



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824



POLITECNICO
MILANO 1863

Rethinking coastal defence and Green-energy Service infrastructures through enHancEd-durAbiLity high-performance cement-based materials

Advanced cement based materials for low-carbon structures and infrastructures: the vision of the H2020 project «ReSHEALience»

Liberato Ferrara

Department of Civil and Environmental Engineering, Politecnico di Milano

Current «societal» challenges for civil engineering

Transportation Infrastructures :

1% GDP investment in infrastructures results into +1.5% GDP in 4 years

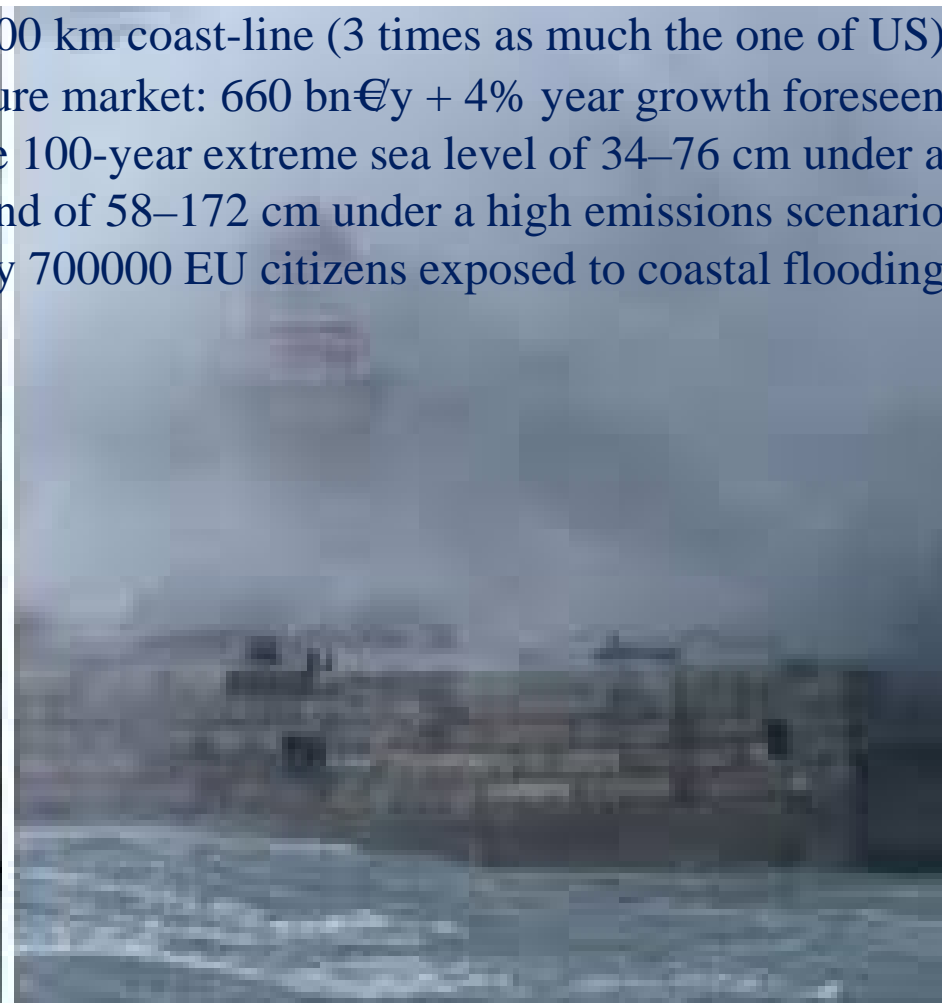
http://ec.europa.eu/growth/sectors/construction/index_en.htm



Every year road interruptions and traffic congestion delays cost an average of EUR 3000 to each household!

Current «societal» challenges for civil engineering

Coastal protection: Europe has a 66000 km coast-line (3 times as much the one of US)
Coastal defense infrastructure market: 660 bn€y + 4% year growth foreseen
a very likely increase of the European average 100-year extreme sea level of 34–76 cm under a moderate mitigation scenario, and of 58–172 cm under a high emissions scenario
Nearly 700000 EU citizens exposed to coastal flooding

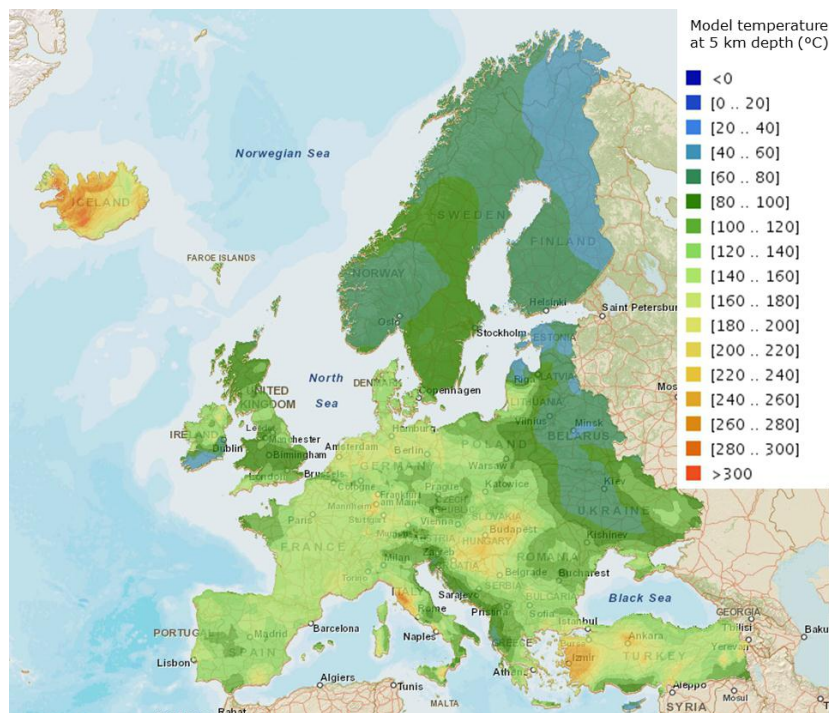


Current «societal» challenges for civil engineering

Green growth: promoting the growth of clean energy production

EGS: engineered geothermal system - stimulating deep hot resources that are otherwise not exploitable - provided technological challenges are overcome, the installed capacity of EGS technology could reach between 1200 GW to 12000 GW worldwide (currently it is 60 GW)

<https://ec.europa.eu/jrc/en/news/new-report-analyses-geothermal-energy-sector>



Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

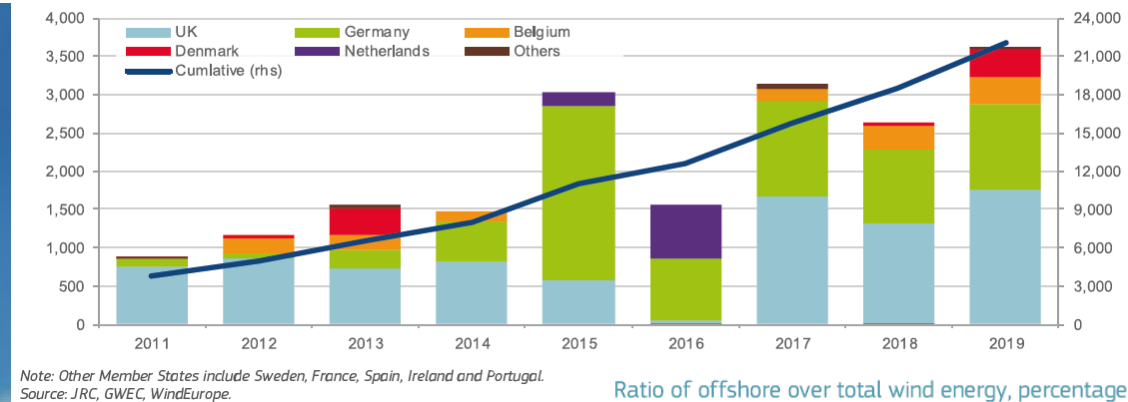
This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

Current «societal» challenges for civil engineering

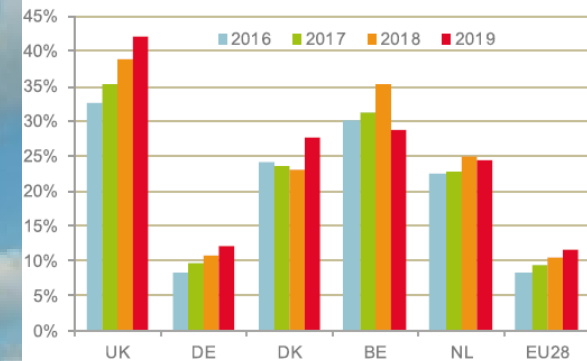
Green growth: promoting the growth of clean energy production

Offshore wind

https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en



Ratio of offshore over total wind energy, percentage



Current «societal» challenges for civil engineering

Blue growth: doubling revenues in 2020-2030 (from 5 to 10 bln€)

70% of the planet is water but only 5% of economy develops in it. The 'blue' economy represents roughly 5.4 million jobs and generates a gross added value of almost €500 billion a year.

https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en



Table 2.3 Preliminary assessment of the impact of the COVID-19 economic crisis on the Blue Economy

Sector	Size	Initial impact	Recovery path
Established sectors			
Marine living resources	Medium	Strong	Lagged
Marine non-living resources	Small	Medium	Prompt
Marine renewable energy	Nascent	Strong	Prompt
Port activities	Medium	Strong	Prompt
Shipbuilding and repair	Small	Medium	Lagged
Maritime transport	Medium	Strong	Prompt
Coastal tourism	Very large	Strong	Very lagged
Emerging sectors			
Blue bioeconomy	Small	Strong	Prompt
Ocean energy	Nascent	Small	Prompt
Desalination	Nascent	Small	Prompt
Maritime defence	Small	Small	Prompt
Cables	Nascent	Small	Prompt
Research and Education	Nascent	Small	Prompt
Marine observation	Nascent	Small	Prompt

Source: Commission Services.

