UNIVERSITÀ DEGLI STUDI DI BERGAMO | Dipartimento di Ingegneria e Scienze Applicate

# How to consider deterioration effects in assessing the potential retrofit of existing RC structures

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# Sustainability of concrete structures: an Italian perspective

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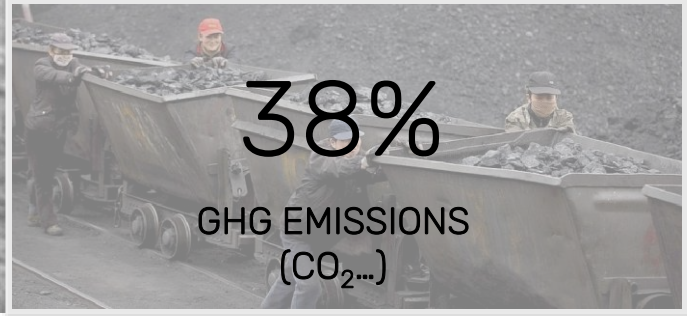
## ITALIAN BUILDING HERITAGE: 63% of RC BUILDINGS BUILT BEFORE 1980's

## ENVIRONMENTAL IMPACTS OF THE BUILDING SECTOR WORLDWIDE







## SAFETY AND SERVICEABILITY

- OBSOLETE AND ENERGY INEFFICIENT BUILDINGS
- 70% BUILDINGS VULNERABLE TO SEISMIC HAZARD (NOT CONCEIVED AND DESIGNED TO RESIST HORIZONTAL LOADS)

## DURABILITY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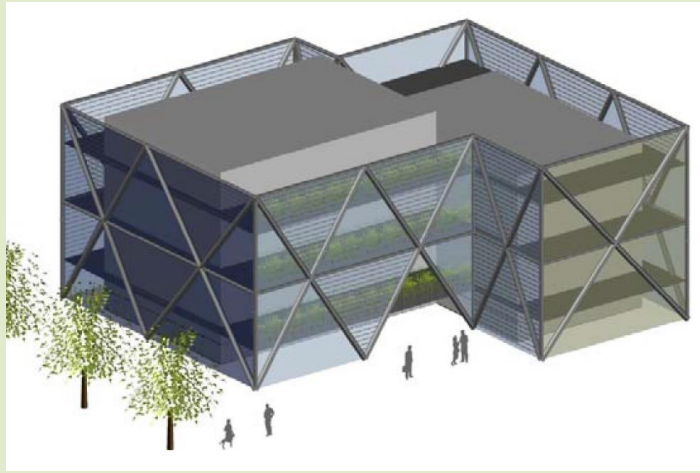
## POSSIBLE APPROACHES ON A LARGE SCALE

### DEMOLITION /RECONSTRUCTION

- WASTE PRODUCTION AND DISPOSAL
- INVASIVE AND IMPACTING OPERATIONS
- LARGE PRODUCTION OF RAW MATERIALS
- RELOCATION OF INHABITANTS

### RENOVATION THROUGH INNOVATIVE/SUSTAINABLE SOLUTIONS



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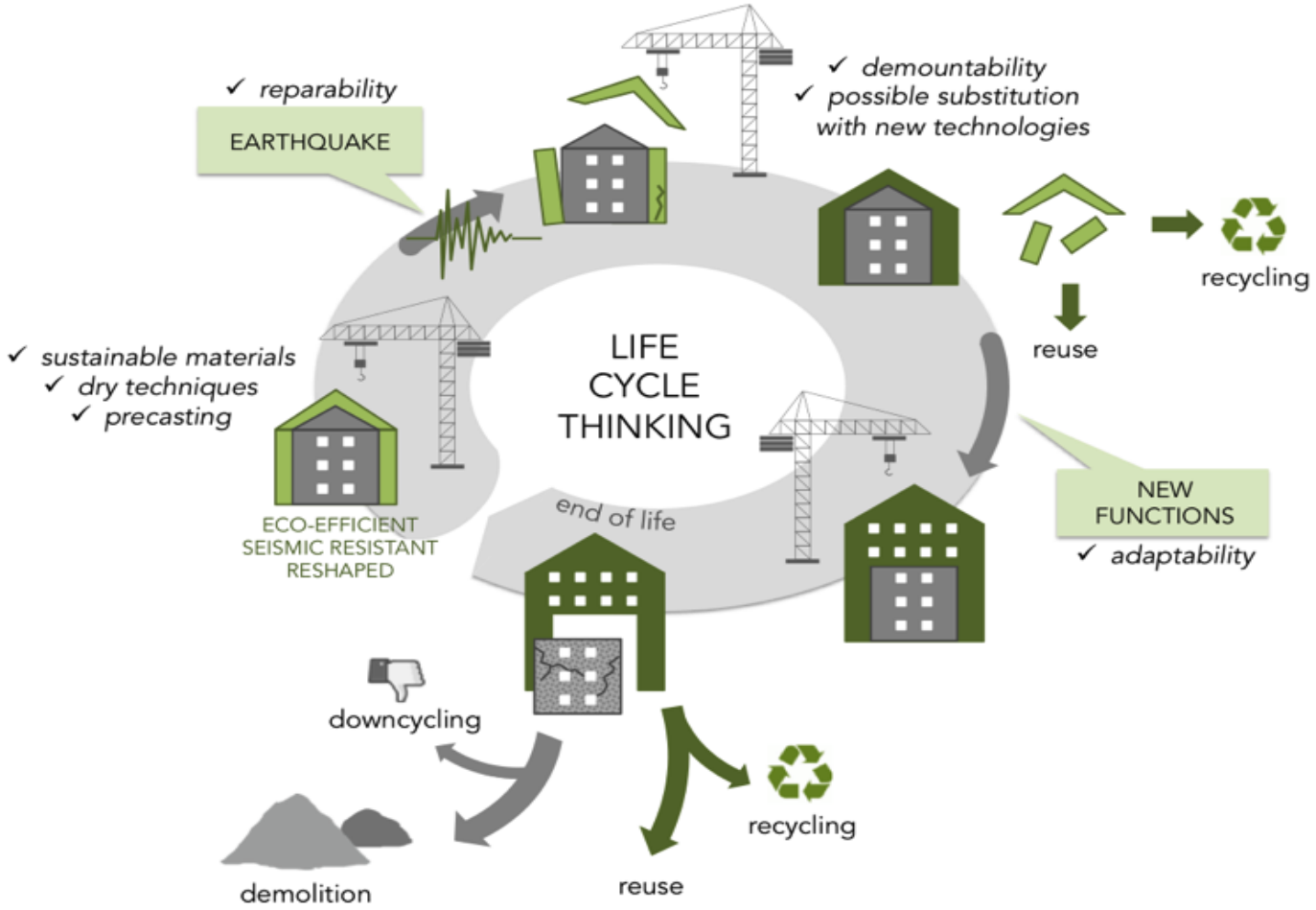
## RENOVATION THROUGH INNOVATIVE/SUSTAINABLE SOLUTIONS




