Engineering
Civil Engineering

McMaster University

Deep Learning Based Approach for Evaluating Concrete Surface Integrity through Crack Identification and Analysis

Presented by: Majdi Flah, P.Eng, M.E.Sc, Ph.D. Candidate
Department of Civil Engineering
McMaster University

Supervised by: Prof. Moncef L. Nehdi, Ph.D., P.Eng, FCAE, FEIC, FACI, FCSCE, FAAIA, FAIIA
College of Engineering and Physical Sciences
University of Guelph

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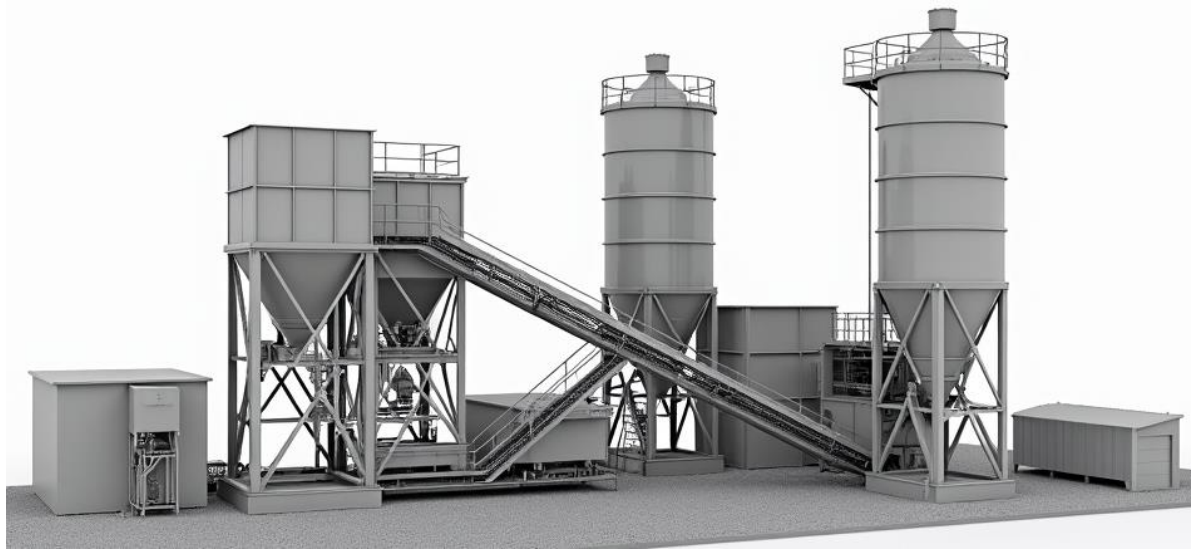
Toronto, ON, Canada

Outline

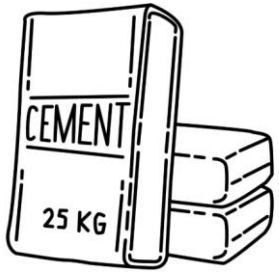
Outline

Shifting the focus: From Formulation to Preservation

Supplementary Cementitious Materials Combinations

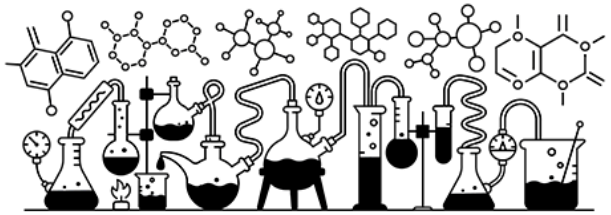


Recycled Aggregates



Various types of cements

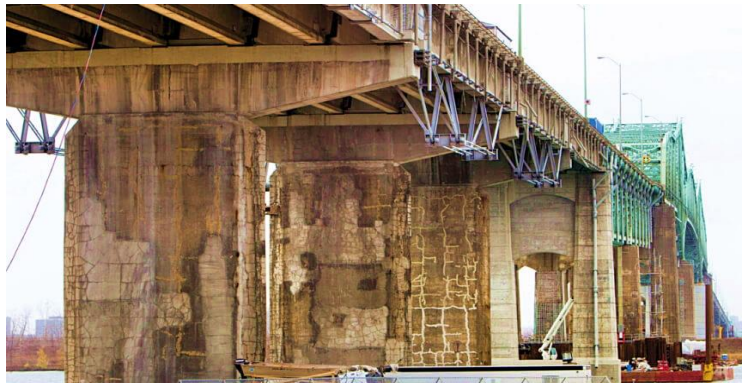
Current research efforts are largely Centered on developing innovative concrete mix designs, often for newly built components!

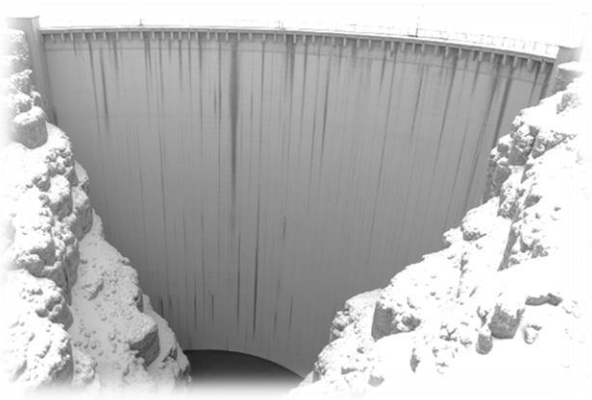


Admixtures

What do we need to do when we can't rebuild?

When the structure is too *important*, too *expensive*, or too *embedded* to replace?





All are aging. None can be destroyed. All must be repaired, sustainably.

Repair is not a fallback; it is the only path forward.

Outline

What is the situation of our vital infrastructure?

