

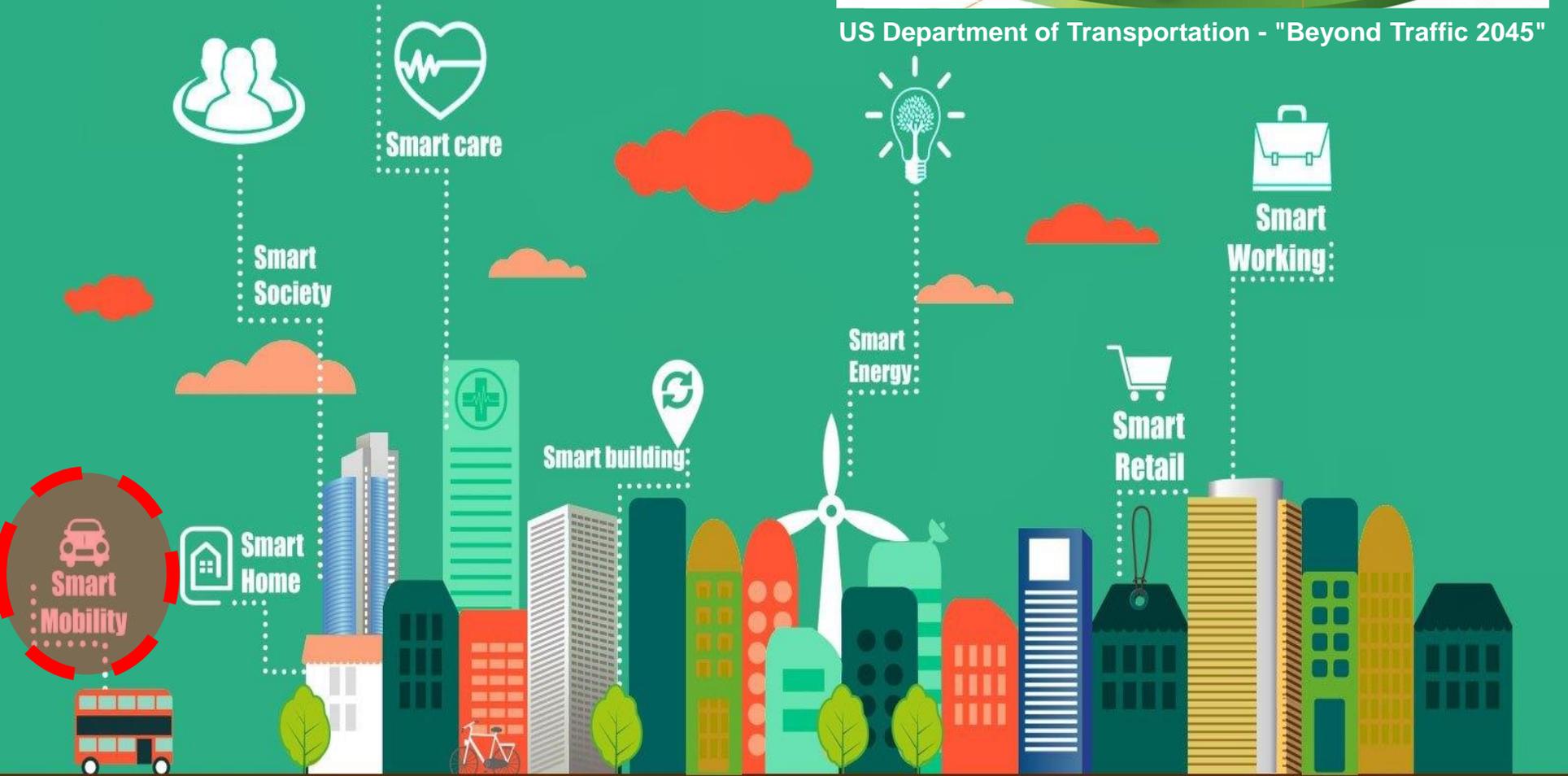
# **Automated Connected Civil Infrastructure**

**Nizar Lajnef**  
**Associate Professor**  
**Civil and Environmental Engineering**  
**Michigan State University**

- Smart and Connected Infrastructure
- Resilient Infrastructure



US Department of Transportation - "Beyond Traffic 2045"



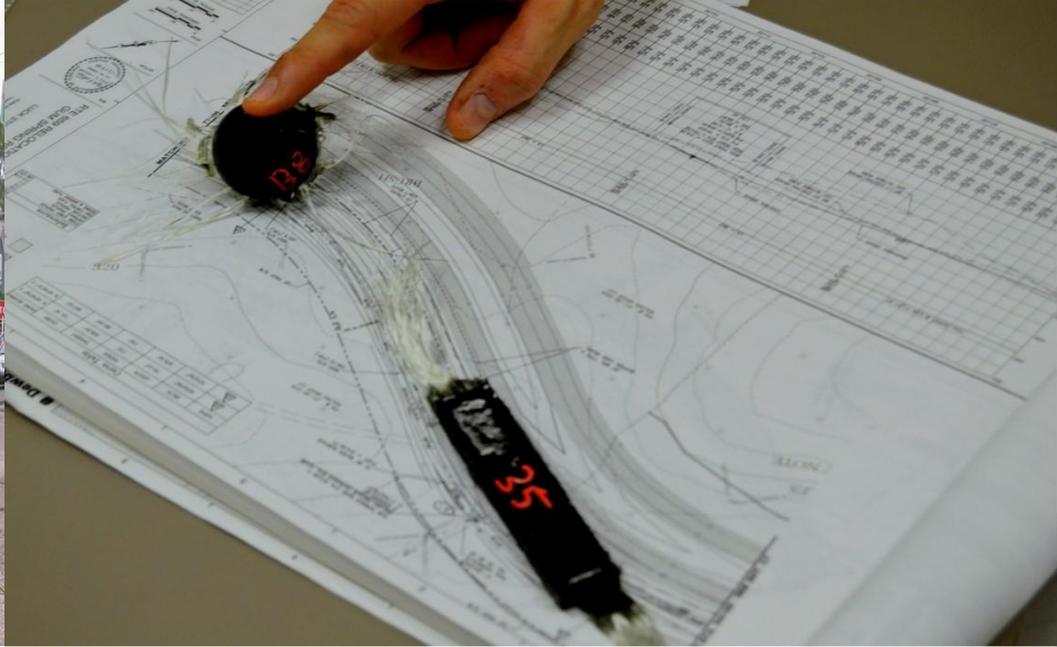


Preventive Maintenance

Condition-Based  
Maintenance



# Material Tagging and Tracking



# Infrastructure-to-Vehicles Communication (I2X)



# Technology Solutions

**Long-term Material  
Tagging Technology**

On site electronic database  
embedded in the material –  
Material tracking / Forensic analysis

**Events Detection and Condition  
Monitoring Technology**

Long-term Continuous  
Monitoring of Structural  
Condition

**Infrastructure-to-  
Everything (I2X)  
Communications Tec**

Magnetic and reflective  
asphalt and concrete for  
lane keeping and I2X

# Tagging Technology: encoder/decoder software

- Store data into tag memory: environmental factors, system properties, etc
- Read data from tag memory
- Eliminate the need for databases



Tag Reader

Reader Information

MAC Address: 00:16:25:10:98:E2 Tag #

**Start**

Michigan state university

Write Pav/Mix/Construction Data | Read Pav/Mix/Construction Data

**Project Information**

Project #: I-75 NB

Date of concrete placement: 11/27/2018

Tag Location: Center

**Construction**

Relative Humidity at the time of concrete placement (%): 60

Ambient temperature at the time of concrete placement (°F): 70

Wind Speed (mph): 5

Curing material: Compound

**PCC Mixture Design**

Cement Content (lbs/yr<sup>3</sup>): 367

Type of cement: I

Coarse Aggregate (lbs/yr<sup>3</sup>): 1205

Aggregate Geology: Limestone

CTE x 10<sup>-6</sup>: 5

Fine Aggregate (lbs/yr<sup>3</sup>): 1139

Aggregate Geology: Limestone

Water (lbs/yr<sup>3</sup>): 277

Admixture(s) (fl.oz/cwt): 1.8

Type of admixture(s): Air Entrainment

**Fresh Concrete Properties**

Slump (inches): 3

Unit Weight (lb/ft<sup>3</sup>): 147

Concrete Temperature (°F): 67

Entrained Air (%): 7

**Hardened Concrete Properties**

Compressive Strength (psi): 3500

Flexural Strength (psi): 650

Elastic Modulus (ksi): 30000

Measure CTE: 5

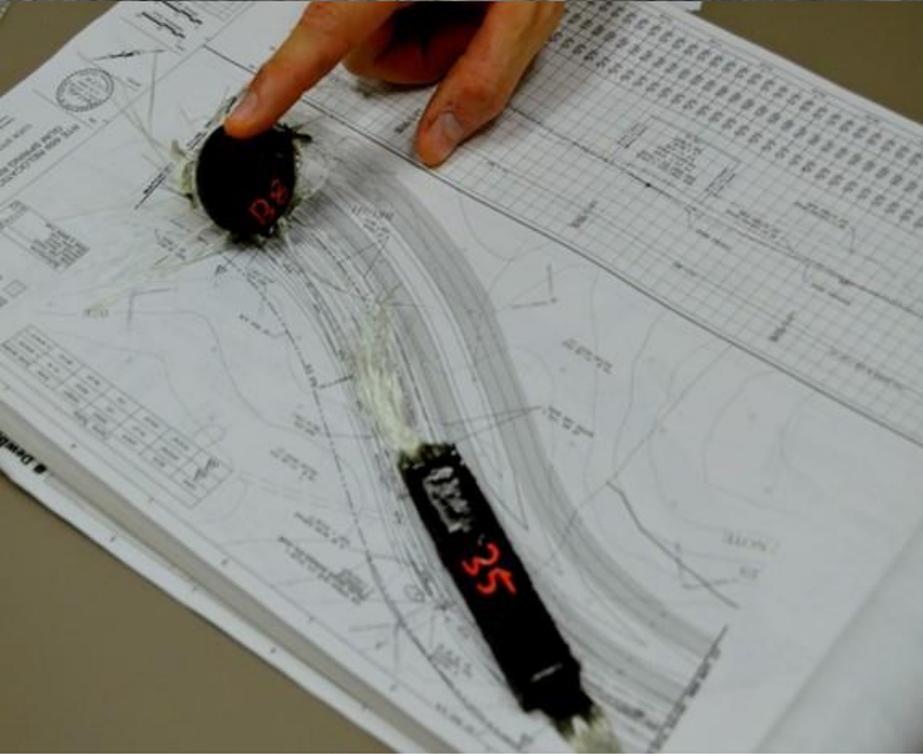
**Pavement Design**

Slab thickness (inches): 10

Base thickness (inches): 6

Base type: Lean Concrete

Resilient Modulus of base (psi): 30000



# Technology Solutions

Long-term Material  
Tagging Technology

On site electronic database  
embedded in the material –  
Material tracking / Forensic analysis

