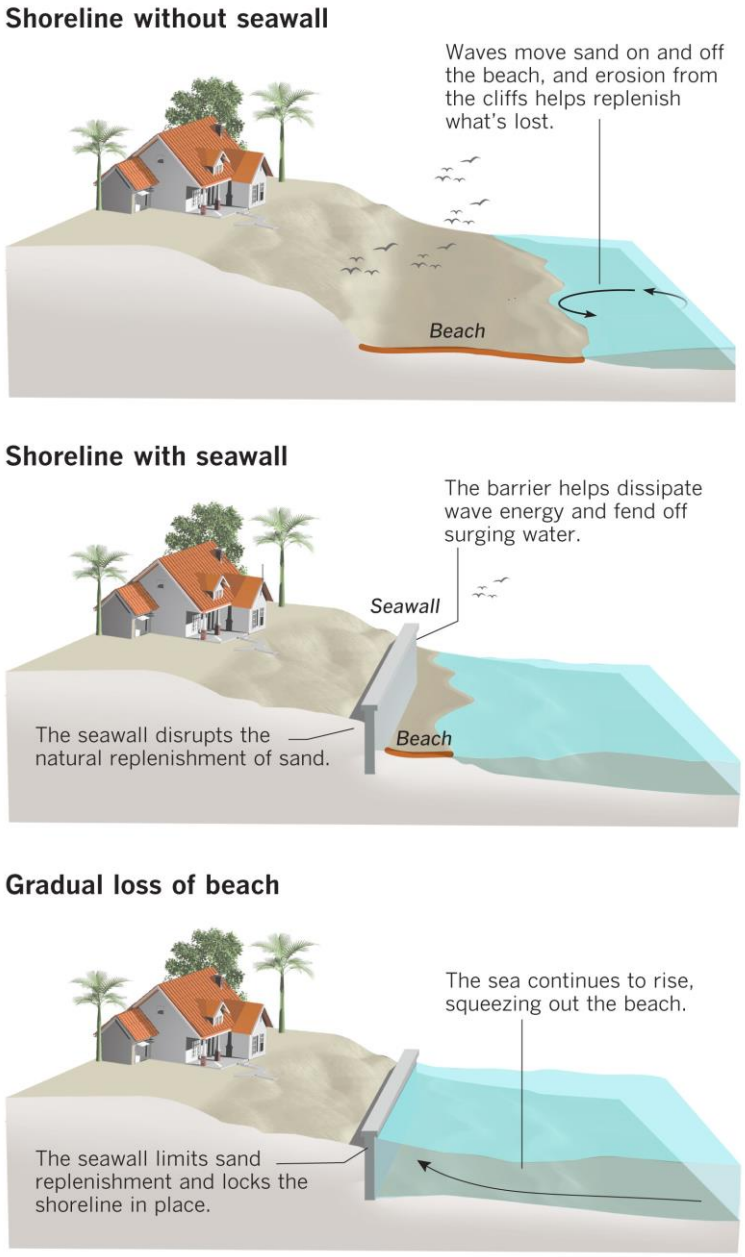
- **35** ports
- **3700** km **navigable ways**
- **450 000** m^3 / yr dredgged sediments
- **90%** sediments are submerged
- Source : Plan d'action St-Laurent,2011-2026

Cement industry

- **800-1000** kg CO_2/t clinker
- **4,6** billions de ciment /yr
- **4-7 % CO_2 emissions**
- $CaCO_3 \rightarrow CaO + CO2$ (60%)

