



Multiscale modelling of  
carbonation in concrete  
made with RCA

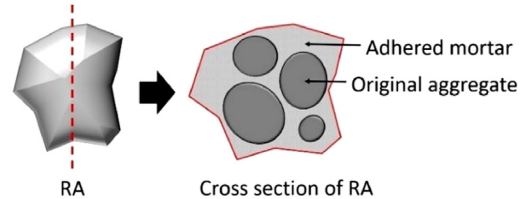
E. Thommes, A. Fanara, L. Courard, F. Collin

EURO-C 2026 - March 10, 2026

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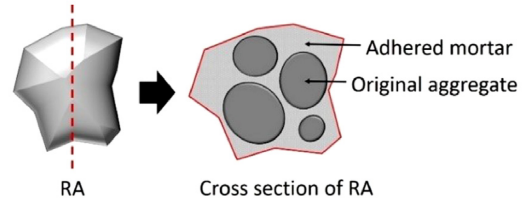


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- ▶ is a natural aggregate surrounded by mortar [[Zhang and Bao, 2023](#)]

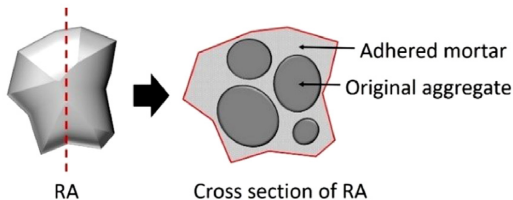


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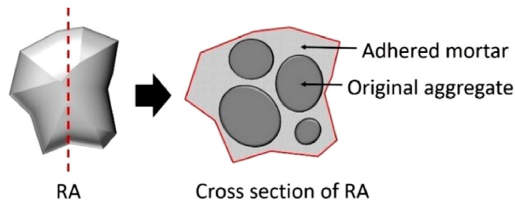


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## Concrete made with RCA (C-RCA)

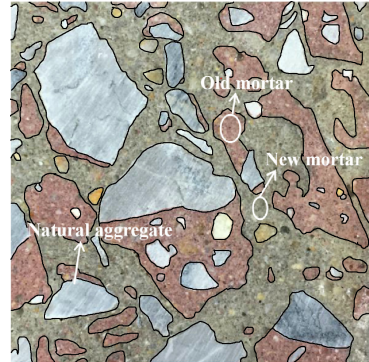


Figure 2: Concrete with pigmented RCA, adapted from [Mi et al., 2019]

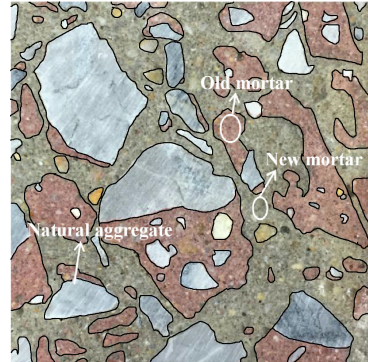
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## Concrete made with RCA (C-RCA)

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## Concrete made with RCA (C-RCA)

- ▶ Strong material heterogeneity
- ▶ Multiple length scales ( $\ell_{c, \text{concrete}} \gg \ell_{c, \text{RCA}}$ )



**Figure 3:** Concrete block [[Ablazejo, 2014](#)]

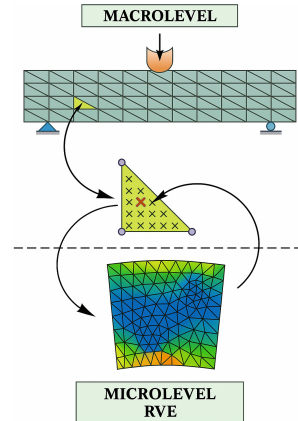
# Multiscale model: FEM<sup>2</sup> framework

## Concept

1. Macroscale gradients define RVE boundary conditions.
2. The RVE is solved and fluxes are homogenized.
3. The macroscale problem is updated accordingly.
4. Iteration continues until convergence.