Marini, A. et al., 2017. **Combining seismic retrofit with energy refurbishment for the sustainable renovation of RC buildings: a proof of concept.** *European Journal of Environmental and Civil Engineering,* Volume 10, p. 1080.

**Integrated deep renovation of existing buildings with prefabricated shell exoskeleton.**
Zanni, Cademartori, Marini, Belleri, Passoni, Giuriani, Riva, Angi, Brumana, Marchetti.
Sustainability 13 (20), 2021

AdESA Adeguamento Energetico Sismico ed Architettonico

Marlegno – SME for XLAM exoskeleton shell industrialization
Harpaceas – SME for BIM application developement
Edilmatic – SME focusing on connection systems
Università di Bergamo – Energy-structural retrofit
Università di Brescia – Architectural/Formal restyiling

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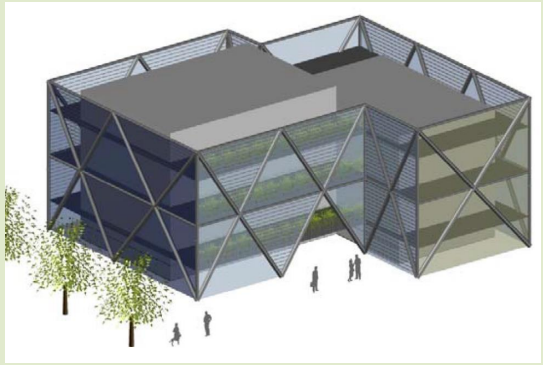
A FUNDAMENTAL ASPECT IN THIS PERSPECTIVE:
BUILDINGS STATE OF PRESERVATION

RENOVATION THROUGH INNOVATIVE/SUSTAINABLE SOLUTIONS



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IS IT ALWAYS POSSIBLE?

ARE THESE KINDS OF INTERVENTION ALWAYS FEASIBLE AND/OR EFFECTIVE FOR THE BUILDING?

HOW TO EVALUATE THE TECHNICAL FEASIBILITY AND THE LC STRUCTURAL PERFORMANCE OF THE BUILDING AFTER THE RETROFIT?

CORROSION OF STEEL IN RC STRUCTURES

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NEED FOR EVOLUTIONARY STRUCTURAL MODELS FOR THE RELIABLE PREDICTION OF THE BUILDING'S SERVICE LIFE