**Events Detection and Condition  
Monitoring Technology**

**Long-term Continuous  
Monitoring of Structural  
Condition**

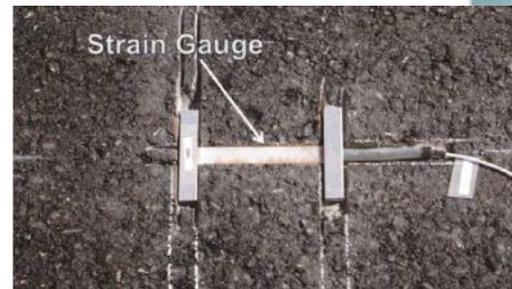
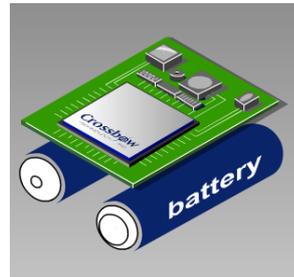
Infrastructure-to-  
Everything (I2X)  
Communications Tec

Magnetic and reflective  
asphalt and concrete for  
lane keeping and I2X

# Current Monitoring Solutions ?

Monitoring systems are expensive, bulky and require a continuous source of power.

Electronic powering is one of the major obstacle !



*Yang Wang, Kenneth Loh, Jerome Lynch and Kincho Law, University of Michigan*

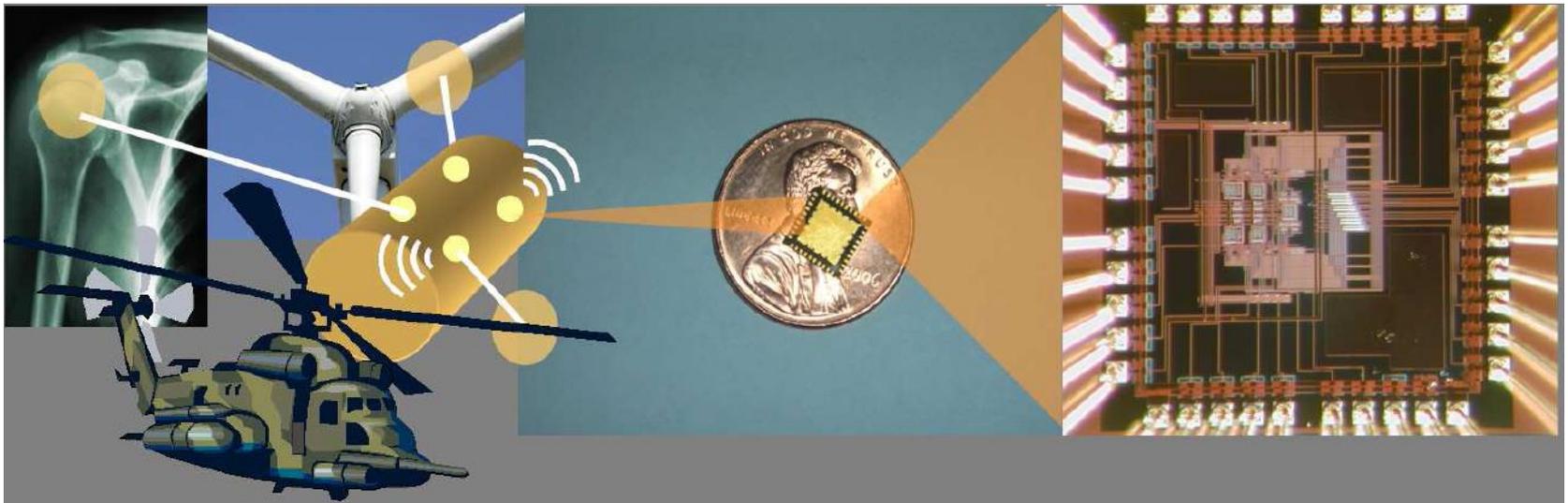
Wired Strain-gauges or implanted batteries are **impractical solutions**

Solution: Self-powered sensing

Harvest computing power from the signal being sensed.

# Piezo-Floating-Gate (PFG) Technology

- Sensors embedded inside “smart structures” that can self-prognosticate damage and mechanical failure.
- **Zero Maintenance Sensors:** Operational life of sensors comparable to the useful life of the structure – **Powering is one of the key challenges.**



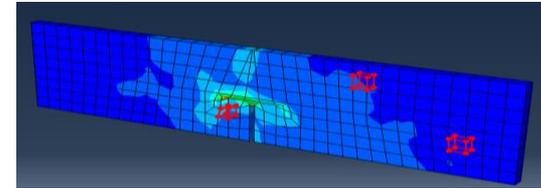
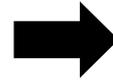
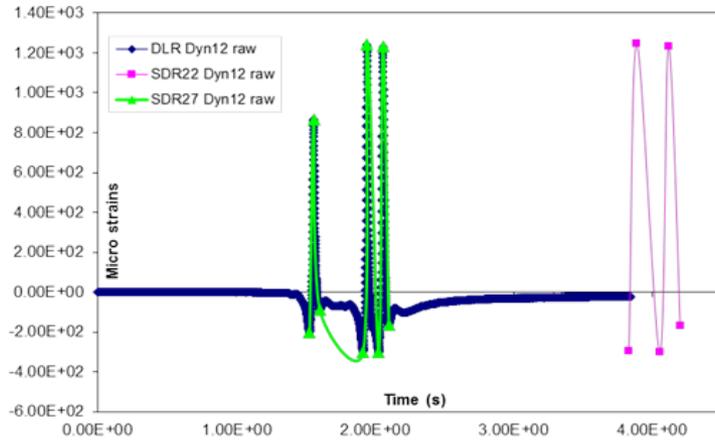
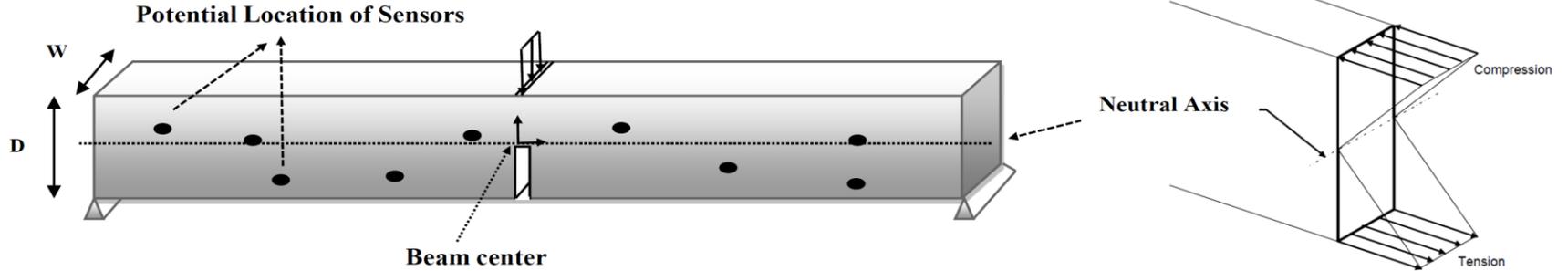
**Sensor Size and Powering**

# Advantages

- *Low power requirements.* - 80nW power consumption harvested directly from the sensing signal. - Battery less operation
- Low Cost – projected to be less than \$10 for mass production
- *Possibility of deployment in dense networks* – small size
- *Autonomous computation and non-volatile storage of sensing variables.*
- *Wireless communication.*
- Modular Design – Different applications



# Data Interpretation – Damage ?

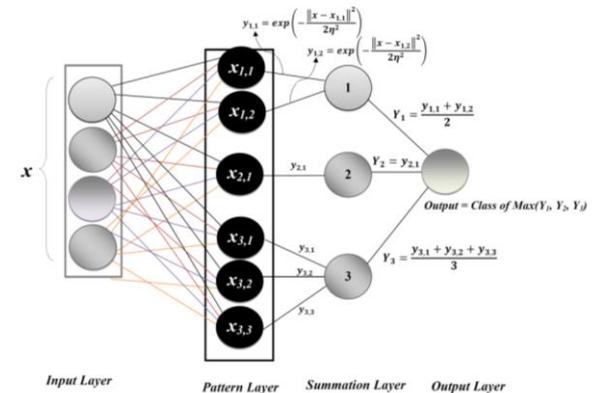
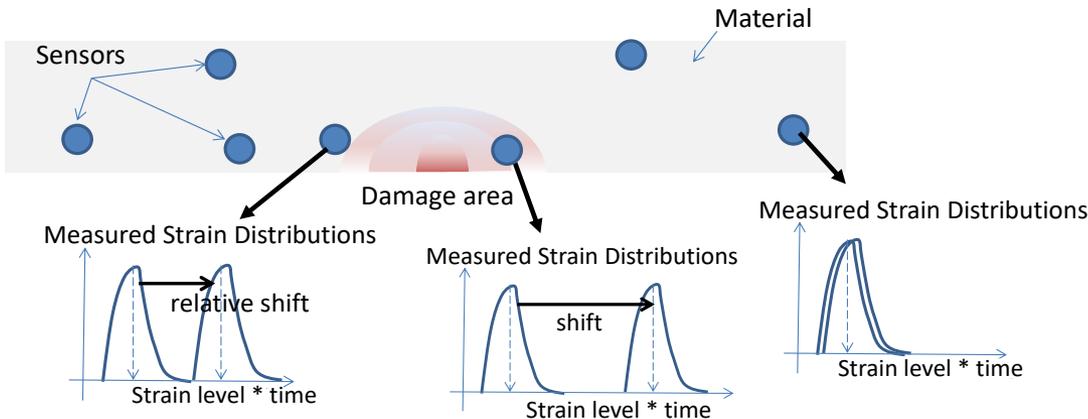