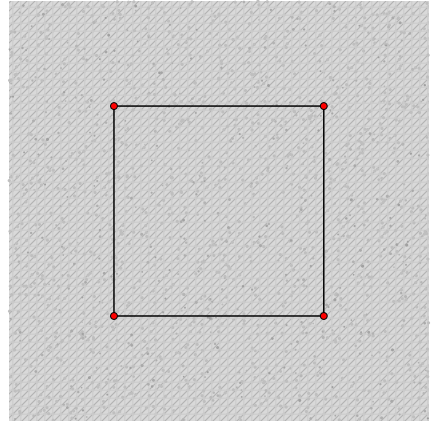
## Key assumptions

- ▶ Scale separation
- ▶ Statistically representative RVE
- ▶ Appropriate RVE boundary conditions



**Figure 4:** Framework of FEM<sup>2</sup> model, adapted from [Sorić et al., 2018]

# Carbonation model

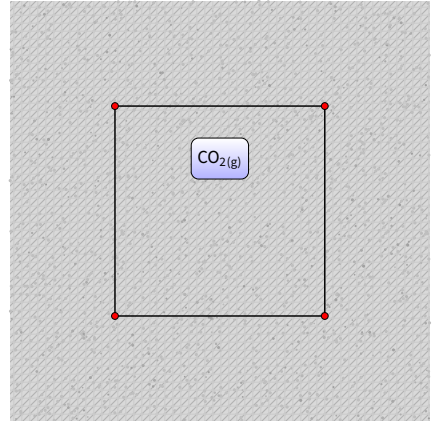


**Figure 5:** Representation of concrete control volume.

# Carbonation model

- Conservation equation of  $\text{CO}_2$  mass:

$$\frac{\partial}{\partial t} (C_{\text{CO}_2}) = 0$$



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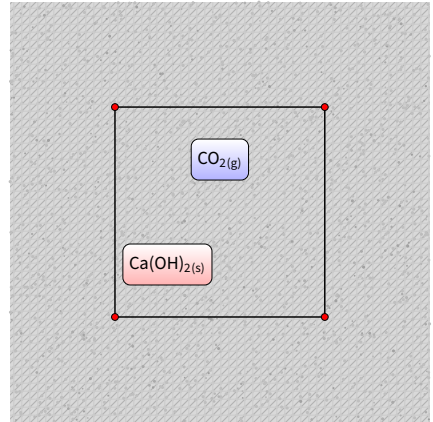
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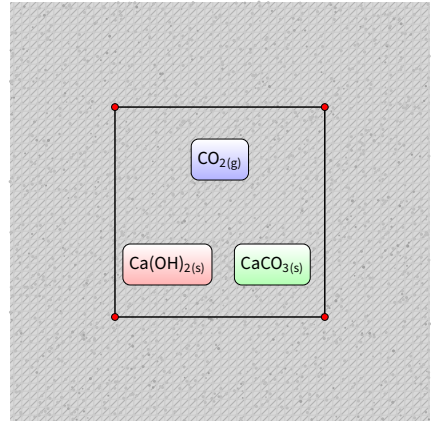
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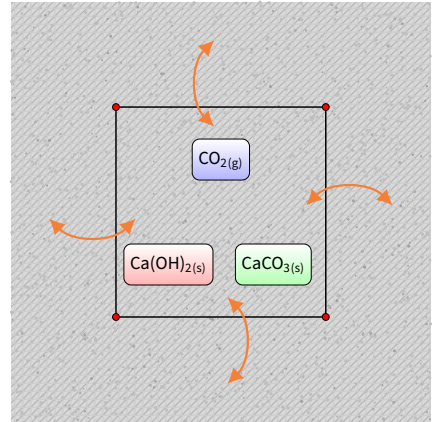
$$\frac{\partial}{\partial t} (C_{\text{CO}_2}) + \nabla \cdot C_{\text{CO}_2} \vec{q}_g = 0$$

- Conservation equation of  $\text{Ca}(\text{OH})_2$  mass:

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- Conservation equation of  $\text{CaCO}_3$  mass:

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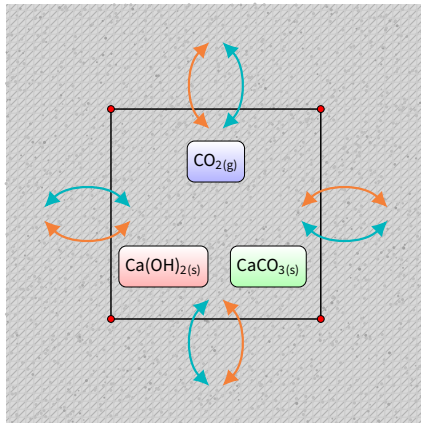
$$\frac{\partial}{\partial t} (C_{\text{CO}_2}) + \nabla \cdot C_{\text{CO}_2} \vec{q}_g + \nabla \cdot (-D_{\text{CO}_2, \text{eff}} \nabla \cdot C_{\text{CO}_2}) = 0$$

