SERVICE LIFE PREDICTION: QUESTIONS AND IMPERFECT ANSWERS

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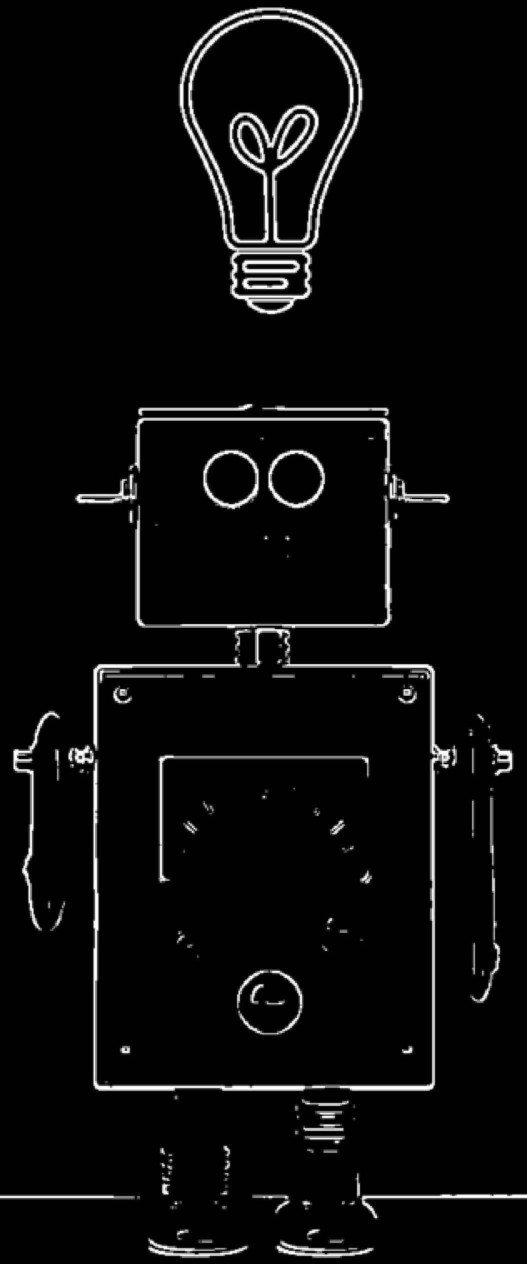


WHAT DO WE KNOW ABOUT SERVICE LIFE PREDICTION?

WHAT IS ALREADY ESTABLISHED?

WHAT ARE PRESENT CERTAINTIES ABOUT SERVICE LIFE PREDICTION?

VERY FEW CERTAINTIES AND MANY DOUBTS.

HOW CAN WE DEFINE THE CONCEPT OF SERVICE LIFE?

“PERIOD OF TIME AFTER INSTALLATION DURING WHICH A BUILDING OR ITS PARTS MEETS OR EXCEEDS THE PERFORMANCE REQUIREMENTS”

ISO 15686: 2011

DOES ANYONE KNOW WHAT THE BUILDING CONSTRUCTION CRITERIA ARE?

- ✓ **ARE THE CRITERIA THE SAME FOR ALL ELEMENTS?**

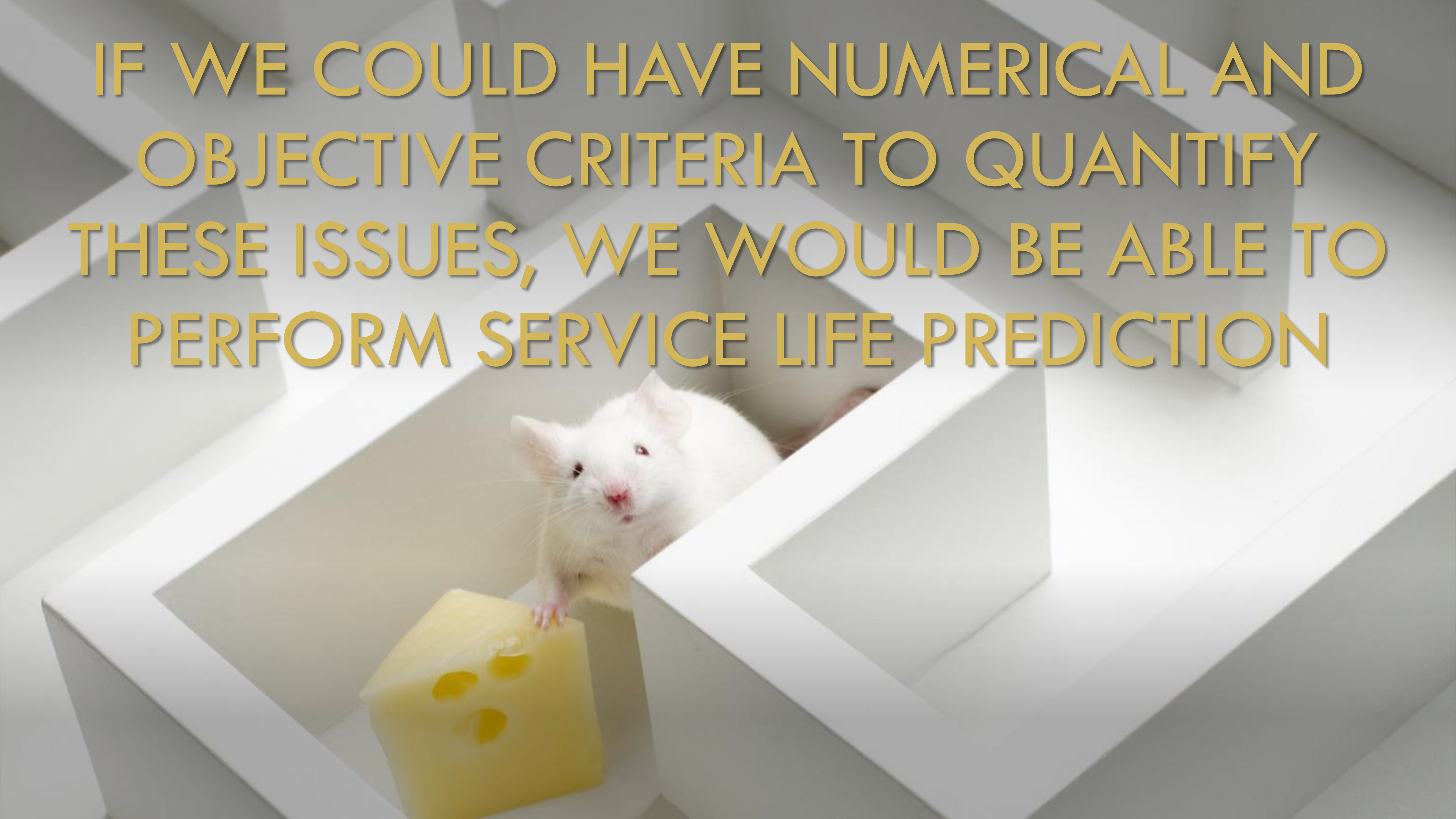
- ✓ **WHEN CHOOSING A CLADDING SOLUTION, DO WE KNOW WHY WE CHOOSE IT?**
- ✓ **WHY THAT CLADDING AND NOT ANOTHER?**
- ✓ **WHAT DO WE WANT FROM A CERTAIN CLADDING?**

FOR EXAMPLE, WHAT DO WE WANT FROM A NATURAL STONE CLADDING?

AESTHETICS?

DURABILITY?

HOW DO WE MEASURE THESE PARAMETERS?

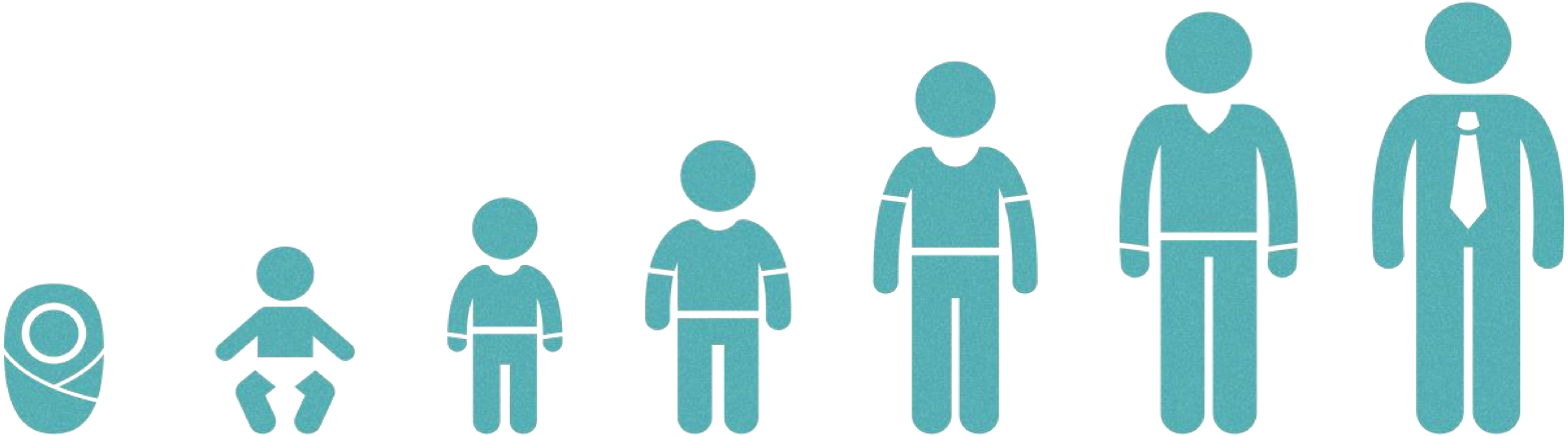

IF WE COULD HAVE NUMERICAL AND OBJECTIVE CRITERIA TO QUANTIFY THESE ISSUES, WE WOULD BE ABLE TO PERFORM SERVICE LIFE PREDICTION

HOW DO WE KNOW THAT SERVICE LIFE HAS ENDED?