$$\epsilon_{xx}^e = \epsilon_{xx}^{11} - \epsilon_{xx}^{33}$$

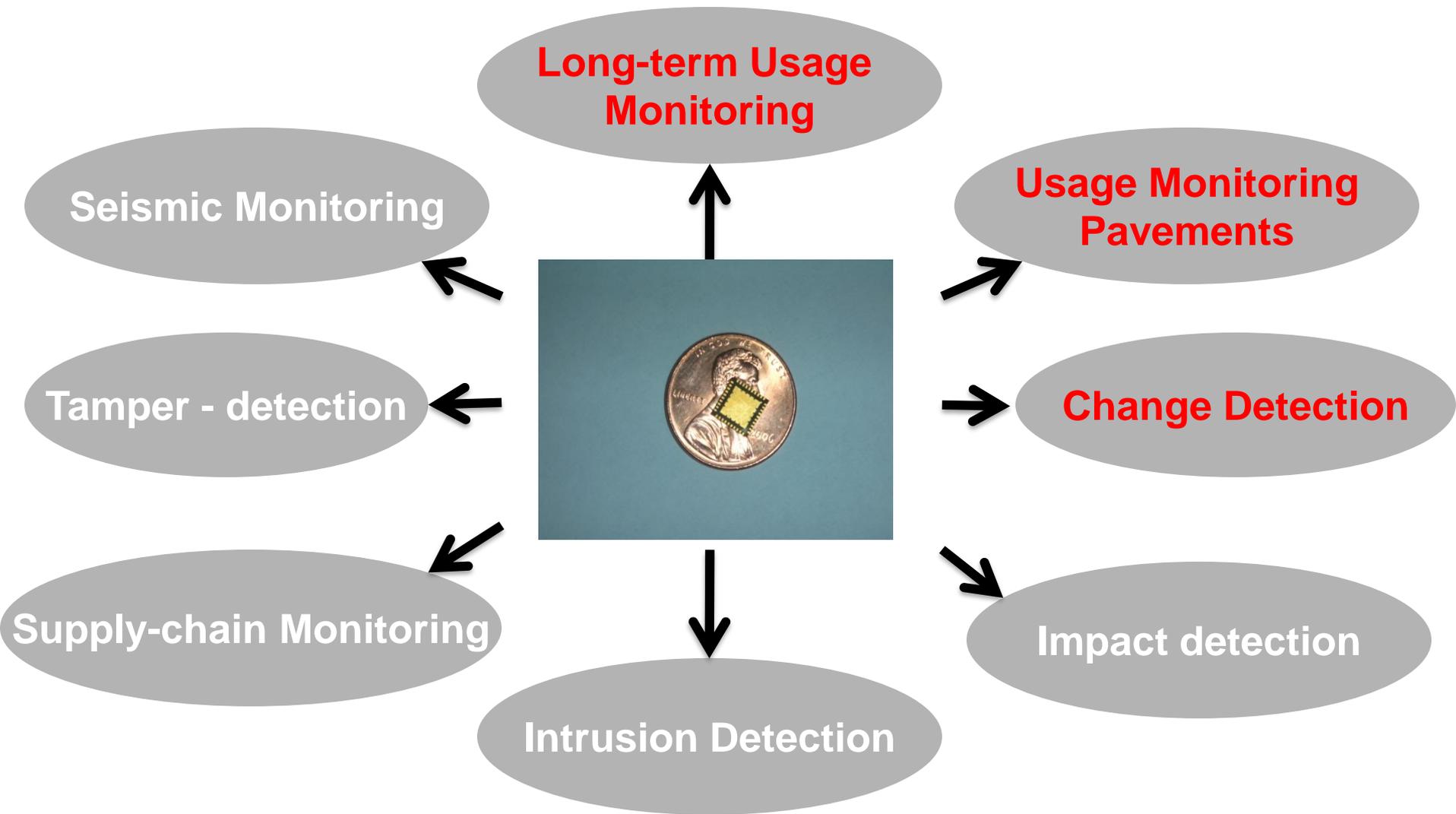
$$\epsilon_{yy}^e = \epsilon_{yy}^{33} - \frac{\omega}{3}$$

$$\epsilon_{zz}^e = \epsilon_{zz}^{11} + \epsilon_{zz}^{22} + \epsilon_{zz}^{33}$$

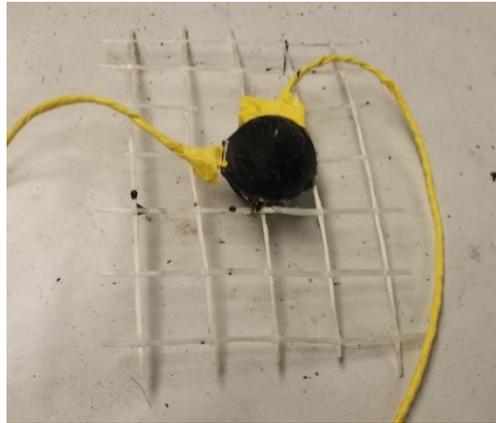
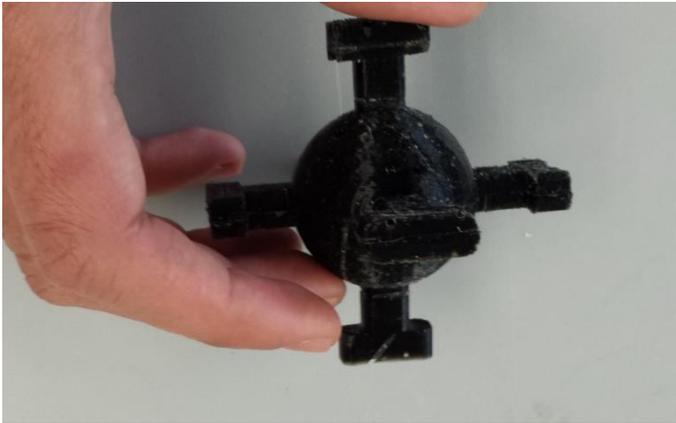
$$M_{xx} = \frac{1}{I} \left[ \sqrt{11} (\epsilon_{xx}^e)_3 + \sqrt{33} (\epsilon_{yy}^e)_3 + \sqrt{33} \epsilon_{zz}^e + \sqrt{11} \left( (\lambda_{11}^{11})_3 + (\lambda_{22}^{22})_3 \right) + \sqrt{33} \left( (\lambda_{11}^{11})_3 + (\epsilon_{zz}^e)_3 \right) \right]$$