↓

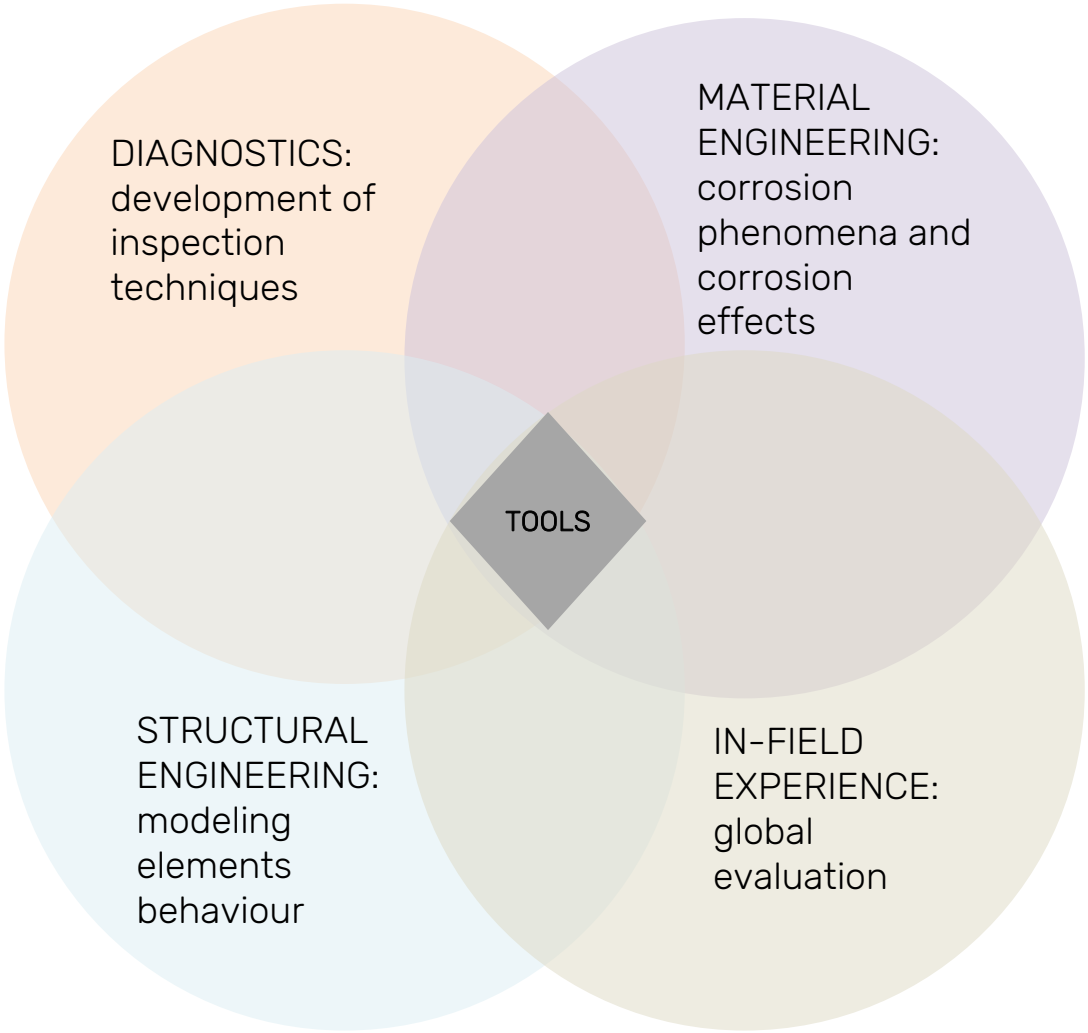
LACK OF A VALIDATED AND SHARED PROCEDURE TO *DETECT, EVALUATE AND MODEL CORROSION EFFECTS* IN STRUCTURAL EVALUATIONS

MULTIDISCIPLINARY AND TRANSVERSAL PROBLEM:

NEED FOR
In-depth research in each field of expertise

+

Cross-contamination among sectors and definition of validated and shared knowledge to be implemented in the structural evaluation



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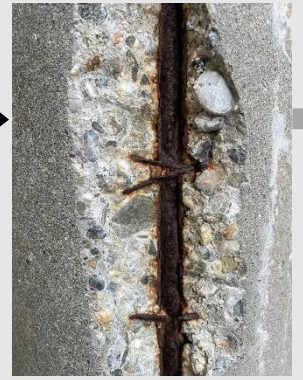
## A PRELIMINARY PROPOSAL: THE DEMSA PROTOCOL

PROCEDURES

**STEP 1**

VISUAL INSPECTION AND DAMAGE DETECTION



**STEP 2**

DETERIORATION RISK IDENTIFICATION

CORROSION RISK SCENARIOS IDENTIFICATION

- SCENARIO 0
- SCENARIO 1
- SCENARIO 2
- SCENARIO 3

**STEP 3**

DETERIORATION LEVEL AND EQUIVALENT DAMAGE PARAMETERS SETTING

- BAR RESIDUAL CROSS SECTION
- CONCRETE SECTION PROPERTIES
- DUCTILITY REDUCTION
- RESIDUAL BOND STRENGTH

**STEP 4**

DETERIORATION EFFECTS RELEVANCE & IMPACT ON MODELLING/RETROFIT STRATEGIES

| | |
|---|---|
| ABSENCE OF SIGNIFICANT DETERIORATION | STRUCTURAL MODEL W/O CORROSION DAMAGE |
| NEGLIGIBLE BUT POTENTIALLY RELEVANT IN THE FUTURE | MATERIAL REPAIR |
| PRESENCE OF RELEVANT CORROSION DAMAGE | IMPLEMENTATION OF EDP IN THE STRUCTURAL MODEL |
| CORROSION DAMAGE IMPAIRING THE STRUCTURAL FUNCTION | INDICATIONS ABOUT RETROFIT |
| COMPROMISED STRUCTURE | DEMOLITION OR DISMISSAL |