PHYSICAL DETERIORATION

HOW TO MEASURE IT?

HOW CAN WE KNOW THAT THIS DEGRADATION IS EXCESSIVE?



PHYSICAL DETERIORATION

PHYSICAL DETERIORATION

Illustrative example of a stone cladding that has reached the end of its service life


ECONOMIC
OBSOLESCENCE

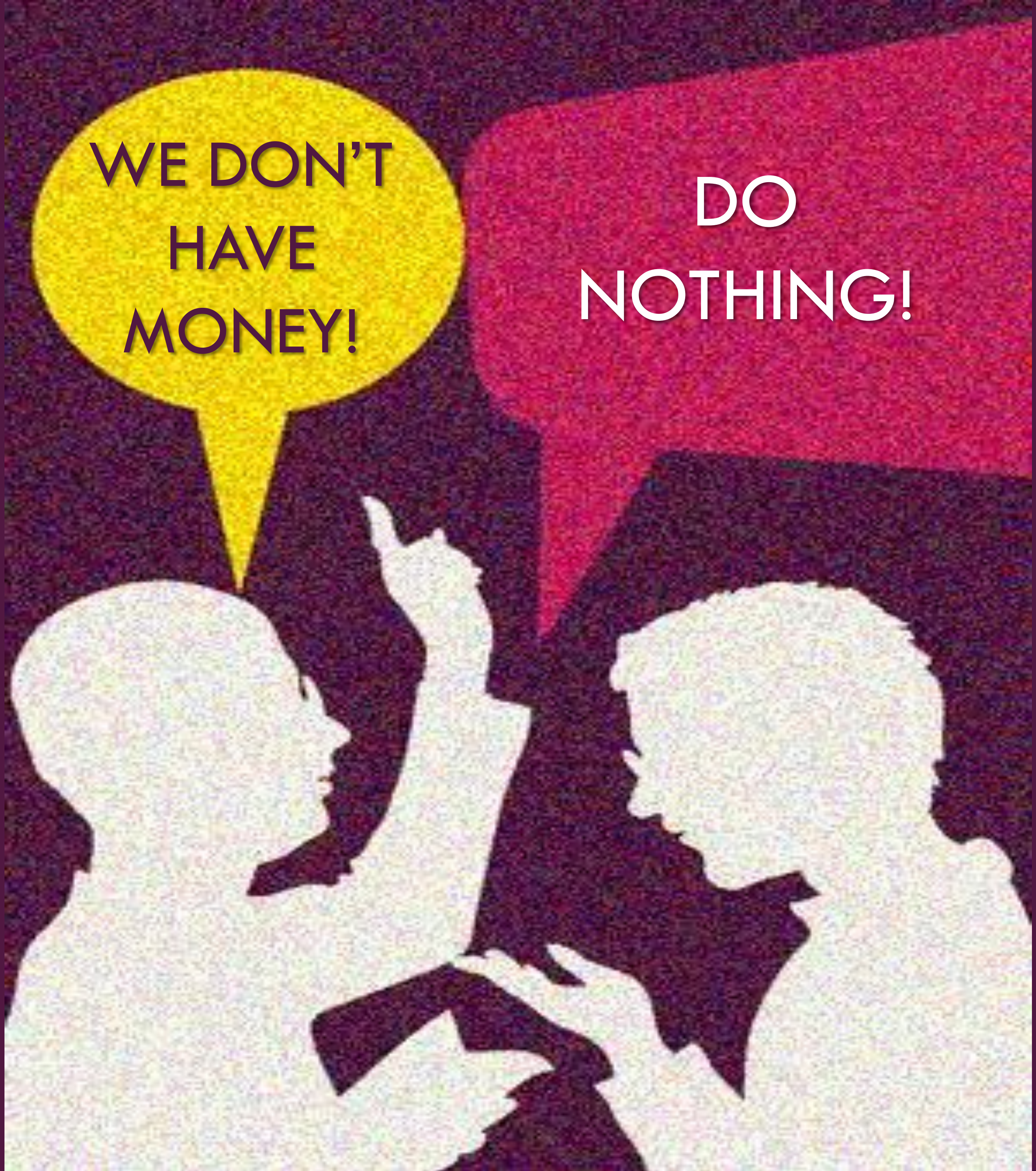
FUNCTIONAL OBSOLESCENCE

AESTHETIC OBSOLESCENCE

TECHNOLOGICAL OBSOLESCENCE

OK, LET'S IMAGINE THAT WE HAVE COME TO THE CONCLUSION THAT THE ELEMENT HAS REACHED THE END OF ITS SERVICE LIFE.

Now what?


WE DON'T HAVE MONEY!
DO NOTHING!


WE HAVE A LOT OF MONEY!
DO THE BEST!


BUT WHAT IS "THE BEST"?

IN REAL WORLD SITUATIONS, WE HAVE SOME MONEY BUT ALSO SOME CONSTRAINTS

HOW TO SELECT THE BEST OPTION?

HOW TO SELECT THE BEST MAINTENANCE ACTIONS?

REPAIR OR REPLACE?

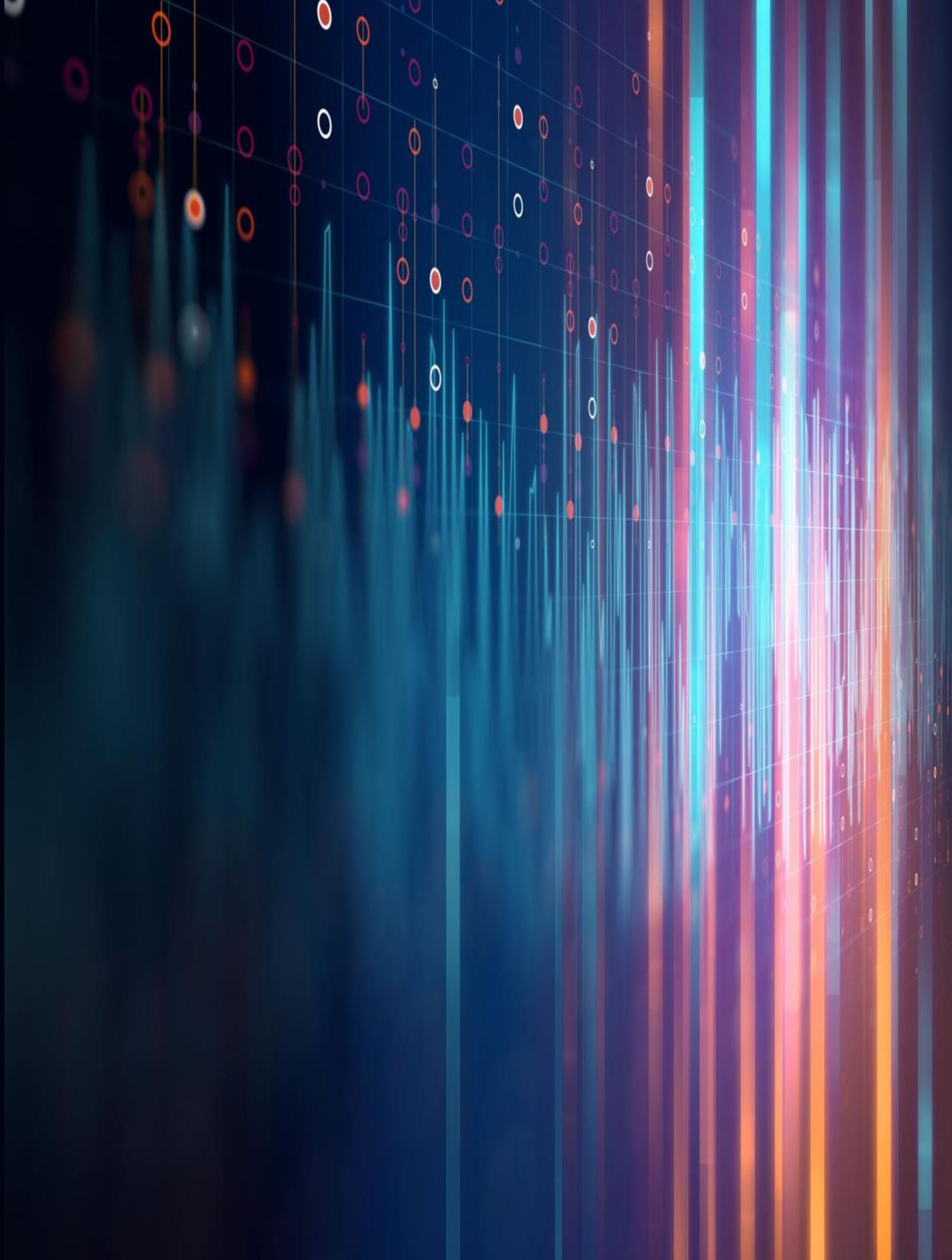
REPLACE WITH THE SAME MATERIAL OR CHOOSE ANOTHER? WHY? AND USING WHICH ALTERNATIVE MATERIAL?

SO, WE HAVE NOW DECIDED WHICH INTERVENTION TO IMPLEMENT.
NEW QUESTIONS ARISE:

HOW TO MAKE SERVICE LIFE PREDICTIONS, AFTER INTERVENTION?

WHAT IS THE NEW CONDITION STATE?
GOOD AS NEW?