# Road-map: One sensor multiple Modalities



# Different prototypes

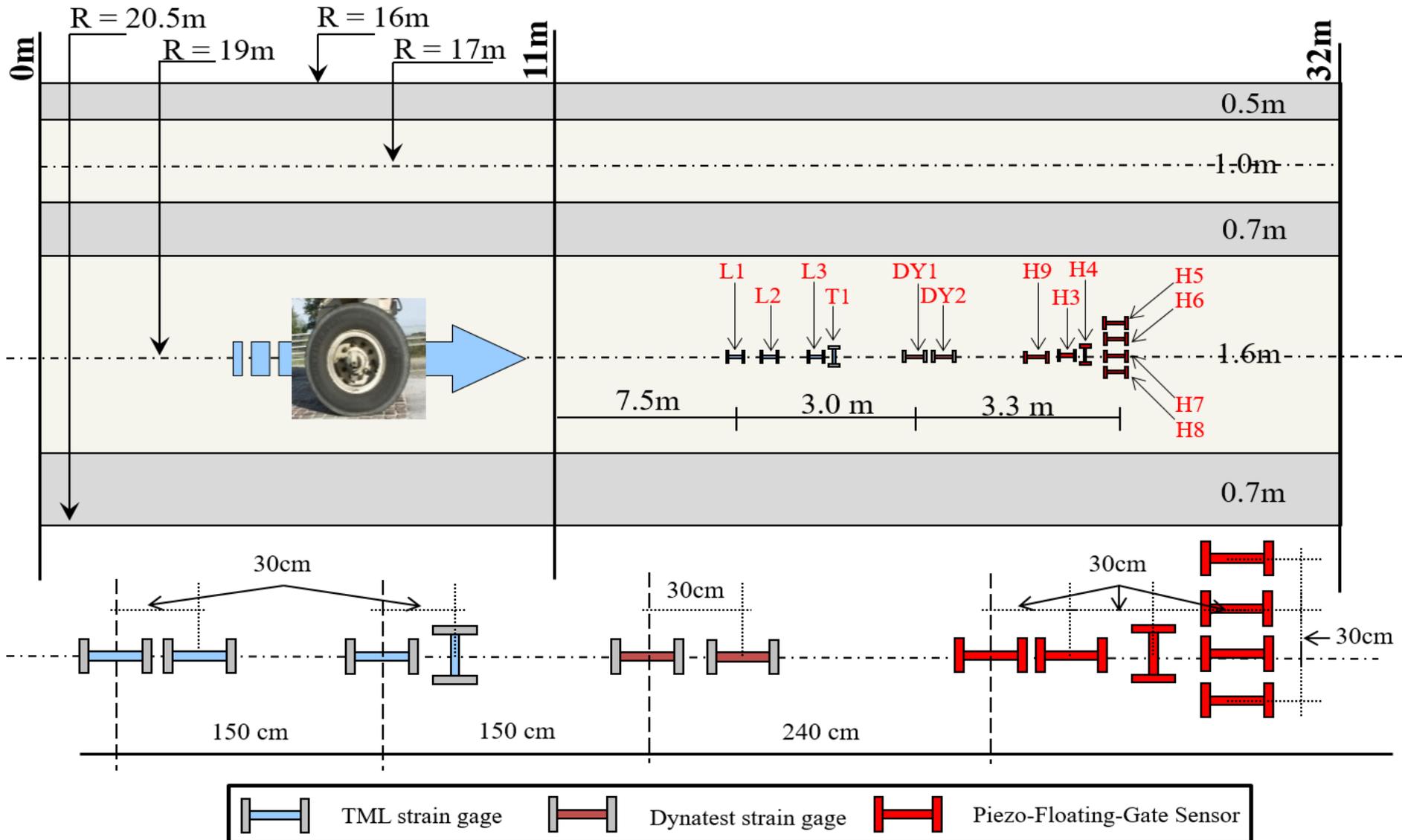




Nantes, France

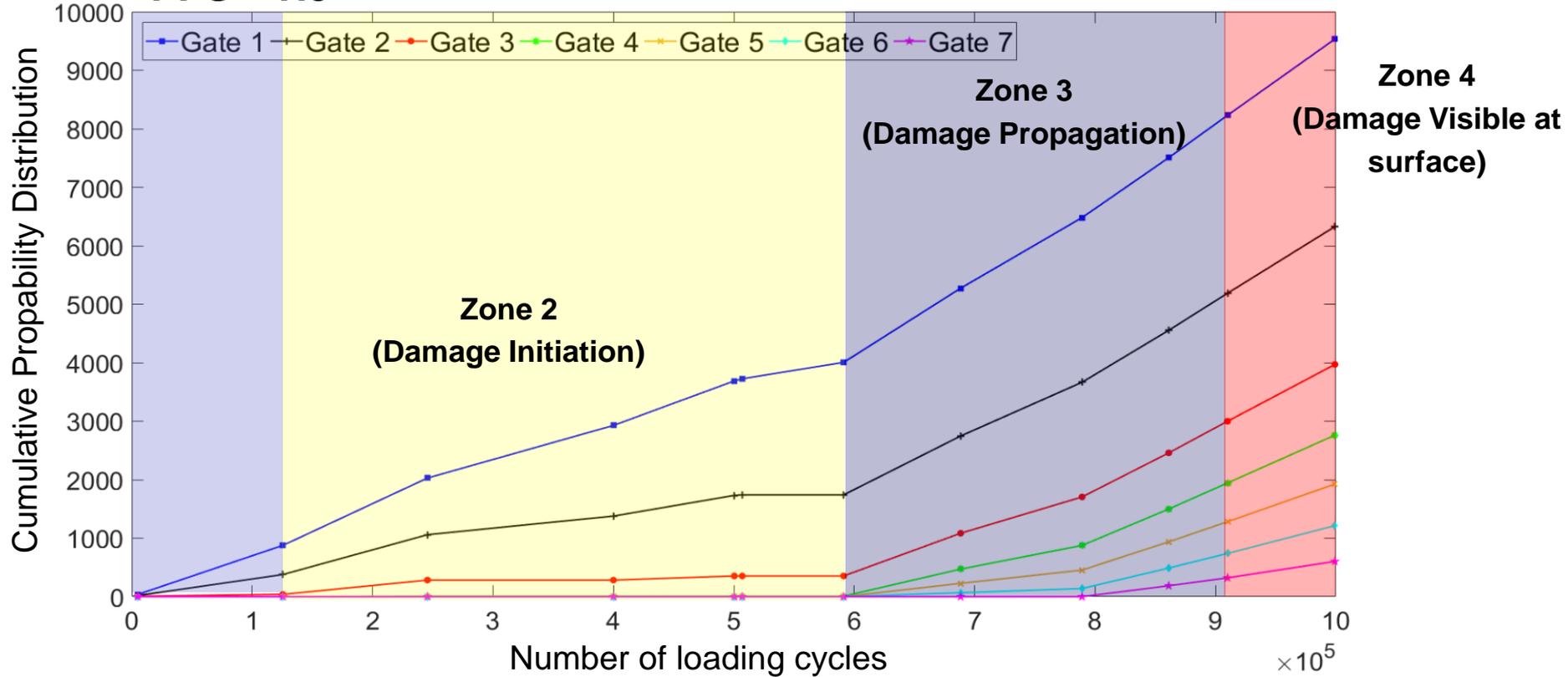


# Pavement instrumentation – HMAM





### PFG – H3



# Automated Smart and Connected Infrastructure: Infrastructural Internet-of-things (I-IoT)



Renewable Energy  
Structures



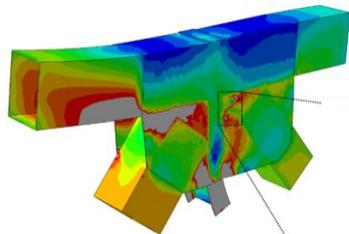
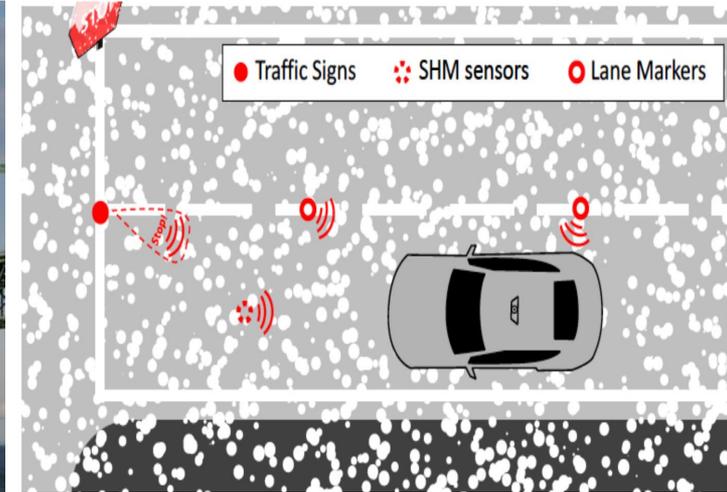
Long-term Monitoring of Critical  
Civil Infrastructure



Federal Aviation  
Administration



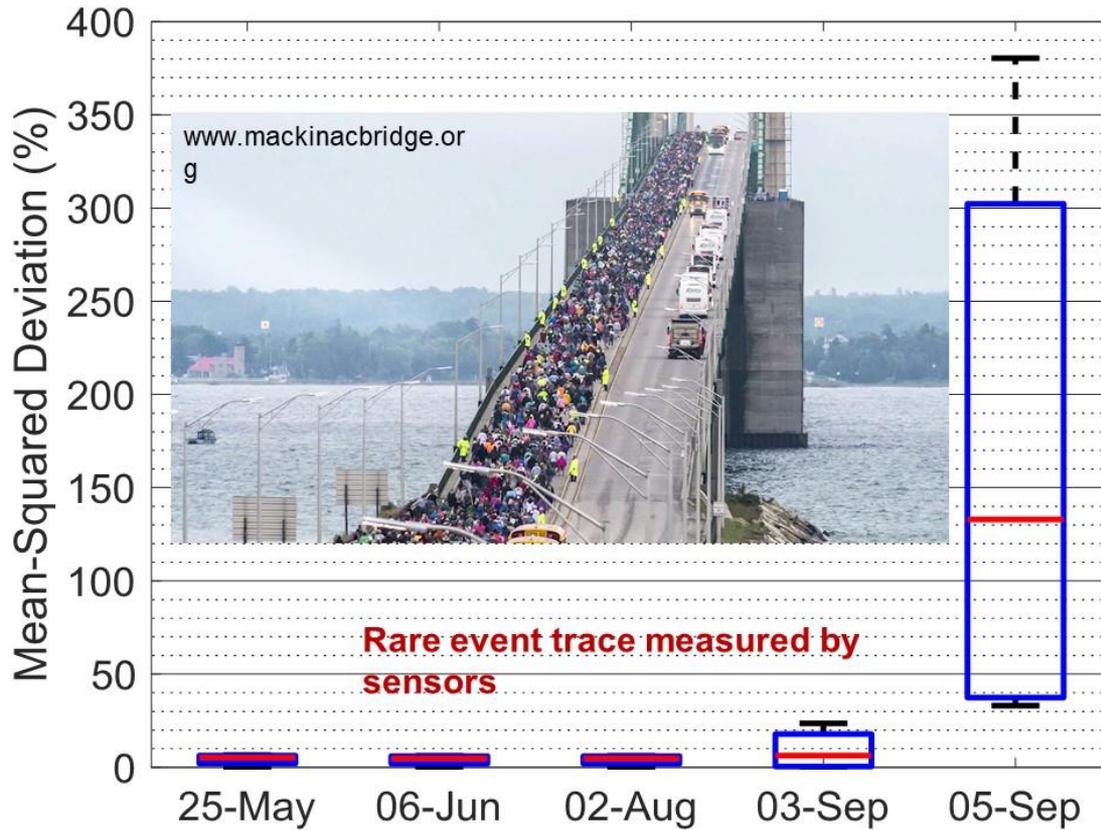
Vehicle-Infrastructure Integration (V2I-I2X)  
Smart Roads/ Smart Runways



# Large Scale Testing – Mackinac Bridge Michigan



# Rare event validation: Sep 4th Labor day walk



*"Bridge open to public – more than 80,000 visitors"*

GLSVLSI 2018, Frontiers 2019

## Michigan's Mighty Mackinac Bridge Has Mega Monitoring System Powered By Traffic



Jeff Kart Contributor @ Science



A freighter passes beneath the 'Mighty Mac' Mackinac Bridge in Michigan. GETTY

# Technology Solutions

Long-term Material  
Tagging Technology

On site electronic database  
embedded in the material –  
Material tracking / Forensic analysis