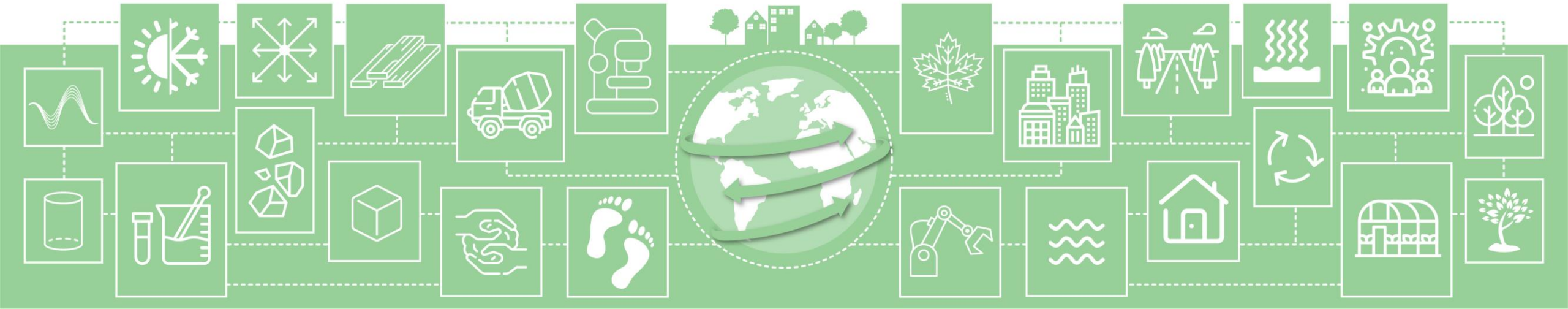
- Source :GCCA

Warning on the use of sea wall



https://www.latimes.com/projects/la-me-sea-level-rise-california-coast/

How 3D printing of concrete can help to design local solutions?



On-going steps

- Discussion with local stakeholders, including First Nations
- Review of the Intergovernmental Panel of Climate Change (IPCC)
- Review of solutions made with 3D printing concrete
- Formulation of printable low carbon printable materials
- Formulation of a local concrete mixture with local dregged sediments
- Planning the experiments to include durability tests

Physical basis

- Coastal erosion: not a simple and robut relationship to global warming.
- Sea level rise is very likely to continue in the 21st century contributing to increased coastal erosion.
- **Coastal erosion: « Along sandy coasts and in the absence of additional sink/source or any physical barriers to shoreline retreat »**

Impact, adaptation, vulnerability

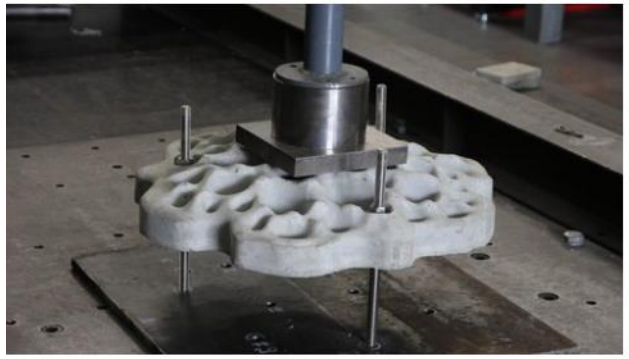
- **Coral reefs** are at risk of widespread decline and transition to a net erosion due to marine heatwaves (v. high confidence)
- The **impacts** from coastal wetlands reduction will be **compounded where coastal development prevents upshore migration of habitats or where terrestrial sediments inputs are limited and tidal ranges are small.**
- Disruption of **ecosystem services: wave-energy attenuation**, biodiversity, climate mitigation, food and fuel

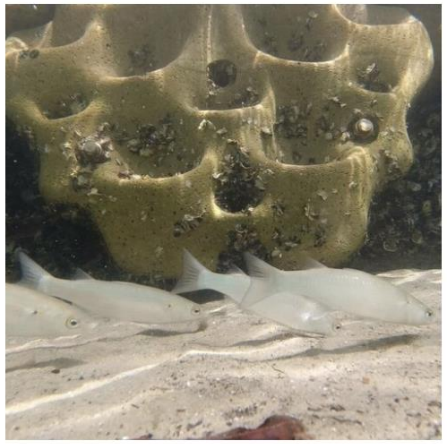
Printed artificial reefs

https://xtreee.com/en/project/32-recifs-artificiels-pour-le-cap-dagde/

- Low cost printed reefs with complex geometry
- Texture adapted to be resistant to chemical attacks
- Promotion of aquatic biodiversity
- Challenge: large infrastructure to dispose in the water

