cinpar2020

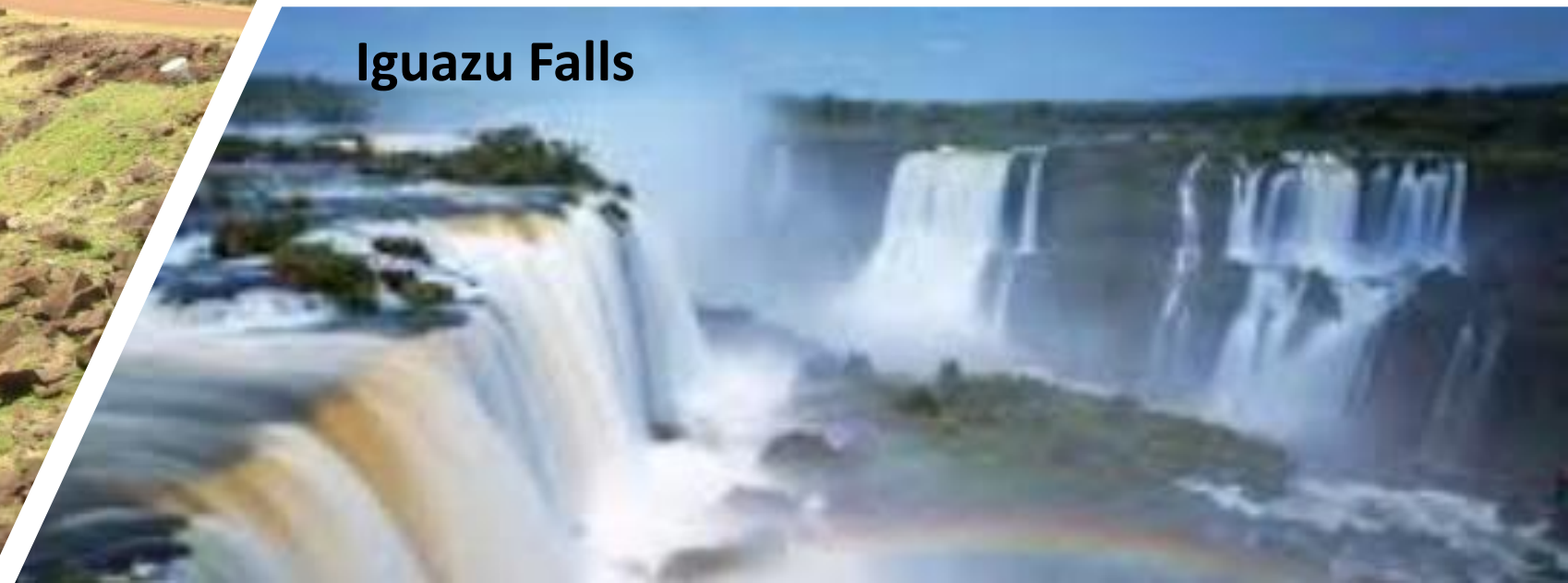
XVI INTERNATIONAL CONFERENCE ON
STRUCTURAL REPAIR AND REHABILITATION
PORTO | PORTUGAL 13-15 JULY 2020
ONLINE CONFERENCE

Carbonation in concrete structures: Advances and sustainability issues

Prof. Dra Edna Possan | epossan@gmail.com

Federal University of Latin American Integration/ Brazil

Itaipu Dam


Iguazu Falls

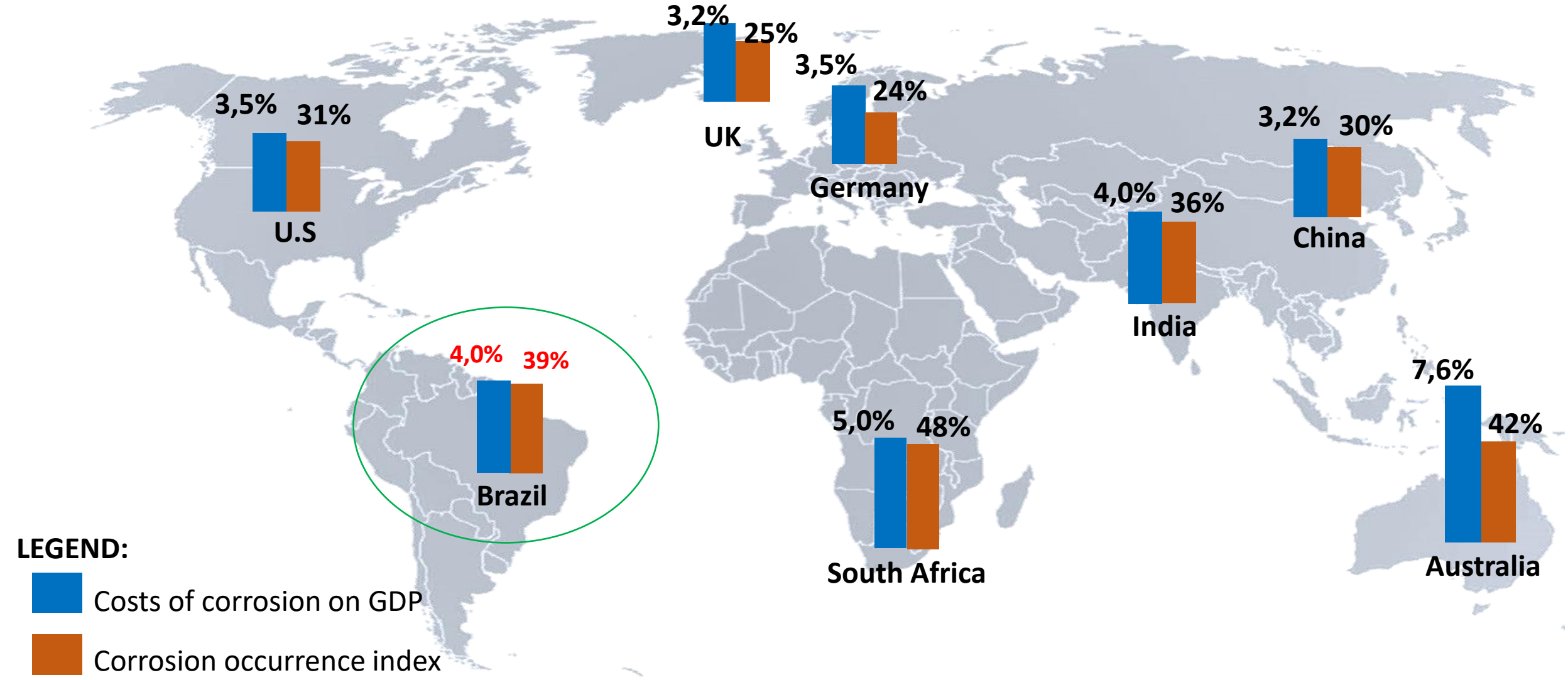
THE CONCRETE CARBONATION PROBLEM

- For more than 60 years the concrete carbonation has been studied
- We have learned → this chemical reaction is harmful to concrete structures durability
  - Because its occurrence → damages the Reinforcements passive film immersed in the concrete
    - **leaving it susceptible to corrosion**

Every year, billions of dollars are required to correct problems related to concrete structures corrosion

Global Scenario

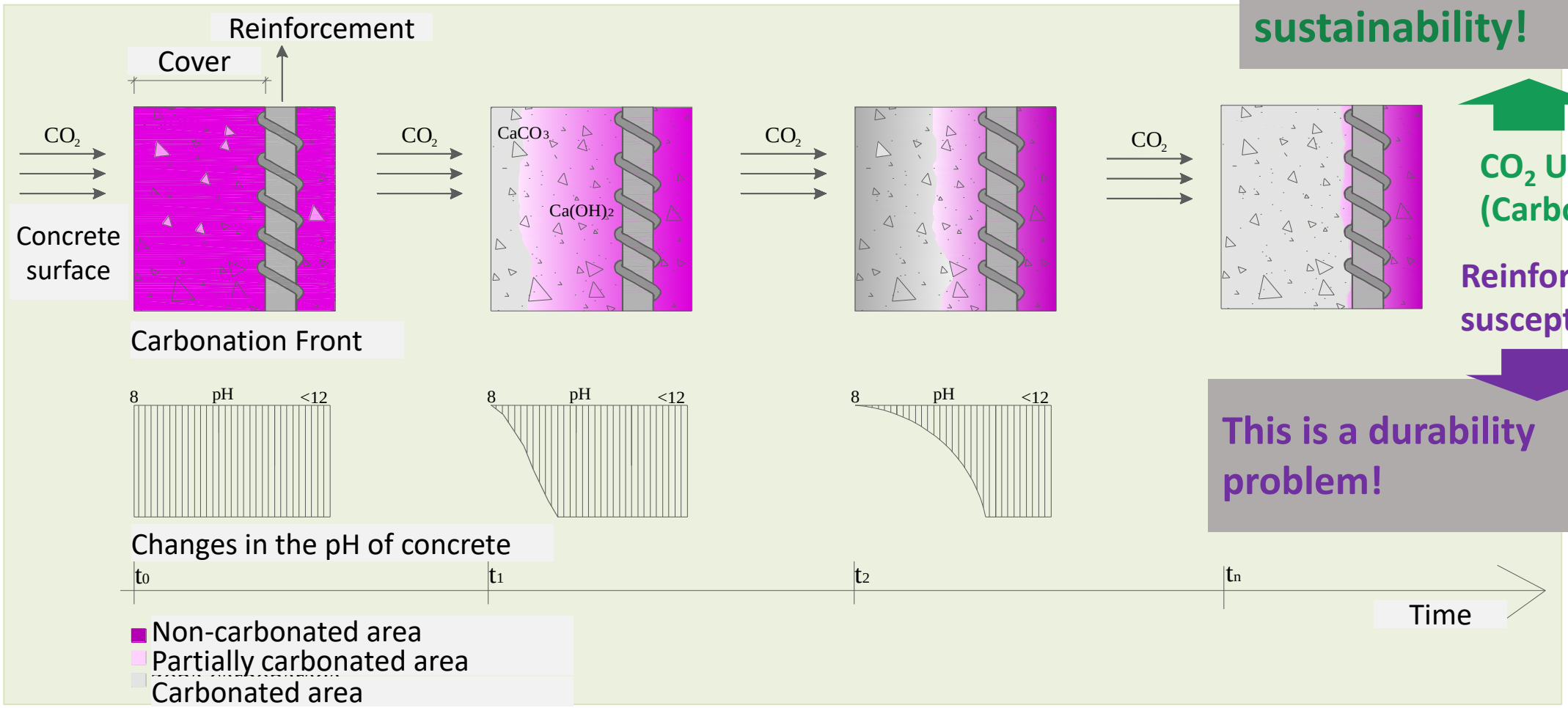
Gross domestic product (GDP) → 3%



Fonte: Felix, Emerson (2018)

Data extracted from the World Corrosion Organization

CONCRETE CARBONATION



This is good for sustainability!

CO_2 Uptake! (Carbon fixation)

Reinforcement susceptible to corrosion

This is a durability problem!