Events Detection and Condition  
Monitoring Technology

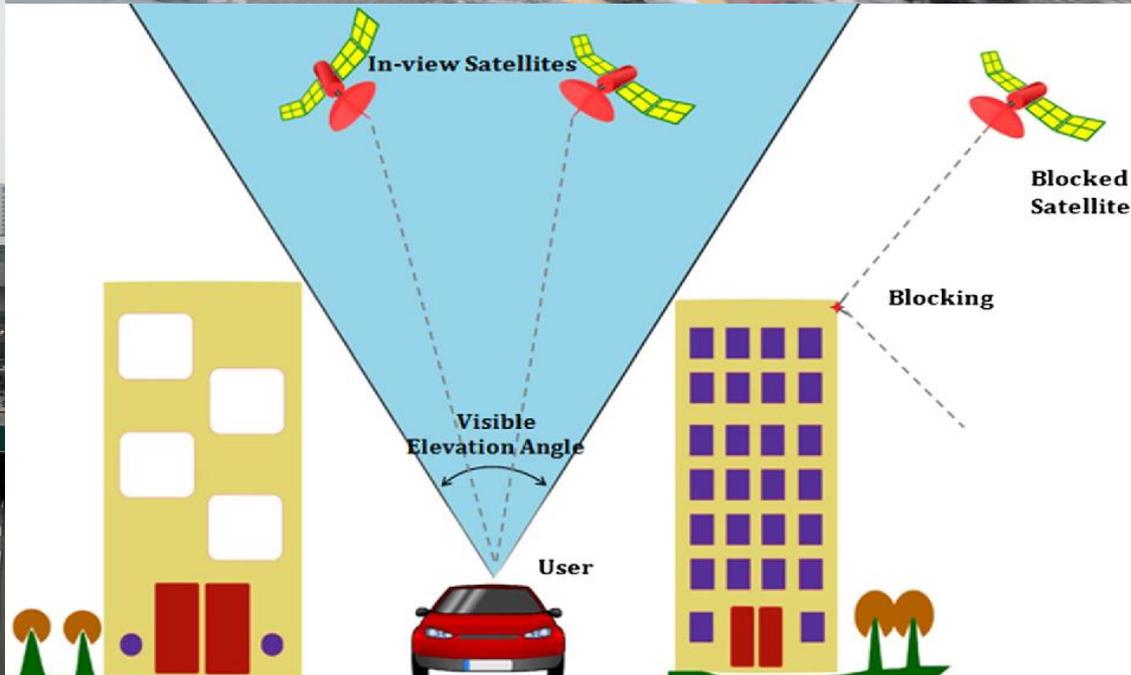
Long-term Continuous  
Monitoring of Structural  
Condition

Infrastructure-to-  
Everything (I2X)  
Communications Tec

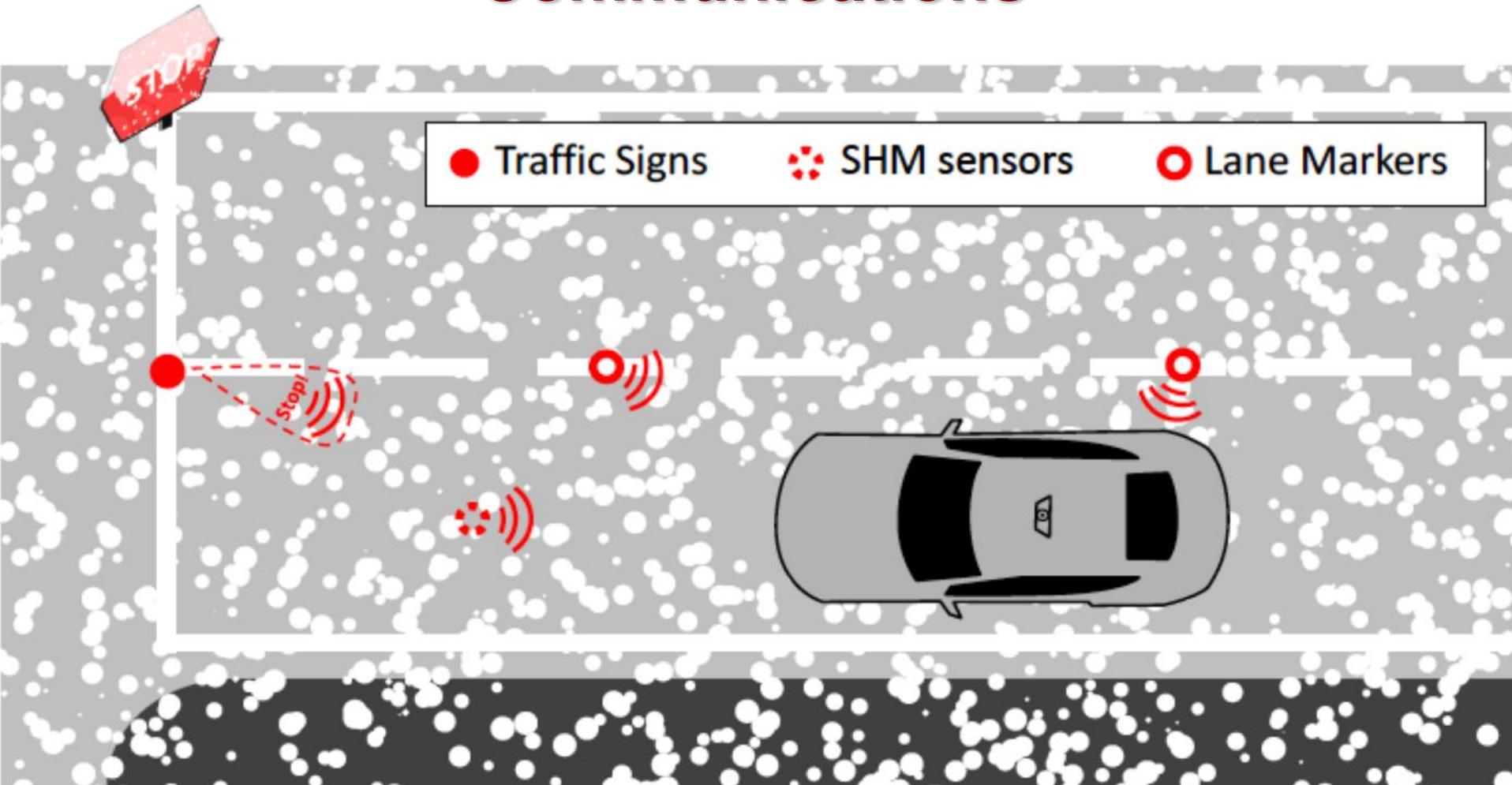
Magnetic and reflective  
asphalt and concrete for  
lane keeping and I2X

# Vehicle-Infrastructure Integration (V2I-I2X)

GPS and Vision based technologies can fail under adverse weather conditions and in coverage blind spots in urban canyons or tunnels



# Framework for Infrastructure-to-Vehicle Communications







## Partners

- **Shantanu Chakrabartty, Washington University StLouis**
- **Kenji Aono, Washington University StLouis**
- **Imen Zaabar, Michigan State University**
- **Karim Chatti, Michigan State University**
- **Davide Lo Presti, University of Palermo**
- **Sami Masri, University of Southern California**
- **Infratico, inc**