Current «societal» challenges for civil engineering



	Maximum w/c	minimum cement content	minimum compressive strength	minimum concrete cover	maximum crack width
		kg/m ³	MPa	mm	mm
XS	0.40 - 0.65	300 - 400	25 - 40/50	25 - 75	0.1 - 0.4
XA	0.45 - 0.65	275	25/30 to 40/50	-	0.1 - 0.3
		325			
		325			

YEARLY COST OF CORROSION: 2.5 USD TRILLION (3.4% WORLD GDP)

The ReSHEALience project challenge

The challenge

Improved material durability in buildings and infrastructures, including offshore

13 (+1) partners + 3 LTPs from 7 (+1) countries

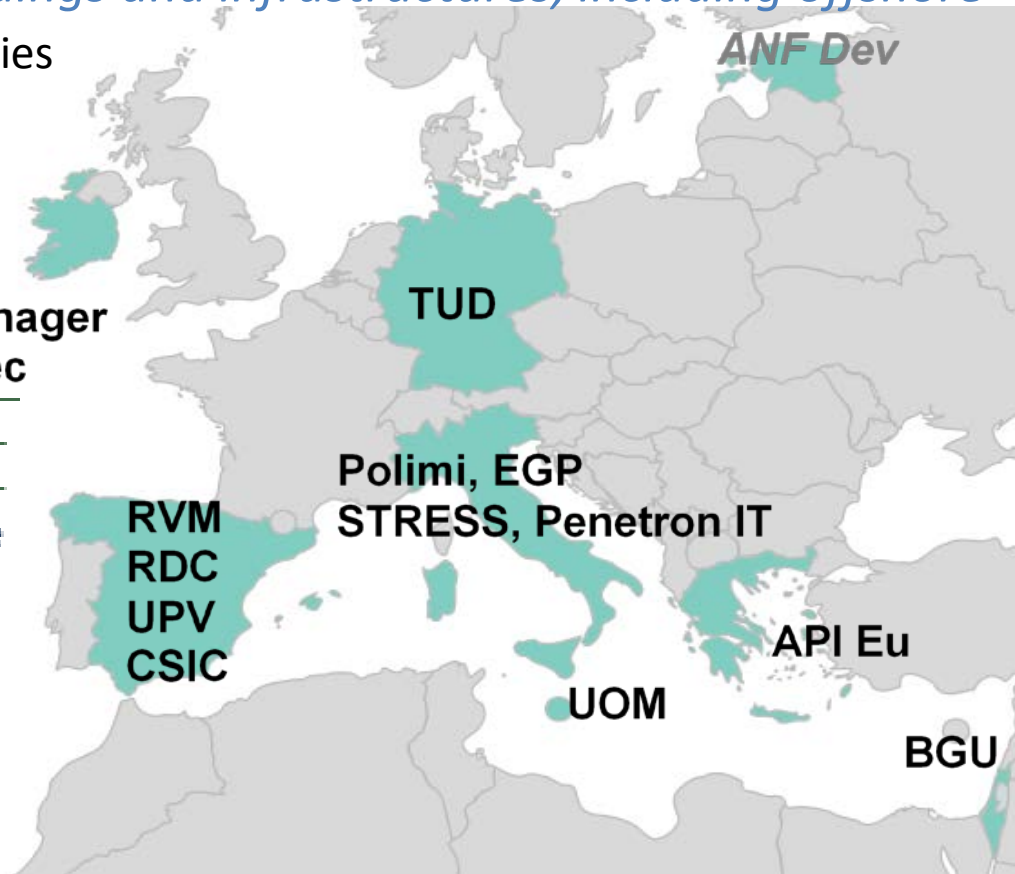
5.5 M€



JANUARY
1
2018



MARCH
31
2022



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

The «ReSHEALience» project consortium

COORDINATOR



POLITECNICO
MILANO 1863

Material production
SMEs



UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA



**TECHNISCHE
UNIVERSITÄT
DRESDEN**



CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



Ben-Gurion University
of the Negev

Large scale
end user



Universities and research centers

*The whole value-chain of
concrete construction industry*



Infrastructure project
and construction



Engineering consultancy - SME



Precast concrete construction and engineering consultancy - SME

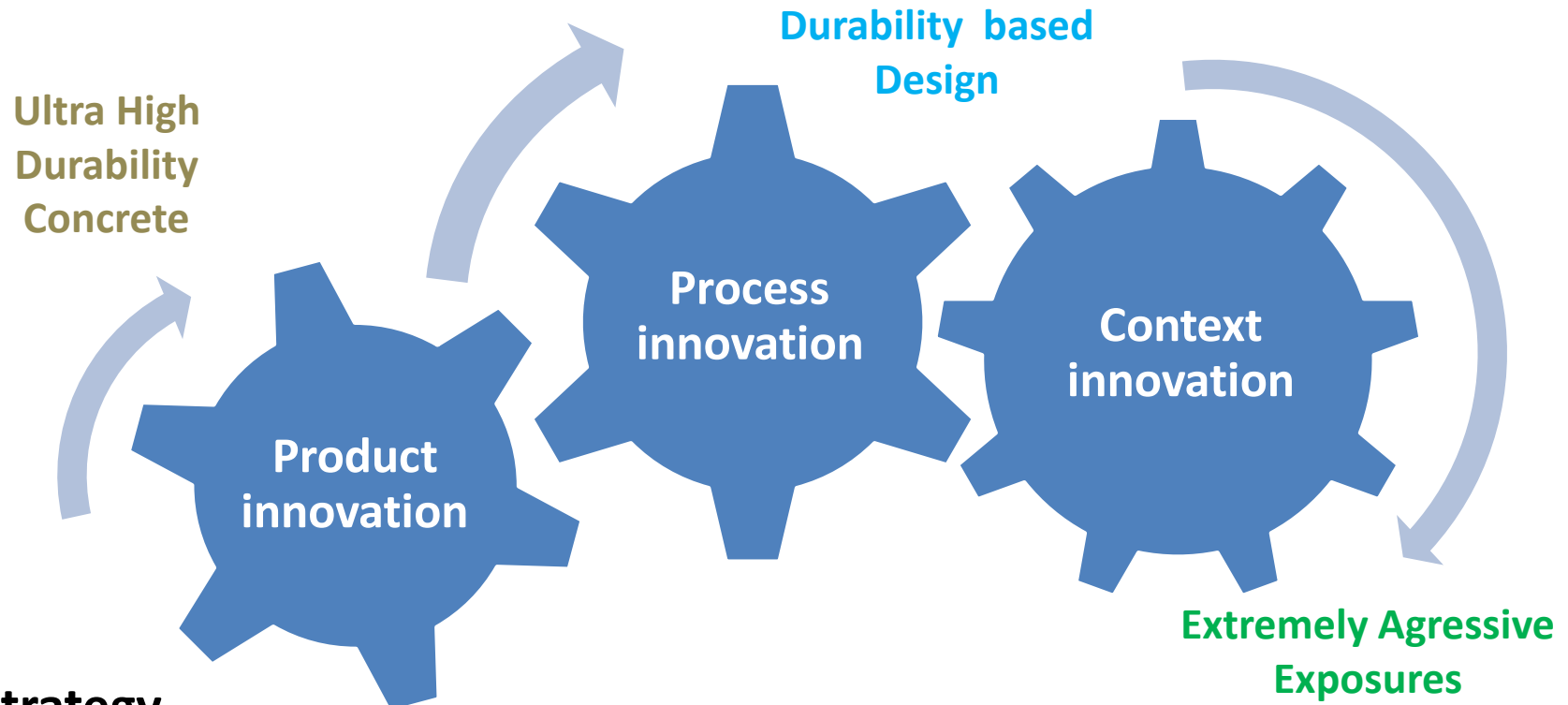
Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

The «ReSHEALience» project strategy



The strategy

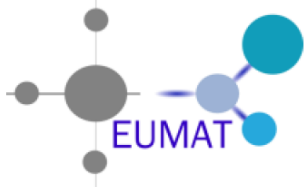
Develop a **Ultra High Durability Concretes (UHDCs)** and a methodology for **Durability modelling** of materials and **Durability Assessment-based Design** of buildings and structures to improve durability and predict their **long-term performance** under **Extremely Aggressive Exposures**

The ReSHEALience project strategy

Material innovation: UHDC

Reflection Paper addresses the role of materials in the post-covid society

Published on 24.09.2020 by EMMC - European Commission - A4M_Alliance for Materials - EUMAT



“The role of Materials in the post-COVID society”

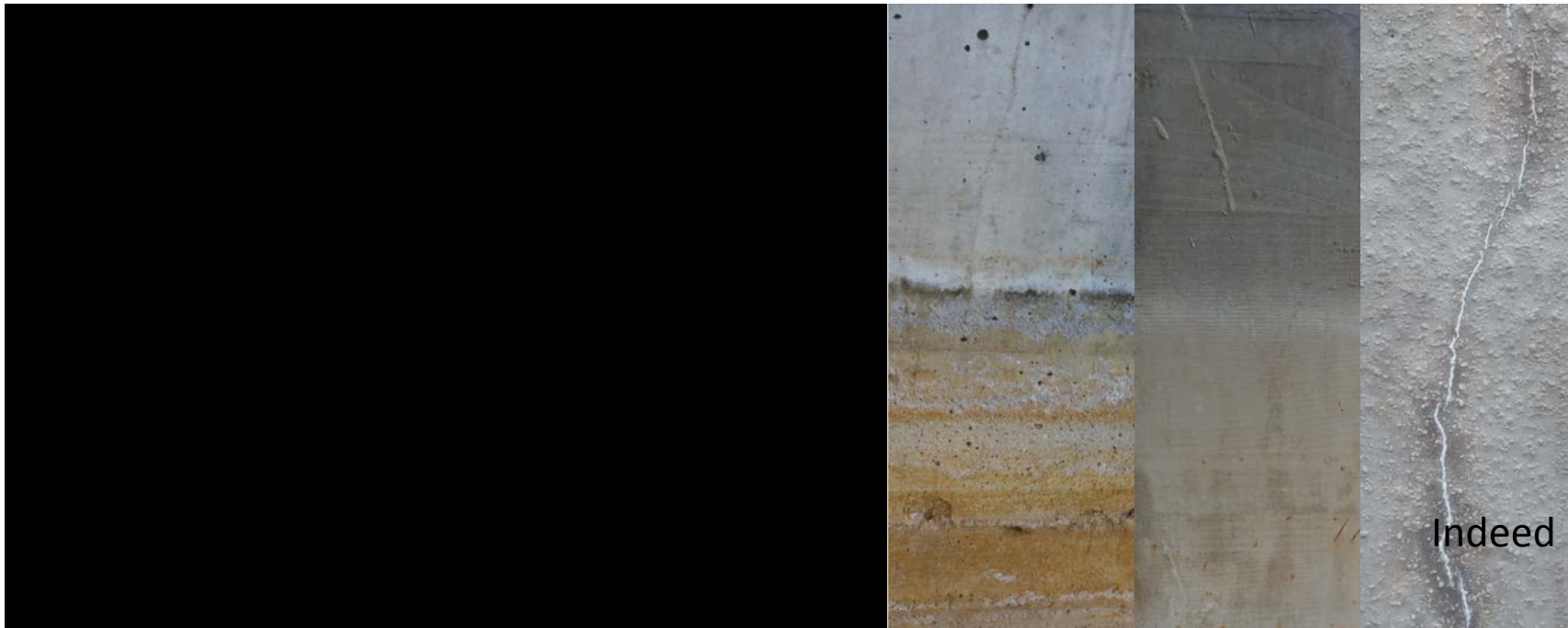
A reflection on how Materials will enable solutions for a healthy, safe, and resilient society to achieve a sustainable, stable, and stronger economy, able to respond to citizen’s demands.