TOOLS

- ABACUS OF VISIBLE DETERIORATION CONDITIONS
- INSTRUMENTAL TESTS
- PARAMETERS CALIBRATION
- SENSITIVITY ANALYSES

NO ACCURATE INFORMATION ABOUT CORROSION BUT EVALUATION OF POSSIBLE **CORROSION EFFECTS** AND OF THEIR **INFLUENCE ON THE STRUCTURAL BEHAVIOUR**

**FLEXIBLE PROCEDURE** OPEN TO RESEARCH ACHIEVEMENTS: REFINED PARAMETERS, NEW MODELS, ADVANCED DIAGNOSTICS

DEMSA Protocol: deterioration effects modelling for structural assessment of RC buildings.
Casprini E, Passoni C, Marini A, Bartoli G. *Buildings.* 2022; 12(5): 574.

How to consider deterioration effects in assessing the potential retrofit of existing RC structures
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## INTRODUCED TOOLS: 1) CORROSION RISK SCENARIOS

| Scenario | S0 | S1 | S2 | S3 |
|---|---|---|---|---|
| Corrosion phenomenon | Carbonation or chloride-induced corrosion | Carbonation-induced corrosion | Carbonation-induced corrosion + $Cl^-$ | Critical $Cl^-$ threshold at rebar level |
| Type of attack | Not relevant | Uniform | Not uniform | Not uniform |
| Corrosion rate ranges [µm/year] | <1 | 2-100* | 2-200* | 4-1000* |
| Maximum to average attack ratio $R_p$ | - | 1 | n.a. | T: 4-8<br>10 |
| Possible attack pattern distribution on the bar length | - | Uniform | Spread with deeper attacks | Spread with deeper attacks – very localized (pitting) |

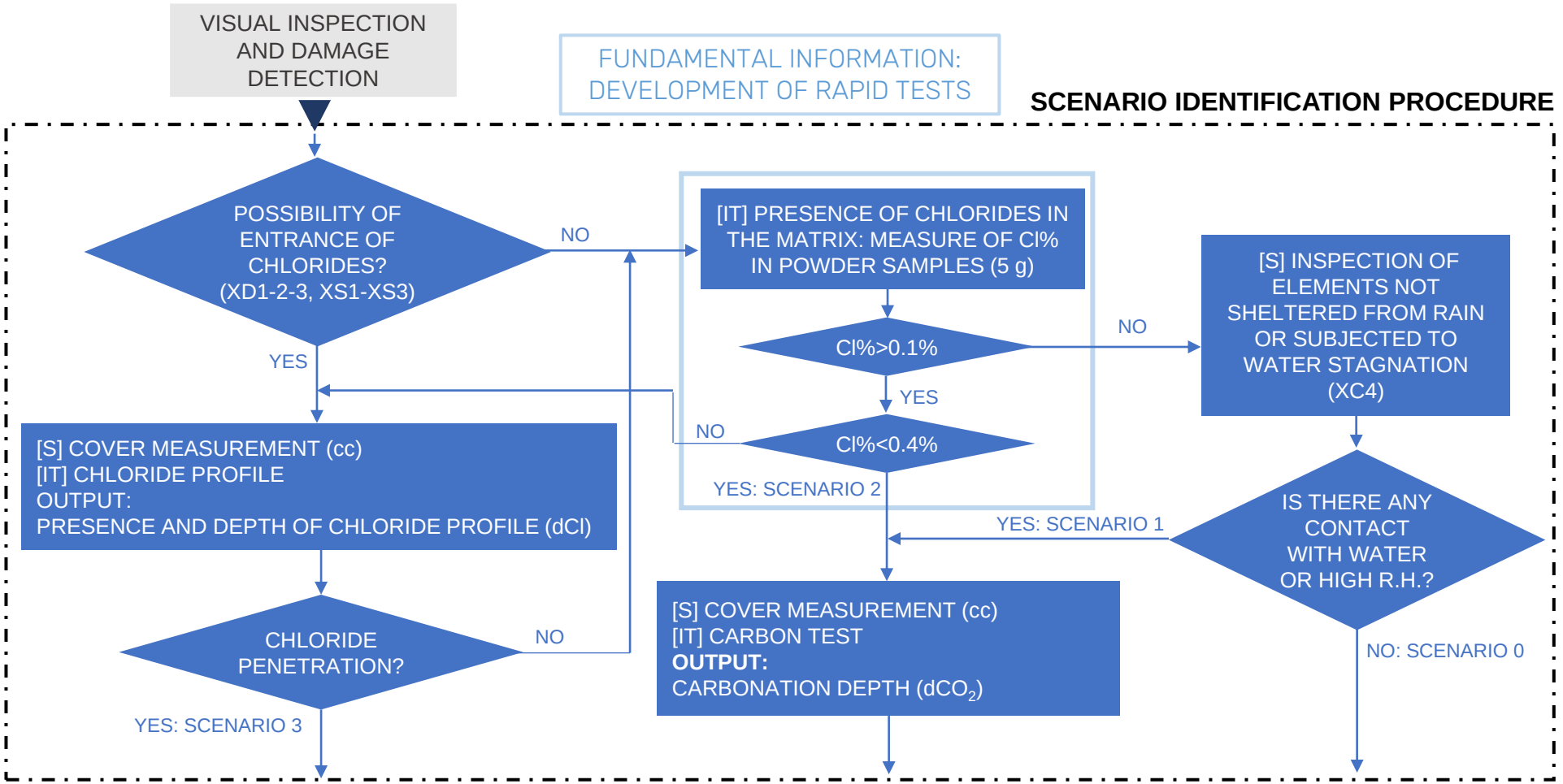
WHY?