WHAT IS THE NEW DEGRADATION PATTERN?



LET'S SUPPOSE WE DECIDE TO CHANGE THE SOLUTION.

DOES THE NEW SOLUTION MEET NEW TECHNOLOGICAL CRITERIA?

ARE THERE GUARANTEES THAT BY REPLACING WE WILL IMPROVE THE ECONOMIC PERFORMANCE?

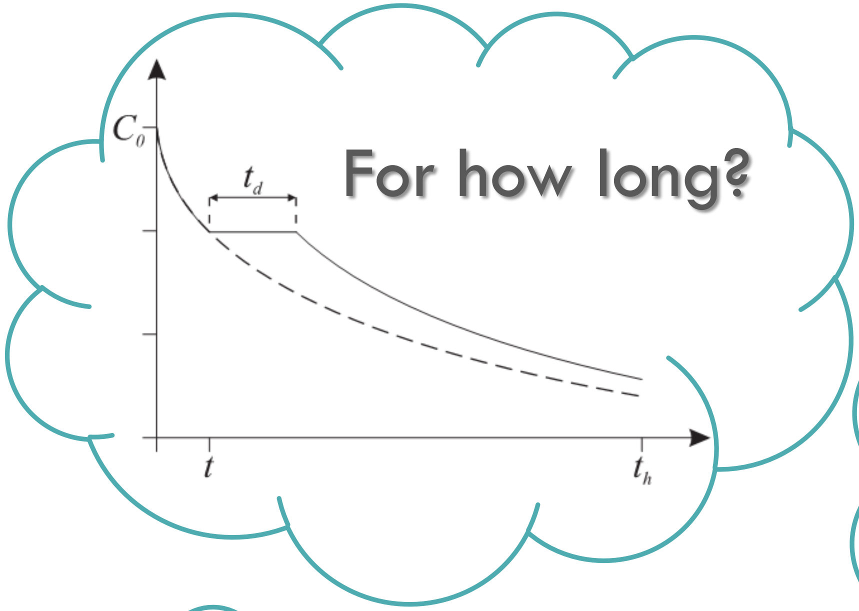
WHICH IS THE DURABILITY OF THE NEW SOLUTION? AND IS THIS SOLUTION THE BEST ONE AVAILABLE?

AND WHAT IS THE ROLE OF MAINTENANCE?

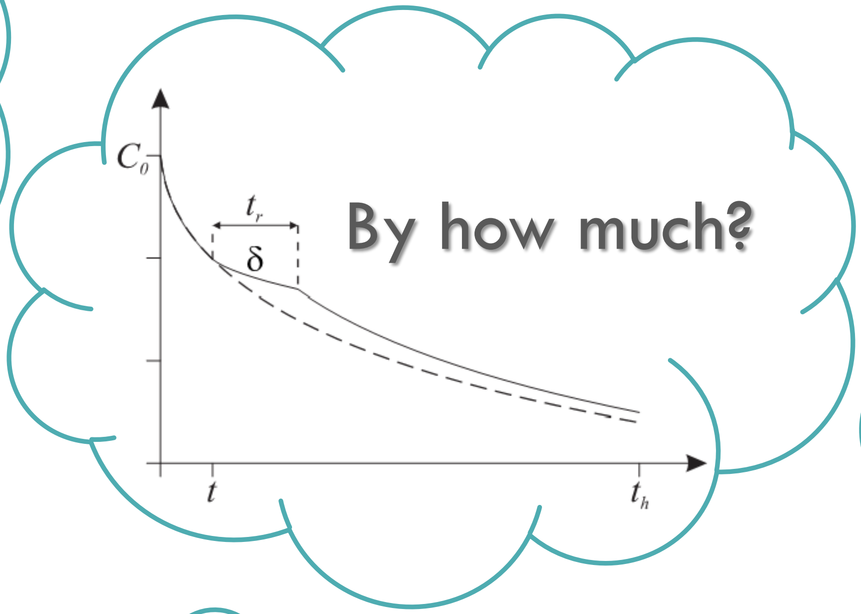
WHAT IS ITS IMPACT ON THE DURABILITY OF THE ELEMENTS?

WHAT IS THE IMPACT OF MAINTENANCE?

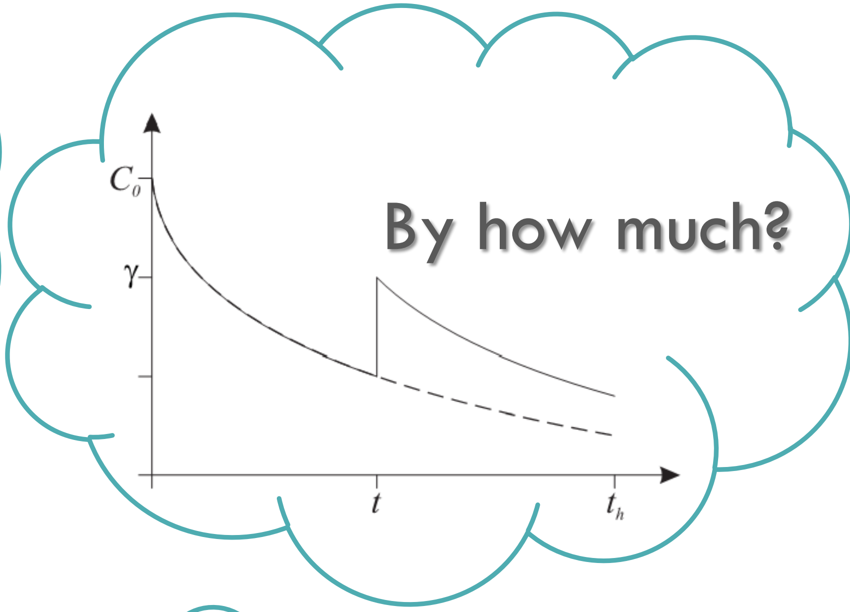
Stops the degradation process?



Mitigates the degradation process?



Decreases the degradation condition?



- - - Without maintenance

—— With maintenance

INTUITIVELY WE KNOW THAT: THE IMPACT OF THE MAINTENANCE ACTIONS DEPENDS ON THE TYPE OF ELEMENT AND THE TYPE OF INTERVENTION

HOW DO WE TAKE EXTERNAL ACTIONS INTO ACCOUNT IN SERVICE LIFE PREDICTION?

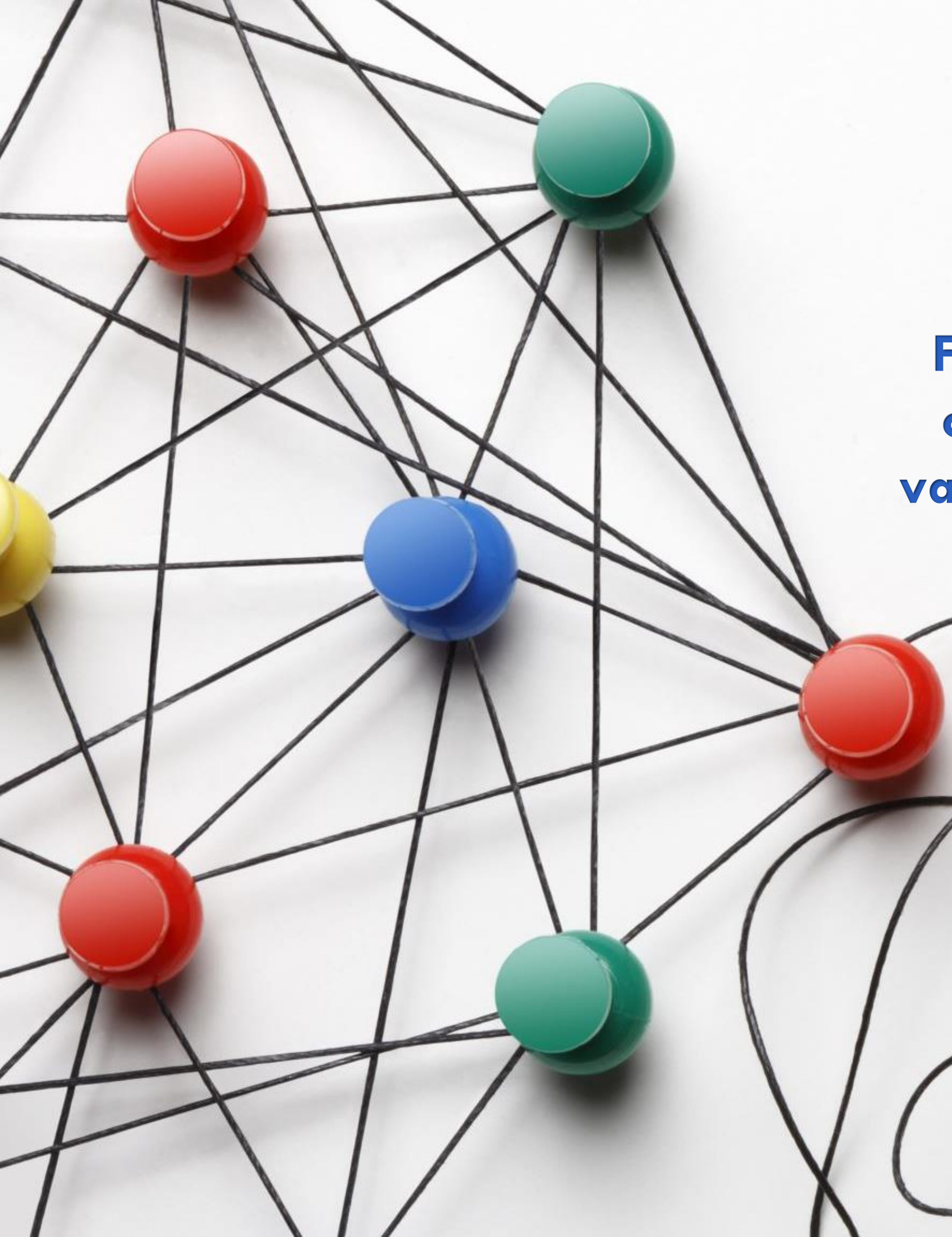
IN MOST SITUATIONS, THE EXISTING MODELS HAVE LIMITATIONS

They depend on the materials, the construction element, its environmental, social and economic context, the deterioration mechanisms, the users' perceptions, etc.