Carbonation in concrete structures: durability and sustainability issues

#madewithcement

BUILDING CARBON NEUTRALITY IN EUROPE

Engaging for concrete solutions

CEMBUREAU
The European Cement Association

BYGGFORSK
Norwegian Building Research Institute

norden
Nordic Innovation Centre

Christian J. Engelsen, Jacob Mehus,
Claus Pade and Dag Henning Sæther

Carbon dioxide uptake in demolished and crushed concrete

CO
Nor

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Cement and Concrete Research

Cement and Concrete Research 37 (2007) 1348–1356

The CO_2 uptake of concrete in a 100 year perspective

ELSEVIER

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

CO_2 uptake potential due to concrete carbonation: A case study

CrossMark

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[b] Center for Advanced Studies on Dam Safety (CEASB/PTI), Brazil
[c] Federal University of Technology—Paraná (UTFPR), Brazil

sustainability

MDPI

Article

Updating Carbon Storage Capacity of Spanish Cements

Carmen Andrade [1,*] and Miguel Ángel Sanjuán [2]

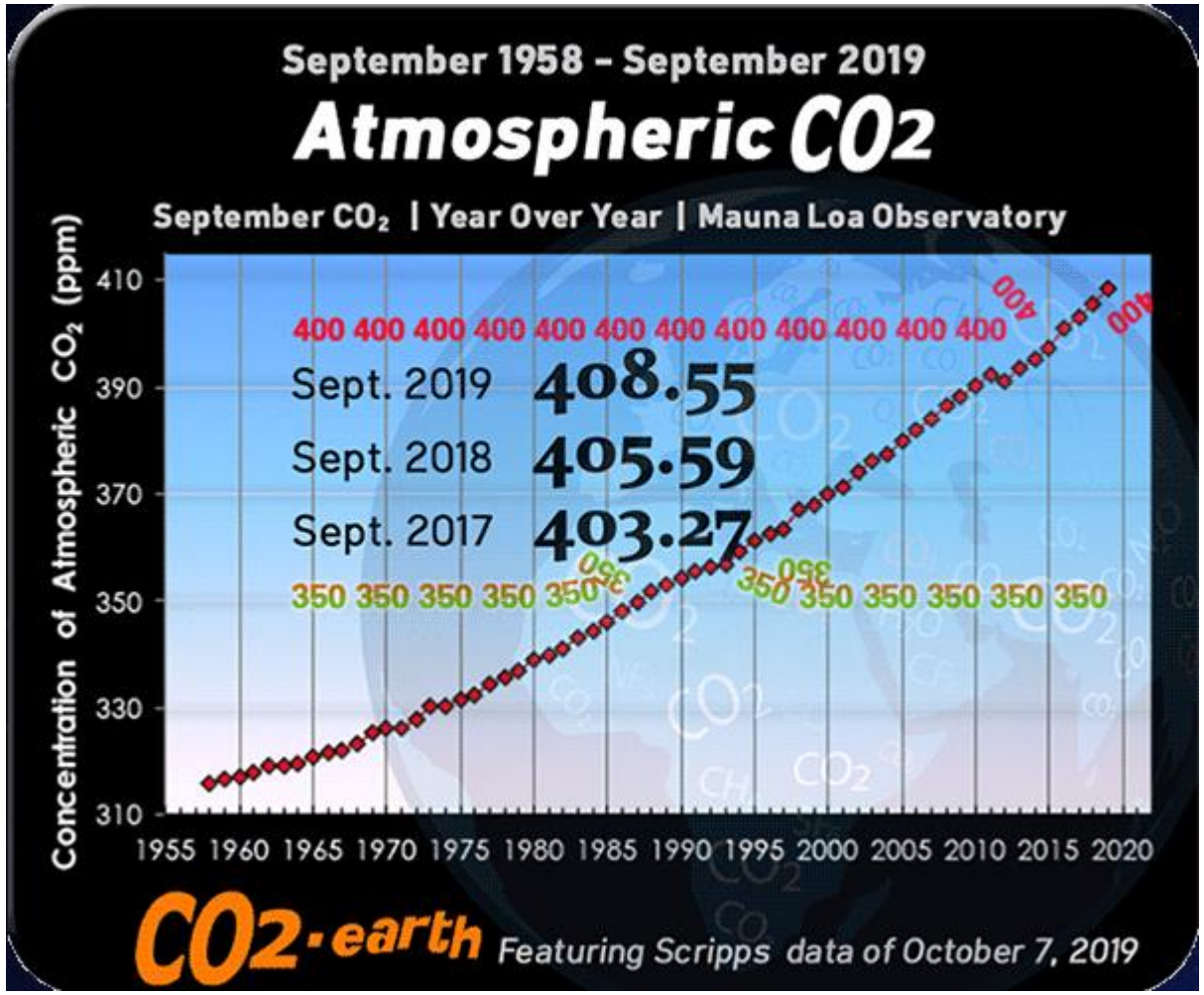
1 International Center of Numerical Methods in Engineering, CIMNE, Paseo General Martínez Campos, 41, 9°, 28010 Madrid, Spain
2 Spanish Institute of Cement and its Applications (IECA), C/José Abascal, 53, 28003 Madrid, Spain; masanjuan@ieca.es
* Correspondence: candrade@cimne.upc.edu

In recent years several publications have paid attention to CO_2 uptake due to carbonation

Why is it important?

- CO_2 is one of the greenhouse gases
  - causes global warming
  - increasing the average atmospheric temperature

Carbon emissions



Average CO_2 emissions are increasing every year

Fossil fuel emissions (including cement production) accounted for about 91% of total CO_2 emissions from human sources in 2014. This portion of emissions originates from coal (42%), oil (33%), gas (19%), **cement (6%)** and gas flaring (1%).

National Oceanic and Atmospheric Administration

https://www.co2.earth/daily-co2

https://www.esrl.noaa.gov/gmd/ccgg/trends/index.html

Carbon emissions

- Cement manufacture is one of the contributors to the CO_2 increase in the atmosphere
  - The cement clinker fabrication releases CO_2 due to the limestone used as raw material calcination, which contributes to the greenhouse effect

Its fabrication releases around **842** kg of CO_2 by ton of clinker

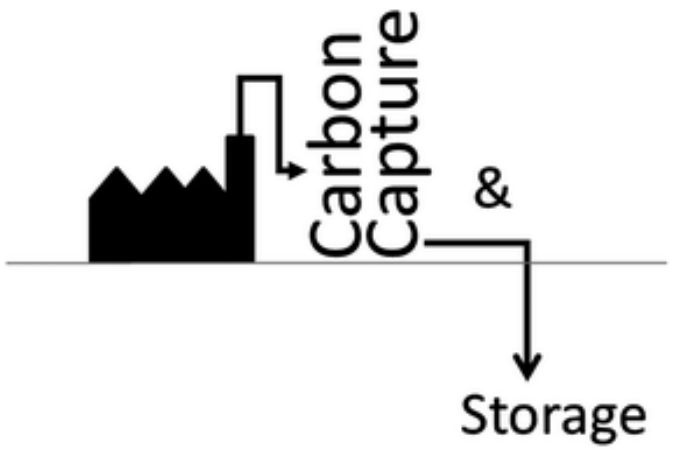
- About **545** kg of CO_2 per ton of clinker is due to limestone and clays **calcination** **~65%**
- 300 kg of CO_2 per ton of clinker → **fuel combustion**

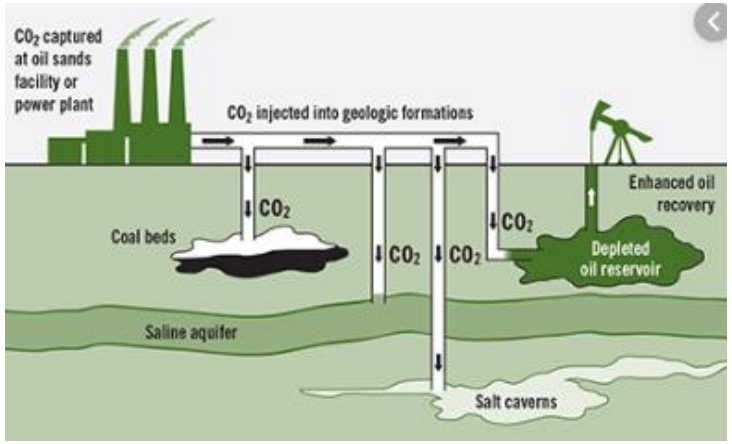
Carbon emissions mitigation levers

- Technology Roadmap

- **Improving energy efficiency:** deploying existing state-of-the-art technologies in new cement plants and retrofitting existing facilities.
- **Switching to alternative fuels (fuels that are less carbon intensive than conventional fuels):** promoting the use of biomass and waste materials in cement kilns to offset the consumption of carbon-intensive fossil fuels.
- **Reducing the clinker to cement ratio:** increasing the use of blended materials and the market deployment of blended cements.
- **Using emerging and innovative technologies that:**
  - contribute to the decarbonisation of electricity generation by adopting excess heat recovery technologies and support the adoption of renewable-based power generation
  - integrate carbon capture into the cement manufacturing process for long-lasting storage.

How can CO_2 be captured?


Carbon
Capture
&
Storage


CO_2 captured at oil sands facility or power plant
CO_2 injected into geologic formations
Coal beds
CO_2
Enhanced oil recovery
Depleted oil reservoir
Saline aquifer
Salt caverns

FORESTS
HELP TO REDUCE
GREENHOUSE GASES
4,419
million tonnes of CO2-equivalents
total greenhouse gas emissions in the EU in 2014 *
*including international aviation and indirect CO2, land use, land use change and forestry
10.9%
equivalent of total EU greenhouse gas emissions absorbed by EU forests every year (2014)

CO_2 Uptake

CO_2 UPTAKE DURING THE LIFE CYCLE DUE TO NATURAL CARBONATATION

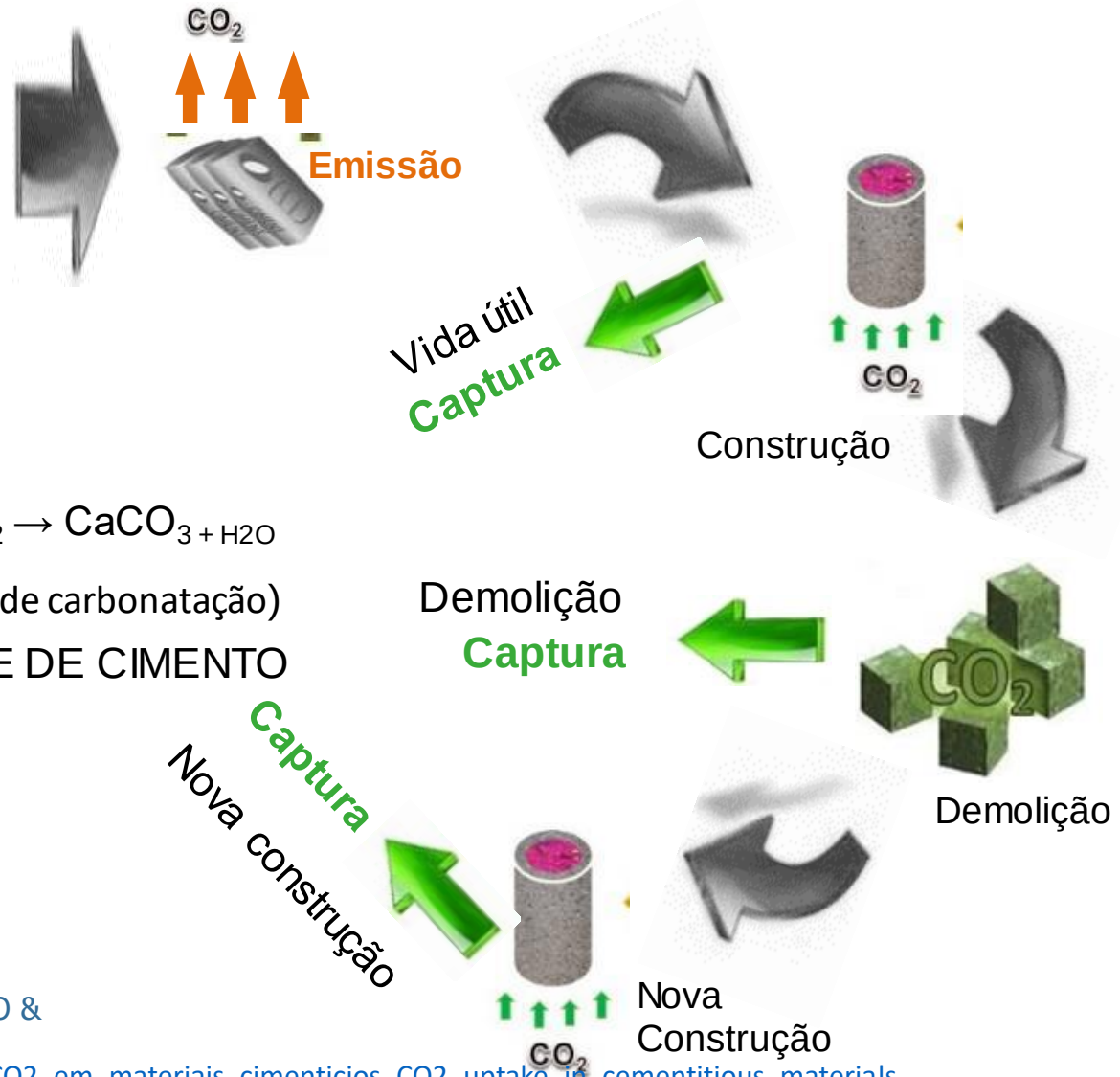
PRODUÇÃO DO CIMENTO
(Descarbonatação + energia para produção)