... to create a less dependent, more resilient European economy by guaranteeing raw material supplies, by ensuring higher materials durability, higher energy efficiency, higher degrees of materials re-cycling and re-use and by material-saving through optimized products by design with enhanced repair

The ReSHEALience project strategy

Material innovation: UHDC

Ultra High Durability Concrete (UHDC): *“strain-hardening fibre/textile reinforced cementitious material with micro- and nano-scale functionalizing constituents, especially added to obtain a high durability in the cracked state under extremely aggressive exposure conditions”.*



Indeed it heals!

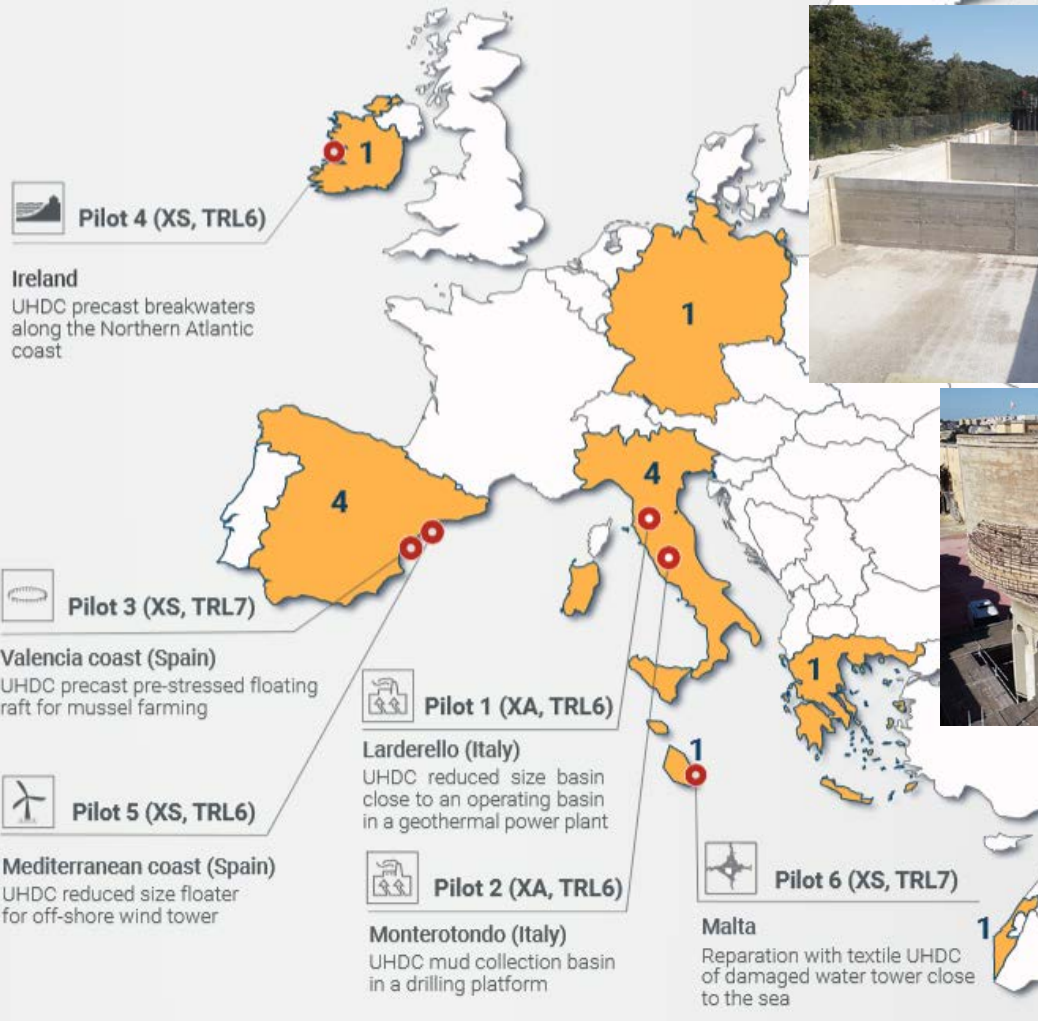
“if you replace concrete/cement-based materials with any other construction material ... it will have a bigger CO2 footprint!”.

The ReSHEALience project strategy

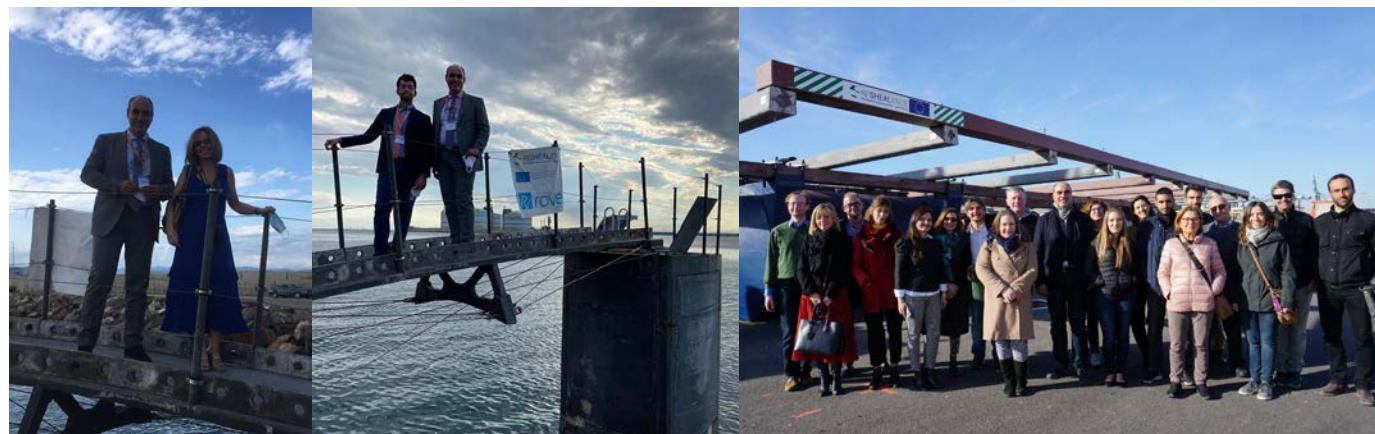
Context innovation: upscaling



The ReSHEALience project strategy - Context innovation: 6 full scale pilots



The ReSHEALience project strategy: towards a novel holistic design approach



Ongoing monitoring, continued after the project conclusions also through e-learning platforms



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept

RDC



Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



Liberato Ferrara, DICA, Politecnico di Milano



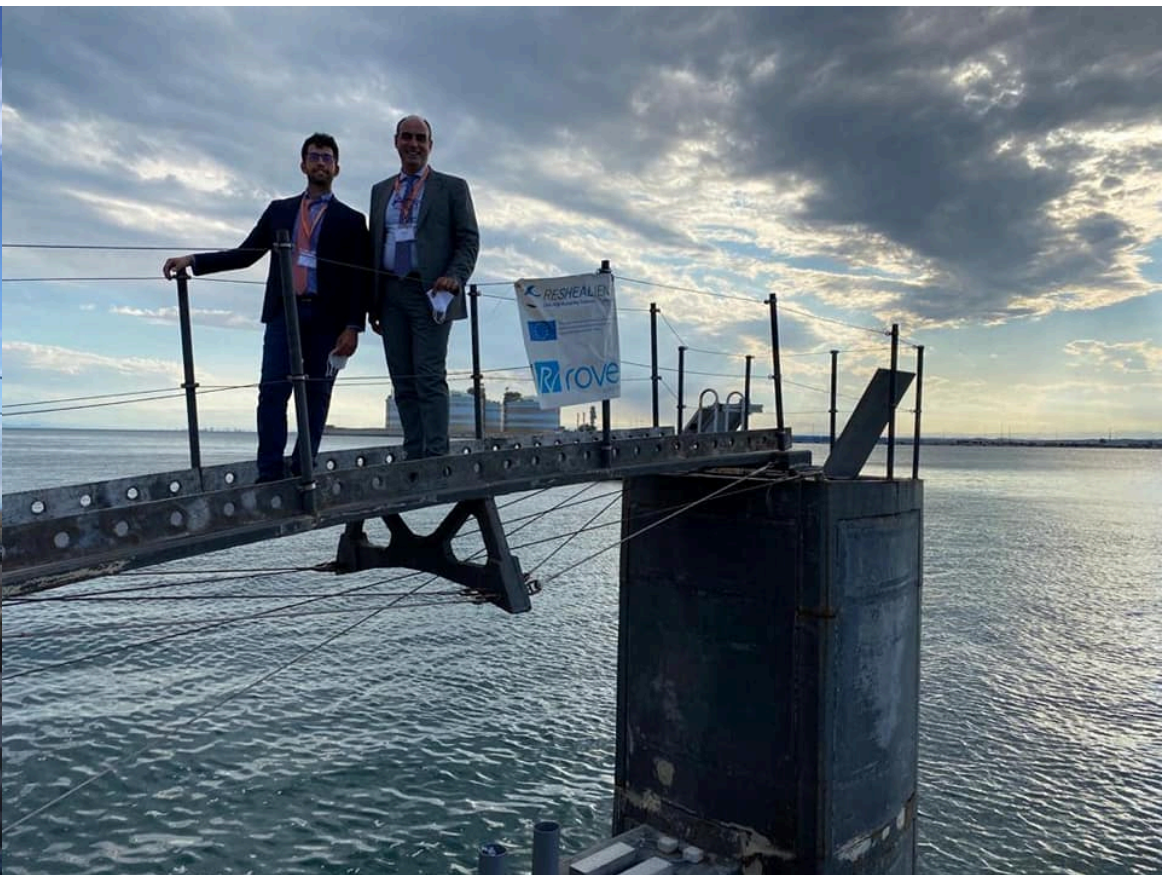
Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA



Liberato Ferrara, DICA, Politecnico di Milano



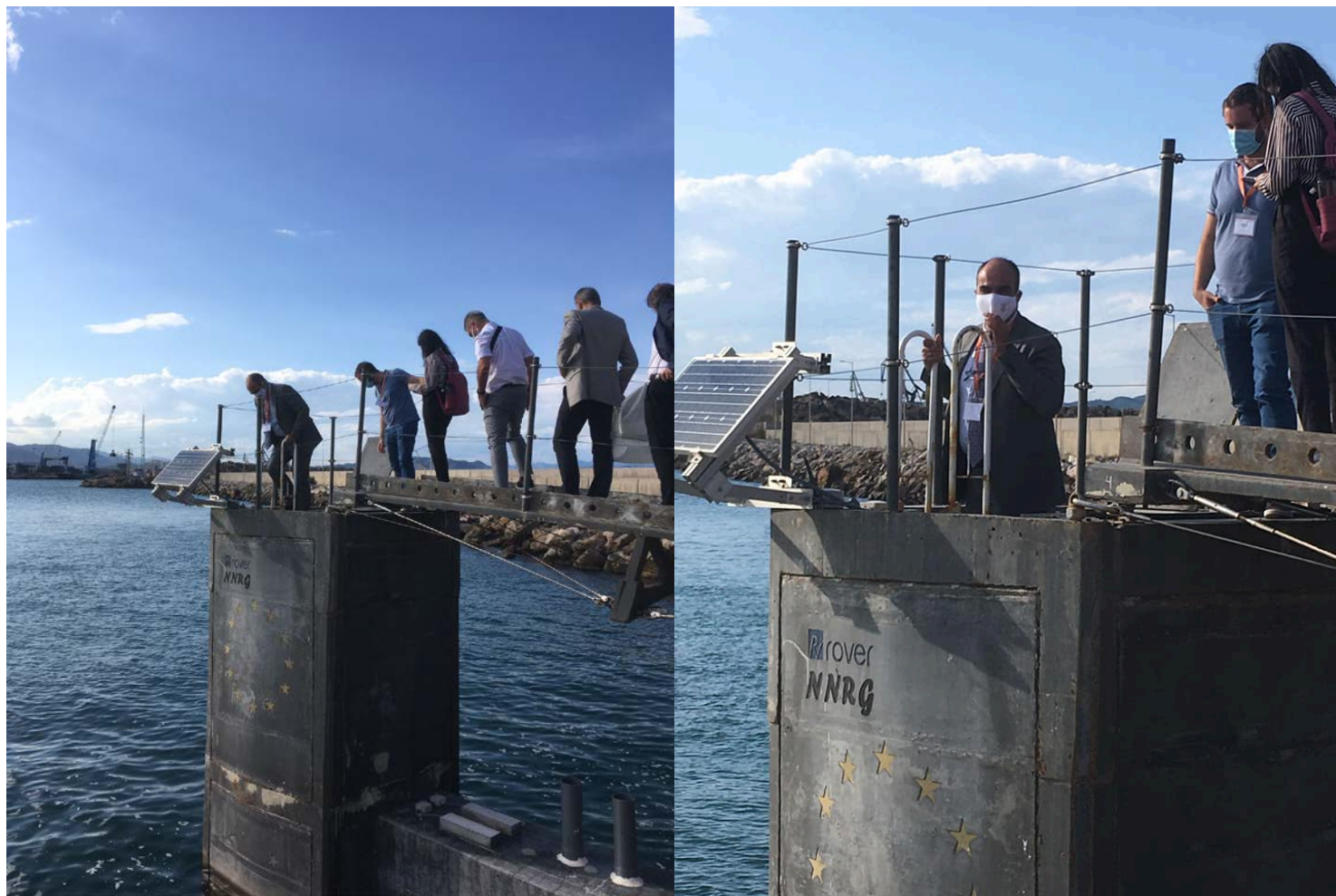
Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA



Liberato Ferrara, DICA, Politecnico di Milano



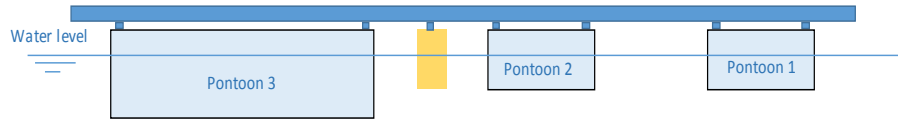
POLITECNICO
MILANO 1863



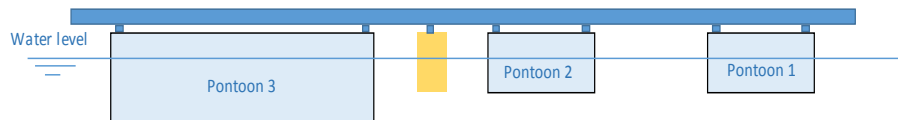
Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



ReSHEALience project: towards a novel holistic design concept



BANAGHER
PRECAST CONCRETE



**TECHNISCHE
UNIVERSITÄT
DRESDEN**

Liberato Ferrara, DICA, Politecnico di Milano



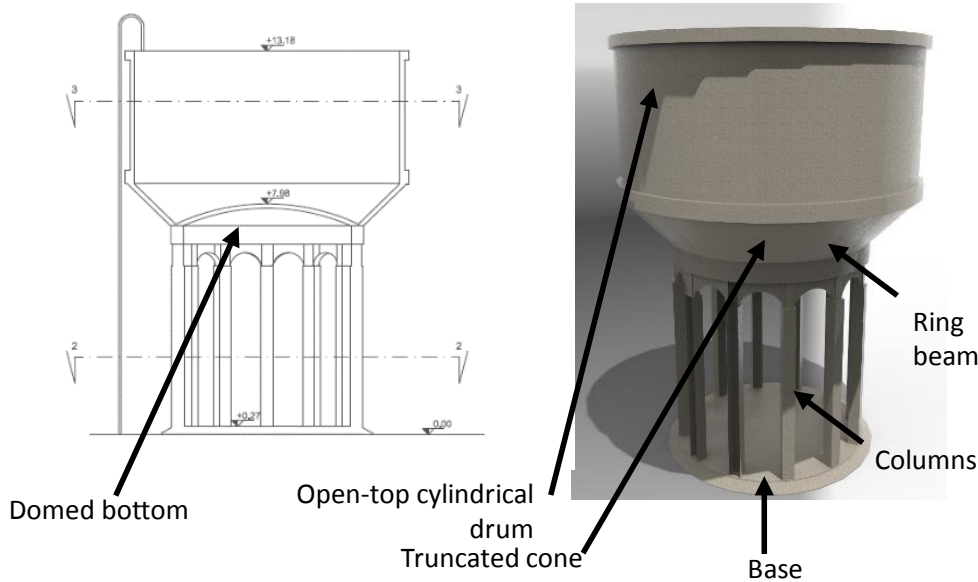
POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



L-Università
ta' Malta



Ben-Gurion University
of the Negev



Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



L-Università
ta' Malta



Ben-Gurion University
of the Negev

Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863

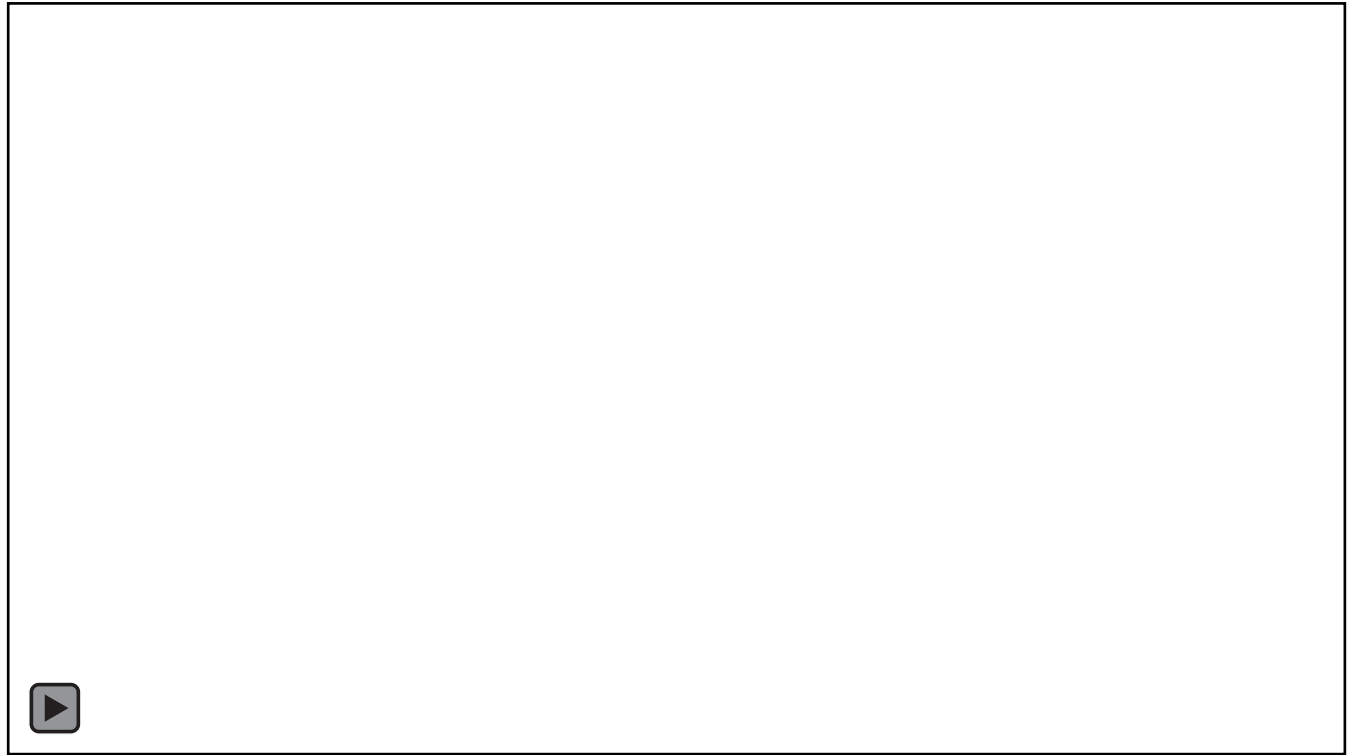


Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept

Ultra High Durable Concrete (UHDC): *“strain-hardening (fibre reinforced) cementitious material with functionalizing micro- and nano-scale constituents (alumina nanofibers, cellulose nanofibers/crystals, crystalline admixtures, especially added to obtain a high durability in the cracked state under extremely aggressive exposure conditions”.*