- Conservation equation of  $\text{Ca}(\text{OH})_2$  mass:

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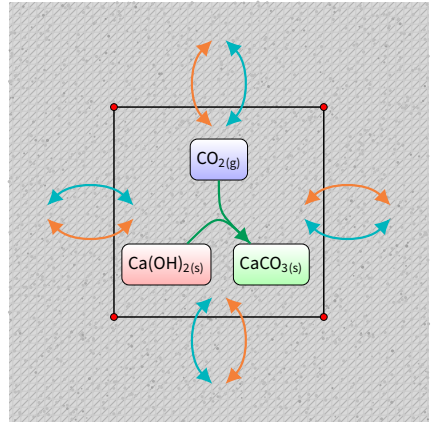
$$\frac{\partial}{\partial t} (C_{\text{CO}_2}) + \nabla \cdot C_{\text{CO}_2} \vec{q}_g + \nabla \cdot (-D_{\text{CO}_2, \text{eff}} \nabla \cdot C_{\text{CO}_2}) + M_{\text{CO}_2} Q_{r,c} = 0$$

- Conservation equation of  $\text{Ca}(\text{OH})_2$  mass:

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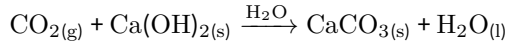


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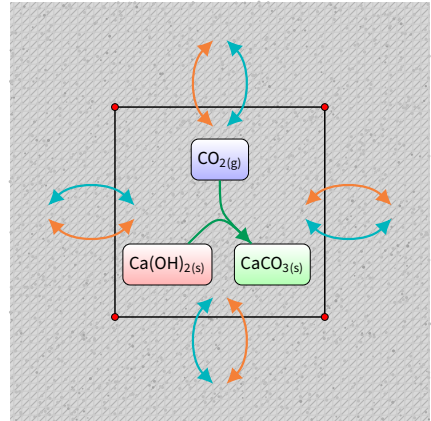
Saetta's model [Saetta et al., 1993] :

► Reaction :



► Mathematical formulation :

$$Q_{r,c} = \frac{C_{\text{Ca}(\text{OH})_2, \text{max}}}{M_{\text{Ca}(\text{OH})_2}} \alpha_1 f_1(RH) f_2(C_{\text{CO}_2}) f_3(C_{\text{Ca}(\text{OH})_2}) f_4(T)$$



**Figure 6:** Representation of concrete control volume.

# Academic application

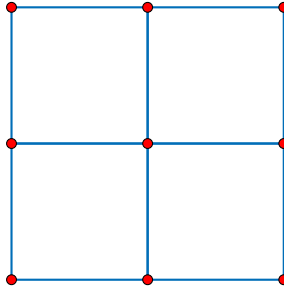
## Case

- ▶ RVE geometry:

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- ▶ RVE geometry:
  - ▶ Homogeneous RVE



**Figure 7:** Representation of homogeneous RVE.

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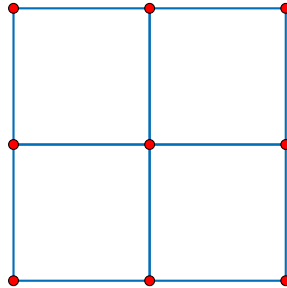
- ▶ Homogeneous RVE
- ▶ C-RCA RVE

- ▶ Transport properties:

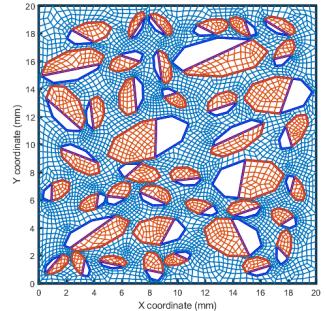
$$D_{\text{CO}_2, \text{eff, NA}} = 0.0 \text{ m}^2 \text{ s}^{-1}$$

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**Figure 7:** Representation of homogeneous RVE.