$CaCO_3 \rightarrow +CaO + CO_2$

$Ca(OH)_2 + CO_2 \rightarrow CaCO_{3 + H2O}$

(Reação de carbonatação)

CAPTURA DE CO_2 EM MATERIAIS A BASE DE CIMENTO



Possan, E. Captura de CO2 em materiais cimentícios. CONCRETO & CONTRUÇÃO, v. 1, p. 60-66, 2019.
https://www.researchgate.net/publication/343178071_Captura_de_CO2_em_materiais_cimenticios_CO2_uptake_in_cementitious_materials

CO_2 UPTAKE DUE TO CO_2 INJECTION DURING CURE CEMENT-BASED MATERIALS

PRODUÇÃO DO CIMENTO

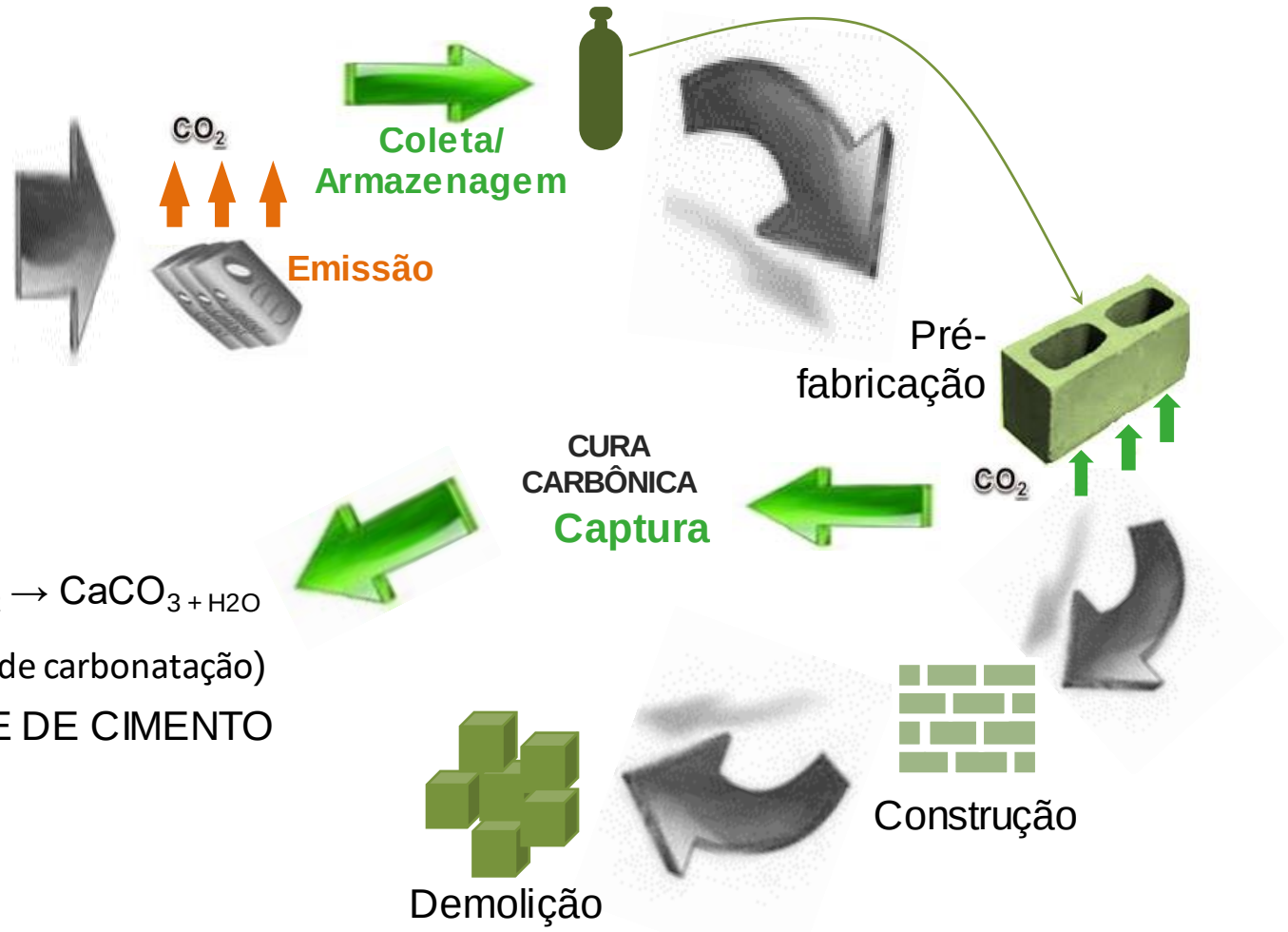
(Descarbonatação + energia para produção)

$CaCO_3 \rightarrow +CaO + CO_2$

$Ca(OH)_2 + CO_2 \rightarrow CaCO_{3 + H2O}$

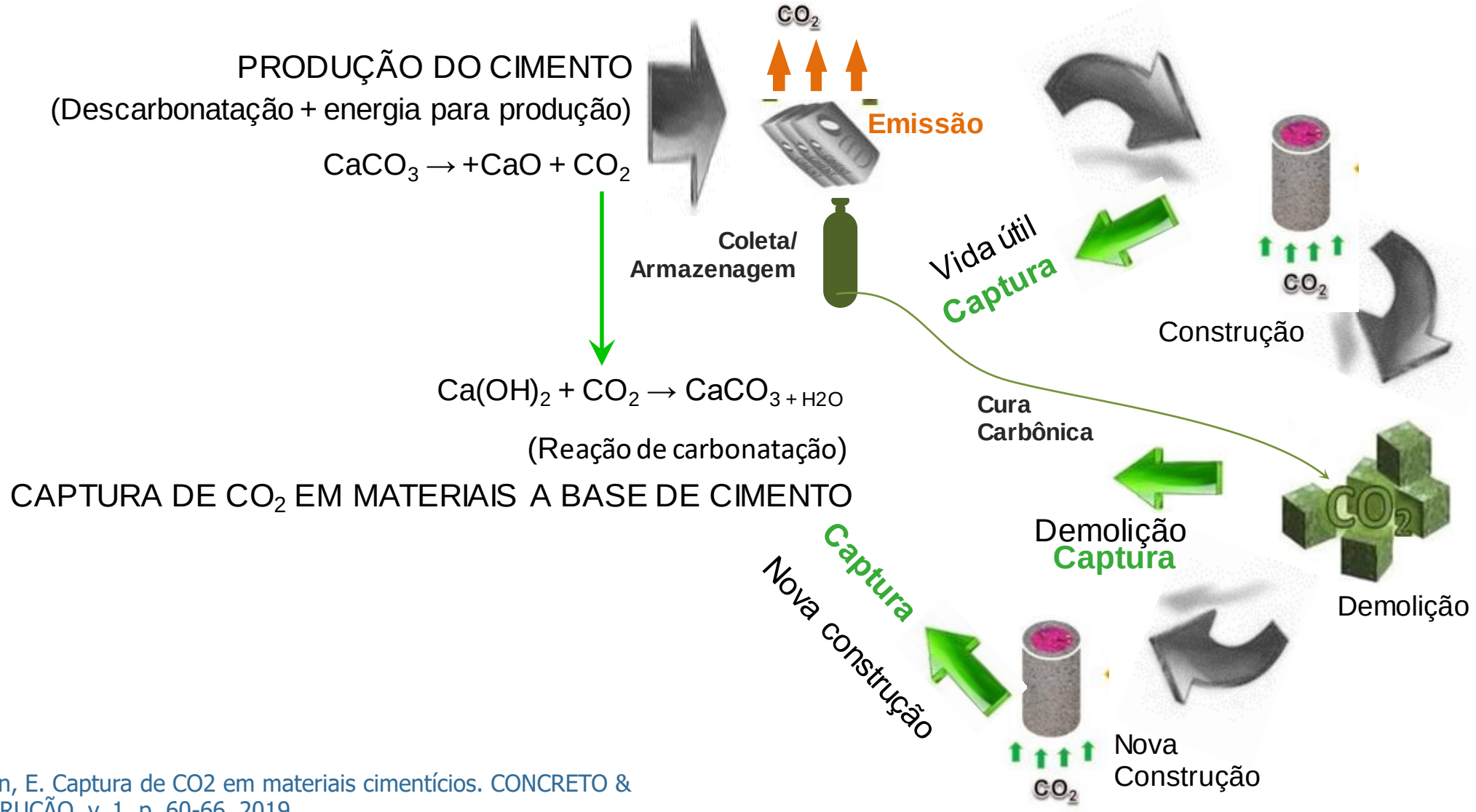
(Reação de carbonatação)