ReSHEALience project: towards a novel holistic design concept



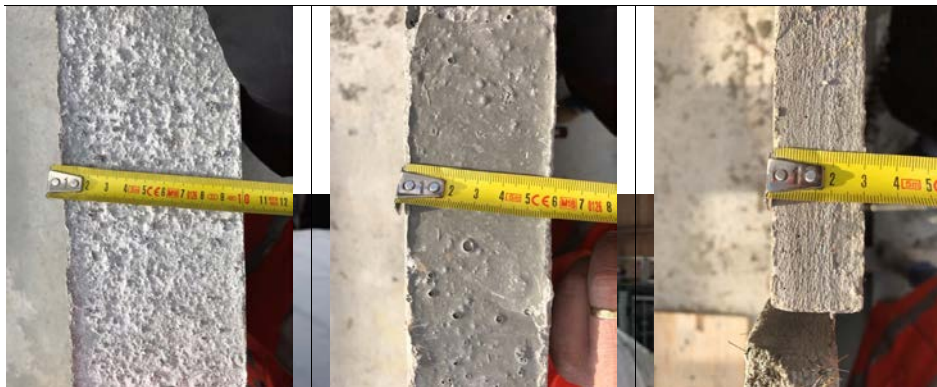
Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept



Liberato Ferrara, DICA, Politecnico di Milano

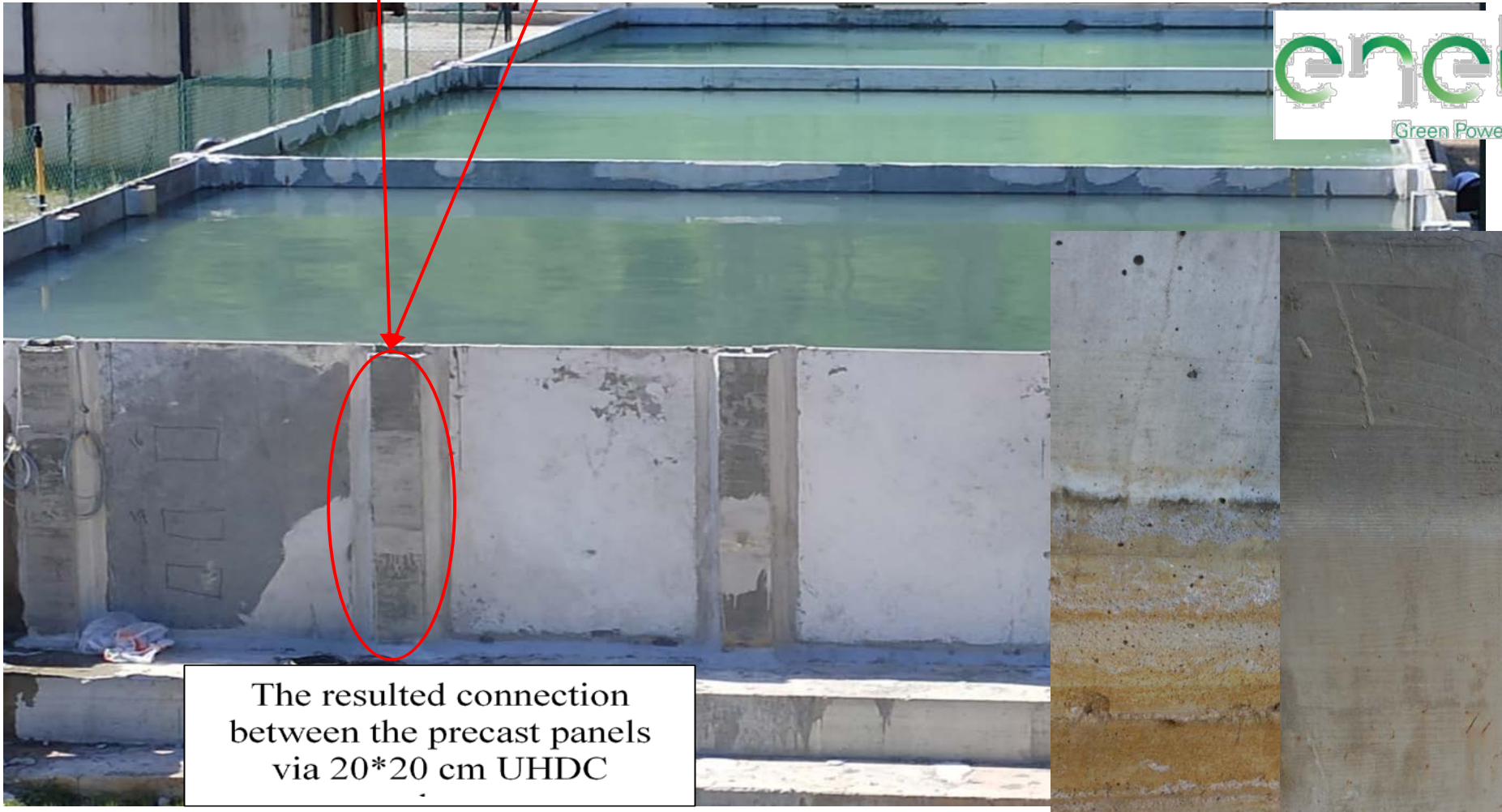


Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept

(a)



The resulted connection
between the precast panels
via 20*20 cm UHDC

ReSHEALience project: towards a novel holistic design concept



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

ReSHEALience project: towards a novel holistic design concept

Can nanotechnology help?

Constituents	XA-CA	XA-CA _CEMIII	XA-CA +ANF	XA-CA +CNC	XA-CA +CNF
CEM I 52,5 R	600	-	600	600	600
CEM III	-	600	-	-	-
Slag	500	500	500	500	500
Water	200	200	200	200	200
Steel fibers		120	120	120	120
Azichem Readymesh 200	120				
Sand 0-2mm	982	982	982	982	982
Superplasticizer Glenium ACE 300	33	33	33	33	33
Crystalline admixtures	3	3	3	3	3
Alumina nanofibers*	-	-	0.25	-	-
Cellulose nanocrystals*	-	-	-	0.15	-
Cellulose nanofibrils*	-	-	-	-	0.15

*% by cement mass

Cuenca et al., NBSC 2019

Schroefl et al., Lorcenis conference 2019

Adapting nanoparticle formulation to UHDC production needs

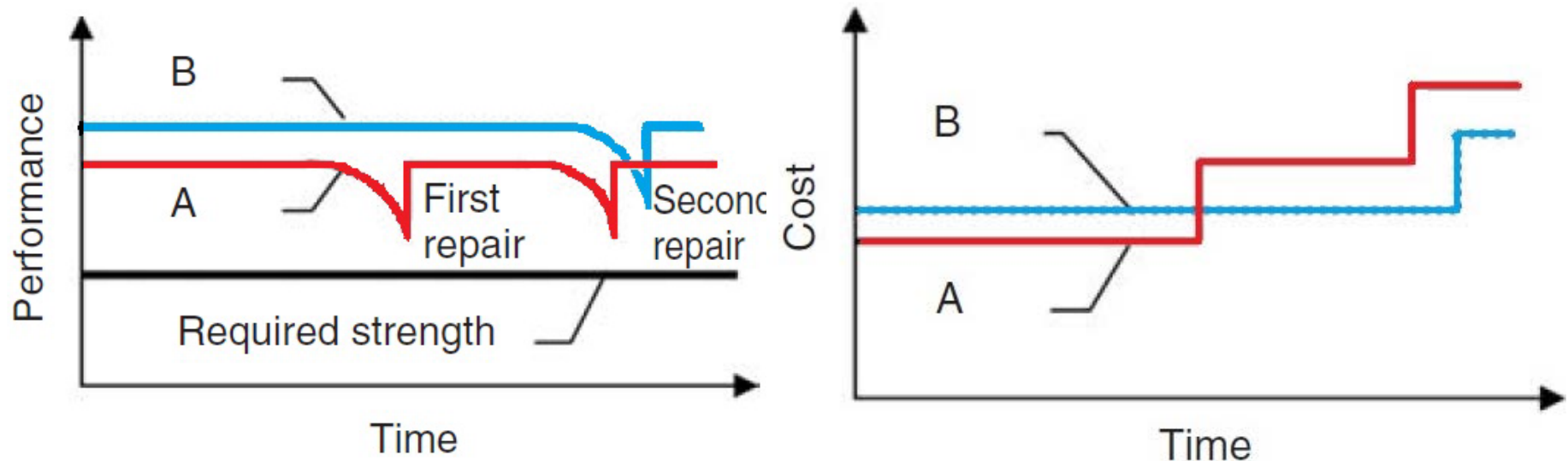
Alumina nanofibers: 0.25% by cement mass = 0.25% x 600 kg/m³ = 1,5 kg/m³

- suspension at 2% solid concentration = 75 lt/m³ suspension
- about 40% of the mixing water in the form of nanoparticle suspension!!!!