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

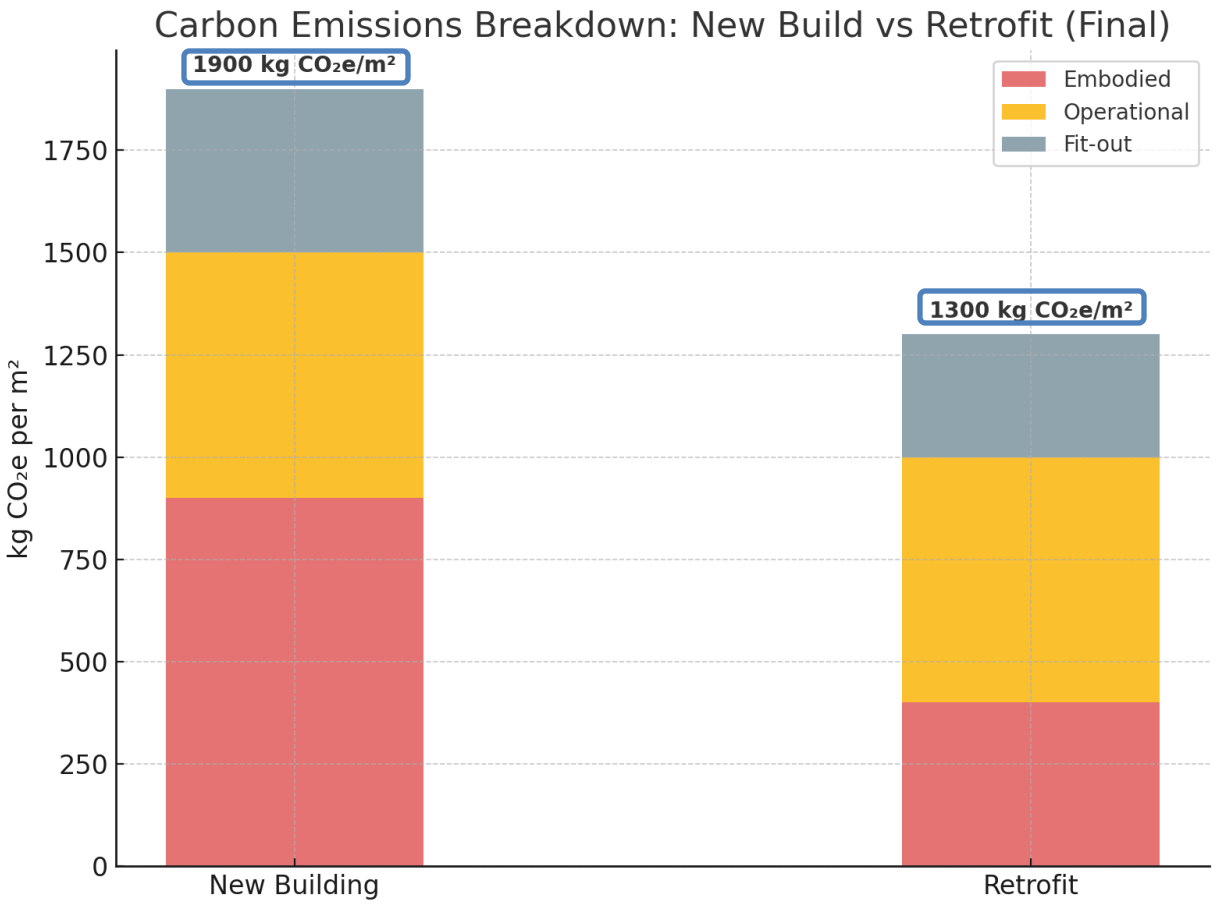
Bridges
C+

FHWA
U.S. Department of Transportation

Bridges
185,100
Urgent Consideration
46,275
Nearing the end of their service life

Retrofitting → $123 Billion!

Is it more sustainable to pour more concrete, or smarter to extend what already exists?



Emissions reduced by **600** kg CO2 eq/m2 through reuse

*Quantities assume a 10,000 m^2 building with a lifetime of 20 years and 1 fit-out

https://2050-materials.com/blog/refurbishment-or-new-build-the-carbon-and-business-case-for-each-option/

Are we truly paying attention to what our aging infrastructure is trying to tell us — or are we still just patching over the symptoms?

Traditionally

Naked Eye

- Dangerous
- Time consuming
- Repetitive
- Subjective

How to process this Big Data?

DEEP LEARNING

Input Dataset

Images

Automated Feature Extraction and Classification

Output

Classification

Outline

What are the specific Research Objectives of this study?

01

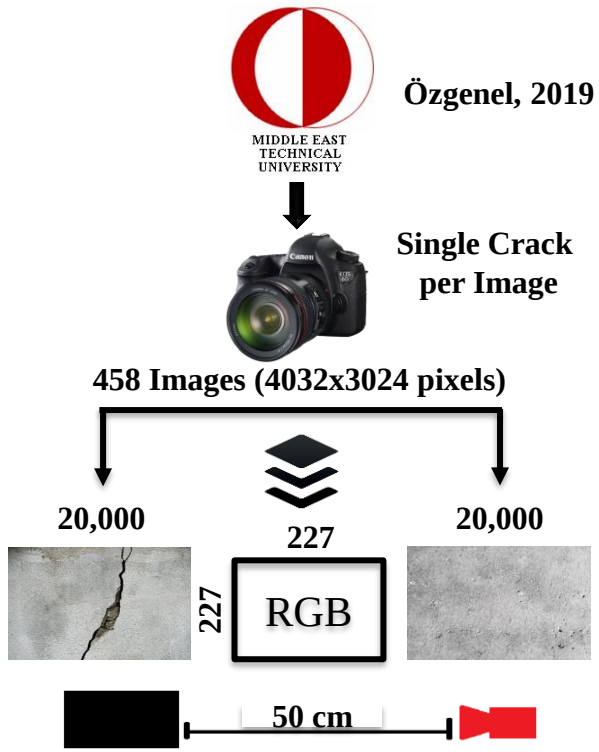
Develop a DL Image Based Technique

High Accuracy

Less Computing Time

How to analyze the data?