CAPTURA DE CO_2 EM MATERIAIS A BASE DE CIMENTO



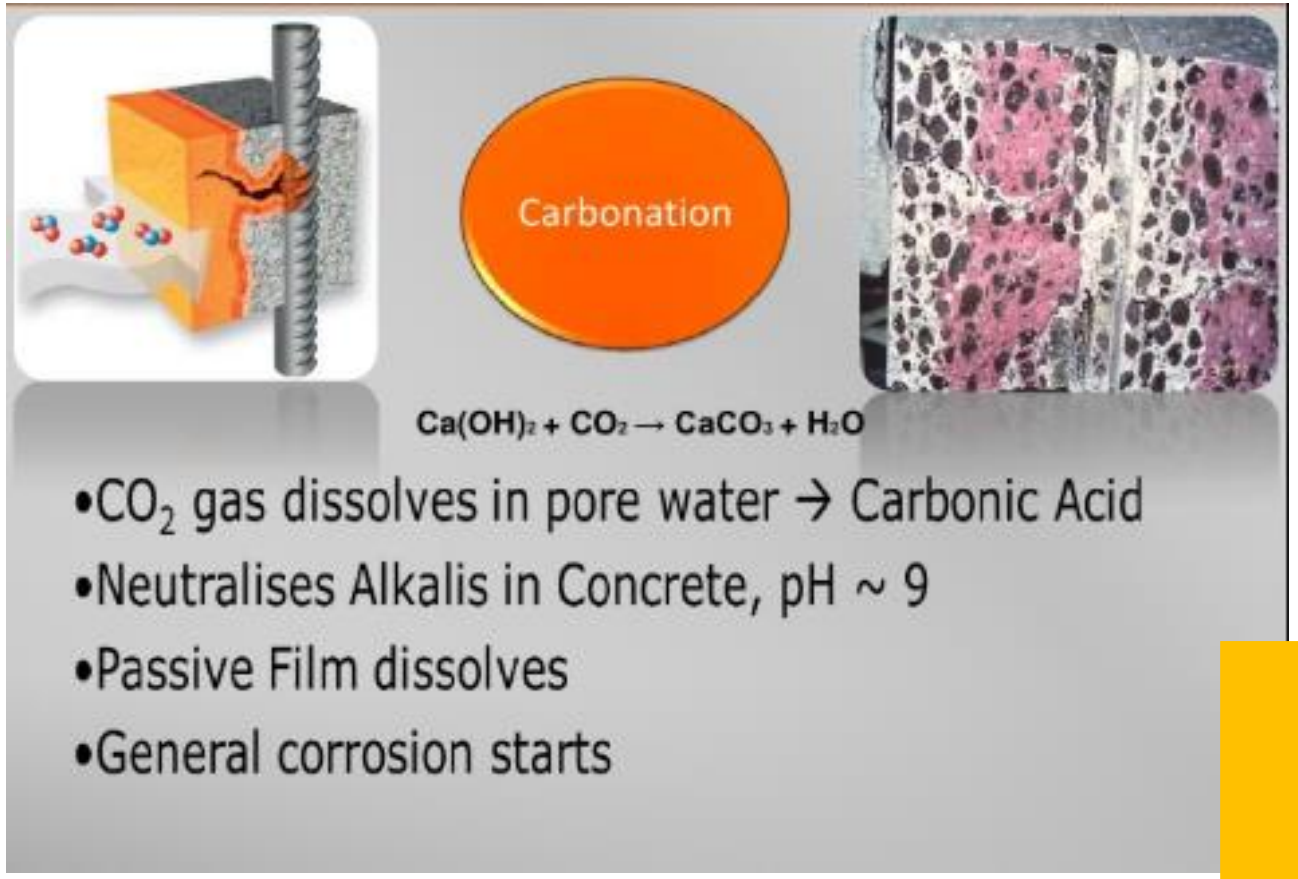
Possan, E. Captura de CO2 em materiais cimentícios. CONCRETO & CONTRUÇÃO, v. 1, p. 60-66, 2019.
https://www.researchgate.net/publication/343178071_Captura_de_CO2_em_materiais_cimenticios_CO2_uptake_in_cementitious_materials

CO_2 UPTAKE IN THE LIFE CYCLE DUE TO NATURAL CARBONATATION AND CO_2 INJECTION IN CDW RECYCLED AGGREGATE



Possan, E. Captura de CO2 em materiais cimentícios. CONCRETO & CONTRUÇÃO, v. 1, p. 60-66, 2019.
https://www.researchgate.net/publication/343178071_Captura_de_CO2_em_materiais_cimenticios_CO2_uptake_in_cementitious_materials

Carbonation x Corrosion



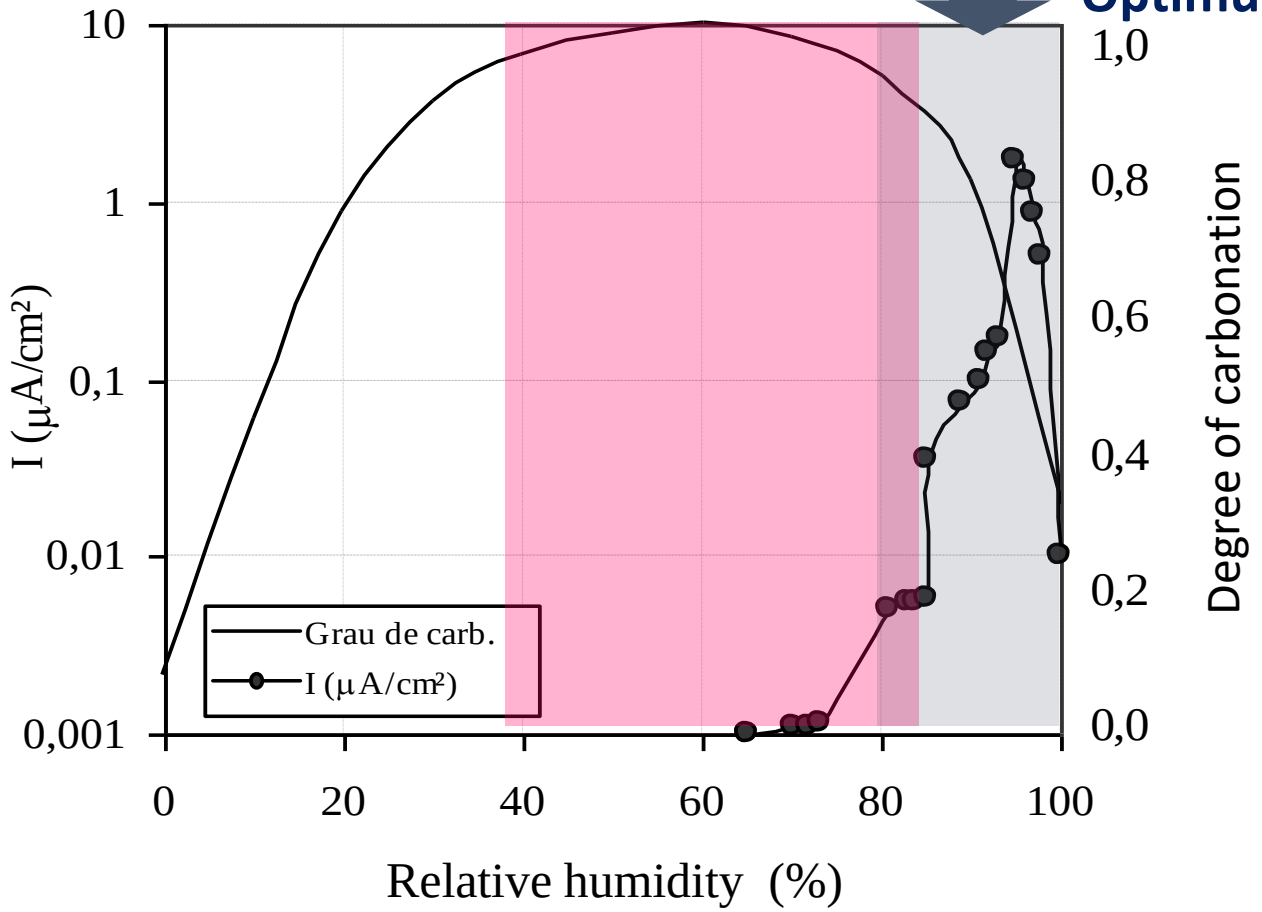
Technological Alternatives

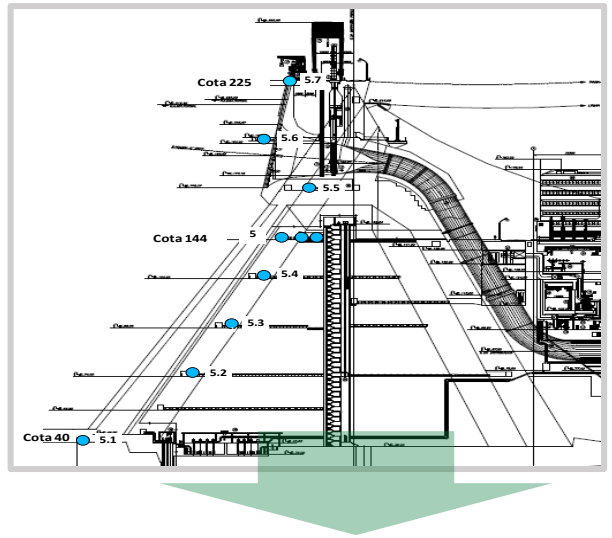
- Replace low carbon steel with more corrosion resistant steels
- use corrosion inhibiting additives
- Increase the Concrete cover thickness

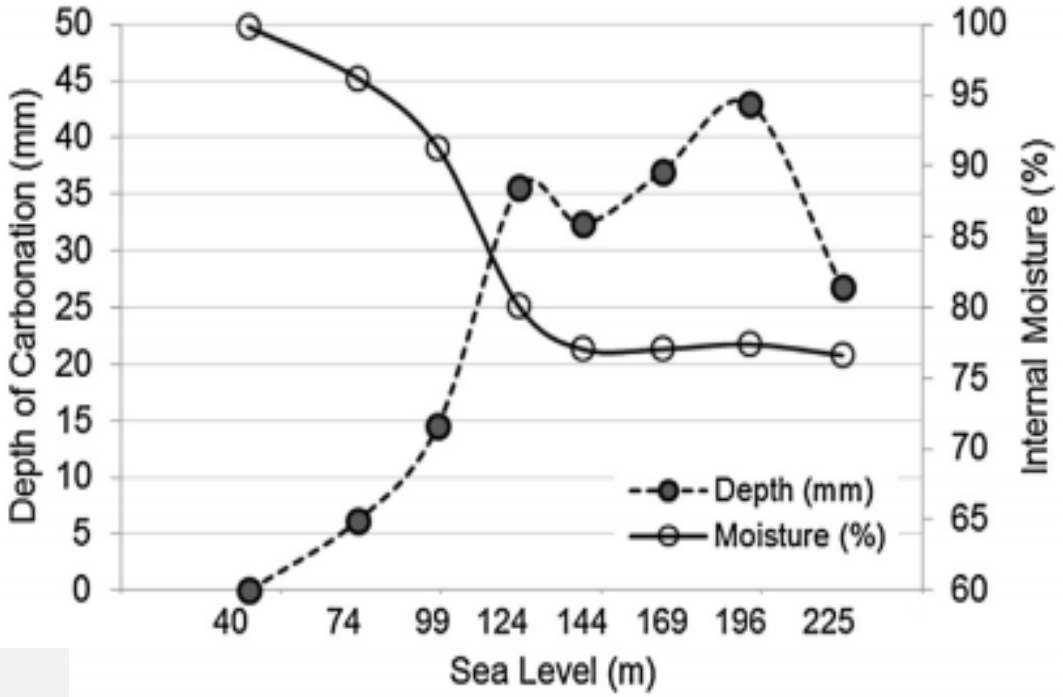
Carbonation x Corrosion

Optimum moisture for Carbonation

Optimum moisture for corrosion







Influence of relative humidity on initiation and propagation of corrosion due to carbonation. (Adapted from Tuutti , 1982 and Andrade, 1992.)