How have all these limitations been addressed?

BY SAMPLING

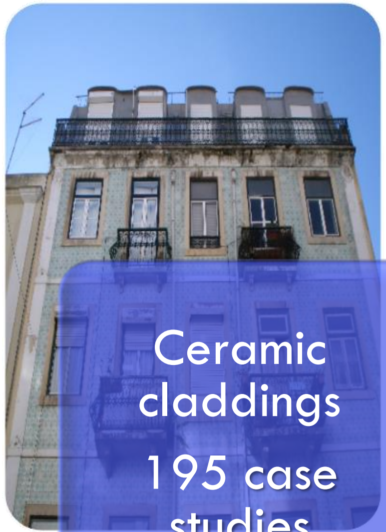
For some elements, for a given climatic context, with samples that statistically validate the service life prediction models



DATASET COLLECTED

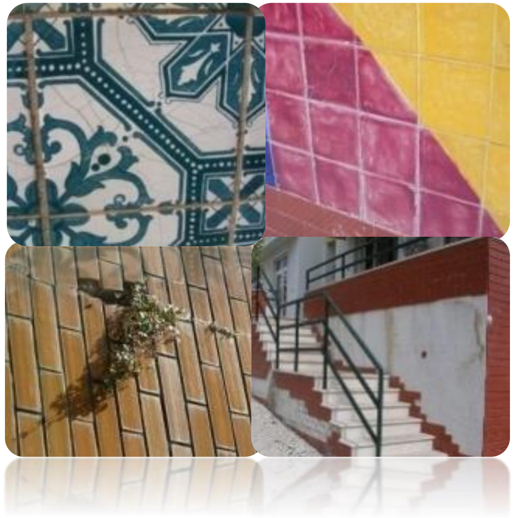
Rendered façades

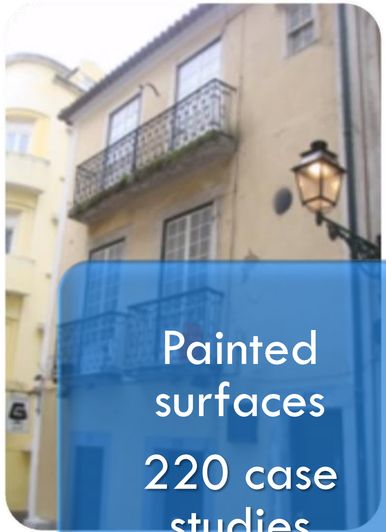
100 case studies



Ceramic claddings

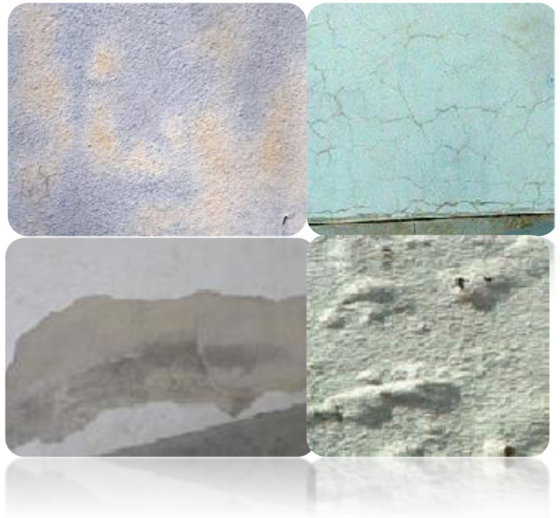
195 case studies





Painted surfaces

220 case studies

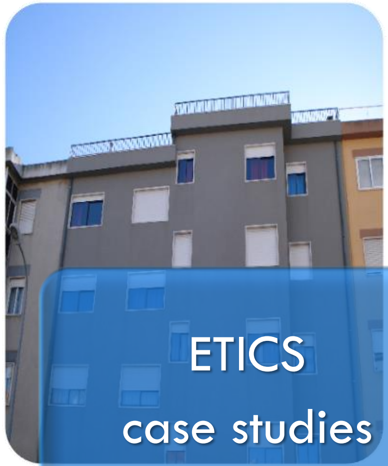


Natural stone claddings

203 case studies, with direct fastening

142 case studies, with indirect fastening

DATASET COLLECTED



ETICS case studies

293 case studies

Architectural concrete surfaces

174 case studies

Pitched roofs' ceramic claddings

146 case studies

Window framing

112 aluminium frames

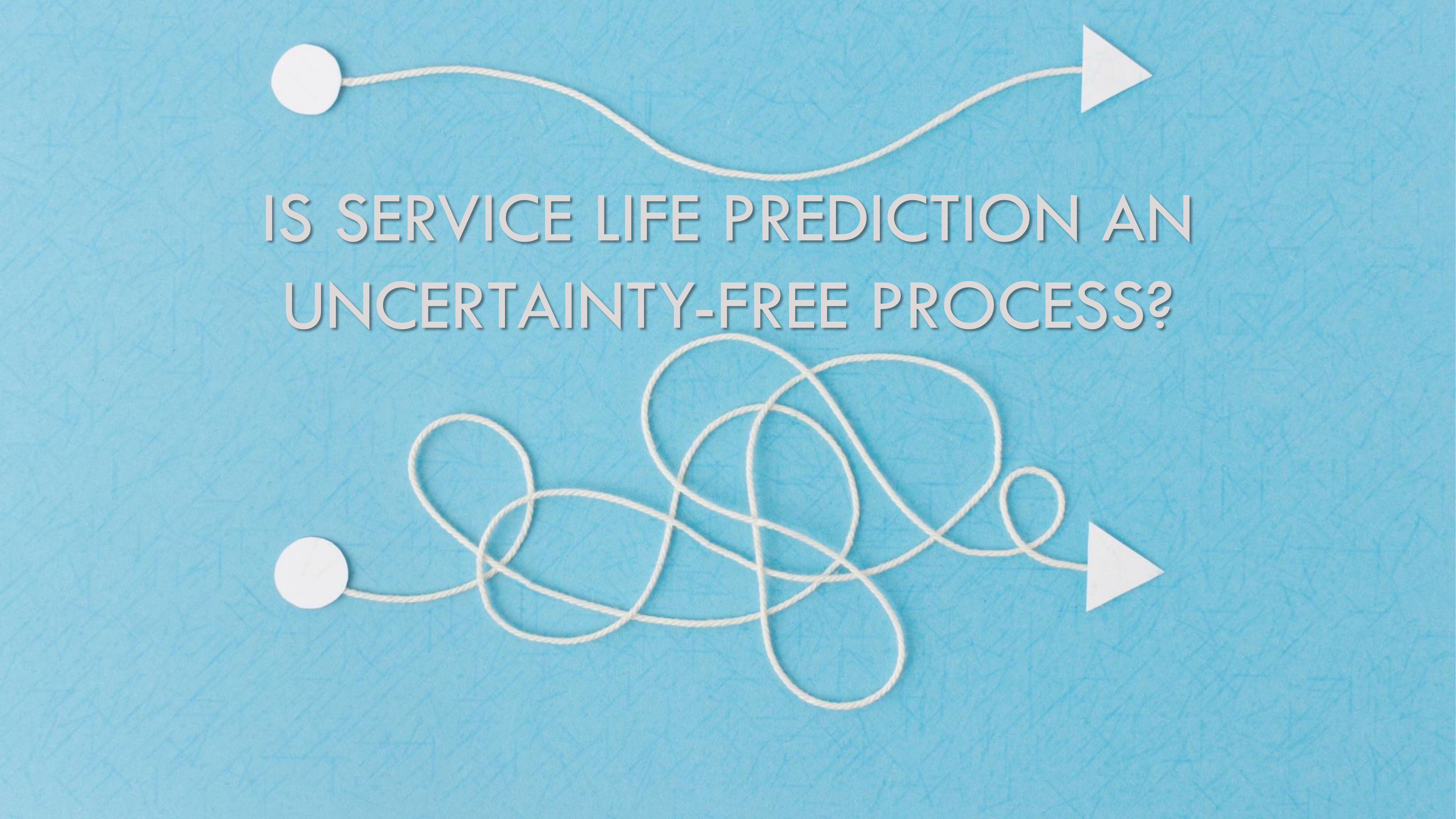
45 wooden frames

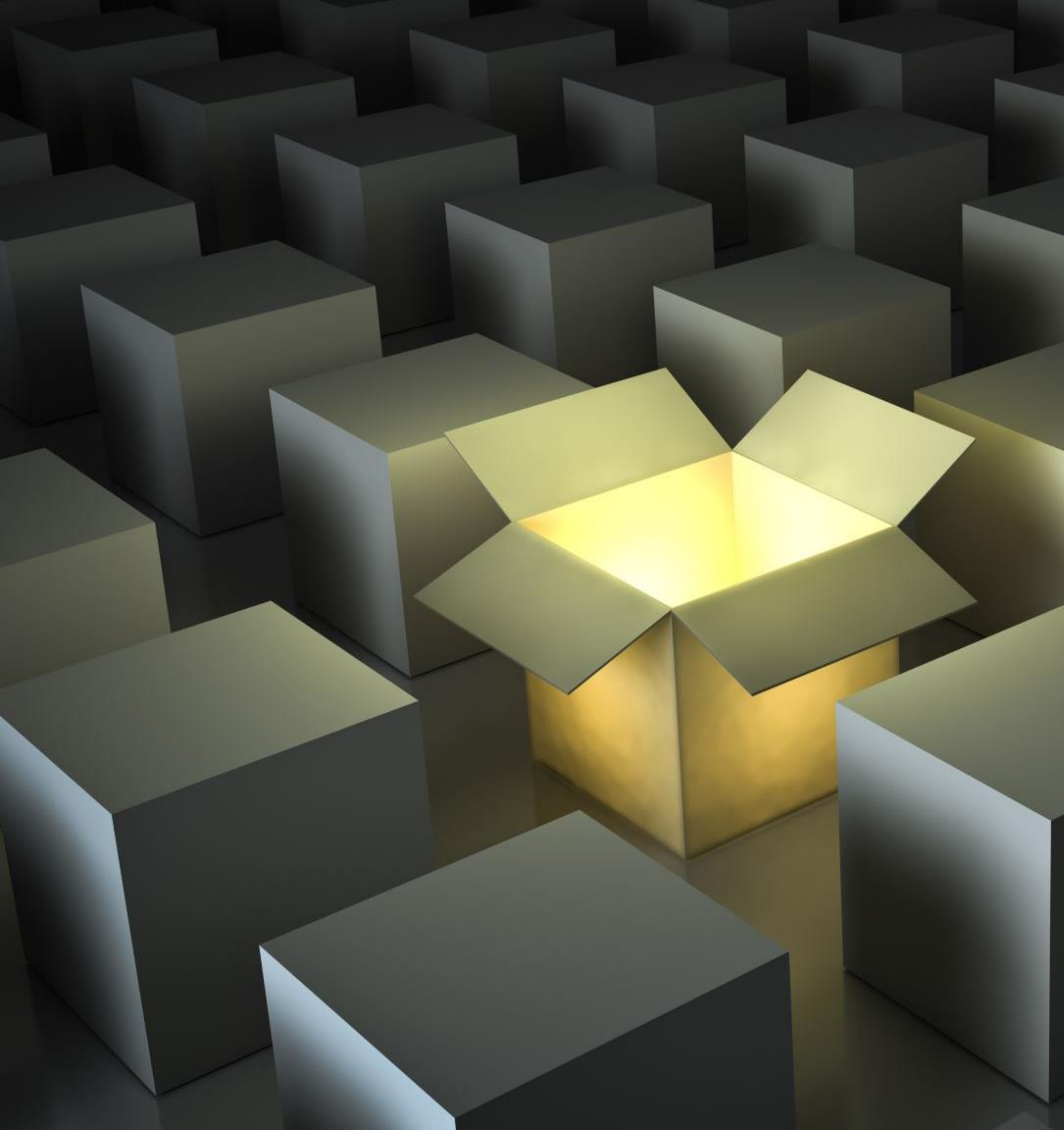
WHAT IF THE EXTERNAL CONDITIONS IN THE SAME LOCATION VARY OVER TIME?

What if a global climate change is taking place?

HOW CAN WE INCLUDE THE IMPACT OF CLIMATE CHANGE IN THE SERVICE LIFE PREDICTION MODELS?

THE WAY FORWARD…


IS SERVICE LIFE PREDICTION AN UNCERTAINTY-FREE PROCESS?



IN VIEW OF ALL THE UNCERTAINTIES, DOES IT MAKE SENSE AT ALL TO EVEN TRY TO PREDICT THE SERVICE LIFE OF BUILDING COMPONENTS?

Definitely, yes!

KNOWLEDGE IS POWER, EVEN IMPERFECT KNOWLEDGE.

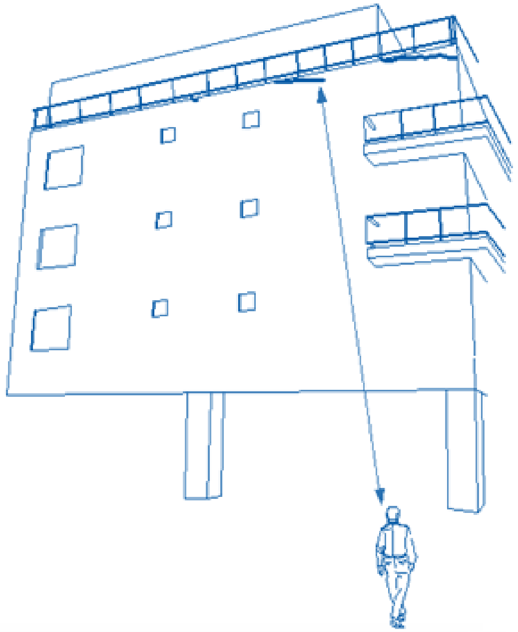
HAVE YOU THOUGHT THAT IT IS NOT POSSIBLE TO CARRY OUT LCC AND LCA STUDIES, OR TO PLAN MAINTENANCE ACTIONS WITHOUT SERVICE LIFE ESTIMATIONS?

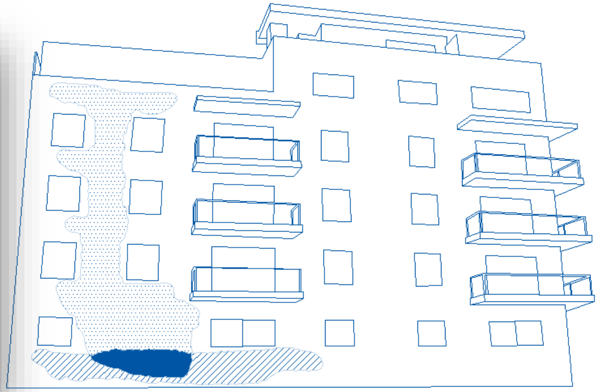
HOWEVER, WE MUST ACCEPT THAT SERVICE LIFE PREDICTION IS NOT AN EXACT SCIENCE

TO PREDICT THE SERVICE LIFE OF BUILDINGS AND COMPONENTS, ONE POSSIBLE PATH IS TO DEFINE A SEMI-QUANTITATIVE INDEX THAT EVALUATES THE FOLLOWING ASPECTS:

- ✓ TYPE OF DEGRADATION OR DEGRADATION MECHANISMS;
- ✓ SEVERITY OF THE DIFFERENT TYPES OF ANOMALIES THAT CAN OCCUR IN THE ELEMENT ANALYSED;
- ✓ EXTENT OR AREA AFFECTED BY THE ANOMALIES.

QUANTIFICATION OF THE OVERALL DEGRADATION CONDITION





Joint defects

Visual or surface degradation defects

Loss-of-integrity defects

Bond-to-substrate defects

QUANTIFICATION OF THE OVERALL DEGRADATION CONDITION

$$S_w = (\sum A_i \, . \, k_n \, . \, k_{a,\, n}) \; / \; (A \, . \, \Sigma k_{max.})$$

S_w - severity of degradation, expressed as a percentage;

k_n - multiplying factor of defects n, as a function of their degradation level, within the range $K = \{0, 1, 2, 3, 4\}$;