Scale to suspension at 10% solid concentration

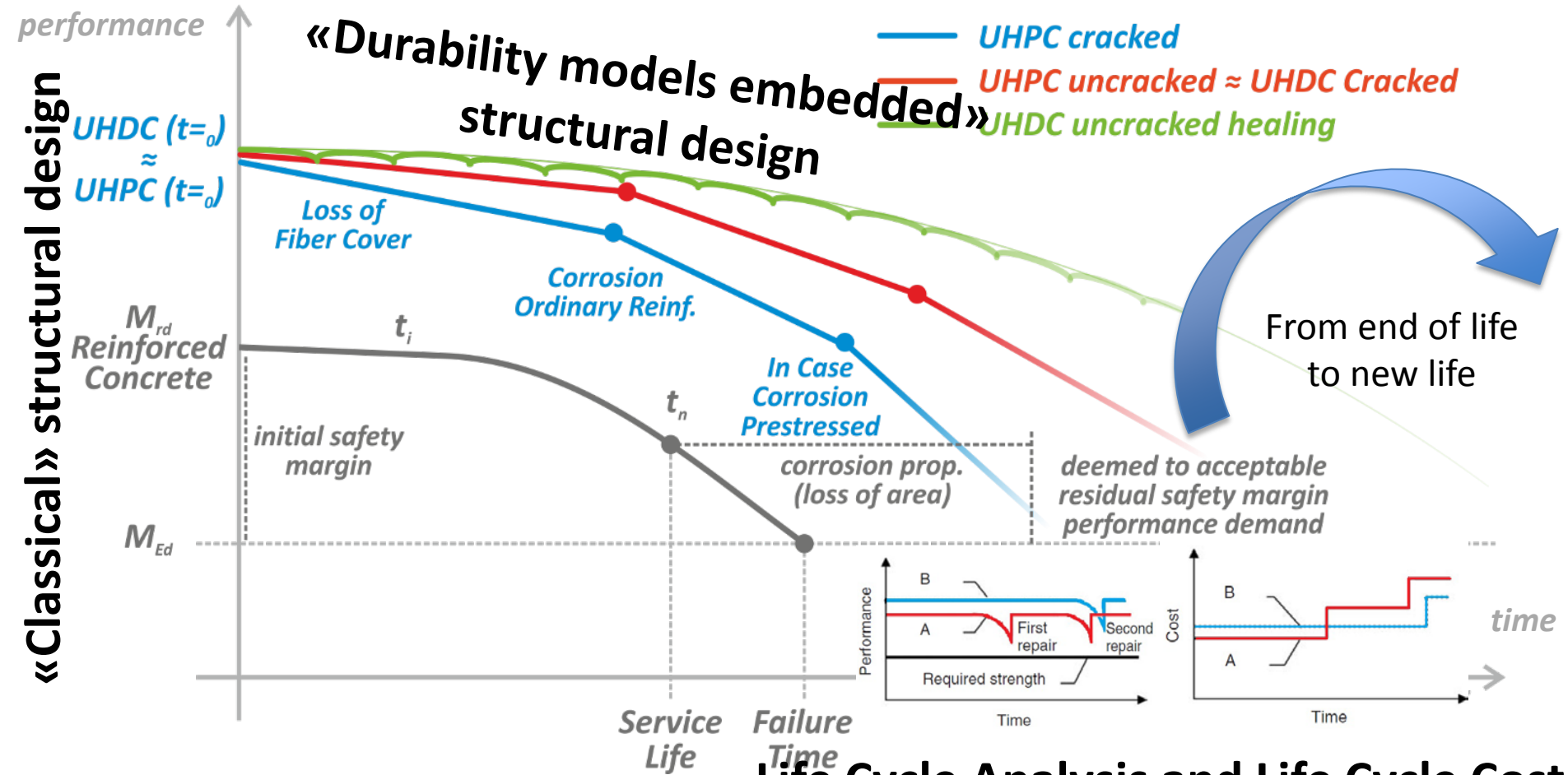
ReSHEALience project: towards a novel holistic design concept

Ultra High Durable Concrete (UHDC): *“strain-hardening (fibre reinforced) cementitious material with functionalizing micro- and nano-scale constituents (alumina nanofibers, cellulose nanofibers/crystals, crystalline admixtures, especially added to obtain a high durability in the cracked state under extremely aggressive exposure conditions”.*



The ReSHEALience project strategy

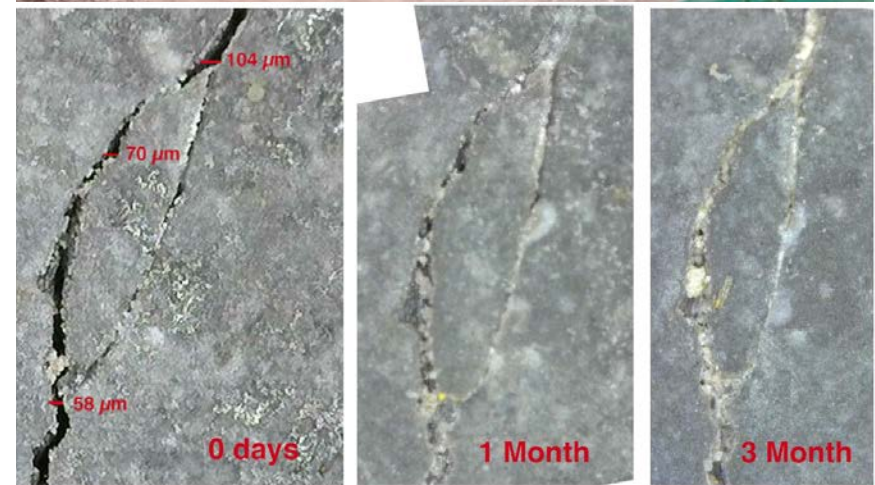
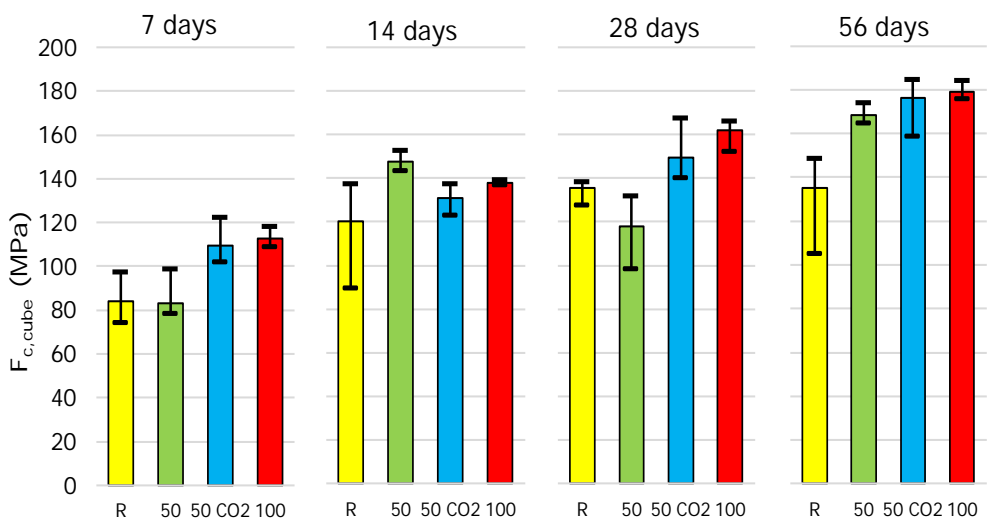
Process innovation: Durability based design



Life Cycle Analysis and Life Cycle Cost

The ReSHEALience project strategy

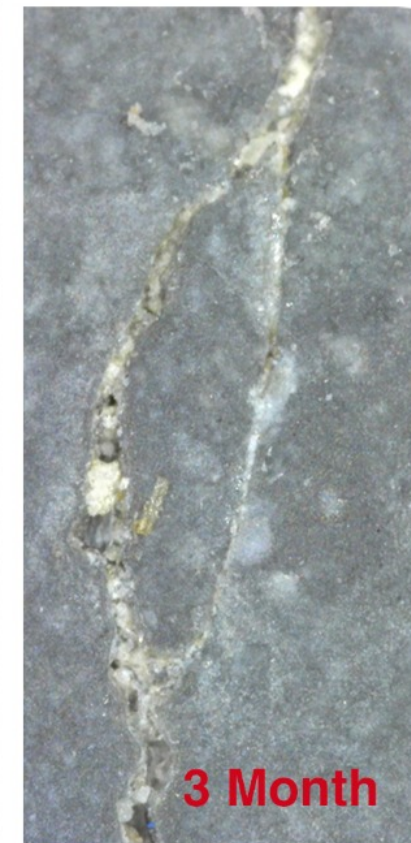
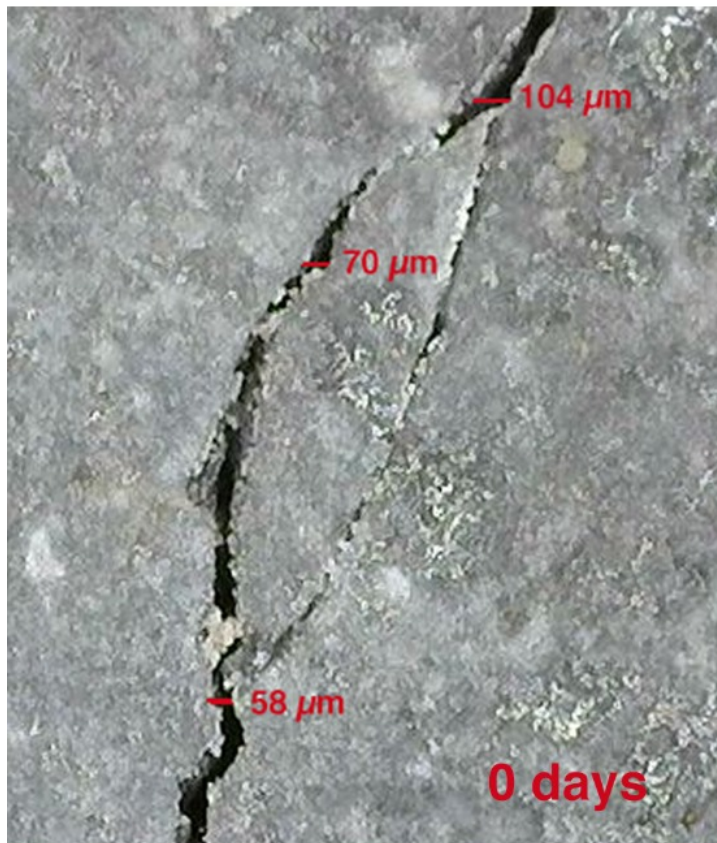
Process innovation: re/up cycling