The corrosion attack, hardly measurable in existing structures, presents similar characteristics in similar environmental and aggressiveness conditions

| Attack | Aggressiveness | CRS 1 | CRS 2 | CRS 3 |
|---|---|---|---|---|
| Average corrosion rate $v_{avg}$ [µm/year] | CLASS Ordinary | | 2÷10 | 10÷50 |
| | CLASS High | 2÷10 | 10÷50 | 50÷100 |
| | CLASS Extreme | 10÷50 | 100÷200 | 100÷300 |
| Maximum to average attack ratio $R_p$ | | 1÷2 | 3÷7 | 4÷10 |

[T] Tuutti, K., 1982. *Corrosion of steel in concrete.* Stockholm: Swedish Cement and Concrete Research Institute.
[B] Bertolini, L., Elsener, B., Pedeferri, P., Redaelli, E., Polder, R. 2013. *Corrosion of steel in concrete – prevention, diagnosis, repair*. Weinheim, Wiley VCH.
[M] Martinez, I., Andrade, C. 2009. *Examples of reinforcement corrosion monitoring by embedded sensors in concrete structures*. Cement & Concrete Composites, vol. 31.
[R] RILEM, 1996. *Durability design of concrete structures*. Report no.14. E&FN Spon, London.

## INTRODUCED TOOLS: 2) GUIDED PROCEDURE FOR THE DIAGNOSTIC CAMPAIGN




WHY?

The on-site collection of information is aimed at identifying the Corrosion Risk Scenario of interest, thus available tests can be systematized in a procedure in which the presence of specific conditions is checked

DEPTH OF CARBONATION NOT ALWAYS NECESSARY



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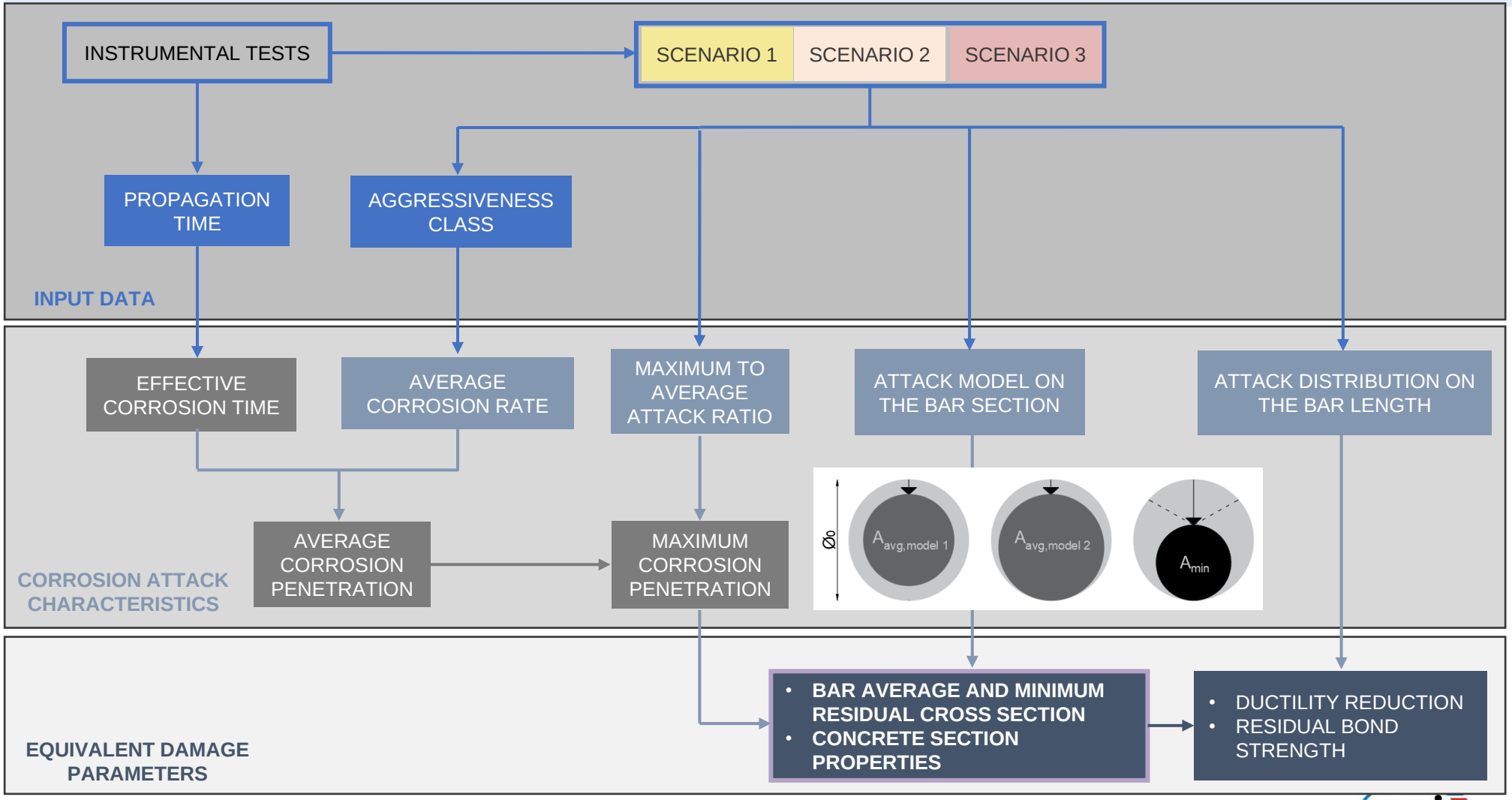
## INTRODUCED TOOLS: 3) EQUIVALENT DAMAGE PARAMETERS