POSSAN (2010)

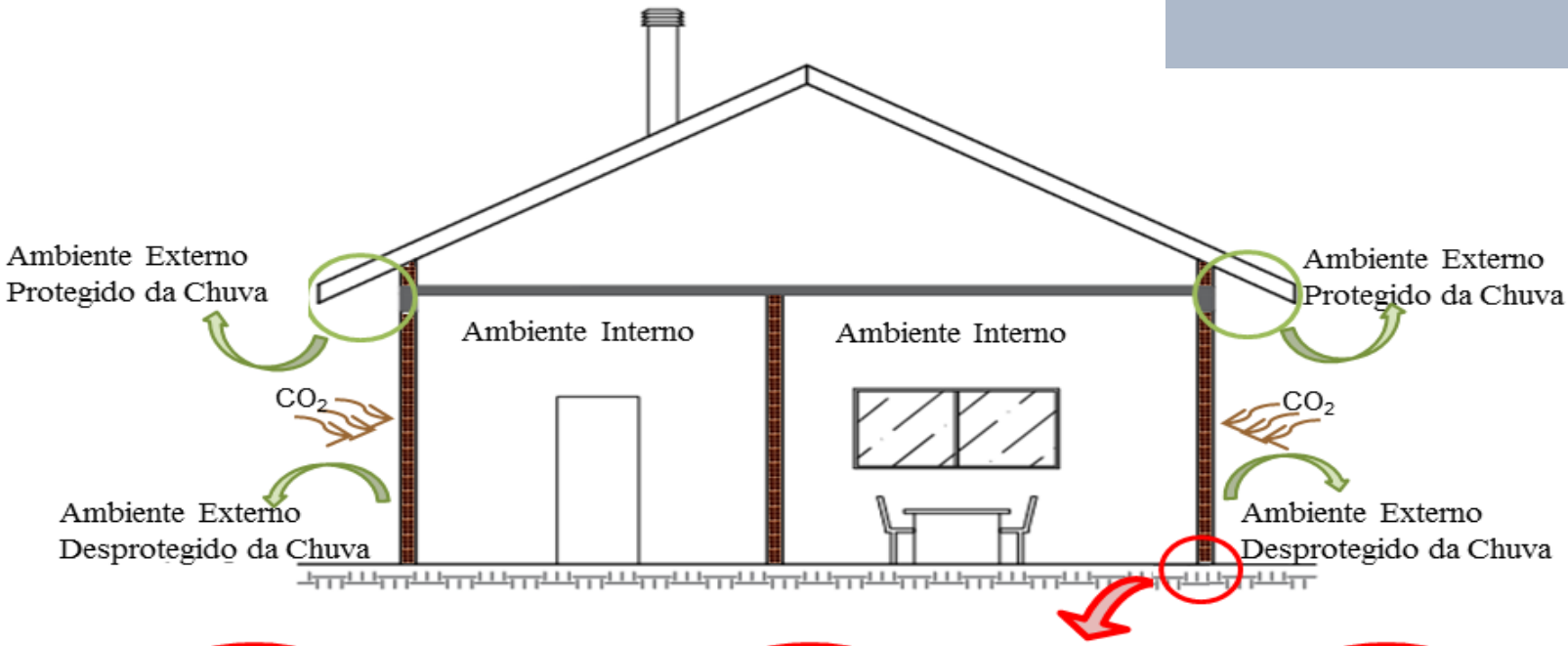
http://dx.doi.org/10.1016/j.cscm.2017.01.007

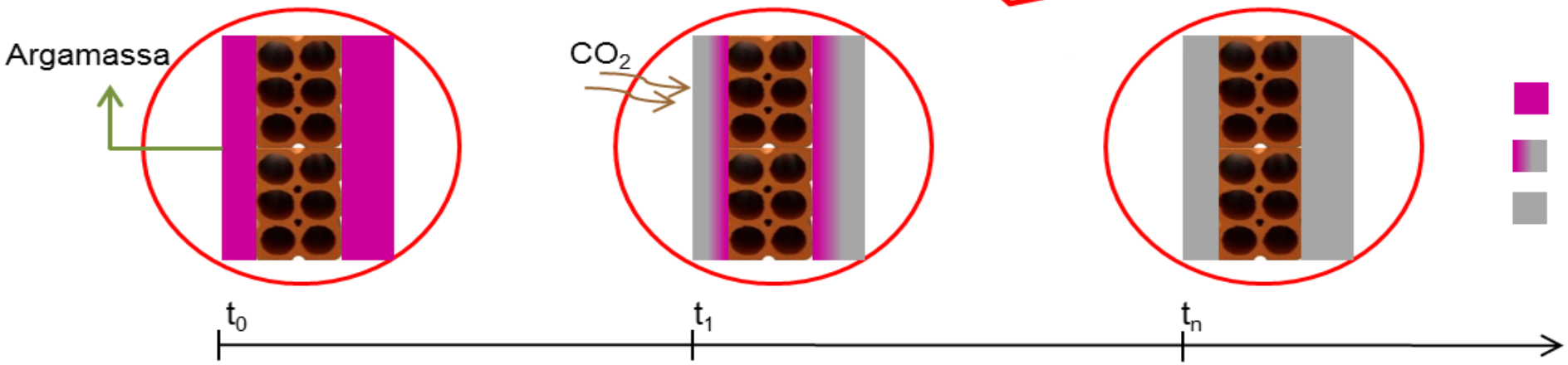
BUT → Several concrete elements do not contain reinforcement

→ and can be carbonated without damage to durability

- ✓ Tiles
- ✓ curb
- ✓ Pavers
- ✓ Mortars

CO_2 Uptake in rendering mortars





- Non-carbonated area
- Partially carbonated area
- Carbonated area

ANTONIO e POSSAN (2016)

Concrete with recycled CDW aggregates

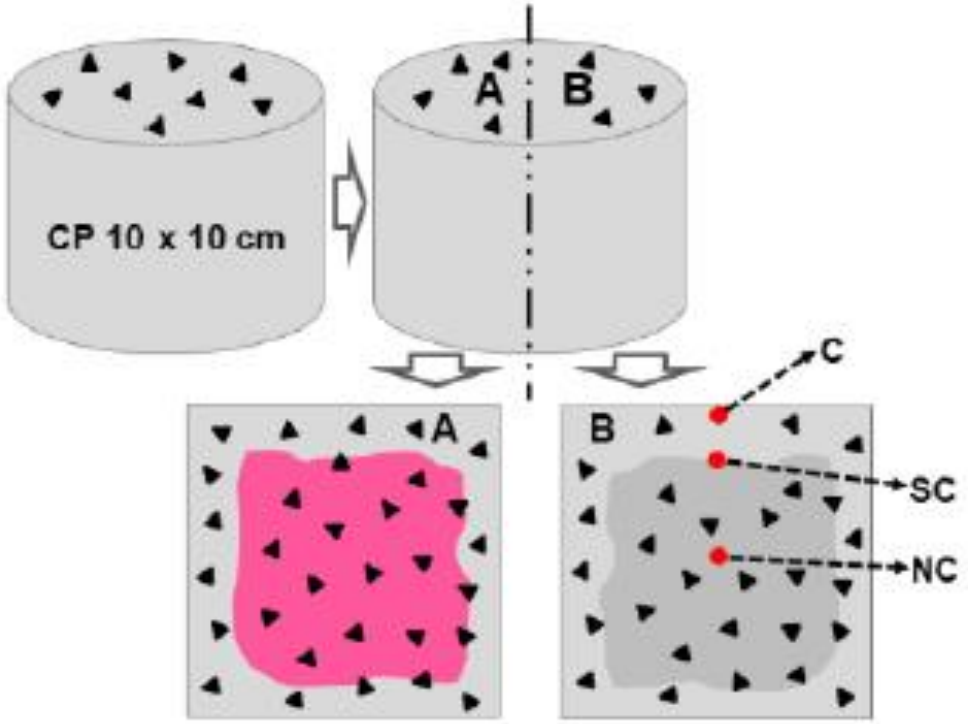


Figura 25: Representação esquemática do processo de coleta de alíquotas de amostras