$k_{a,n}$ - weighting factor corresponding to the relative weight of the defect detected ($k_{a,n}$ Є R+) according to the cost of repair;

A_n - area of coating affected by a defect n, in m^2;

A - façade area, in m^2;

k - multiplying factor corresponding to the highest degradation level of a cladding, as defined in K above, of area A.

QUANTIFICATION OF THE OVERALL DEGRADATION CONDITION

Proposed degradation levels for natural stone claddings

Degradation level	Defects		% area of cladding affected
Level A ($S_w \leq 1\%$)	No visible degradation		-
Level B Good ($1\% < S_w \leq 8\%$)	Visual or surface degradation defects	Surface dirt	> 10%
		Moisture stains | Localized stains |Colour change	≤ 15%
		Flatness deficiencies	≤ 10%
	Loss-of-integrity defects	Material degradation(*)≤ 1% plate thickness	-
		Material degradation (*)≤ 10% plate thickness	≤ 20%
		Cracking width ≤ 1 mm	
Level C Slight degradation ($8\% < S_w \leq 20\%$)	Visual or surface degradation defects	Moisture stains | Localized stains |Colour change	> 15%
		Moss, lichen, algae growth | Parasitic vegetation | Efflorescence	≤ 30%
		Flatness deficiencies	> 10% and ≤ 50%
	Joint anomalies	Joint material degradation	≤ 30%
		Material loss - open joint	≤ 10%
	Bond-to-substrate defects	Scaling of stone near the edges Partial loss of stone material	≤ 20%
	Loss-of-integrity defects	Material degradation (*)≤ 10% plate thickness	≤ 20%
		Material degradation (*) > 10% and ≤ 30% plate thickness	> 20 %
		Cracking width ≤ 1 mm	≤ 20%
		Cracking width > 1 mm and ≤ 5 mm	≤ 20%
		Fracture	≤ 5%
Level D Moderate degradation ($20\% < S_w \leq 45\%$)	Visual or surface degradation defects	Moss, lichen algae growth | Parasitic vegetation |Efflorescence	> 30%
		Flatness deficiencies	> 50%
	Joint defects	Joint material degradation	> 30%
		Material loss - open joint	> 10%
	Bond-to-substrate defects	Scaling of stone near the edges | Partial loss of stone material	> 20%
		Loss of adherence	≤ 10%
	Loss-of-integrity defects	Material degradation (*) > 10% e ≤ 30% plate thickness	> 20%
		Material degradation (*) > 30% plate thickness	≤ 20 %
		Cracking width > 1 mm and ≤ 5 mm	> 20%
		Cracking width ≥ 5 mm	≤ 20 %
		Fracture	> 5% and ≤ 10 %
Level E Generalized degradation ($S_w \geq 45\%$)	Bond-to-substrate defects	Loss of adherence	> 10%
	Loss-of-integrity defects	Material degradation (*) >30% plate thickness	> 20%
		Cracking width > 5 mm	
		Fracture	> 10%