WHY?
With the corrosion attack characteristics defined for each Scenario, existing models from the literature can be implemented to calibrate parameters to perform sensitivity analyses on the structural behaviour

**Toward the definition of equivalent damage parameters for the assessment of corroded RC structures.**
Casprini, Passoni, Marini, Bartoli.
*Structural Concrete* 2022.
https://doi.org/10.1002/suco.202200368

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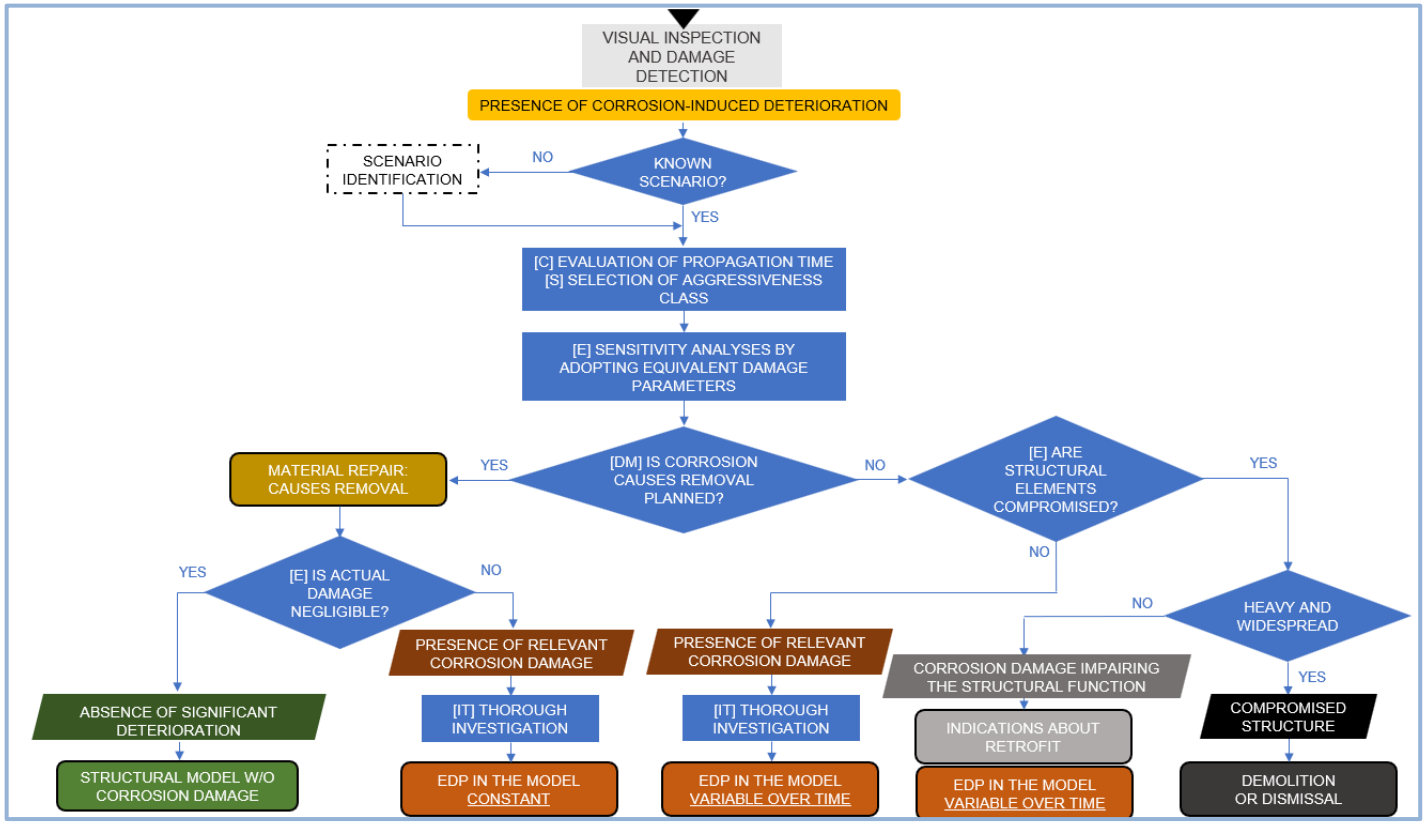
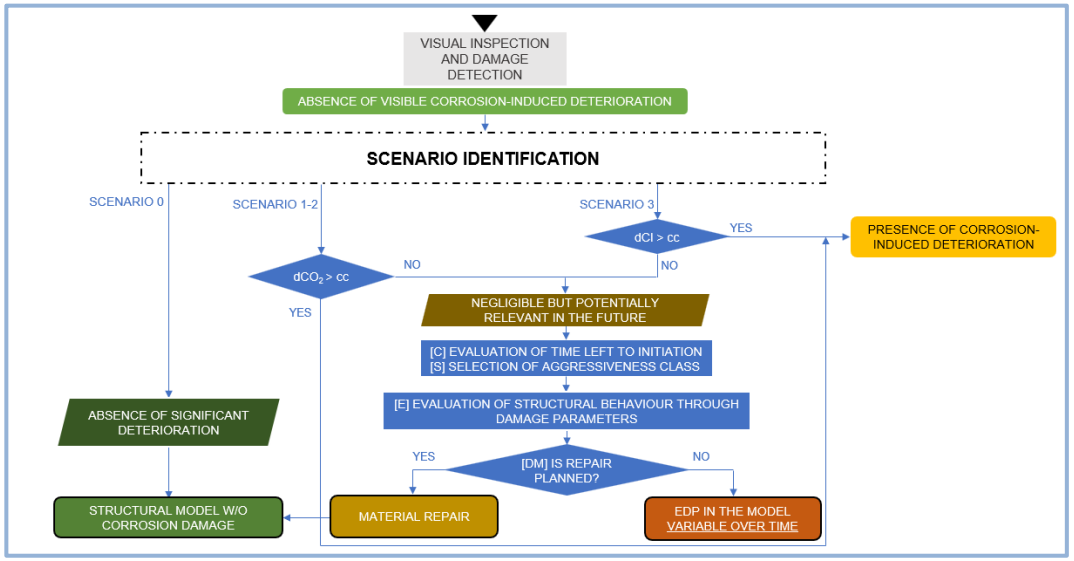
## INTRODUCED TOOLS: 4) FLOW-CHARTS GUIDING THE USER THROUGH THE WHOLE EVALUATION PROCEDURE