# A Road Map for Permeable Pavements

John Harvey

University of California Pavement Research Center

City and County Pavement Research Center

National Center for Sustainable Transportation

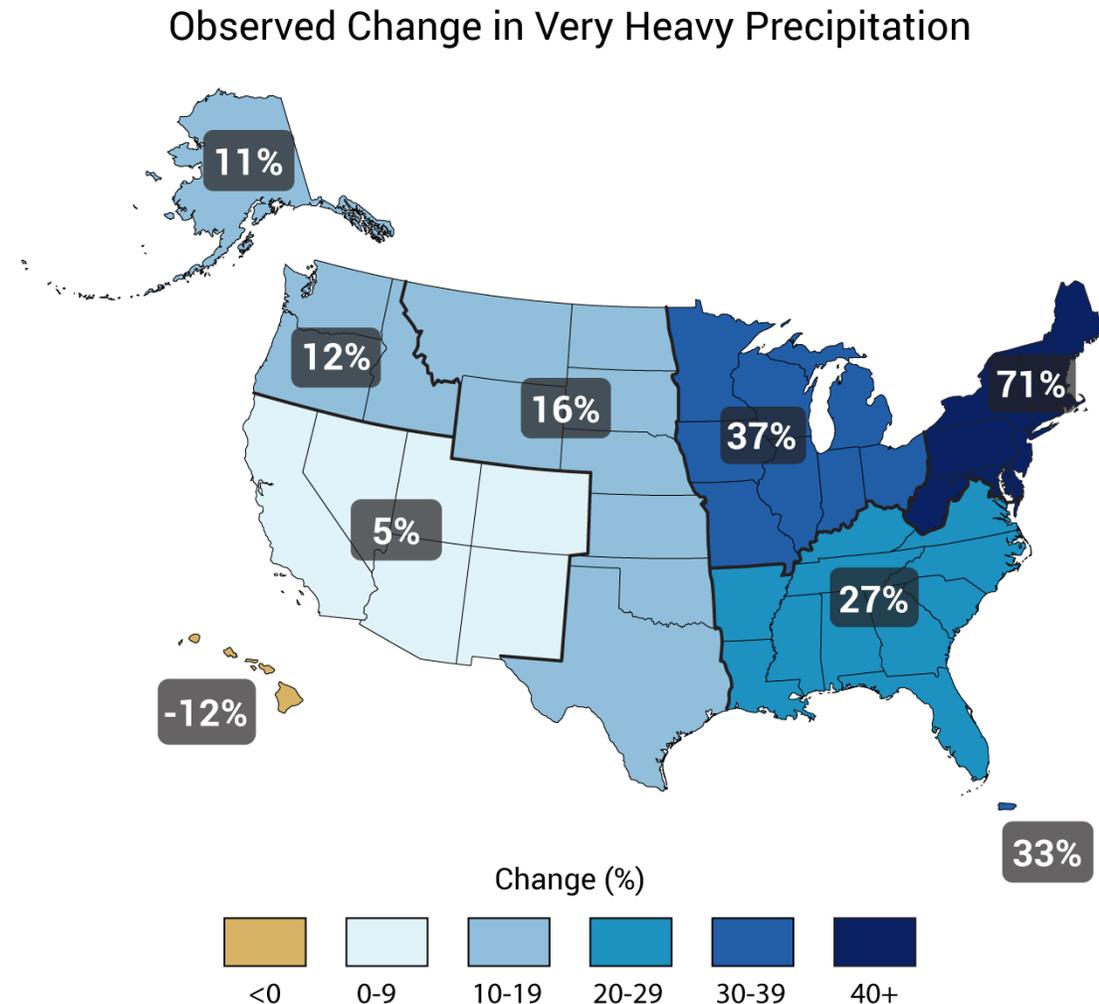
University of California, Davis

David Smith

Interlocking Concrete Pavement Association

# Observed Change in Intensity of Very Heavy Precipitation Events in US 1958 to 2012

National Climate Assessment 2014



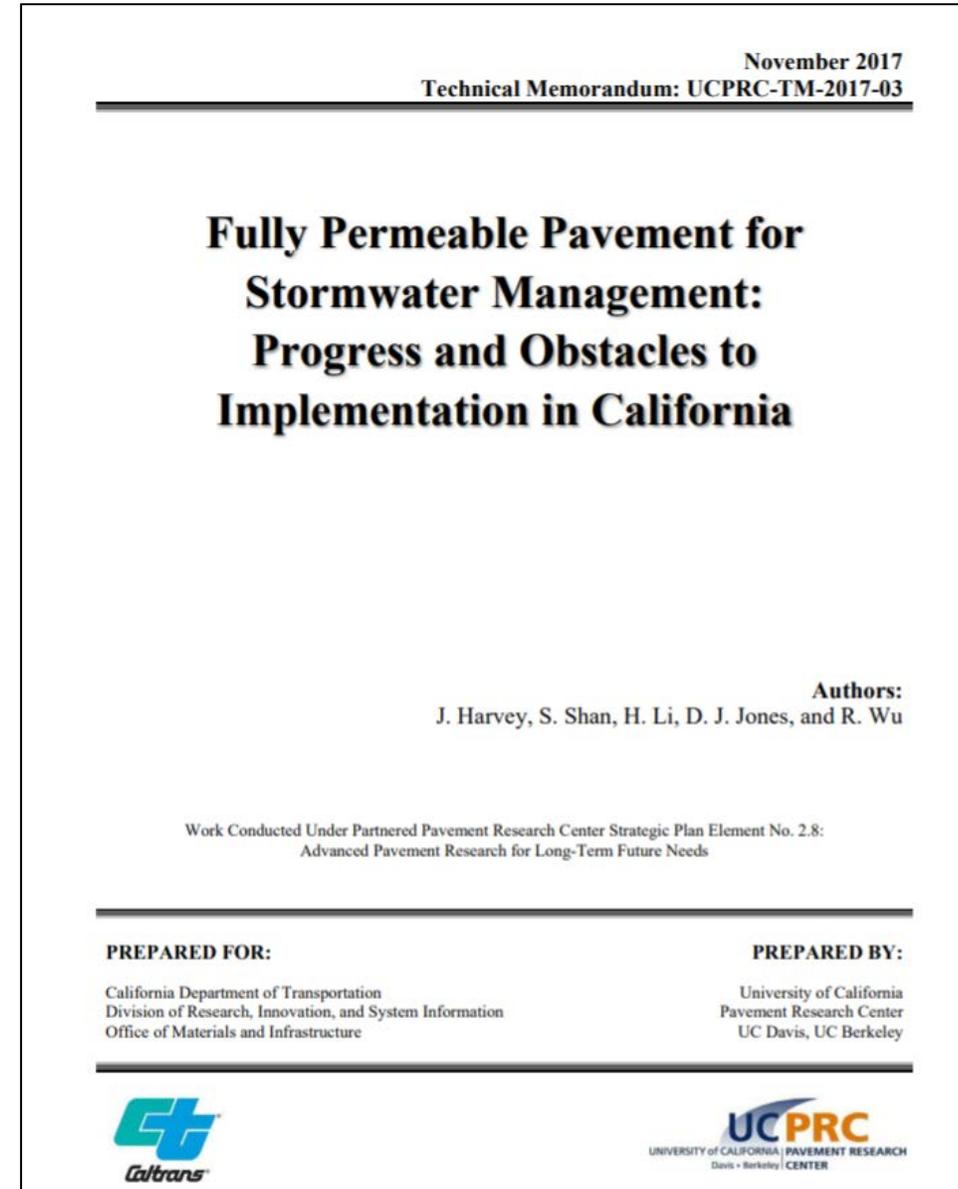
- Defined as 99<sup>th</sup> percentile events
- By 2080
  - Approximately 2X more often with rapid reductions in CO<sub>2</sub> emission rate
  - Up to 5X more often with current CO<sub>2</sub> emission rates

# What was the problem?

- National feedback from ASCE conferences in transportation and water
  - Success stories in a number of places
    - Millions of \$\$ saved in Atlanta using permeable pavement in place of cisterns
    - Grant program for cities from California Water Board
  - But also
    - Concern about costs, maintainability, who is responsible for maintaining functionality
    - Not generally being considered for use with other stormwater best management practices

# What was the problem?

- UCPRC/Caltrans survey of agencies and consultants in early 2017
  - 33 with experience
  - 31 without experience
- Conclusions:
  - There are still many gaps
  - Stormwater and pavement people both have concerns





## Workshop Nov 14-15, 2017 in Davis, CA

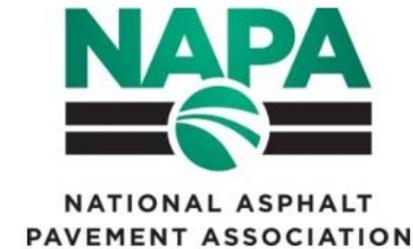
- Goal of workshop:
  - Identify knowledge, information, and communication barriers to adoption of permeable pavement of all types
- Outcome:
  - Road map document with program of projects to fill gaps, to be used to fund, organize and deliver the recommended program

# PERMEABLE PAVEMENT Road Map Workshop 2017

- Organized by:



- Sponsored by:



# Who was invited and why?

	Practice Sector				
Expertise	Government	Consulting	Construction & Materials	Academia	Total
Pavement	4	1	12	10	27
Stormwater Quality	6	3	0	2	11
Flood Control	10	3	0	0	13
Planning	3	1	0	0	4
Landscape Architecture	1	1	0	0	2
<b>Total</b>	<b>24</b>	<b>9</b>	<b>12</b>	<b>12</b>	<b>57</b>

# Day 1:

## prepared presentations to get all perspectives

<b>Overview</b>	Where are we and what is missing? Summary of survey results; workshop goals, deliverables and structure; <i>John Harvey</i>
<b>Pavement industry perspectives</b>	Thoughts on the future of permeable pavement from materials producer and contractor perspectives, meeting pavement and stormwater needs <i>Richard Willis (NAPA), David Smith(ICPI), Brian Killingsworth (NRMCA)</i>
<b>Stormwater and pavement, thoughts on the future from recent experience</b>	Thoughts on the future of permeable pavement from a stormwater perspective, what kind of future do permeable pavements have meeting pavement and stormwater needs? <i>Amir Ehsaei/Tom Sweet, AECOM</i>
<b>Planning and conceptual design</b>	How and where do decisions about permeable pavement occur in planning and conceptual design, what is working, what is not, what is missing? <i>Janet Attarian, City of Detroit</i>
<b>Stormwater regulation and codes</b>	What do pavement people need to know about stormwater regulation, codes, and basic stormwater considerations? <i>Keith Lichten, California Water Board</i>

<b>Design, maintenance and performance</b>	What are gaps regarding permeable pavement design, maintenance, and performance, for vehicle traveled ways and other urban hardscapes? <i>Dave Hein, ARA</i>
<b>Specifications and Construction</b>	What are gaps regarding permeable pavement specifications and construction, and are specs and other technical information enough to overcome pre-conceived notions, fears, the status quo, and the personal bias of civil engineers who are permeable pavement skeptics? <i>Mike Adamow, San Francisco Public Utilities Commission</i>
<b>Life cycle cost analysis</b>	Is the framework correct (just pavement or does it capture stormwater benefits and costs)? Do we have the numbers for both permeable pavement and other BMPs? <i>Dave Hein, ARA</i>
<b>Life cycle assessment (LCA) and other demands on streets</b>	What are the new demands on pavement besides safety and structural capacity and how does permeable fit in or not? What is an LCA framework to look at these new pavement demands and stormwater? <i>John Harvey</i>
<b>Communication between storm water and pavement</b>	What are common communications gaps between the knowledge domains and goals of stormwater and pavement, and ideas on fixing them? <i>Mike Carlson, Contra Costa County Flood Control and Water Conservation District</i>

# Fundamental disconnects stopping the widespread use of permeable pavement

- Stormwater function managed by environmental engineers controlled by water quality discharge permits
  - They get taken to court and fined if too much pollution
  - Requires frequent measurement of water quality
- Transportation function managed by pavement people using pavement management system
  - No consideration of permeability, pollutant measurement
  - Uncertainty about maintenance and rehabilitation practices and costs for both stormwater and transportation functions
- Flood control function is managed through planning and development codes
  - Permeable pavement generally not allowed to be considered in planning and development because of performance uncertainty
  - Flood control people have no maintenance money and no control
- Who owns permeable pavement, who is responsible for maintaining multi-functionality, who pays?