QUANTIFICATION OF THE OVERALL DEGRADATION CONDITION

Weighting coefficients ($k_{a,n}$) for natural stone claddings

Defect		Performance criteria Requirements		Possibility of generating new anomalies	Repair operation (cost in €/m^2)	Ratio between repair cost and replacement cost (*)	Weighting coefficient $k_{a,n}$
		Safety	Watertightness				
Visual or surface degradation		○○	●○	●○	Cleaning (11.7 €/m^2)	13%	**0.13**
Joints	Degradation of filling material	●○	●○	●●	Joint repair (23.4 €/m^2)	25%	**0.25**
	Loss of filling material				Replacement of the joint material in cladding directly adhered to the substrate involves some risks, and may damage the natural stone	100%	**1.0**
Bond to substrate		●●	●●	●●	Replacement of stone plates always costs at least as much as executing a new cladding, and may cost more because of having to remove the degraded original cladding	120%	**1.2**
Loss of integrity		●●	●●	●●	Repairing loss-of-integrity anomalies may involve only surface repair (epoxy resins or equivalent) or replacement of the stone plate	100%	**1.0**

○○ - no correlation; ●○ - probable correlation; ●● - high correlation

(*) - The cost of building a vertical granite cladding façade with a cementitious adhesive is around 93.10 €/m^2