Living marine walls





https://www.livingseawalls.com.au/

- Increasing the ecological value of aquatic infrastructure
- 20 years of research in Australia
- Rapid increase in species quantity in 1-2 years
- Improved water quality
- Promotion of 20 habitat types

Concrete tide pools

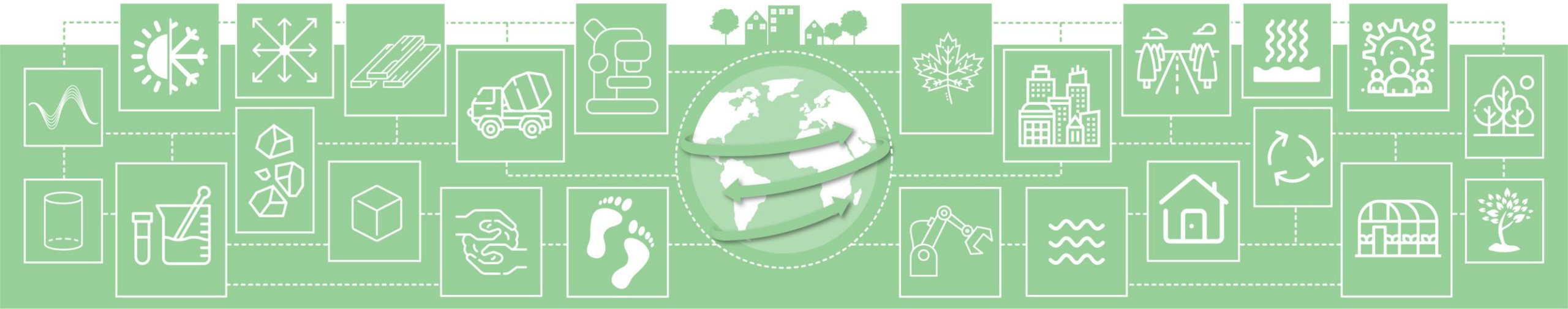
After 6 months

After
14 months

https://econcretetech.com/

- Holistic solution
- Prefabricated shoreline basins
- Suitable for rocky shores
- Promotion of local biodiversity

Challenge: greater focus on biodiversity than erosion control



Effect on erosion

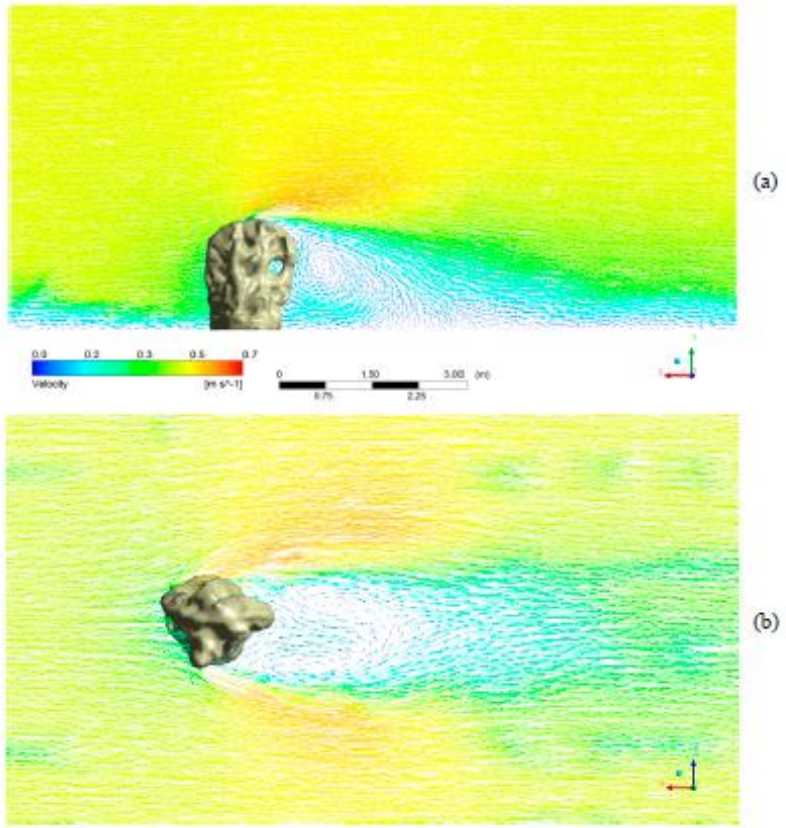


Figure 9. Velocity vectors of the numerical simulation of the flow around a single AR unit (with code A5—refer to Figure 4c). The inlet velocity was 0.5 m/s. (**a**) A vertical cross-section of the flow. (**b**) A horizontal cross-section of the flow.