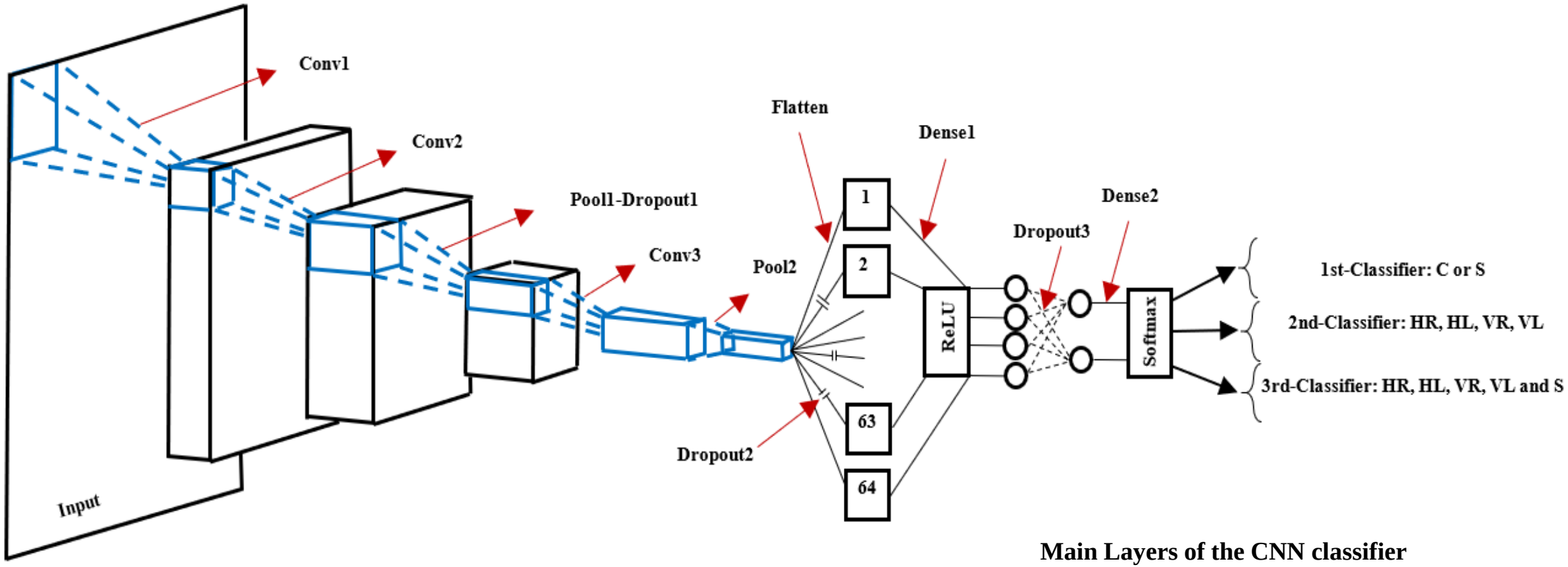
Data Preparation



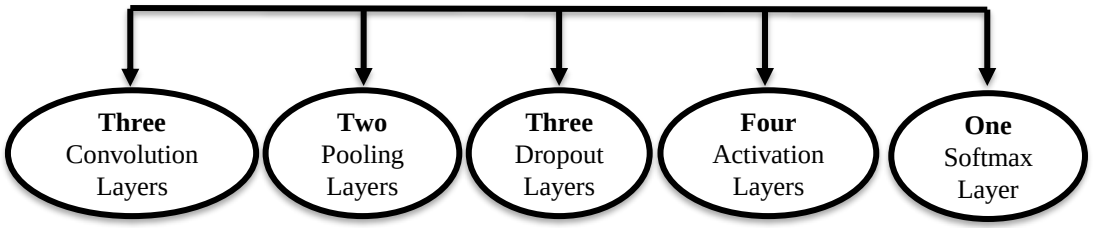
Data Processing

Data Labelling

What is the main architecture of the CNN classifier?

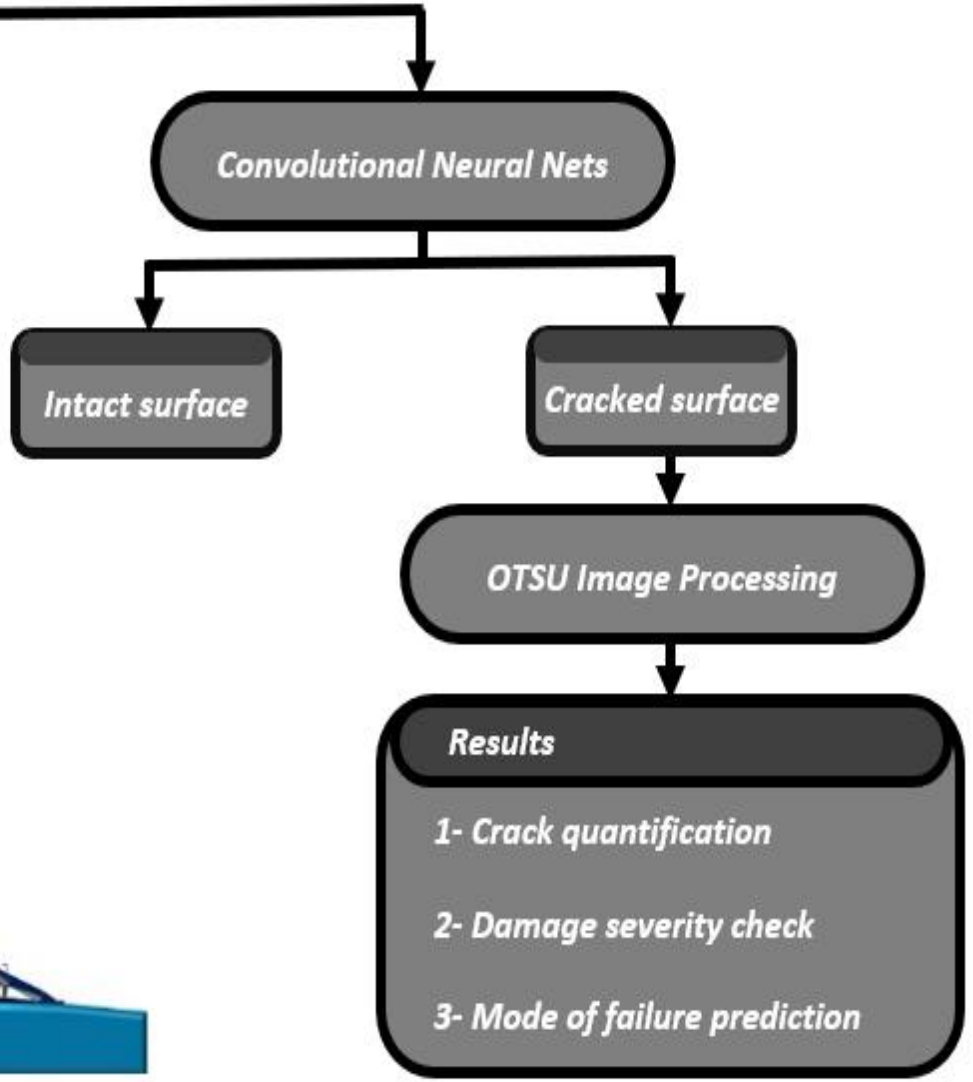


Main Layers of the CNN classifier



***CNN: Convolutional Neural Networks**

What is the mechanism of the proposed study?



What are the steps of Image Segmentation?