**Figure 8:** Representation of C-RCA RVE.

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- C-RCA RVE

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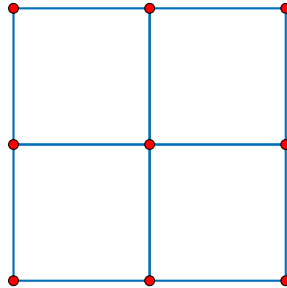
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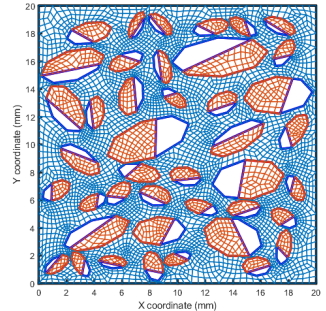
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## Objectives

- Analyse concentration profiles

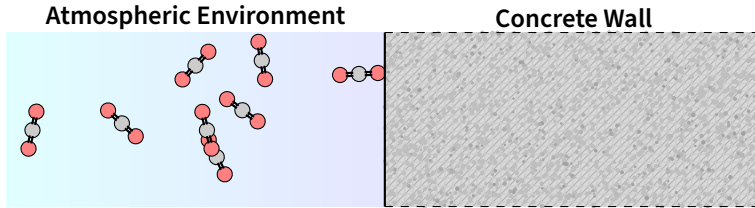


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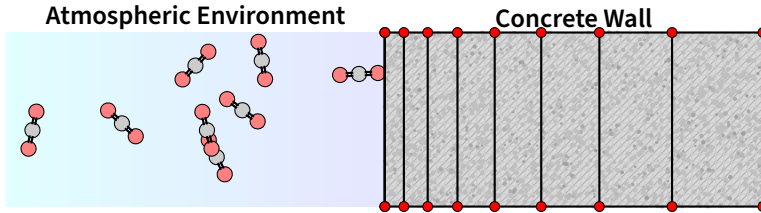


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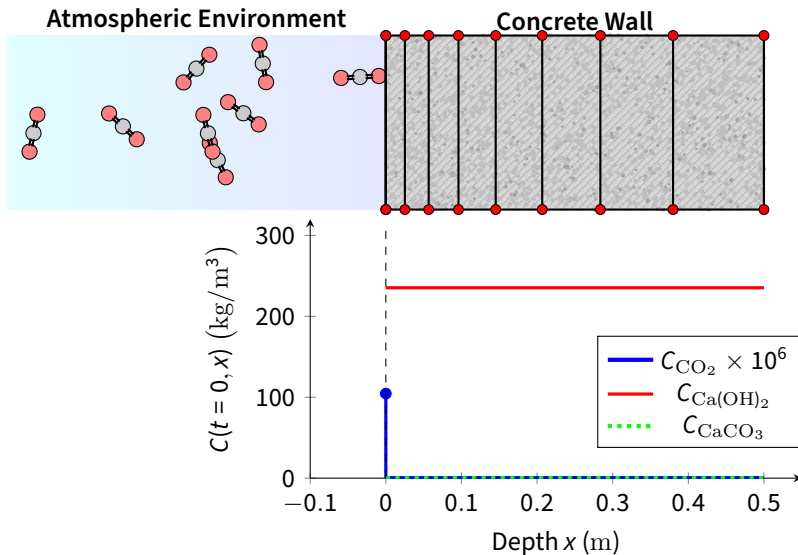
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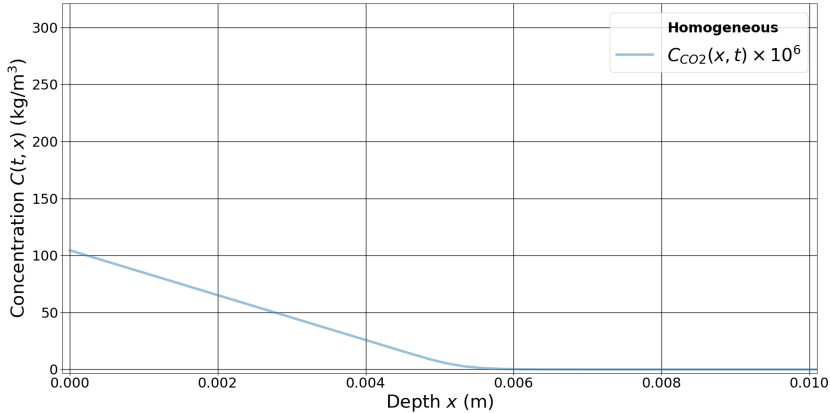
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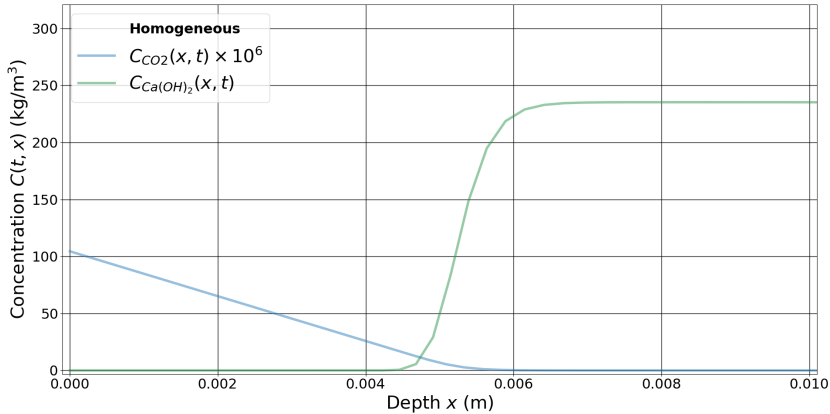