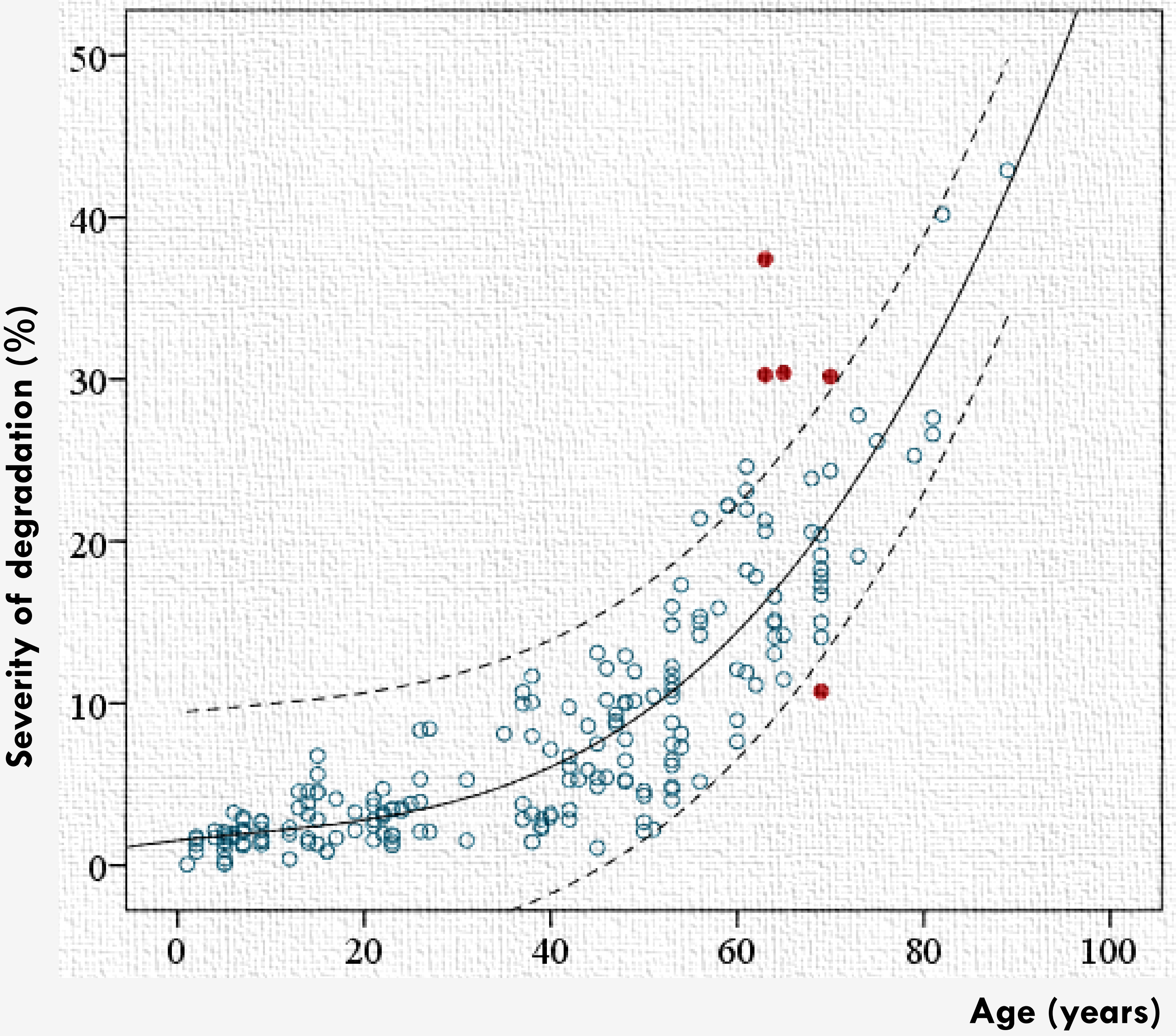
SERVICE LIFE ESTIMATION

203 NATURAL STONE CLADDINGS ARE ANALYSED IN REAL LIFE USE CONDITIONS, BASED ONLY ON VISUAL INSPECTIONS

S_w = 6E-05.(Age^3) - 0.0013.(Age^2) + 0.065.Age + 1.5379

$R^2 = 0.775$

N=203



SERVICE LIFE ESTIMATION

Definition of the end of service life of stone claddings

$S_w = 10\%$

ESL = 52 years

Sw = 20%

ESL = 68 years

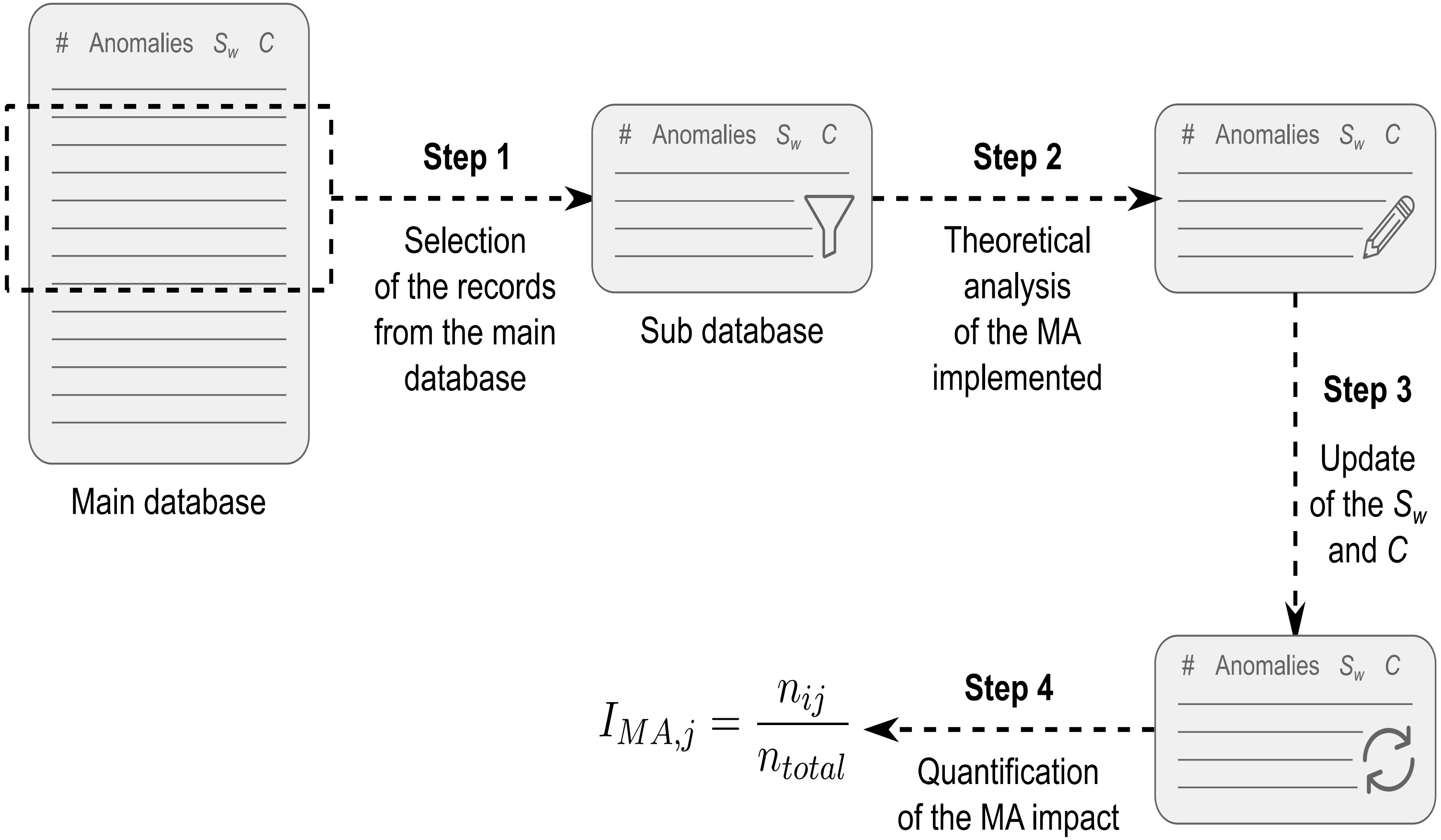
$S_w = 30\%$

ESL = 79 years

METHODOLOGY FOR THE QUANTIFICATION OF THE IMPACT OF THE MAINTENANCE ACTION

STOCHASTIC APPROACH
BASED ON PETRI NETS

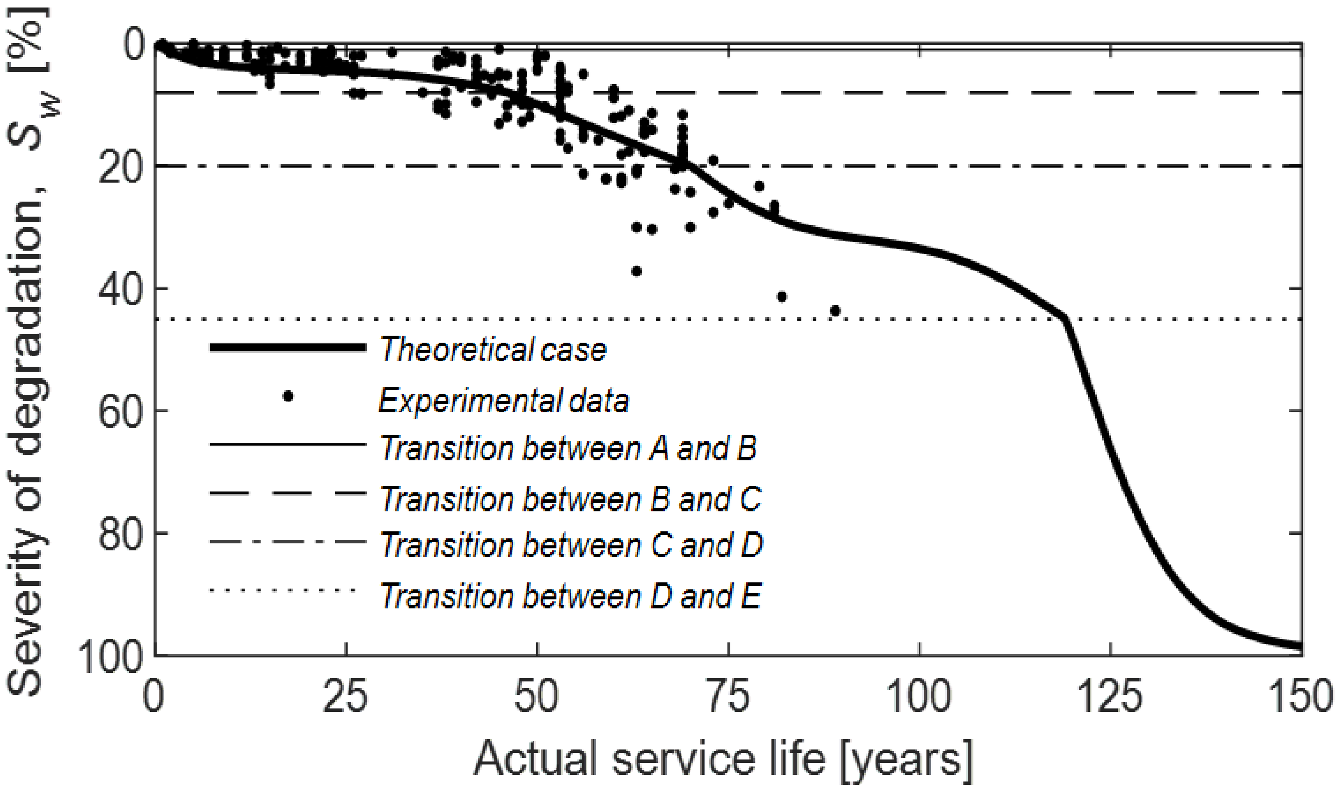
Methodology for the quantification of the impact of the maintenance action (I_{MA})



$$I_{MA,j} = \frac{n_{ij}}{n_{total}}$$

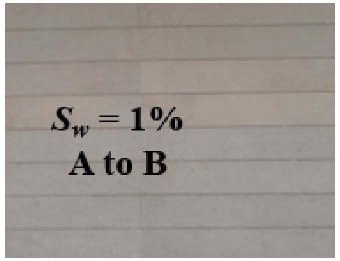
- ✓ Typify the various types of intervention, element by element;
- ✓ Define the consequences of each action in each degradation mechanism;
- ✓ Evaluate the impact of each action on the severity of degradation index.

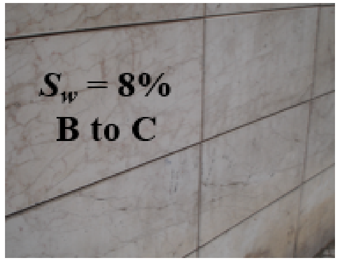
Methodology for the quantification of impact of the maintenance action

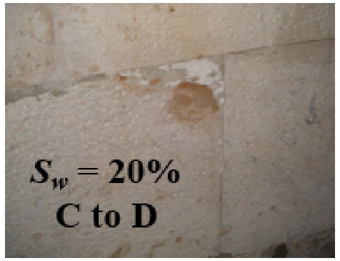


Overlap of the mean degradation curve (in terms of severity of degradation index) with the experimental data

Illustrative examples

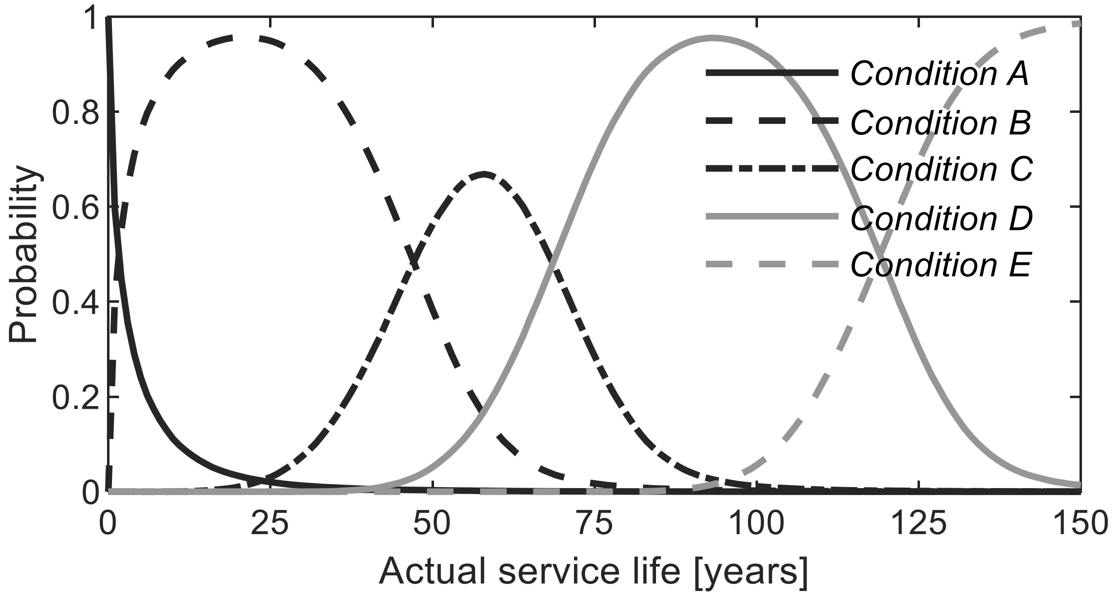




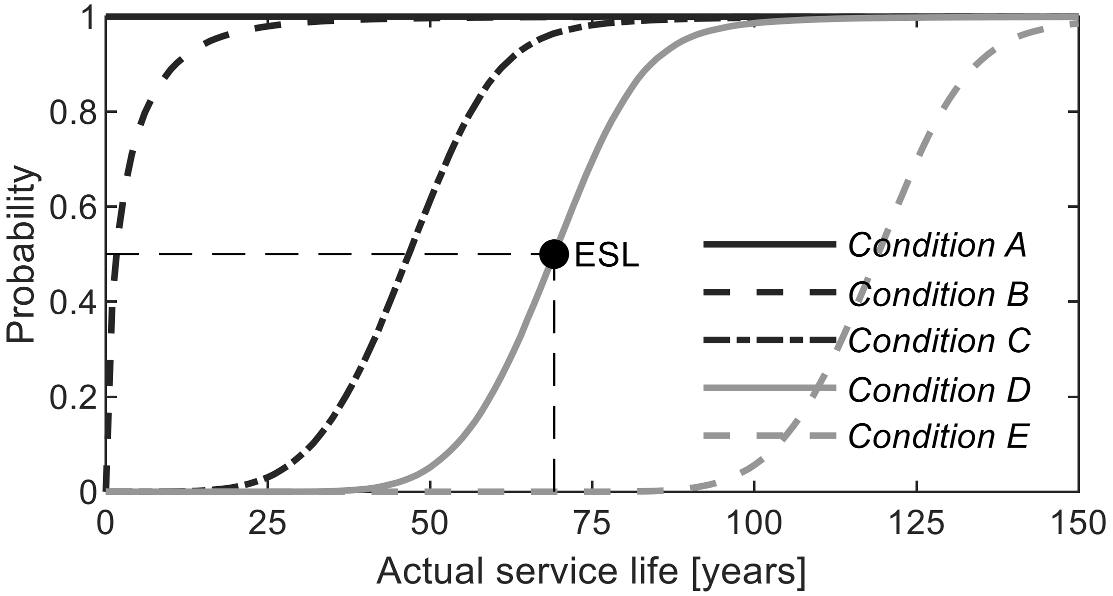


None of the case studies are in condition E

Methodology for the quantification of impact of the maintenance action



Probability density functions of the degradation conditions over the time horizon



Cumulative distribution functions of the degradation conditions over the time horizon

HOW CAN WE OPTIMISE THE MAINTENANCE POLICIES?