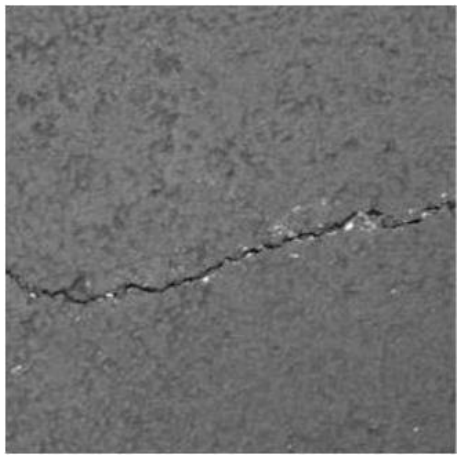
MATLAB

01 Image Improvement
Convert to Grayscale

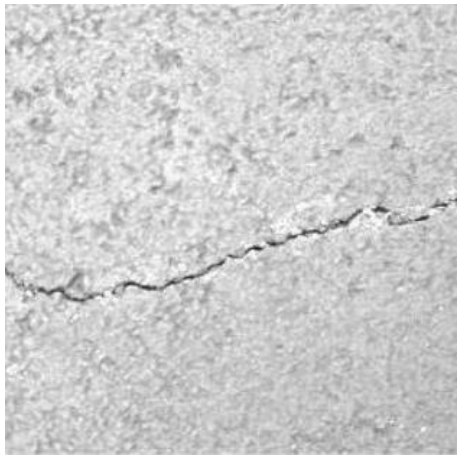
02 Thresholding Otsu Method
Form a binary image

03 Noise Removal
Remove all Noise

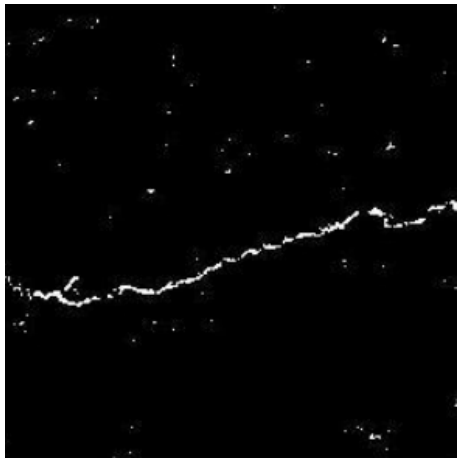
04 Image Connection
Perform closing operation techniques



Original Image



Improved Image



Binary Image

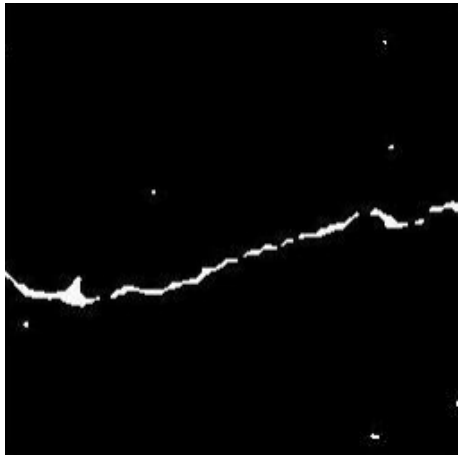
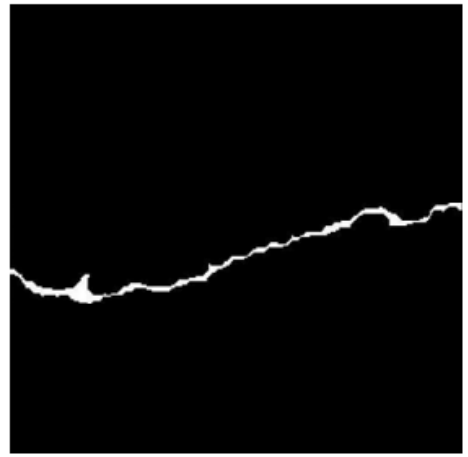


Image after closing operation

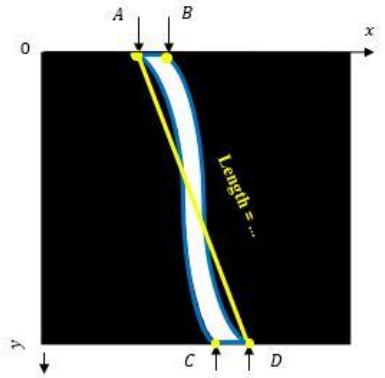


Final Image

Algorithm uncovered: How Digital Segmentation Measures Concrete Cracks?

Apply boundaries

Length of the Crack



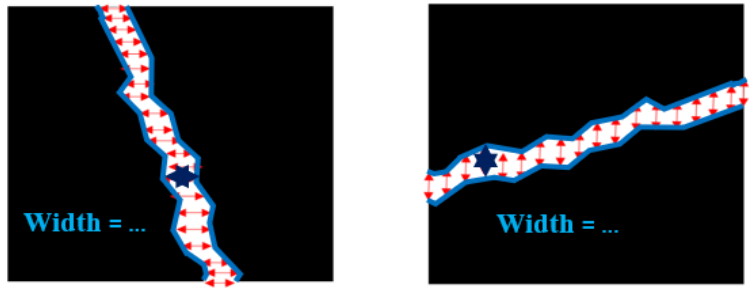
$d_{A,B}$, $d_{A,C}$, $d_{A,D}$, $d_{B,C}$ and $d_{B,D}$

pdist2

$$d_{A,B} = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2}$$

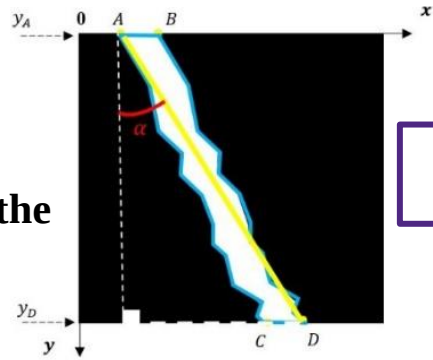
Compute the maximum distance between them