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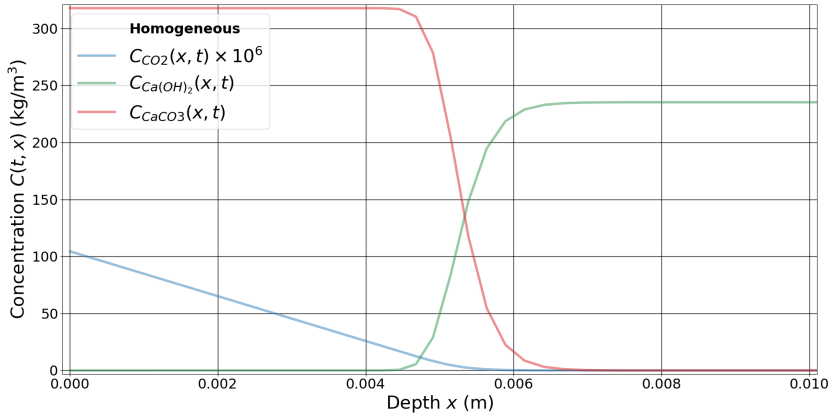
**Figure 9:** Multiscale analysis of the homogeneous concrete at  $t = 25.0$  yr.

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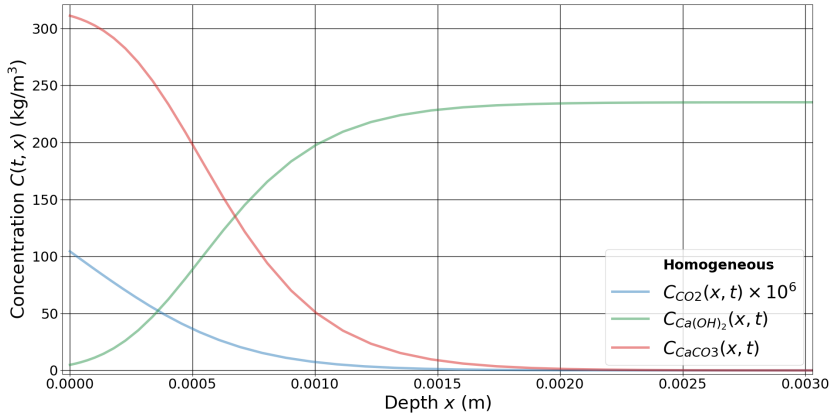
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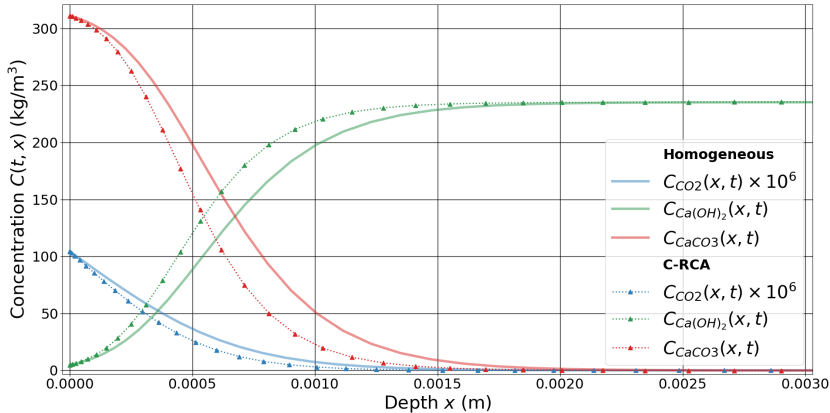
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# Homogeneous vs C-RCA RVE



**Figure 10:** Multiscale response of homogeneous and C-RCA concretes under identical environmental conditions at  $t = 0.5$  yr.

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## Future Work

- ▶ Enhanced chemical and transport modelling
- ▶ Experimental validation & calibration



### **Acknowledgements:**

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