## Day 1: Participants developed unanswered 76 questions grouped in these areas:

- Costing and cost-decision support
- Materials and pavement performance
- Education and training
- Communication
- Project-level design issues
- Watershed and flood control design issues
- Designing for additional benefits and impacts
- Construction standards and issues
- Maintenance
- Asset management
- Funding for research, development, implementation
- Planning and development codes

## Day 2:

### Breakout sessions and group discussions

- Small groups of 5 to 7 people with different backgrounds
  - Discussion of assigned questions, identify gaps
  - Ideas for projects to fill gaps
- Presentations by groups
- Summary discussion with everyone together



# Main points from presentations and discussion

- “Permeable pavement” is a system for meeting four functional requirements: transportation, stormwater quality, flood control, and place making, needing a new name:
  - Integrated Stormwater Pavement Systems
  - Combined Stormwater Transportation Systems
- Enough technical information available for all topic areas for practitioners to move ahead, while efforts are underway to fill gaps and update outdated elements
  - Information needs to be pulled together and organized
  - Comprehensive detailed package of guidance, standards, example specifications, and tools usable in practice at each step in project development
  - Communication strategy

# Main points from discussion

- Guidance must take an integrated view addressing watershed, urban area, neighborhood, and project scales; also life cycle impacts not just initial
- Communications strategy to address all audiences who need information, covering the four functional areas
- Existing training programs need to be targeted, links established and training delivered
- Information for use in university classes across the four functionalities needs to be developed
- New work processes, code changes need to address multi-functionality
- Partnerships needed between pavement, stormwater and flood control agencies to identify and standardize roles and responsibilities, get funding, work together

# Main points from discussion

- New potential stakeholders need to be identified and engaged
  - Flood insurance industry
  - Federal Emergency Management Agency (FEMA)
- Establish a university-based research, development, and implementation center to organize efforts to create and communicate the information needed
  - Regional associated centers
- Central clearinghouse for organization and dissemination of quality, up-to-date information, maybe at center
- Program of intense, focused, well-funded research, development, and implementation work to fill gaps
  - Funding and program model could be the 1988-1993 Strategic Highway Research Program (SHRP)
- Starting point is the Road Map

# Road Map

- 10 routes to arrive at the destination
- Each route in road map has:

Objectives	Gap	Approach to Fill Gap	Proposed Projects	Time line	Estimated Cost	Who Should Do It
------------	-----	----------------------	-------------------	-----------	----------------	------------------

# Road Map Routes

- **Route 1. Infrastructure management organizations that consider the full functionality of permeable pavements**
  - **Integration of Multi-Functional Priorities and Responsibilities**
  - **Planning and Development Codes**
  - institutional changes, i.e., bridging the gap between stormwater agency and road agency priorities and cultures
- **Route 2. Planning guidance that considers the multi-functionality of permeable pavements**
  - **Comprehensive Planning**
  - **Planning and Designing for Benefits and Impacts Across the Four Functions**

# Road Map Routes

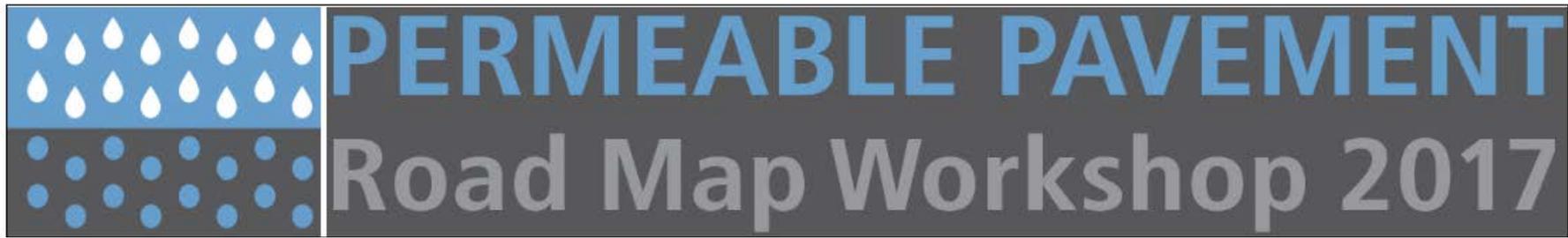
- **Route 3. Accurate life cycle cost analysis and environmental life cycle assessment tools**
- **Route 4. Reduction of target pollutants to meet water quality requirements**
  - Develop design decision trees/menus for reduction of target pollutants from existing and additional research
  - Include runoff reduction as an integral part of water quality management objectives, pollutant reduction credits
- **Route 5. Reduction of urban flooding risks**
- **Route 6. Reliable pavement structural designs**
  - **Pavement Structural Design Approaches**
  - Hybrid designs using pavers, asphalt and concrete
  - Permeable next to impermeable pavement and foundations
  - **Materials and Pavement Performance**

# Road Map Routes

- **Route 7. Routine achievement of high-quality construction**
- **Route 8. Maintenance and rehabilitation costs and methods**
  - Standard maintenance practices and cost guidance
  - Rehabilitation and end-of-life guidance
- **Route 9. Incorporation of permeable pavements into asset management systems**
- **Route 10. Efficient and comprehensive access to the best information**
  - **Communication between Industries and Users**
  - **Education and Training**
  - **Funding for Research, Development, Implementation**

# Next Steps

- Summer 2018:
  - Identify potential partners and existing groups
  - Begin to apply for funding
- Fall 2018:
  - Identify a Technical Working Group with existing and new stakeholders to guide implementation of road map
- 2018 to 2025:
  - Based on road map, implement a comprehensive plan and funding mechanism for collecting, communicating, and distributing information for use by local government, consultants, private developers, and state agencies
- 2019 to 2021:
  - Based on road map, complete a focused, intensive program of research, development, implementation tasks to fill gaps

The logo for the Permeable Pavement Road Map Workshop 2017. It features a dark grey background with a blue border on the left. The top part of the border contains a pattern of white water droplets, and the bottom part contains a pattern of blue dots. The text "PERMEABLE PAVEMENT" is written in large, bold, blue capital letters at the top, and "Road Map Workshop 2017" is written in smaller, grey capital letters below it.

# PERMEABLE PAVEMENT

## Road Map Workshop 2017

- Road map downloadable
  - Search “national center sustainable transportation permeable pavement”
  - [https://ncst.ucdavis.edu/wp-content/uploads/2018/08/NCST-Harvey Permeable-Pave-Road-Map-Sym Aug-2018.pdf](https://ncst.ucdavis.edu/wp-content/uploads/2018/08/NCST-Harvey%20Permeable-Pave-Road-Map-Sym%20Aug-2018.pdf)
- All presentations, breakout documentation, road map at web site:
  - Search “permeable pavement workshop davis 2017”
  - <http://www.ucprc.ucdavis.edu/permPvmt/>

Questions?



**University of  
Nottingham**

UK | CHINA | MALAYSIA



**UNIVERSITÀ  
DEGLI STUDI  
DI PALERMO**

# Towards SMARTI and automated road pavements

**Davide Lo Presti, Euro-PhD**

Visiting academic UNOTT (UK) / Assistant Professor UNIPA (IT)

TRB webinar, online event - 19 November 2020

# Why Me?



University of Nottingham

Nottingham Transportation Engineering Centre



UNIVERSITÀ DEGLI STUDI DI PALERMO

dij dipartimento di ingegneria unipa



multi-disciplinary, fundamental and applied Research and Education for preserving existing transport infrastructure and shaping future transport systems

# Why SMARTI?

## TODAY

### Current Transport Infrastructures are:

- high-impact buildings using very limited amount of secondary materials
- passive structure subject to fast ageing and changes
- requires on-site survey and expensive and extensive maintenance
- not designed to cope with climate and traffic change

## IMPACT

### Trained professional, Research products and guidelines of SMARTI:

low impact structures designed-to-last, being self-repairing and adaptable to extreme change, furthermore they will harvest energy to be self-sustaining and eventually provide energy to the surrounding buildings