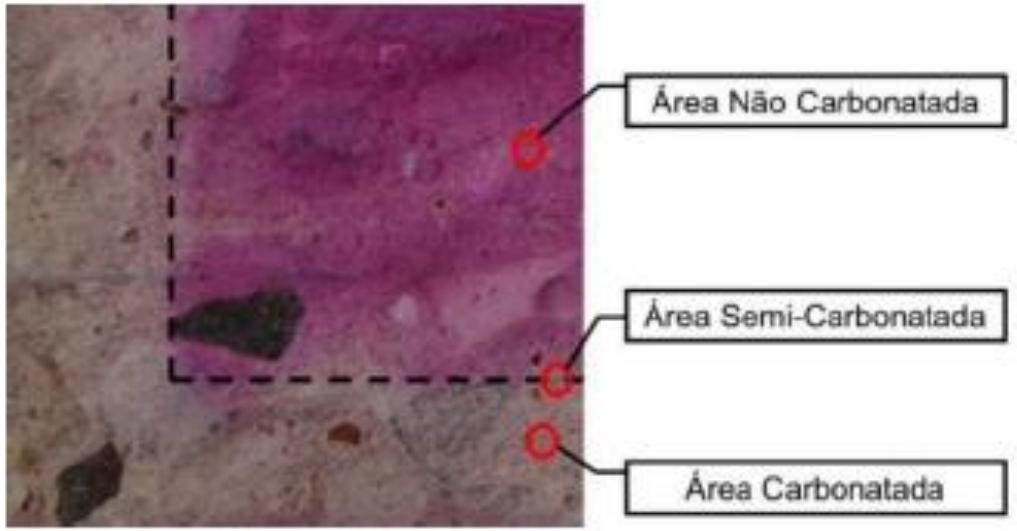


Figura 26: Representação real do processo de coleta das alíquotas das amostras

Fonte: Rigo, 2019

Concrete with recycled CDW aggregates

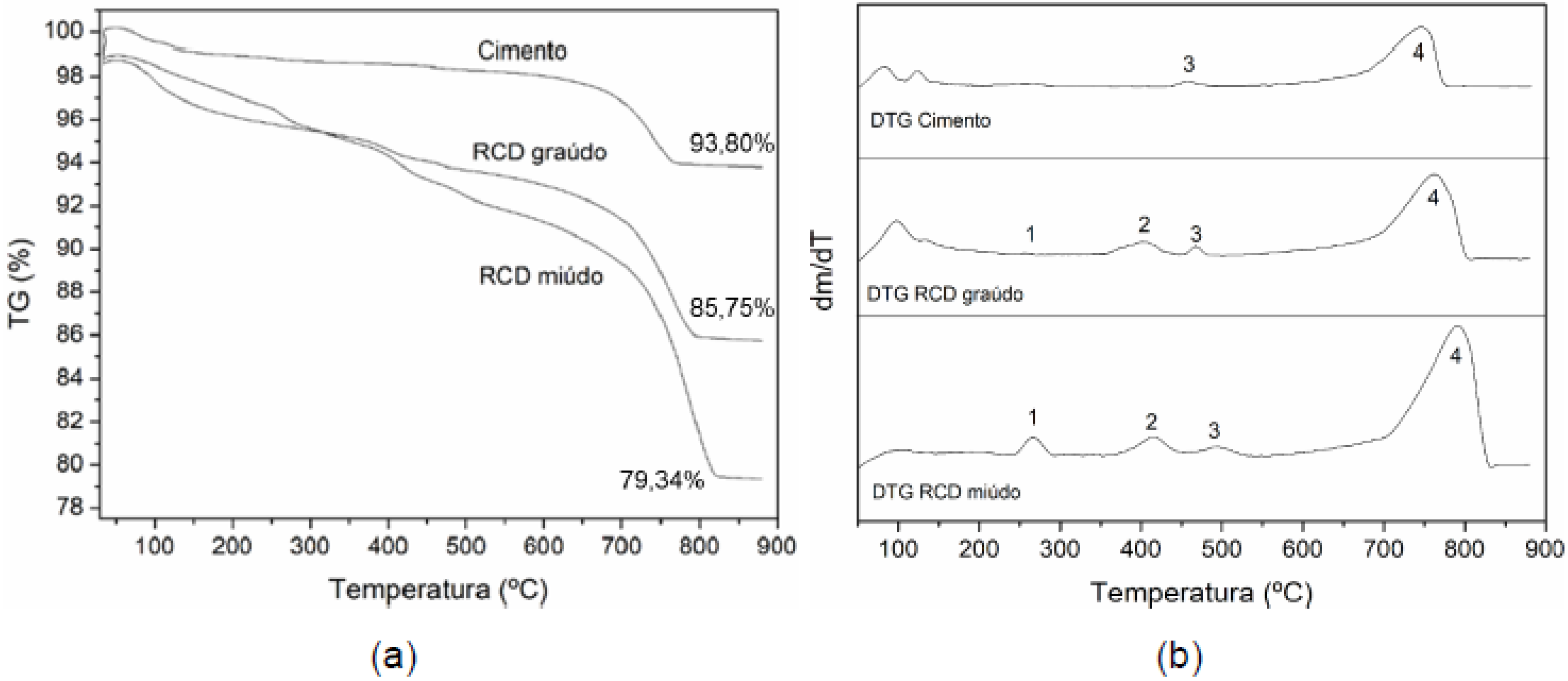
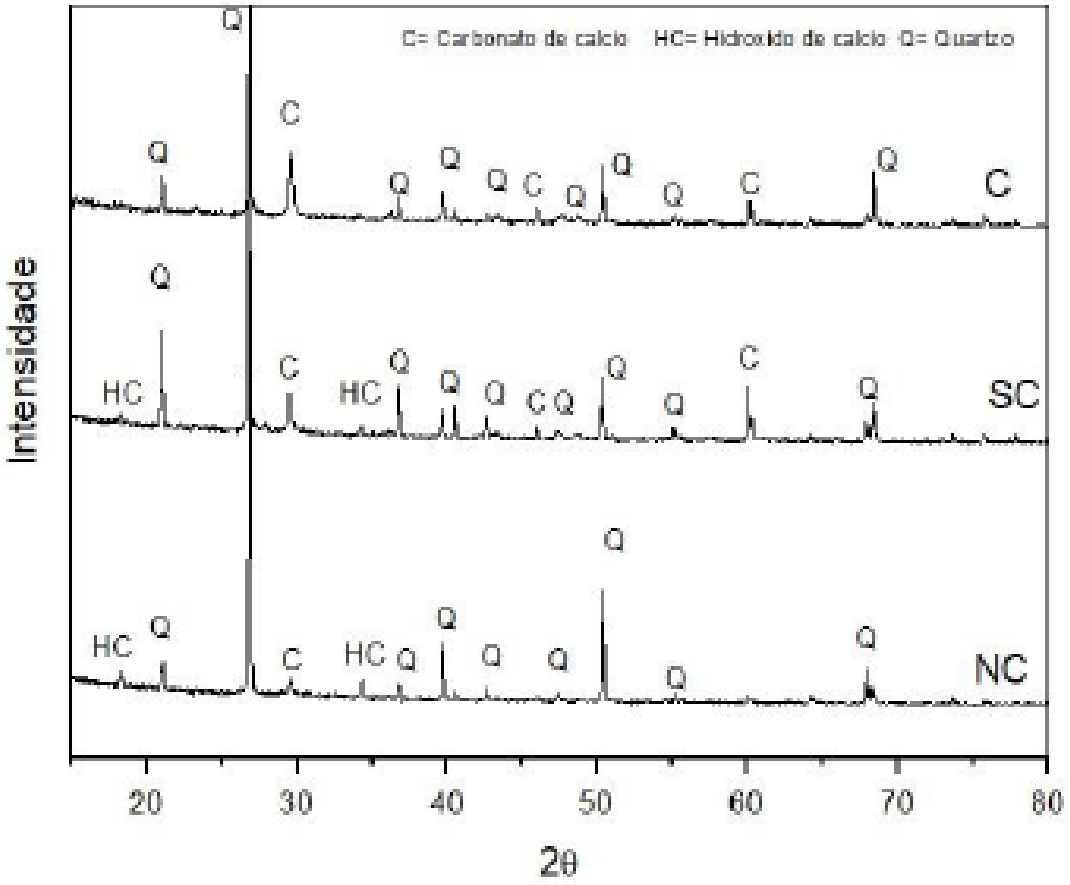


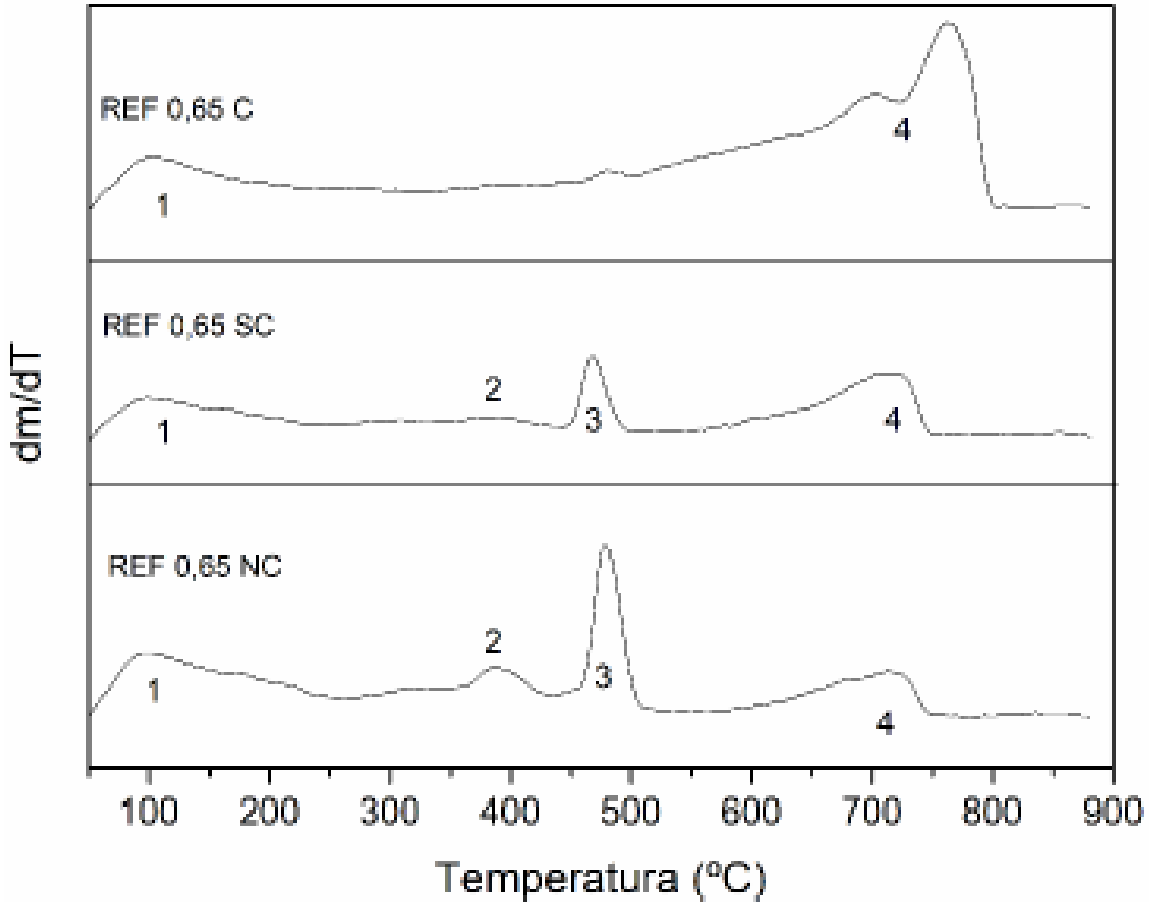
Figura 31: TGs (a) e DTGs (b) dos materiais carbonatáveis

Fonte: Rigo, 2019

Concrete with recycled CDW aggregates



(a)



(b)

Fonte: Rigo, 2019

Concrete with recycled CDW aggregates

Concretos	Emissões dos concretos ($kg.CO_2/m^3$)	Captura de CO_2 ($kg.CO_2/m^3$)		Balanço de emissões (%)*	
		BRE	TG/DTG	BRE	TG/DTG
REF 0,45	430,39	137,08	39,80	31,85	9,25
REF 0,55	370,61	110,75	49,10	29,88	13,25
REF 0,65	330,08	92,90	15,26	28,14	4,62
50%AM 0,45	430,99	144,98	50,82	33,64	11,79
50%AM 0,55	371,27	119,43	71,06	32,17	19,14
50%AM 0,65	330,79	102,11	28,76	30,87	8,70
100%AM 0,45	431,59	152,88	94,94	35,42	22,00
100%AM 0,55	371,93	128,10	130,24	34,44	35,02
100%AM 0,65	331,49	111,31	69,38	33,58	20,93
50%AG 0,45	424,48	141,89	33,19	33,43	7,82
50%AG 0,55	364,71	115,55	50,03	31,68	13,72
50%AG 0,65	324,19	97,70	12,08	30,14	3,73
100%AG 0,45	418,58	146,70	57,01	35,05	13,62
100%AG 0,55	358,81	120,35	80,78	33,54	22,51
100%AG 0,65	318,30	102,50	64,29	32,20	20,20
50%AM 50%AG 0,55	365,37	124,23	31,60	34,00	8,65

* Considerando as emissões totais relacionadas à produção do concreto

Fonte: Rigo, 2019

Case study: CO_2 uptake estimation of Itaipu Dam

- Estimate the CO_2 uptake due to the concrete carbonation of the Itaipu Hydroelectric Power Plant Dam, by mathematical modeling

The concrete dam

Case Studies in Construction Materials 6 (2017) 147–161

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case study

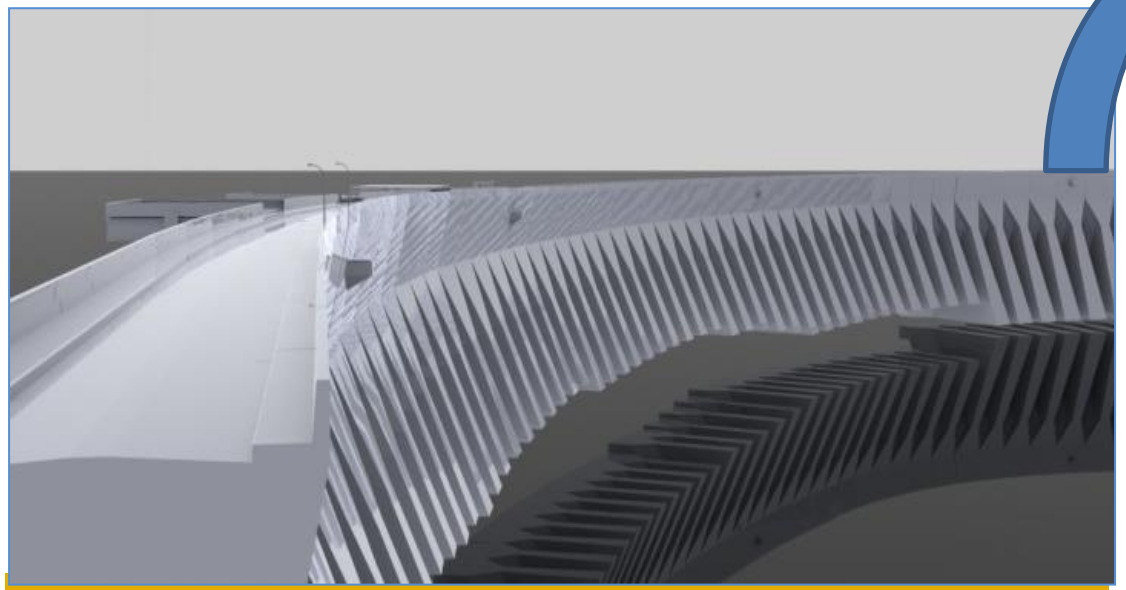
CO_2 uptake potential due to concrete carbonation: A case study