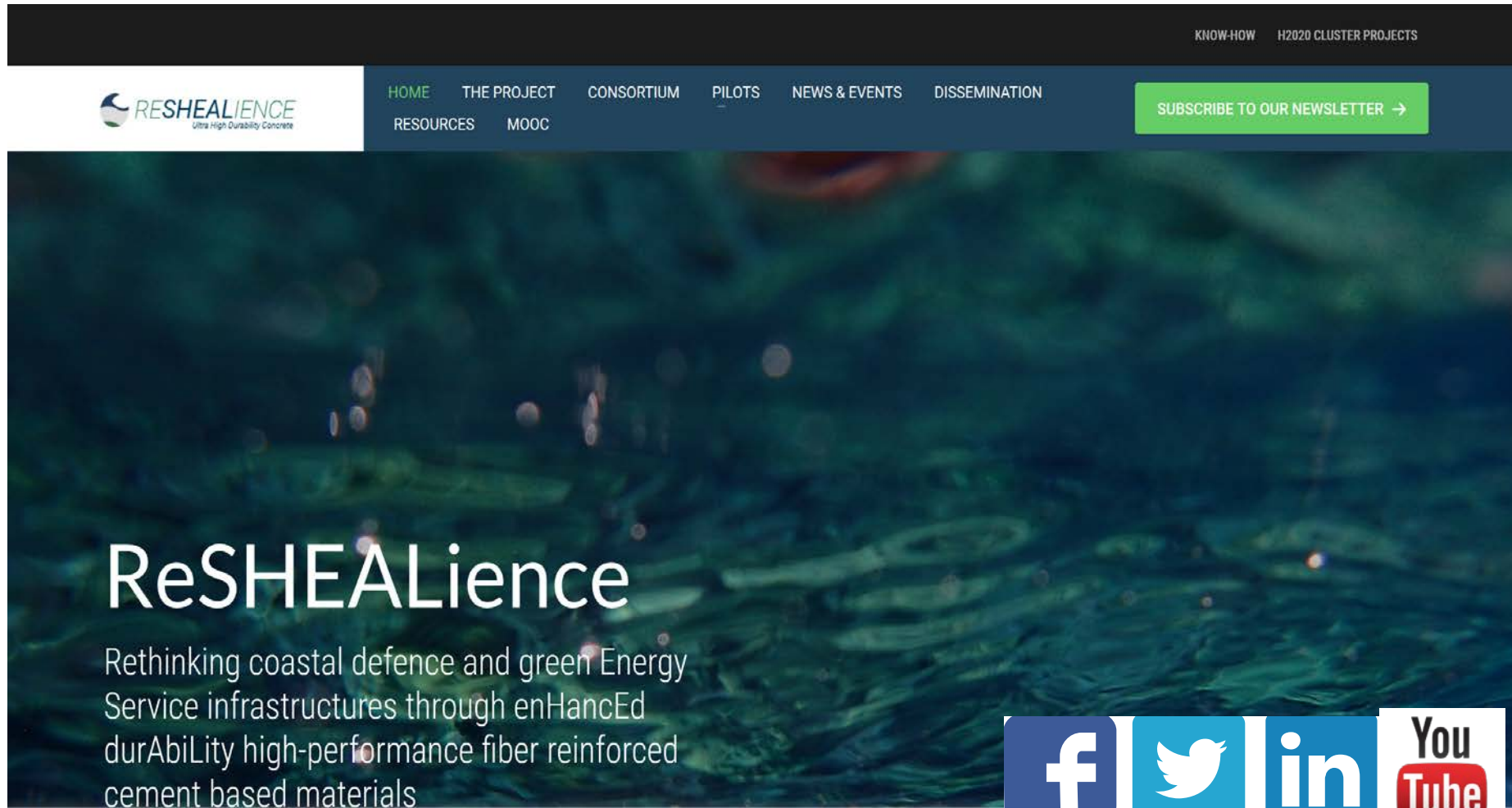
The ReSHEALience project concept

Process innovation: re/up cycling

Niranjan K. Prabhu PhD thesis, unpublished image



Our website www.uhdc.eu and social network profiles



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

Our Open access and open data papers

www.uhdc.eu

Tensile behaviour identification in Ultra-High Performance Fibre Reinforced Cementitious Composites: indirect tension tests and back analysis of flexural test results

Francesco Lo Monte¹, Liberato Ferrara

Construction and Building Materials 206 (2021) 121447

Check for updates

Self-healing characterization of UHPFRCC with crystalline admixture: Experimental assessment via multi-test/multi-parameter approach

Francesco Lo Monte¹, Liberato Ferrara

Cement and Concrete Composites 118 (2021) 100956

Check for updates

Performance Assessment of Ultra-High Durability Concrete Produced From Recycled Ultra-High Durability Concrete

Ruben Paul Borg¹, Estefania Cuenca², Roberto Garofalo¹, Fabrizio Schillari¹, Milena Lozano Nasoro¹ and Liberato Ferrara^{1*}

Cement and Concrete Composites 115 (2021) 103854

Check for updates

Synergy between crystalline admixtures and nano-constituents in enhancing autogenous healing capacity of cementitious composites under cracking and healing cycles in aggressive waters

Estefania Cuenca¹, Alessandro Mezzena, Liberato Ferrara

Construction and Building Materials 232 (2020) 117141

Check for updates

Mechanical properties and self-healing capacity of Ultra High Performance Fibre Reinforced Concrete with alumina nano-fibres: Tailoring Ultra High Durability Concrete for aggressive exposure scenarios

Estefania Cuenca^{1*}, Leonardo D'Ambrosio², Dennis Lizunov^{3,4}, Aleksei Tretjakov^{5,6}, Olga Volobujeva⁴, Liberato Ferrara^{1*}

Construction and Building Materials 232 (2020) 117141

Check for updates

Direct procedure to characterize the tensile constitutive behavior of strain-softening and strain-hardening UHPFRCC

Eduardo J. Mezquida-Alcaraz¹, Juan Navarro-Gregori, Pedro Serna-Ros

Cement and Concrete Composites 110 (2020) 103096

Check for updates

Durability-Based Design of Structures Made with Ultra-High-Performance/Ultra-High-Durability Concrete in Extremely Aggressive Scenarios: Application to a Geothermal Water Basin Case Study

Salam Al-Obaidi^{1,2,*}, Patrick Bamonte¹, Massimo Luchini³, Jacopo Mazzantini³ and Liberato Ferrara¹

Construction and Building Materials 232 (2020) 117141

Check for updates

The effect of compatibility and dimensionality of carbon nanofillers on cement composites

Amr Alatawna^{1,2}, Matan Birenboim³, Roey Nativ³, Matat Buzaglo³, Sivan Peretz-Damari³, Alva Peled³, Oren Reggev^{3,4,5}, Raghu Sripathi^{6,7}

Construction and Building Materials 232 (2020) 117141

Check for updates

Effects of Autogenous and Stimulated Self-Healing on Durability and Mechanical Performance of UHPFRCC: Validation of Tailored Test Method through Multi-Performance Healing-Induced Recovery Indices

Estefania Cuenca, Francesco Lo Monte, Marina Moro, Andrea Schiona and Liberato Ferrara^{1*}

Cement and Concrete Composites 110 (2020) 103096

Check for updates

Innovative Design Concept of Cooling Water Tanks/Basins in Geothermal Power Plants Using Ultra-High-Performance Fiber-Reinforced Concrete with Enhanced Durability

Salam Al-Obaidi^{1,2,*}, Patrick Bamonte¹, Francesco Animato³, Francesco Lo Monte³, Jacopo Mazzantini³, Massimo Luchini³, Sandra Scaliari³ and Liberato Ferrara¹

Construction and Building Materials 232 (2020) 117141

Check for updates

Self-healing efficiency of Ultra High-Performance Fiber-Reinforced Concrete through permeability to chlorides

Hesami Doostkani¹, Marta Roig-Flores², Pedro Serna^{3*}

Cement and Concrete Composites 110 (2020) 103096

Check for updates

Potential step voltammetry: An approach to corrosion rate measurement of reinforcements in concrete

J.E. Ramón^{1,2}, J.M. Gandía-Romero^{3,4,5}, R. Battaler⁶, M. Alcañiz^{6,7}, M. Valcuenca⁸, J. Soto^{9,10}

Cement and Concrete Composites 115 (2021) 103854

Check for updates

Meta-Analysis and Machine Learning Models to Optimize the Efficiency of Self-Healing Capacity of Cementitious Material

Shashank Gupta^{1,*}, Salam Al-Obaidi^{1,2} and Liberato Ferrara¹

Construction and Building Materials 232 (2020) 117141

Check for updates

Crystalline Admixture as Healing Promoter in Concrete Exposed to Chloride-Rich Environments: Experimental Study

Estefania Cuenca¹; Stefano Rigamonti²; Enricomaria Gastaldo Brac³; and Liberato Ferrara⁴

Construction and Building Materials 232 (2020) 117141

Check for updates

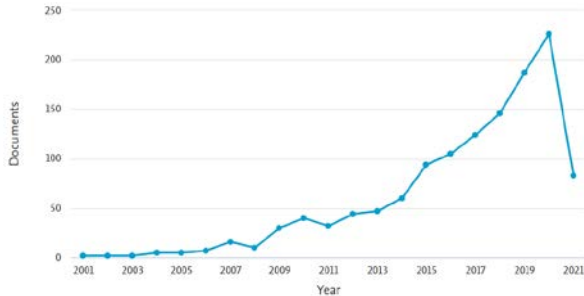
Case Studies in Construction Materials

Effects of tension stiffening and shrinkage on the flexural behavior of reinforced UHPFRCC beams