- Possibility of mitigating the effects of waves with underwater structures.
- Need for fluid mechanics analysis to test effectiveness of solutions.

Androulakis, D. N., Dounas, C. G., Banks, A. C., Magoulas, A. N., & Margaris, D. P. (2020). An assessment of computational fluid dynamics as a tool to aid the design of the HCMR-artificial-reefsTM diving oasis in the underwater biotechnological park of Crete. *Sustainability, 12*(12), 4847.

Concrete exposition conditions

Known

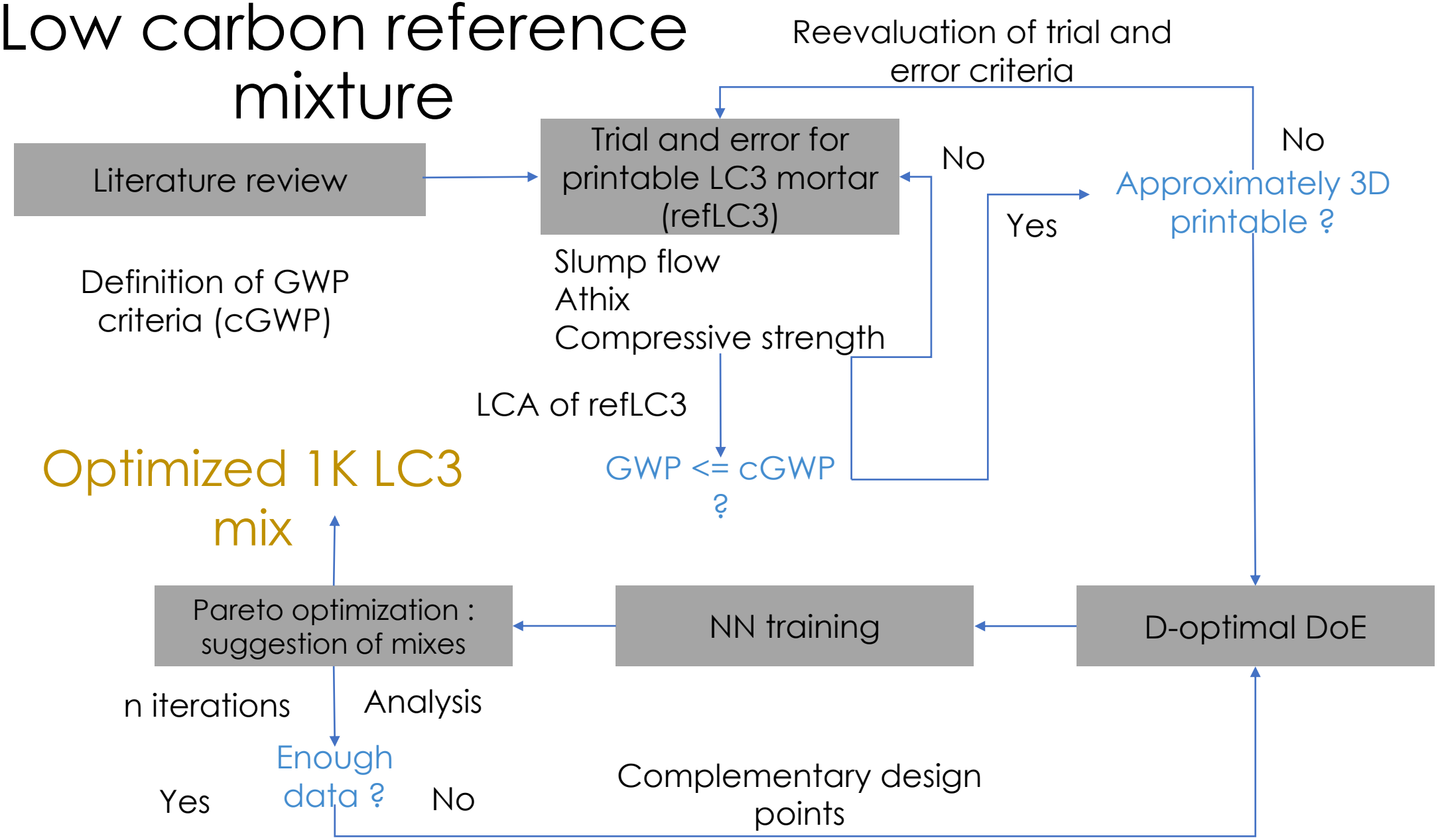
- Chlorine concentration: fresh vs salt water
- Freeze-thaw resistance in northern regions