Edna Possan[a,b,*], William A. Thomaz[c], Gustavo A. Aleandri[c], Emerson F. Felix[a], Ana C.P. dos Santos[a]

[a] Federal University of Latin American Integration (UNILA), Brazil
[b] Center for Advanced Studies on Dam Safety (CEASB/PTI), Brazil
[c] Federal University of Technology—Paraná (UTFPR), Brazil

http://dx.doi.org/10.1016/j.cscm.2017.01.007

Estimated CO_2 Uptake



3D view of the Itaipu Dam

Surface area

Information on the concrete used in the dam

Itaipu's Hydroelectric Power Plant technical collection

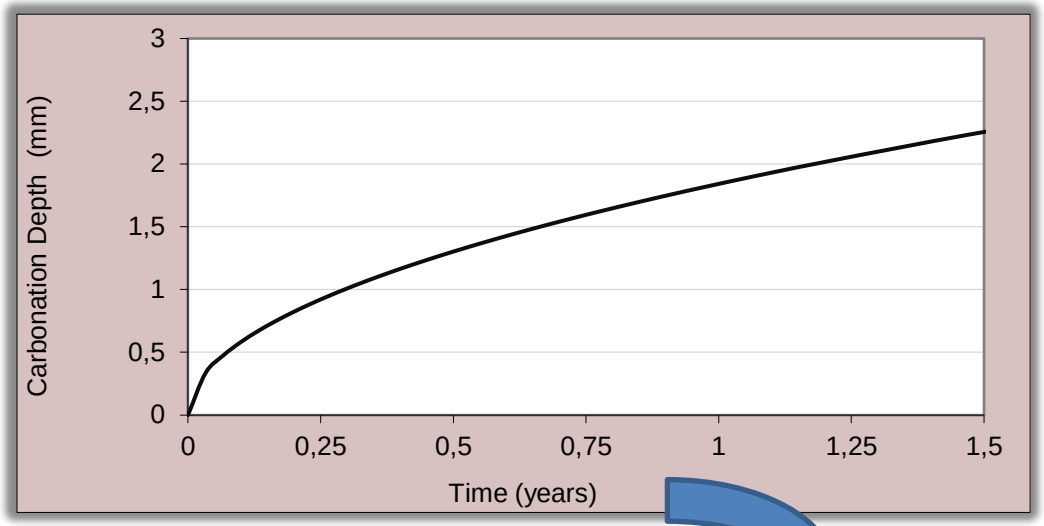
Samples core extracted

Concrete carbonation depth measurement

Estimated CO_2 Uptake

$$y = k_c \left(\frac{20}{f_c}\right)^{k_{fc}} \cdot \left(\frac{t}{20}\right)^{\frac{1}{2}} \cdot \exp\left[\left(\frac{k_{ad}.ad^{\frac{3}{2}}}{40+f_c}\right) + \left(\frac{k_{co_2}.CO_2^{\frac{1}{2}}}{60+f_c}\right) - \left(\frac{k_{RU}.(UR-0{,}68)^{\cdot}}{100+f_c}\right)\right].k_{ce}$$

Possan (2010)