Construction and Building Materials 232 (2020) 117141

Check for updates

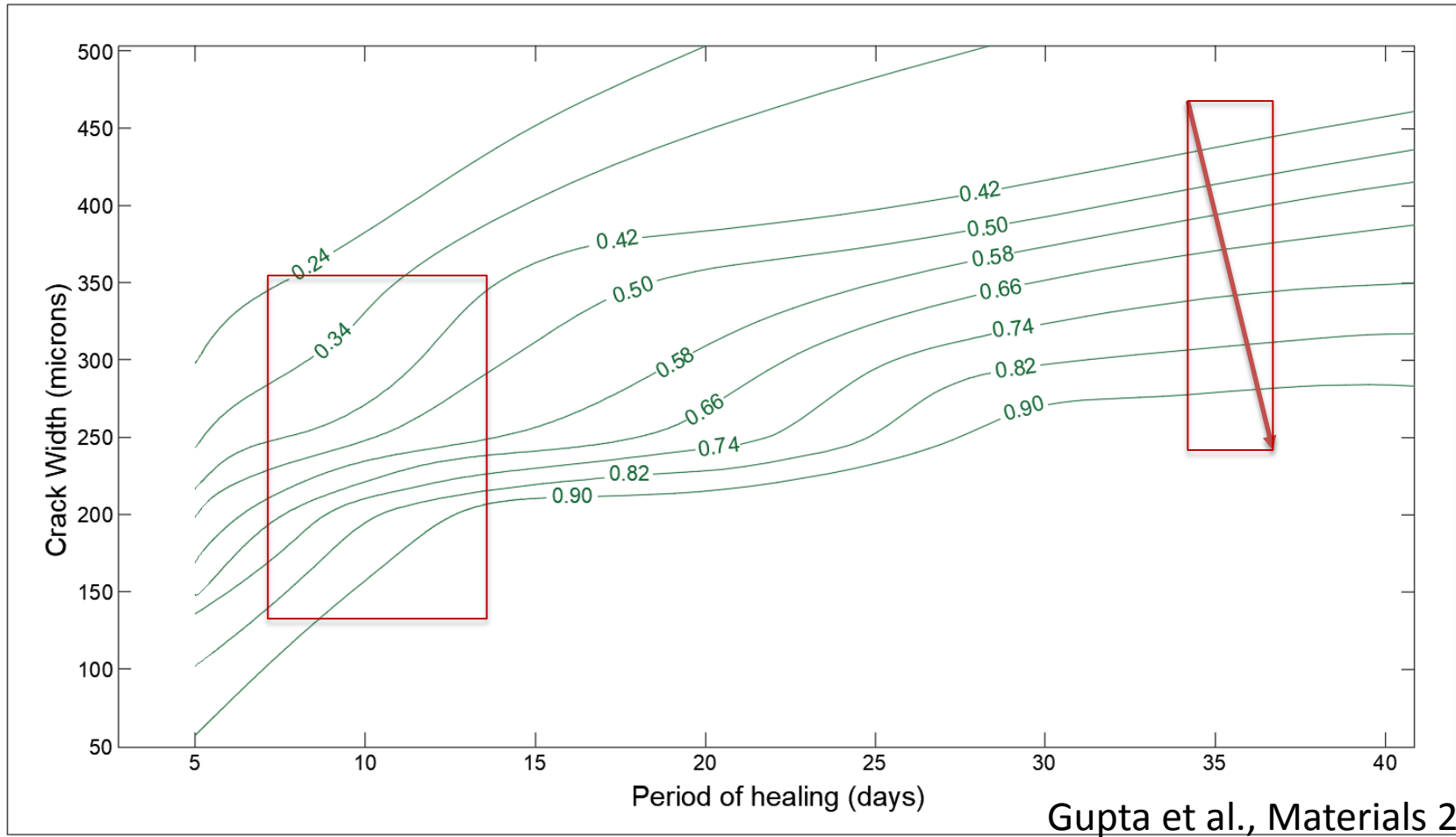
ReSHEALience project: looking further data learning in construction industry



S. No.	Experiment	Parameters	Formula
1	Crack Size	w_i = initial width & w_f = final width	$(w_i - w_f) / w_i$
2	Permeability Test	Q_i = initial flow & Q_f = final flow	$(Q_i - Q_f) / Q_i$
3	Ultrasonic Pulse Velocity (UPV) Test	U_h = UPV of healed sample & U_c = UPV of cracked sample	$(U_h - U_c) / U_h$
4	Electrical Resistivity/Impedance	E_h = Reading of healed sample & E_c = Reading of cracked sample	(E_h / E_c)
5	Mechanical Strength	M_h = Strength of healed sample & M_c = Strength of cracked sample	$(M_h - M_c) / M_h$

- Self-healing of concrete has been extensively studied over the last few decades:
 - Parameters affecting the autogenous healing have been well investigated qualitatively, **less quantitatively**.
 - **Lack of self-healing** concepts into **durability-based design** approaches for reinforced concrete structures.
- Overarching Motivation: **Standardization and codification** of the existing findings on Self-healing of cementitious materials.
- Study Objectives:
 - Preliminary Meta-analysis through Forest plots.
 - Develop predictive design charts for self-healing efficiency.

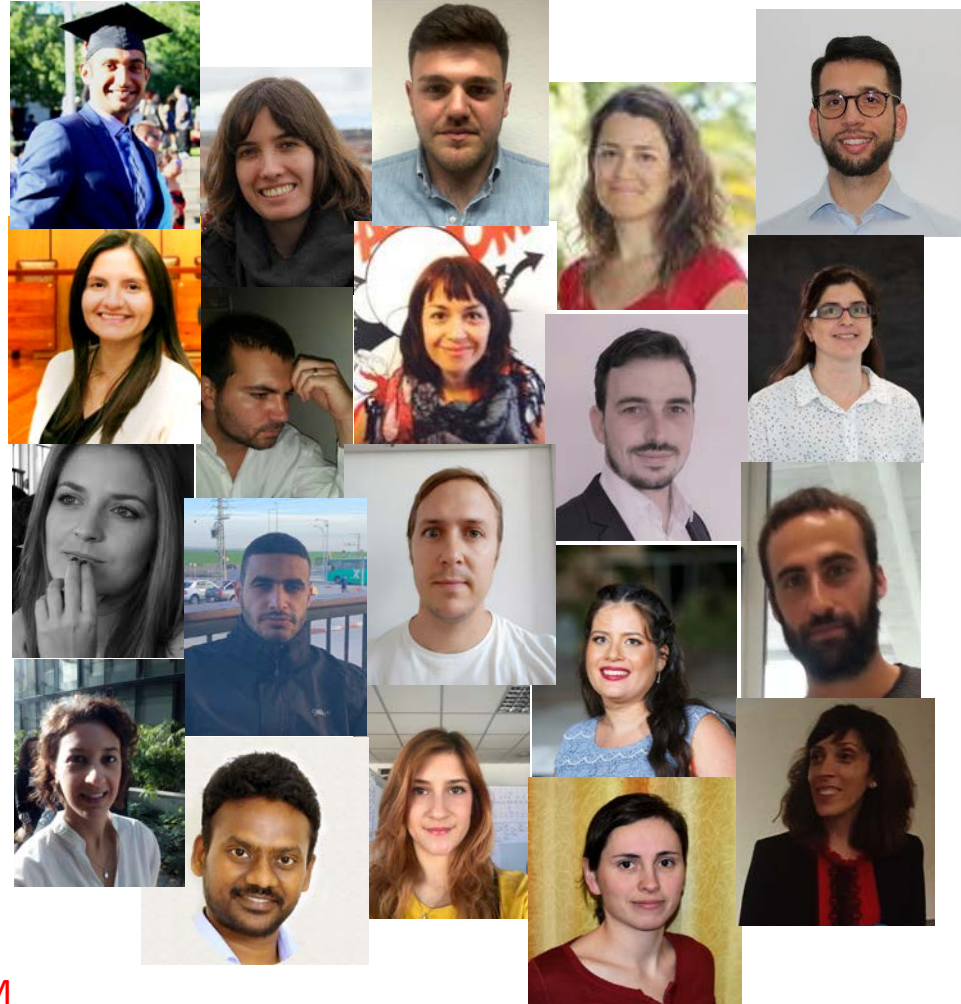
ReSHEALience project: looking further data learning in construction industry



Gupta et al., Materials 2021

The ReSHEALience project strategy: ... creating a new educational pathway ...

Estefania Cuenca, Assistant professor, PoliMi
Francesco Lo Monte, Assistant professor, PoliMi
Antonio Cibelli, PhD student, PoliMi
Salam Maytham Al Obaidi, PhD student, PoliMi
Maria Chiara Caruso, LCA expert, STRESS
Cristina Maestre, Communication expert, RDC
Evangelia Enteze, Post-doc researcher, API Europe
Michail Iakovlev, Post-doc researcher, API Europe
Valentina Violante, Project engineer, Penetron IT
Marta Roig Flores, Post-doctoral student, UPV
Eduard Mezquida, PhD student, UPV
Roman Bataller, researcher, UPV
Philipp Kuntz, PhD student, TUD
Michaela Reichardt, PhD student, TUD
Maria Criado, Post-doctoral student, CSIC
Mercedes Gimenez, PhD student, CSIC
Radhu Sripada, Post-doctoral student, BGU
Amer Alatawna, PhD student, BGU
Lior Nahum, PhD student, BGU
Tal Yadlin, PhD student, BGU
Milena Nasner Albany, Post-doctoral researcher, UoM



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

The ReSHEALience project strategy: ... creating a new educational pathway ...



Liberato Ferrara, DICA, Politecnico di Milano



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

on behalf of the ReSHEALience consortium

Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824

... of the ReSHEALients@DICAPolimi ...



If you always do what you always did, you'll always get what you always got!

Liberato Ferrara, DICA, Politecnico di Milano



POLITECNICO
MILANO 1863



Horizon H2020 European Union Funding for Research & Innovation

This project receives funding from the European Union's Horizon H2020 research and innovation programme under grant agreement N° 760824