Width of the Crack



a) Vertical Crack b) Horizontal Crack

Angle of the Crack

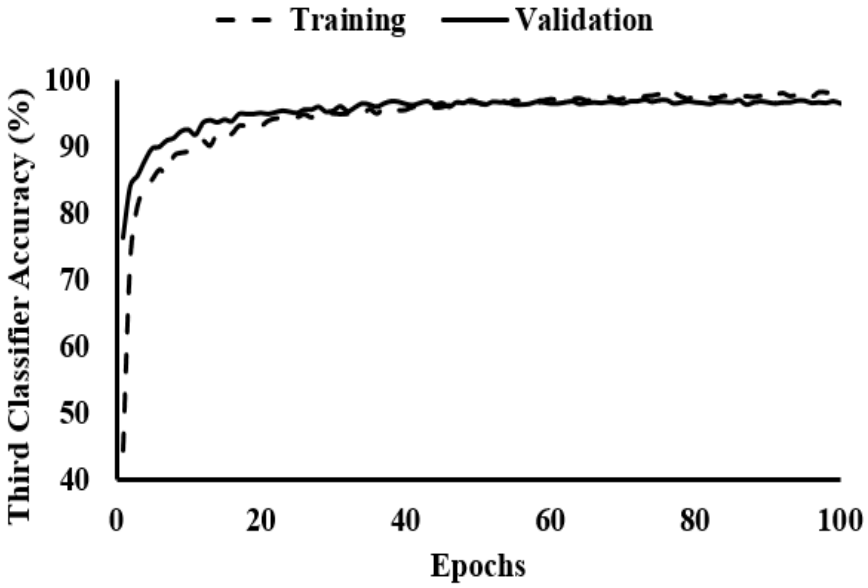


$$\alpha = cos^{-1}\left(\frac{y_D - y_A}{d_{A,D}}\right)$$

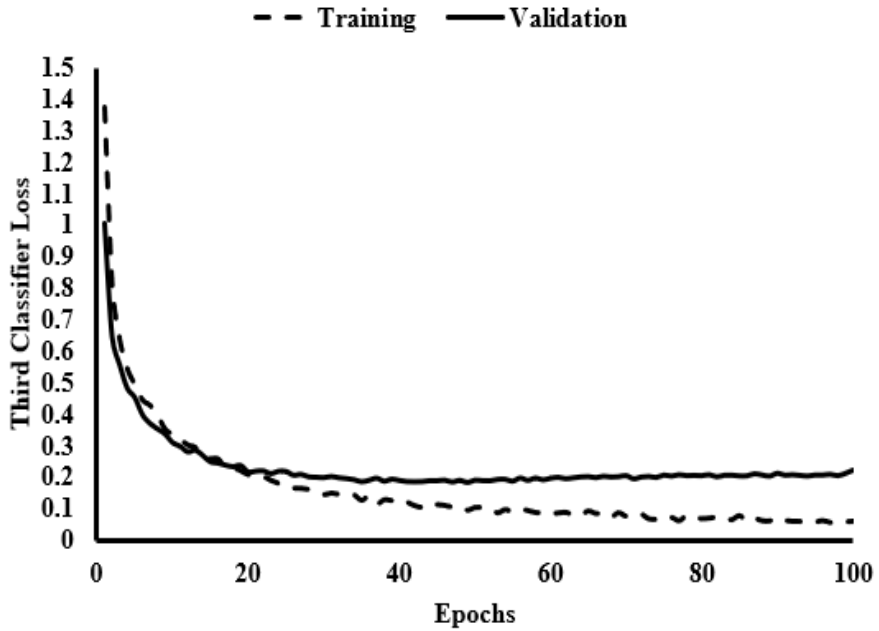
Outline

Can we predict concrete cracks with certainty?

96.17%



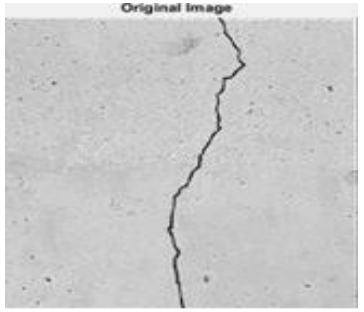
(e) Third Classifier Accuracy

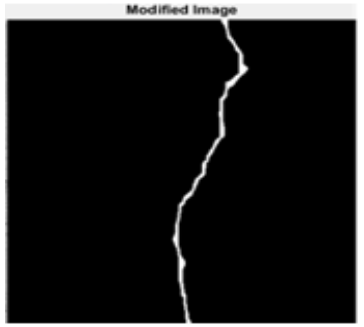


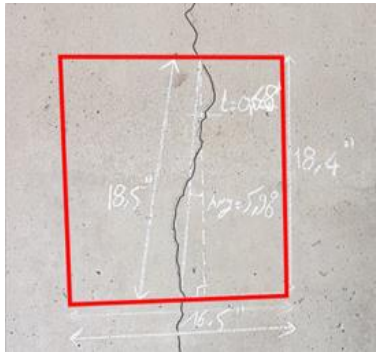
(f) Third Classifier Loss

0.14

Can Digital Algorithms Accurately Measure Concrete Cracks?







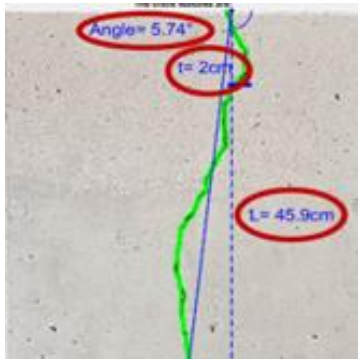


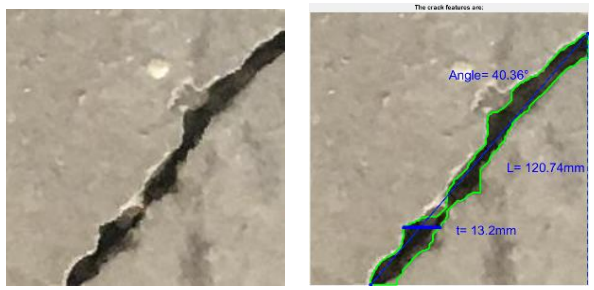
Figure	Method	Orientation	Area (m^2)	L (cm)	L_ε (%)	W (cm)	W_ε (%)	Ang (°)	Ang_ε (%)
Fig 20	Experimen.	HR	0.38	69.85	0.07	2.85	5.26	14.53	0.61
	Algorithm	HR		69.9		3		14.44	
Fig 21	Experimen.	VR	0.196	46.9	2.14	2.09	4.3	5.96	3.7
	Algorithm	VR		45.9		2		5.74	
Global Avg.	For the total number of the tested Samples				~1.5%		~5%		~2%

Length Error | **Width Error** | **Angle Error**

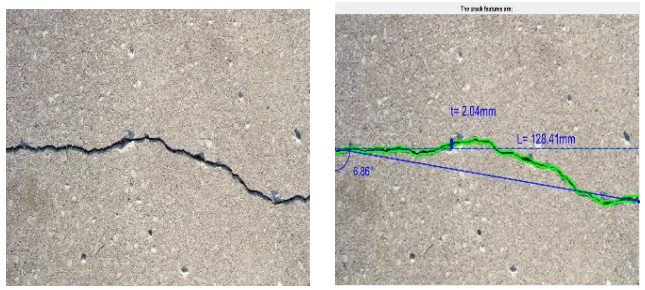
Outline

Intersecting vs. Non-intersecting: How Does Crack Complexity Affect Accuracy?