Less known

- Little data on the push from the ice
- Fatigue stress from the waves

Required strength: target in discussion

Low carbon reference mixture

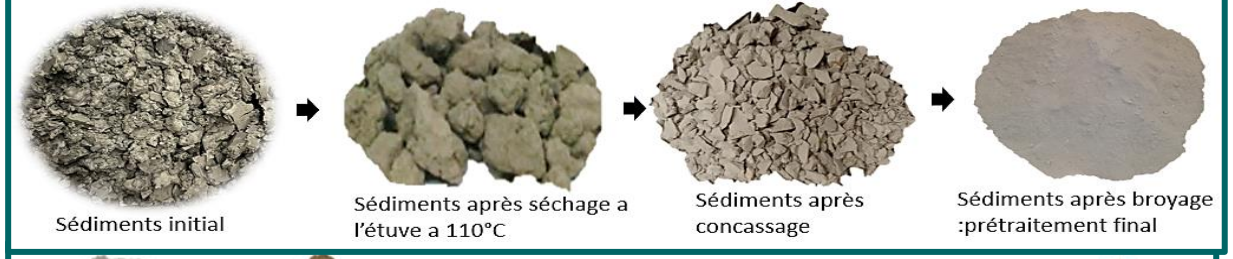


Evaluation of the reactivity of local sediments

St-Lawrence River Contrecœur

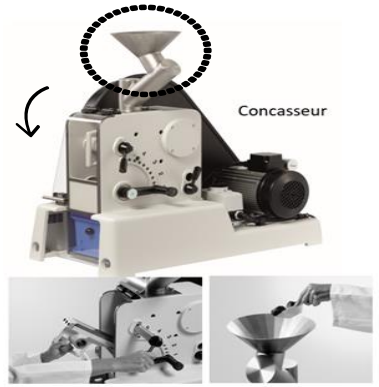
The sediments collected on the shore of a zone with higher erosion where additional construction is planned.

1 Thermal treatment



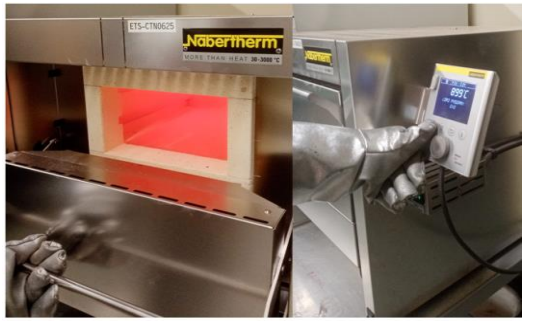
2

Change in color of the sediments at various temperature



Granulometry control

Pulverisette 9



Calcination oven (Nabertherm)

Conclusion

- Erosion control is pressing issue
- Design criteria for the concrete mixtures and structure are in discussion
- Importance of a low carbon concrete
- Local sediments allow to use local resources
- Potential application for 3D printing of concrete

Acknowledgment

Chaires de recherche du Canada
Canada Research Chairs

Canada

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Québec
Fonds de recherche – Nature et technologies
Fonds de recherche – Santé
Fonds de recherche – Société et culture