WE NEED TO DEFINE:

- ✓ THE ACTIONS THAT MIGHT BE PERFORMED
- ✓ THEIR PERIODICITY OVER THE TIME OF ANALYSIS
- ✓ DIFFERENT PLAUSIBLE POLICIES, EVALUATING THE IMPACT OF EACH ONE ON THE BUILDING'S ELEMENT

ANALYSIS OF DIFFERENT STRATEGIES

Three maintenance strategies were analysed:

i) Total replacement (MS1), which is the maintenance strategy currently implemented by most owners;

ii) Combination of minor intervention and total replacement (MS2). This maintenance action allows delaying or mitigating the degradation process, while avoiding compromising important characteristics of the cladding, and preventing unnecessary risks;

iii) Combination of cleaning operations, minor intervention and total replacement (MS3).

SELECTION OF A MAINTENANCE STRATEGY

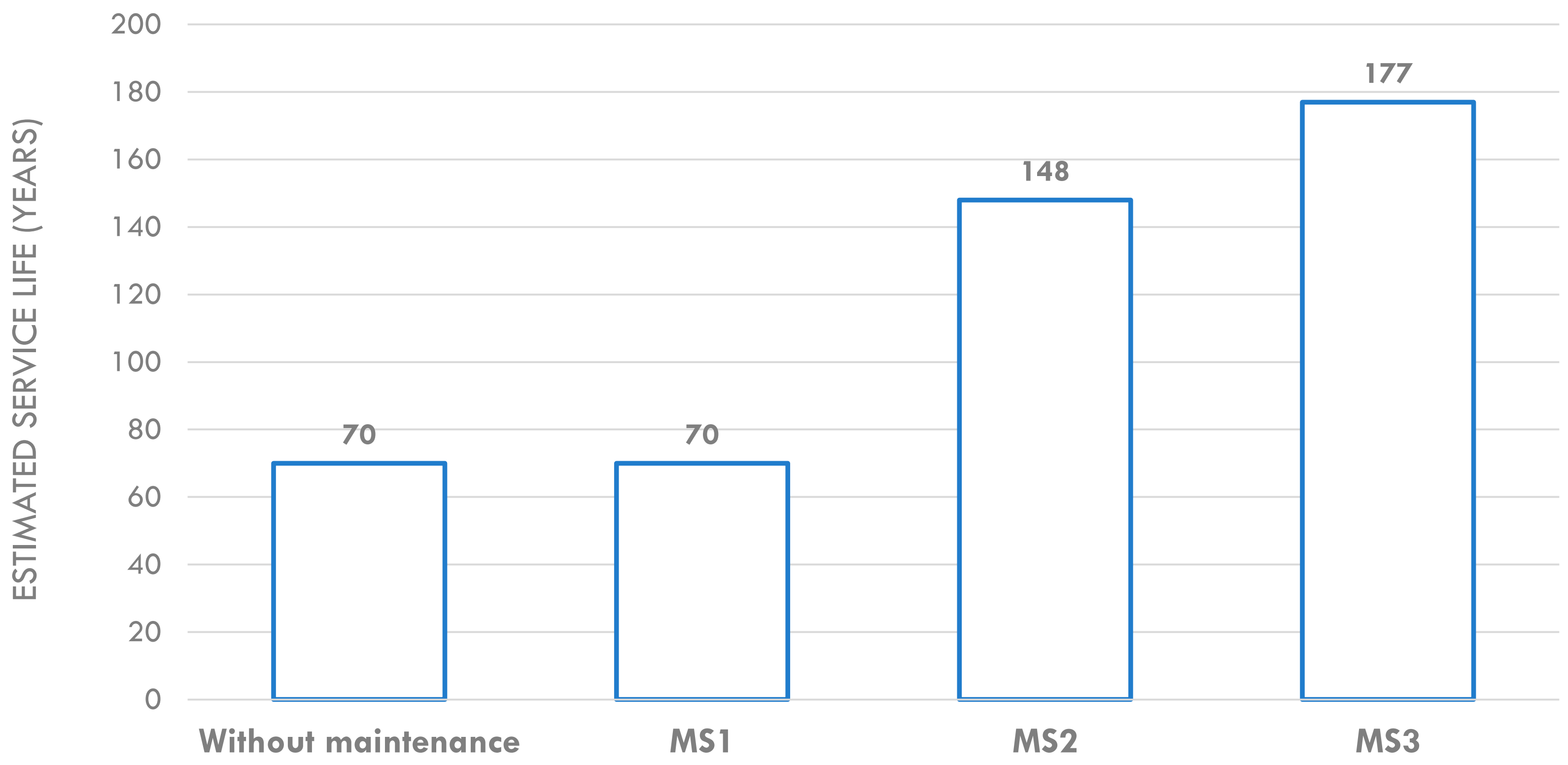
Fixed costs, application scope and impacts of the different types of maintenance actions analysed

Interventions		Cost (year 0) [€/m²]	Application scope	Impact of the maintenance actions		
				P_A [%]	P_B [%]	P_C [%]
Inspections		1.03	All	-	-	-
Cleaning operations	Minor	26.20	B	4.4	95.6	-
	Moderate	31.37	B	15.0	85.0	-
	Extensive	37.11	B	15.0	85.0	-
Minor interventions	Minor	54.33	C	0.0	76.8	23.2
	Moderate	68.80	C	0.0	80.4	19.6
	Extensive	83.26	C	1.8	78.6	19.6
Total replacement		149.51	D, E	100	-	-

Comparison of the costs for the three maintenance strategies

Maintenance strategies	Discount rate of 6%		
	MS1	MS2	MS3
Total cost [€/m²]	5.98	9.10	44.65
Annualised cost [€/m²]	0.04	0.06	0.30

SELECTION OF A MAINTENANCE STRATEGY



Impact of the maintenance strategies in the estimated service life of natural stone claddings (NSC)

FROM THE RAW RESULTS, THE FOLLOWING CONCLUSIONS CAN BE DRAWN:

- All maintenance strategies improve the efficiency of the NSC compared with the situation without maintenance;
- MS3 is the strategy with the highest maintenance costs, since a higher number of interventions are considered;
- The combination of total replacement with other maintenance activities increases the service life of NSC;
- MS3 is slightly more efficient than the other two maintenance strategies, maintaining the cladding in good conditions for longer periods of time.

BUT… IT IS IMPOSSIBLE TO FIND THE OPTIMAL SOLUTION BEYOND REASONABLE DOUBT!

MULTI-CRITERIA DECISION ANALYSIS CAN HELP FIND THE BEST STRATEGY, ACCORDING TO THE STAKEHOLDERS' POINTS OF VIEW.

SELECTION OF A MAINTENANCE STRATEGY

Multi-criteria analysis with equal weights

	Criterion 1 - Efficiency index	Criterion 2 - Cost	Criterion 3 - Number of total replacements	Total rating	Standardized total rating
MS1	0	1	0	1	0
MS2	0.5	0.92	1	2.42	1
MS3	1	0	1	2	0.70
Weights	1	1	1		

Multi-criteria analysis with a higher weight of the efficiency index

	Criterion 1 - Efficiency index	Criterion 2 - Cost	Criterion 3 - Number of total replacements	Total rating	Standardized total rating
MS1	0	1	0	1	0
MS2	0.5	0.92	1	2.92	0.96
MS3	1	0	1	3	1
Weights	2	1	1		

Through a simplified multi-criteria analysis, other conclusions can be drawn:

i. If the number of total replacements is considered, over the time horizon, MS1 is no longer the most advantageous strategy. A higher number of replacements has disadvantages in terms of the normal use and also has a relevant environmental impact;

ii. If the weight of the three criteria is considered the same, MS2 is the most advantageous maintenance strategy;

iii. If a higher weigh is given to the efficiency index, MS3 is the best option.

MUCH WORK HAS ALREADY BEEN DONE IN THIS AREA, BUT THERE ARE STILL MANY UNCERTAINTIES

IN ANY CASE, THERE ARE ALREADY RELIABLE ESTIMATES REGARDING THE SERVICE LIFE OF THE ELEMENTS

AND IT IS ALREADY POSSIBLE TO ESTIMATE WITH A KNOWN ACCURACY THE INFLUENCE OF THE MAINTENANCE ACTIONS, IN TERMS OF THEIR COST AND THEIR IMPACT ON THE DEGRADATION OF THE ELEMENTS

HOW SHOULD WE DEAL WITH THE EVOLUTION OF DEGRADATION, WHICH IS VARIABLE THROUGHOUT THE YEAR?

This parameter ends up losing relevance when the element has a long service life, and an estimated average service life can be used throughout the year.

AND HOW ARE WE GOING TO DEAL WITH CLIMATE CHANGE?

WE STILL DON'T HAVE AN ANSWER TO THAT.

FURTHER RESEARCH IS NEEDED...

THANK YOU