Single Crack Pattern



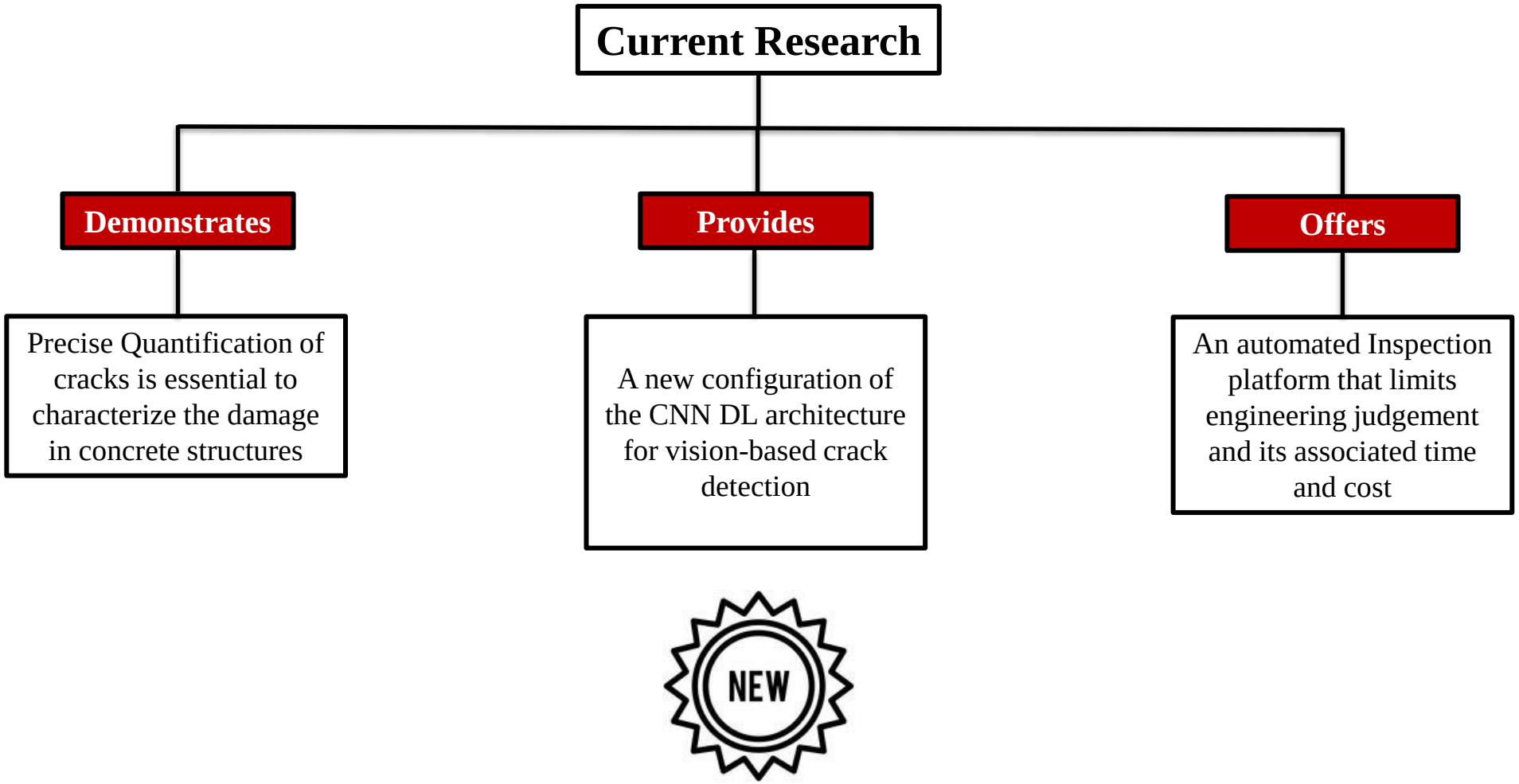
(a) Accurate quantification for a single VR crack



(b) Accurate quantification for a single HL crack

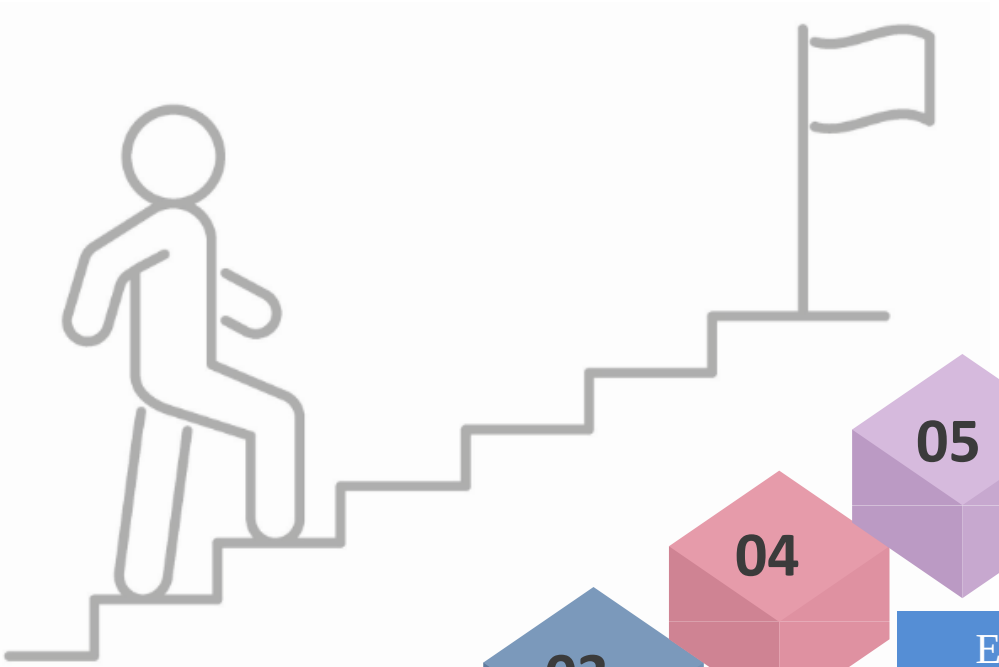
Outline

Novelty and Contributions



Outline

How Far Are We from Fully Automated Repair Recommendations?