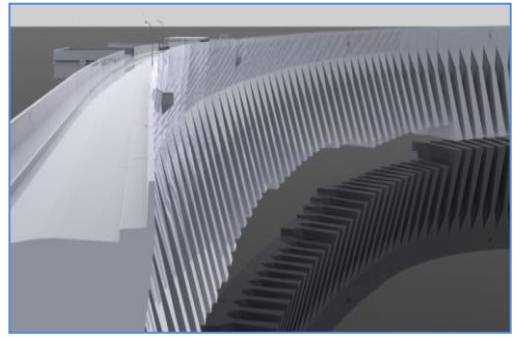


Carbonation modeling during the structure life cycle

Calculation of CO_2 uptake due to carbonation of concrete

$$CO_2 = y.c.CaO.r.A.M$$

Surface area of the Dam

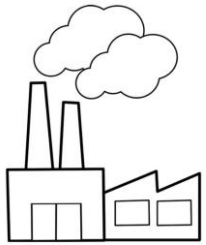


Concrete Carbonation Depth

Samples core extracted

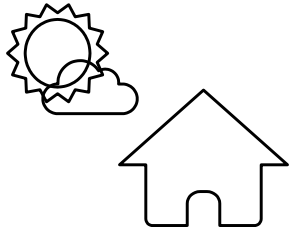
The CO_2 Uptake is directly related

Condições ambientais



Concentração de CO_2, UR

Proteção à chuva

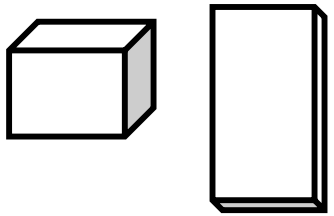


Grau de saturação dos poros

Composição química

Reserva alcalina

Área de exposição



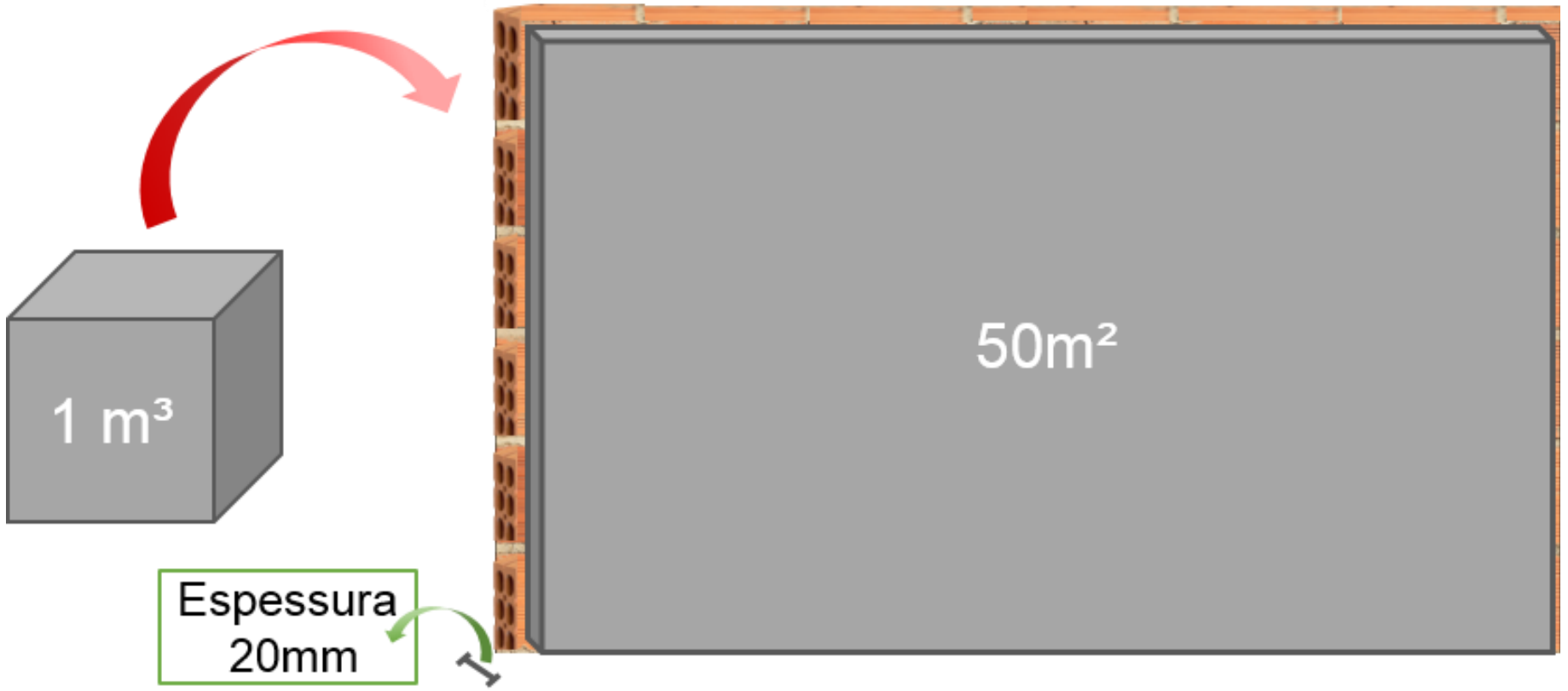
Relação m^2/m^3

Proteção superficial

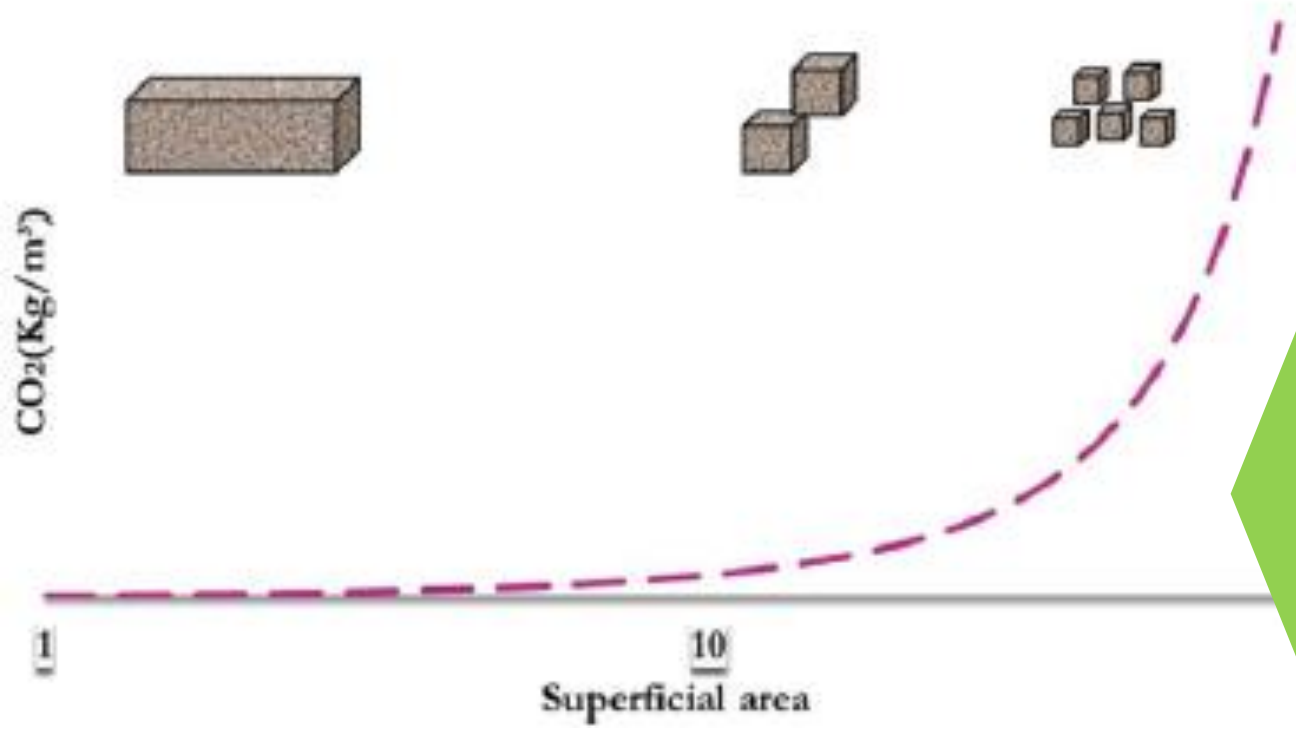
Difusibilidade de CO_2

ÁREA SUPERFICIAL EXPOSTA A AÇÃO DO CO_2

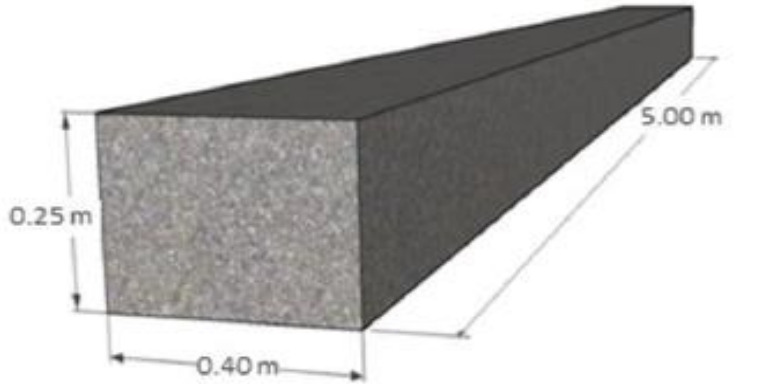
(RELAÇÃO M^2/M^3)



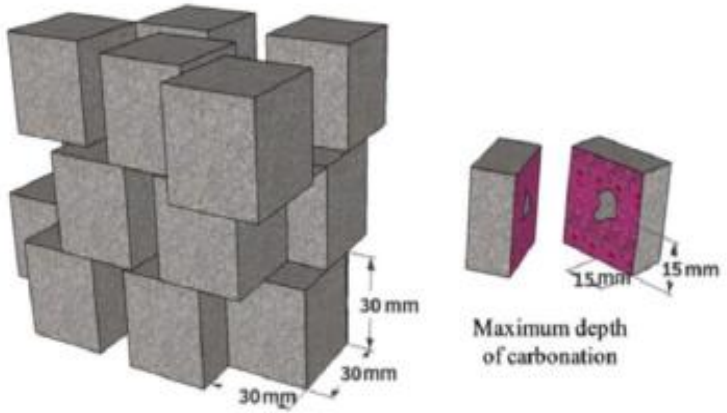
CO_2 uptake occurs through out the service life of the concrete structure or element and continues to occur after demolition → where this process can be intensified



CO_2 uptake as a function of the concrete element superficial area



A Concrete element (life cycle)



B Concrete element (post-demolition)

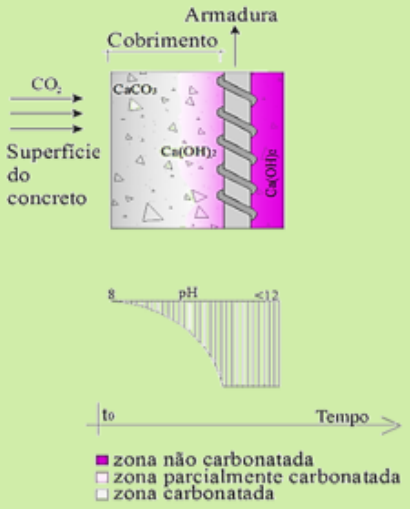
Software for estimation of CO_2 uptake due to concrete carbonation

CARBEM 1.0

Formulário Sistema

CARBEM V 1.0

O software CARBEM apresenta-se como um modelo de estimativa da profundidade de carbonatação do concreto, em mm, com variáveis de entrada de fácil obtenção, como: tipo de cimento, resistência à compressão, teor de adições, umidade relativa do ar, teor de CO_2 do ambiente de exposição e condições de exposição da estrutura.



A partir da profundidade carbonatada o modelo também permite:

- **Estimar a vida útil de projeto (VUP) de uma dada estrutura, em anos;**
- **Determinar a espessura de cobrimento do concreto para garantir a vida útil de projeto;**
- **Calcular o potencial de captura de CO_2 do concreto;**

O Software CARBEM foi desenvolvido com base em Redes Neurais Artificiais (RNA's) junto ao Centro Avançado de Segurança de Barragens/Parque Tecnológico de Itaipu (CEASB/PTI), se apresentado como uma potencial ferramenta para projetistas, engenheiros, consultores, construtores entre outros, para simular o desempenho de durabilidade de estruturas expostas à ação de CO_2.

O erro médio estimado na modelagem, para o banco de dados que deu origem ao modelo, foi de aproximadamente 5 mm, considerado aceitável que para os estudos de carbonatação, dado o número de variáveis que influenciam no processo.

Os desenvolvedores alertam que o uso do Software CARBEM nas simulações não elimina a necessidade de testes de laboratório para comprovação da durabilidade.

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Carbonation Depth

Concrete cover thickness

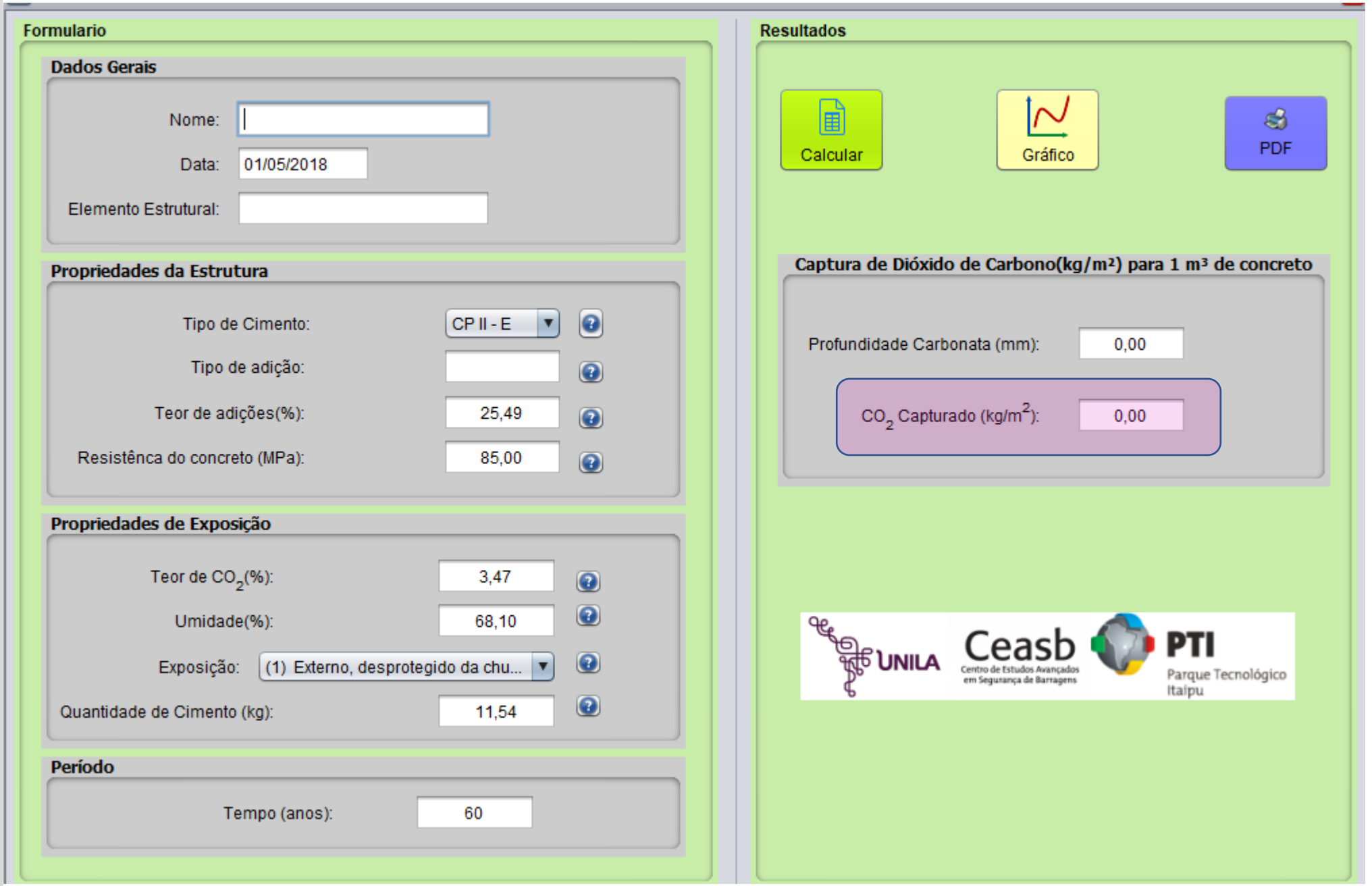
Service Life

CO_2 uptake

Felix e Possan (202?)

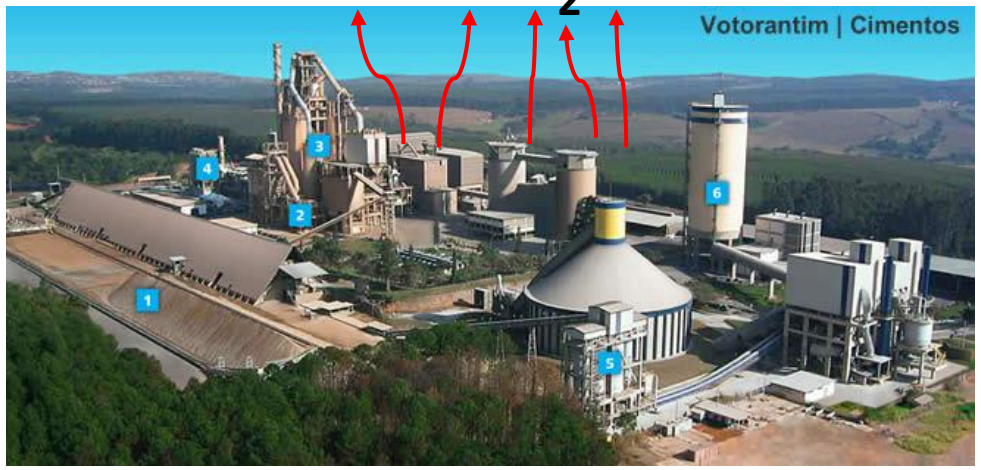
Software for estimation of CO_2 uptake due to concrete carbonation

CARBEM 1.0



Felix e Possan (202?)

44,8 million ton of CO_2



Cement-based constructions → can absorb part of these emissions throughout the life cycle

The Future

We must produce resilient and sustainable cement-based elements/structures!

- With adequate durability
- That capture CO_2 during the life cycle and the post-demolition period

Future generations will be grateful!

TOWARDS AGENDA 2030!!

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Thank!

Obrigada!

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