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MITACS

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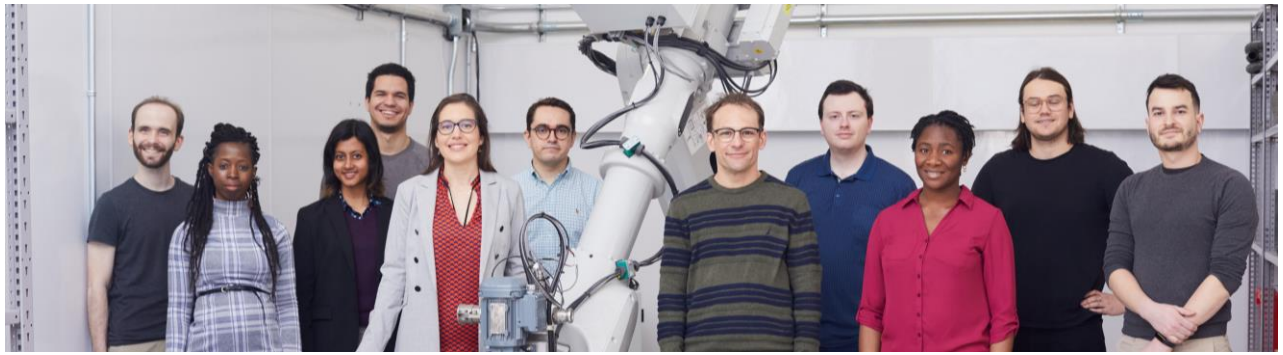
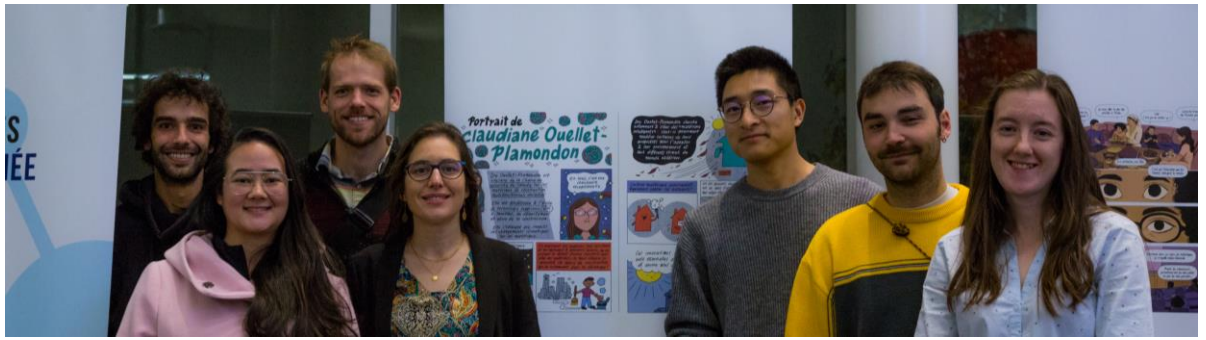
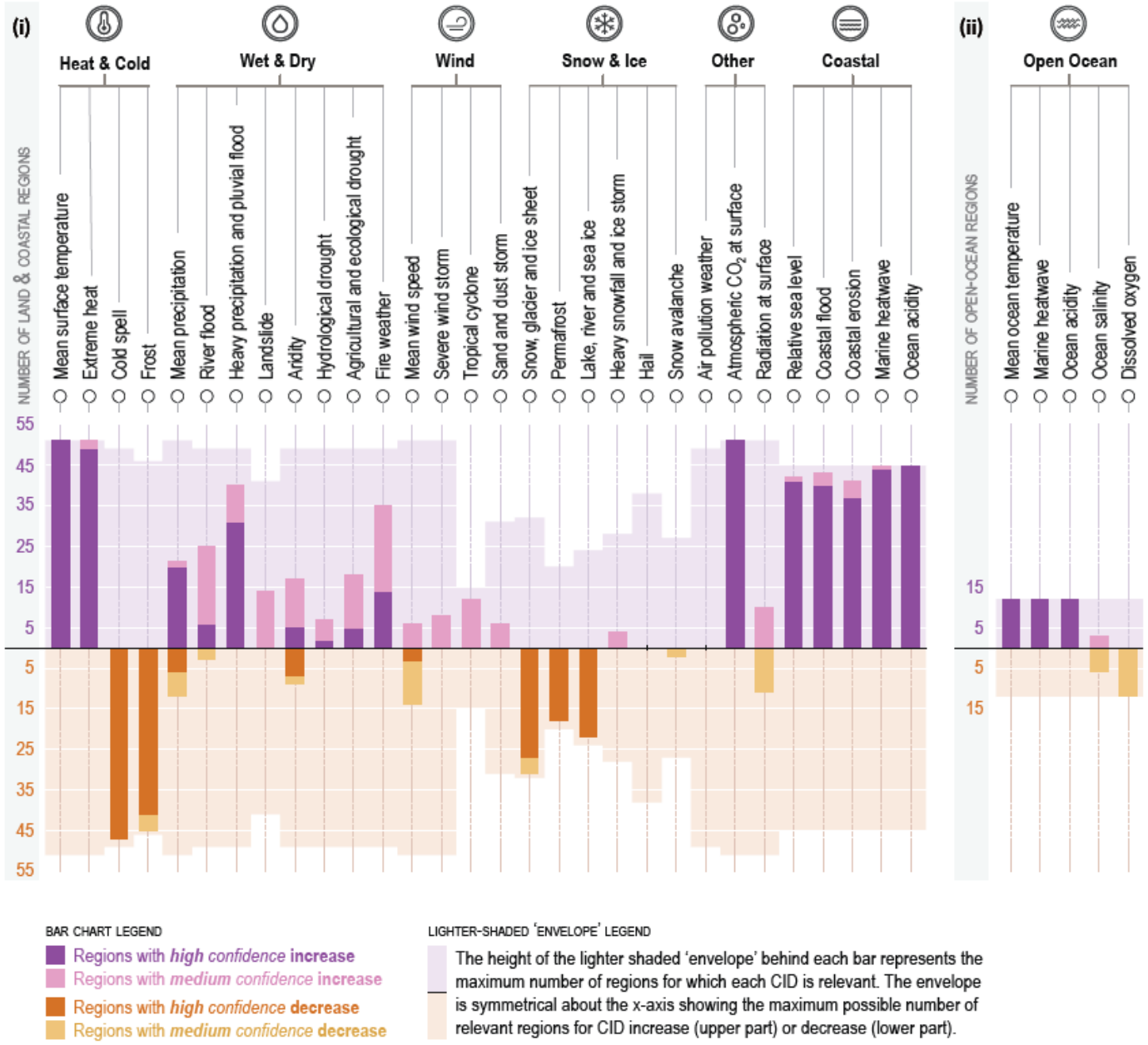