01 AI-based Crack Detection

02 Crack Classification & Quantification

03 Failure Mode Inference

04 Exposure & Context Mapping

05 Functional Repair Requirements

06 Material Filtering

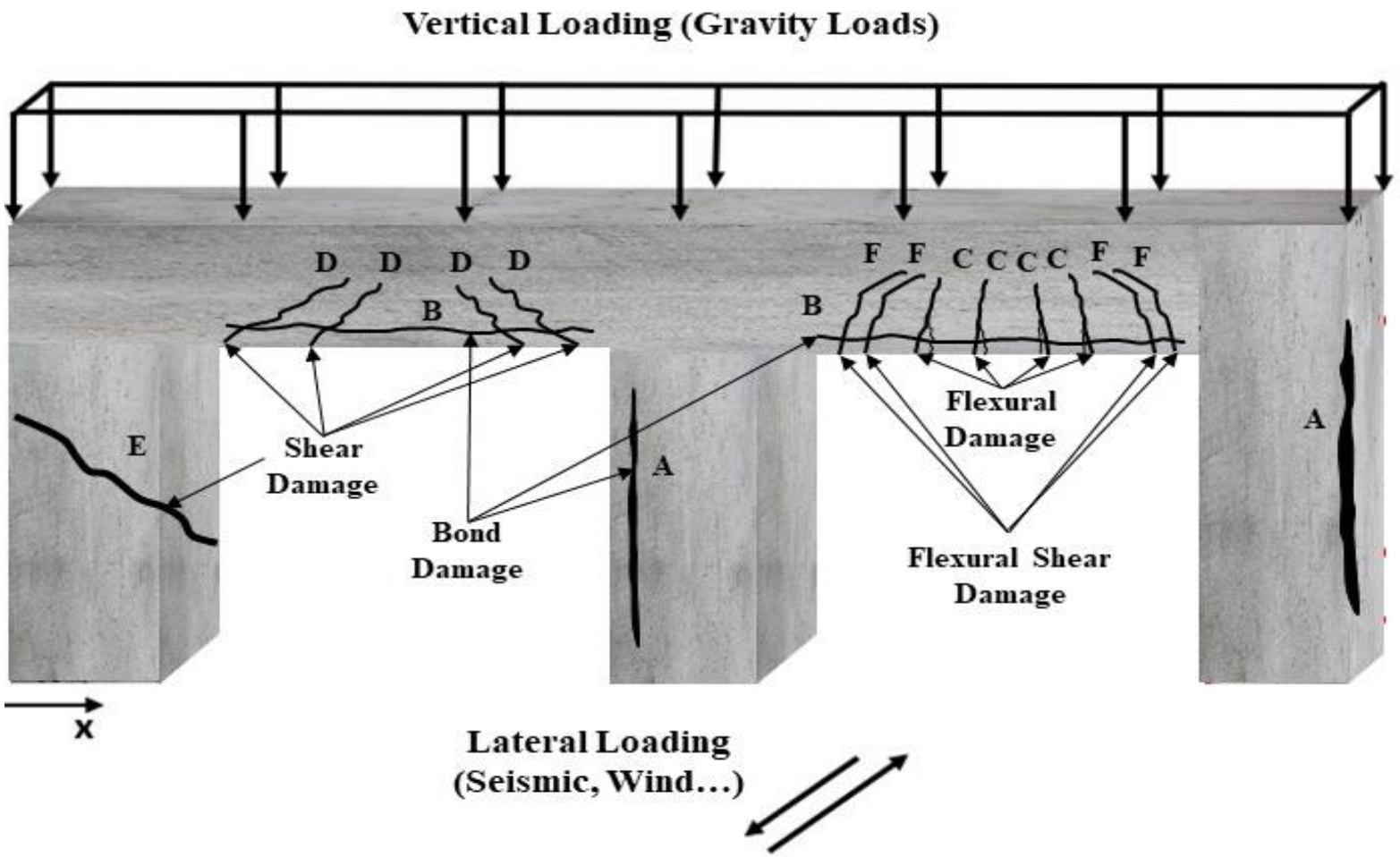
07 Optimization & Ranking

08 AI-driven Repair Recommendation Output

AI-Repair Recommendation Engine

Completed
Current Stage (Future Work)
Next Steps

How to predict the mode of failure and its degree of severity?