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https://www.mdpi.com/1611052

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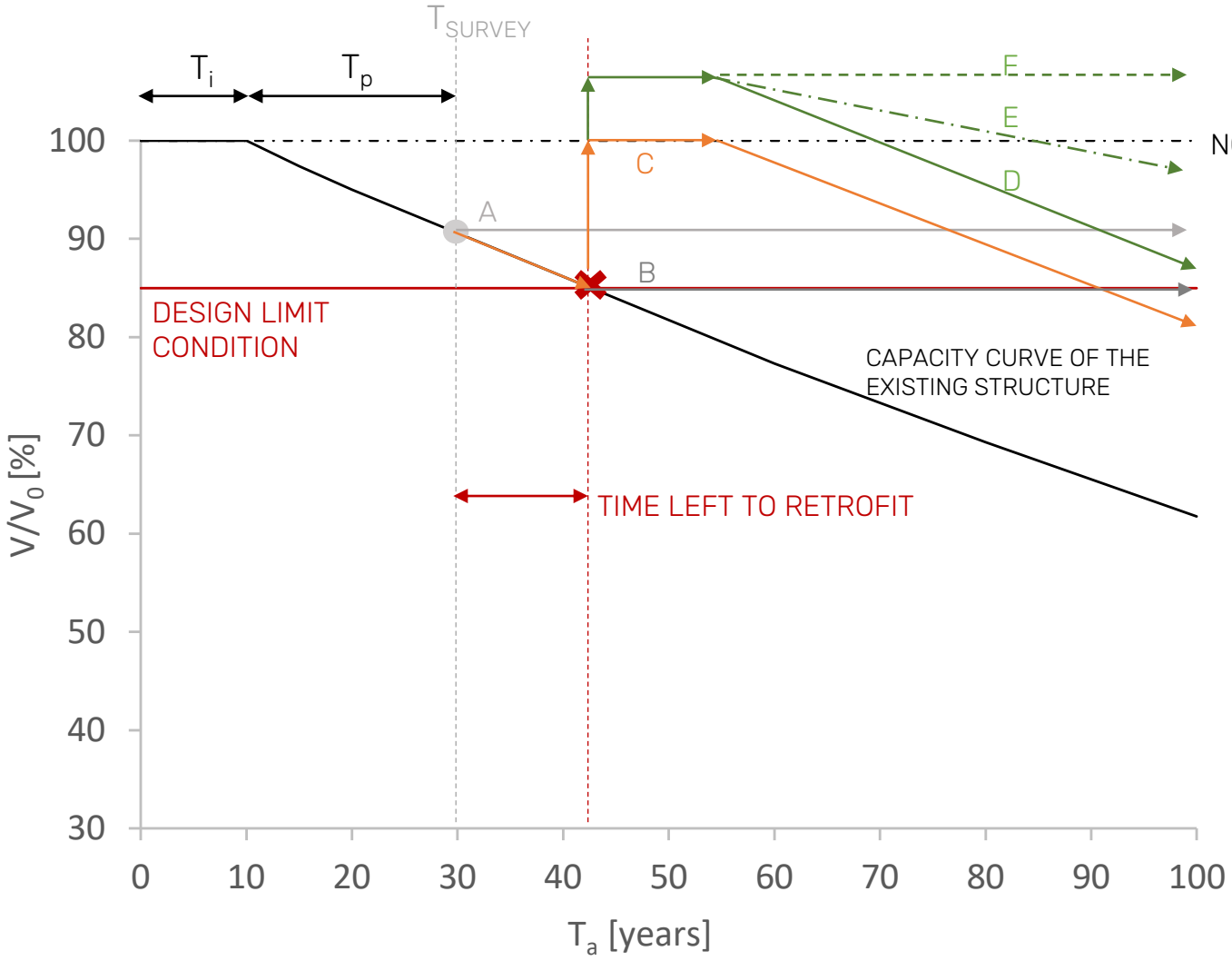
## THE DEMSA PROTOCOL AS A LIFE CYCLE STRUCTURAL ENGINEERING TOOL