Climate change: mitigation

- Carbon dioxide removal
- Enhanced weathering: enhanced plant growth (12.3), TRL 3-4


(i)
Heat & Cold
Wet & Dry
Wind
Snow & Ice
Other
Coastal
(ii)
Open Ocean
NUMBER OF LAND & COASTAL REGIONS
NUMBER OF OPEN-OCEAN REGIONS
Mean surface temperature
Extreme heat
Cold spell
Frost
Mean precipitation
River flood
Heavy precipitation and pluvial flood
Landslide
Aridity
Hydrological drought
Agricultural and ecological drought
Fire weather
Mean wind speed
Severe wind storm
Tropical cyclone
Sand and dust storm
Snow, glacier and ice sheet
Permafrost
Lake, river and sea ice
Heavy snowfall and ice storm
Hail
Snow avalanche
Air pollution weather
Atmospheric CO_2 at surface
Radiation at surface
Relative sea level
Coastal flood
Coastal erosion
Marine heatwave
Ocean acidity
Mean ocean temperature
Marine heatwave
Ocean acidity
Ocean salinity
Dissolved oxygen
55
45
35
25
15
5
5
15
25
35
45
55
15
5
5
15
BAR CHART LEGEND
Regions with high confidence increase
Regions with medium confidence increase
Regions with high confidence decrease
Regions with medium confidence decrease
LIGHTER-SHADED 'ENVELOPE' LEGEND
The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).