01 Quantified Cracks (Length, width, Angle)

02 Vertical or Horizontal Concrete Element

03 Crack Angle of Orientation Intervals

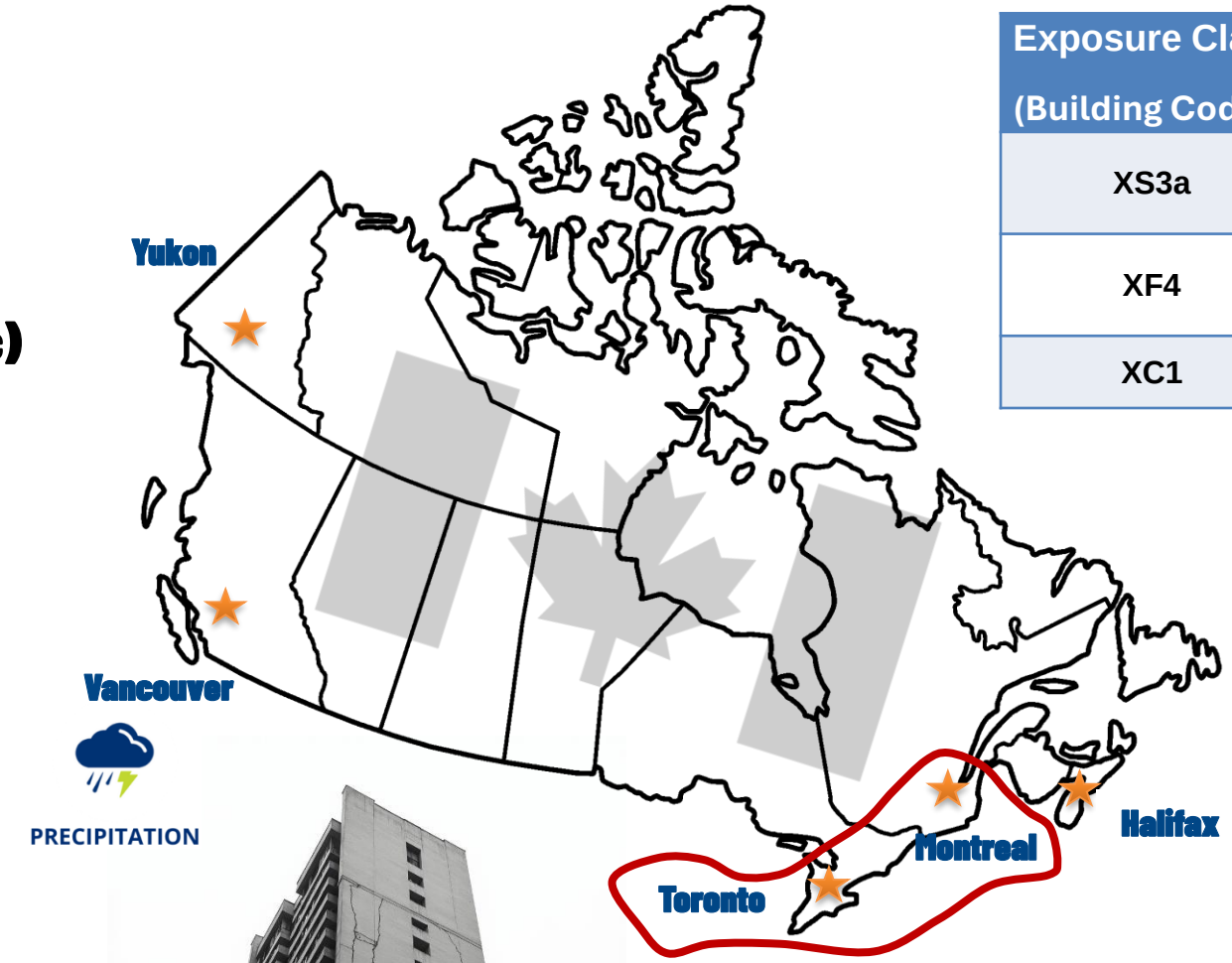
04 Proximity

05 Predicted Creation Cause

Are We Patching Symptoms or Healing the Cause?

Exposure Class (Building Codes)	Environment	Risk
XS3a	Tidal/splash	Chloride ingress
XF4	Freeze/thaw	Scaling/spalling
XC1	Dry indoor	Carbonation

Northern Canada (Arctic)



Coastal regions (Marine)

Central regions (Urban)

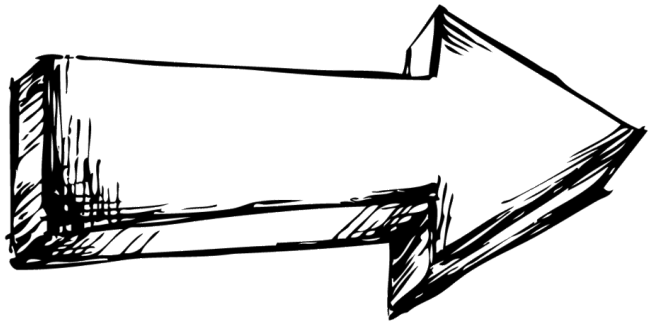
Canada

Shouldn't Concrete Repairs Address the Real Problem, Not Just the Surface?

Failure Type

+

Exposure Risk



Functional Repair Requirements

Durability
- Impermeability
- FT Resistance
- Thermal compatibility

Structural
- Load-carrying capacity
- Flexural and Shear
- Bond strength and Adhesion
- Ductility and toughness

Serviceability
- Crack control
- Deflection control

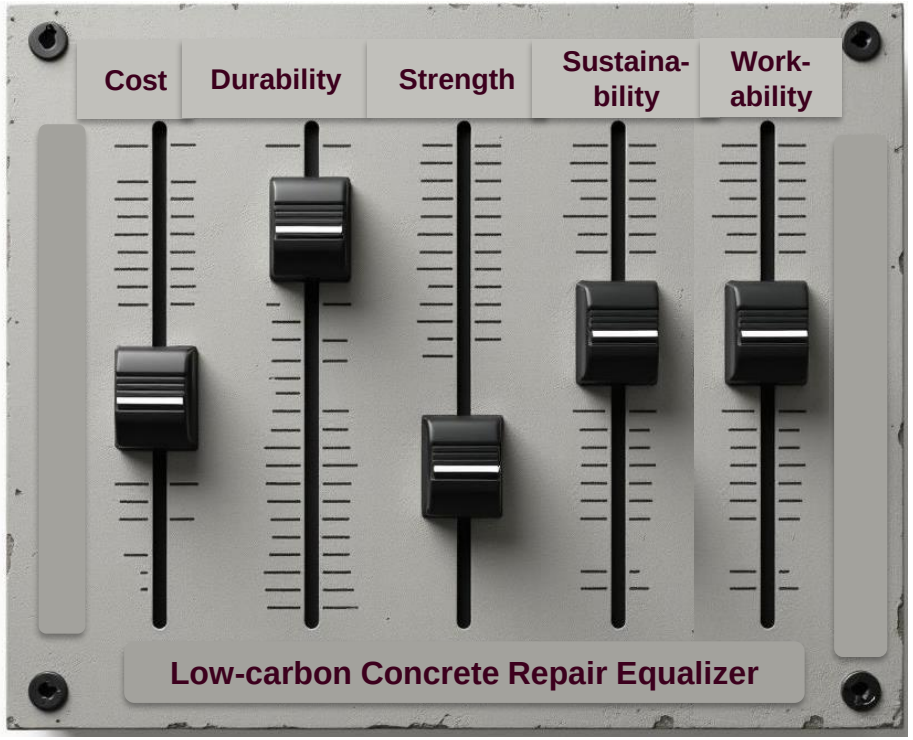
Constructability
- Rapid strength gain
- Ease of placement
- Workability

Sustainability & LCA
- Increased durability
- Reduced maintenance
- Environmental Impact

Are Your Concrete Repairs Truly Optimized or Just Compromised?

1

Evaluate trade-offs



3

Apply Multi-criteria decision making

2

Identify optimal mix designs for diverse environments.

Material	Bond	CO_2 e	Region	Life Expectancy	Cost	Rank
GGBFS mortar	High	Low	Ontario	30 yrs	$	1
LC3 grout	High	Very Low	BC	25 yrs	$$	2
OPC patch	Medium	High	All	15 yrs	$	3

Outline

Conclusions

1. **DL model combined with IPTs accurately classifies and quantifies various crack types, significantly reducing manual effort.**

2. **From new construction towards precise preservation of existing infrastructure.**

3. **AI-driven repair solutions can offer optimized and context-sensitive recommendations.**

For more research updates!

How soon can we fully trust AI with critical CONCRETE infrastructure decisions?

Thank You!

SCAN ME

flahm@mcmaster.ca