A) MATERIAL REPAIR + BARS PROTECTION
CONSTANT EQUIVALENT DAMAGE PARAMETERS
90% RESIDUAL CAPACITY

B) WAIT TO LIMIT CONDITION + A)
85% RESIDUAL CAPACITY

C) WAIT TO LIMIT CONDITION + REMOVE CARBONATED CONCRETE +
STRUCTURAL RETROFIT TO INITIAL CAPACITY
(NEW COVER THICKNESS AND PROPERTIES TO ESTIMATE $T_i$)
EQUIVALENT DAMAGE PARAMETERS (VARIABLE)

D) WAIT TO LIMIT CONDITION + REMOVE CARBONATED CONCRETE +
STRUCTURAL RETROFIT TO HIGHER CAPACITY
EQUIVALENT DAMAGE PARAMETERS (VARIABLE)

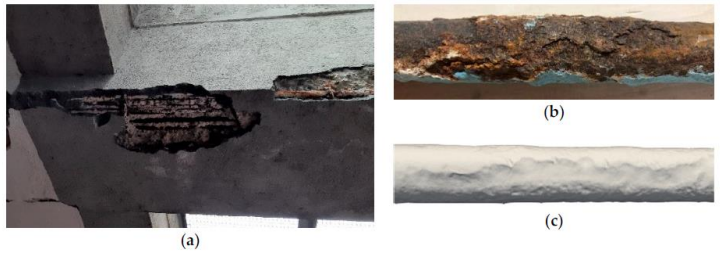
E) D + REDUCE R.H.

F) D + BARS PROTECTION

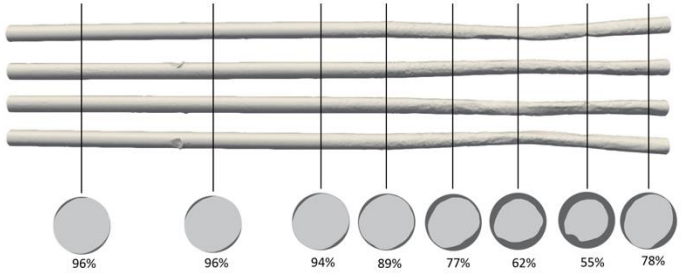
Including corrosion effects in the structural evaluation allows performing prediction on the future structural behaviour, accounting for structural and material repair interventions

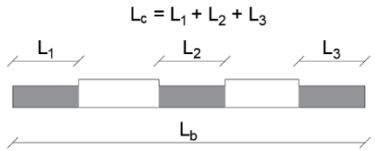
## ON-GOING RESEARCH AND CHALLENGES

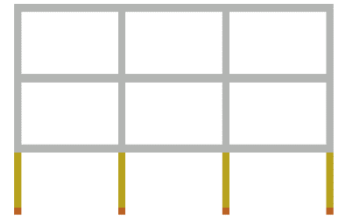
- **Knowledge of corrosion patterns** in existing structures belonging to different Scenarios: in-field data collection and measurement of corrosion attack characteristics




- Definition of **simplified corrosion patterns** for modelling the uneven attack distribution along the bar length



- Extension of the procedure to other structural typologies, such as **bridges**

- **Cooperation and interaction** among different fields of expertise is necessary to increase the reliability and effectiveness of the proposed procedure



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