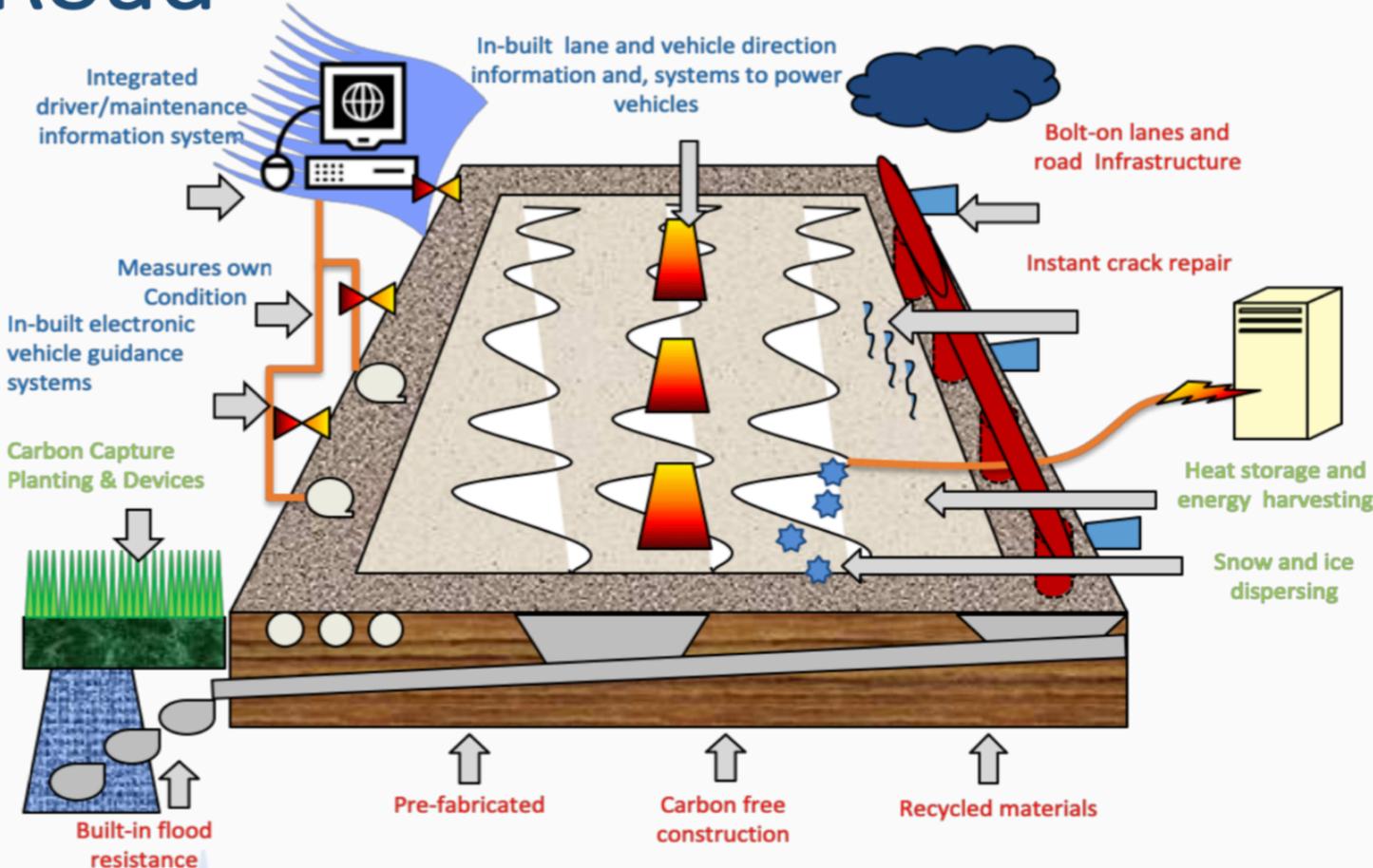


# The Forever Open Road

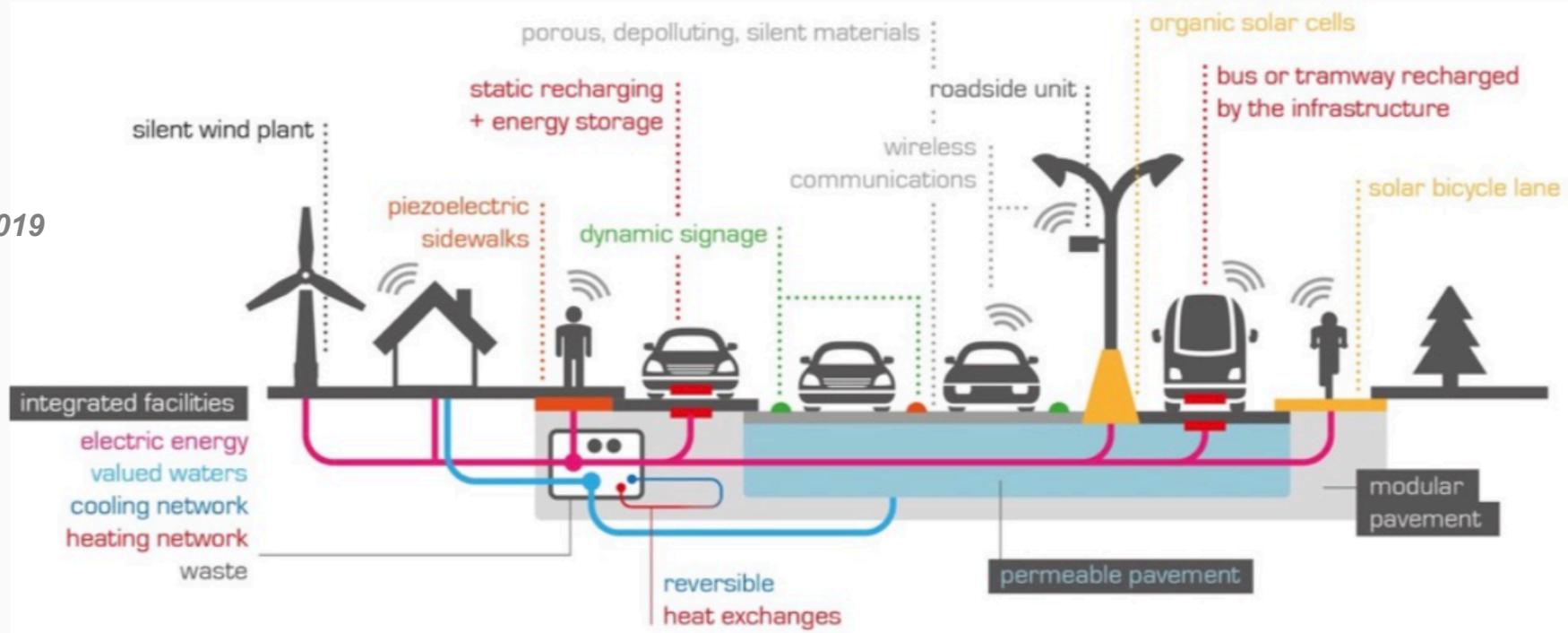
- Takes all our existing ideas and produces one solution that will support all our future needs....

- the Adaptable Road
- the Automated Road
- the Resilient Road

- **The Forever Open Road**

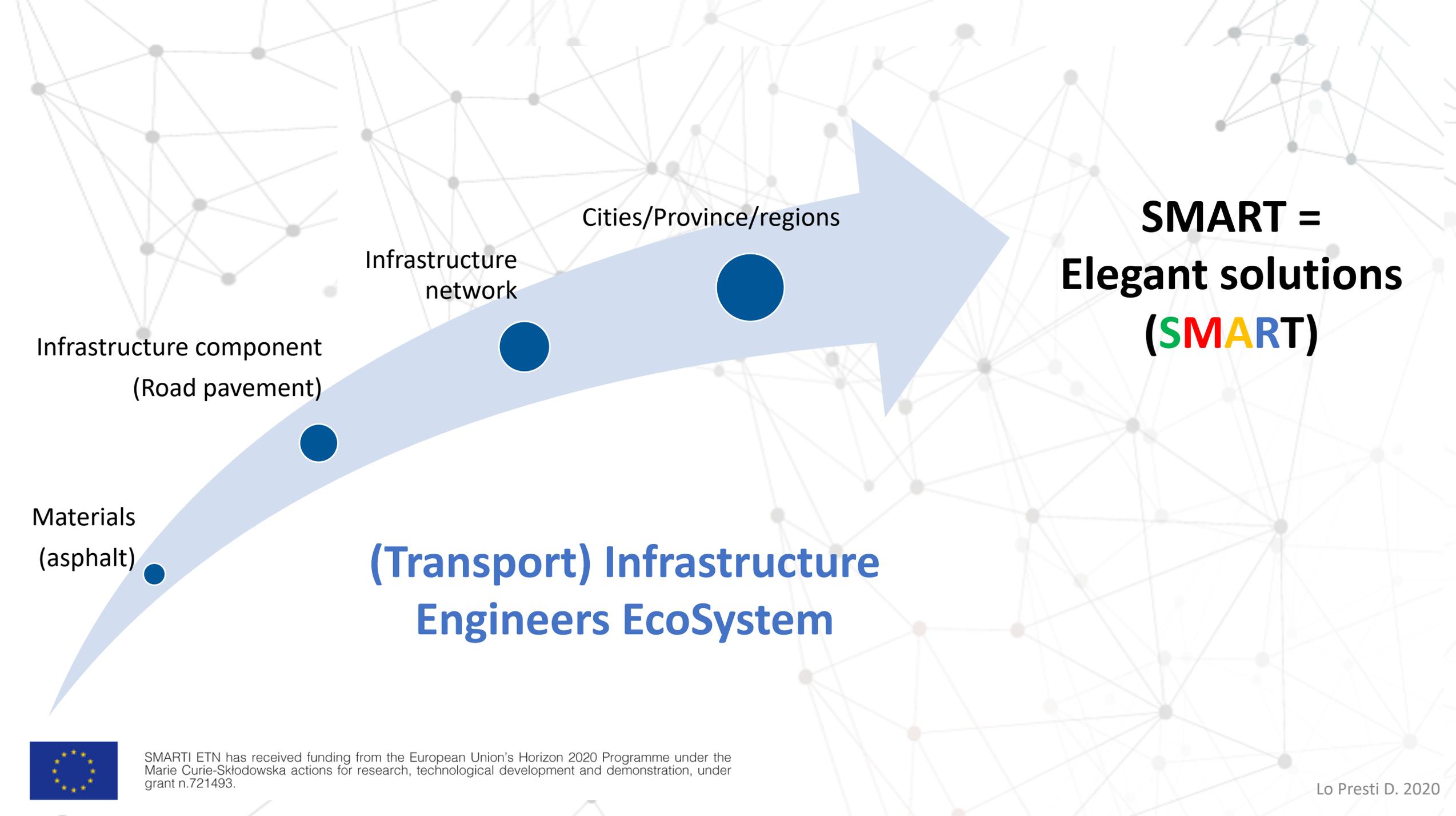


Hautiere, 2019



Hautiere, 2019

La roadmap "évolutions de la route" : route de 5e génération : route communicante / Nicolas Hautière in *Revue générale des routes et de l'aménagement (RGRA)*, (2018)955 (Juin 2018)



Infrastructure component  
(Road pavement)

Materials  
(asphalt)

Infrastructure  
network

Cities/Province/regions

# (Transport) Infrastructure Engineers EcoSystem

**SMART =  
Elegant solutions  
(SMART)**



SMARTI ETN has received funding from the European Union's Horizon 2020 Programme under the Marie Curie-Skłodowska actions for research, technological development and demonstration, under grant n.721493.

# What is SMARTI?

**S**

Sustainable

**M**

Multi-Functional

**A**

Automated

**R**

Resilient

# Transport Infrastructure

**S**ustainable  
**M**ulti-functional  
**A**utomated  
**R**esilient  
**T**ransport  
**I**nfrastructures

# SMARTI

European Training Network  
2017-2021



SMARTI ETN has received funding from the European Union's Horizon 2020 Programme under the Marie Curie-Skłodowska actions for research, technological development and demonstration, under grant n.721493.

# Who is in SMARTI ETN?



University of  
**Nottingham**  
UK | CHINA | MALAYSIA



UNIVERSITÀ  
DEGLI STUDI  
DI PALERMO



IFSTAR



UGR | Universidad  
de Granada

**AECOM**



**Dynatest**<sup>®</sup>  
THE ROAD FOR FUTURE TRAVEL



**EIFFAGE**

**GDG**  
GAVIN & DOHERTY  
GEOSOLUTIONS

A3IP (A3IP)  
Senceive LTD (SNCV)  
Piezonix llc (PZNX)  
GHT Photonics Srl (GHT)  
ELAB Srl (ELAB)  
GreenDelta Gmbh (GD)  
FIP Industriale (FIP)  
REPSOL (REPSOL)  
University College Dublin (UCD)  
University of California, Davis (UCDAVIS)  
Ecole Polytechnique, Paris (LPCIM)  
Polytechnic University of Hong Kong (HKPU)

University of NewCastle (UONAUS)  
Highways England Company Ltd (HE)  
Società per l'Aeroporto Civile di  
Bergamo-Orio al Serio (SACBO)  
Conference of European Directors of  
Roads (CEDR)  
Smart Transport Alliance (STA)  
Cardno IT Transport (CGNTV)  
Comune di Palermo (MUNPA)  
Research Driven Solutions (RDS)



SMARTI ETN has received funding from the European Union's Horizon 2020 Programme under the Marie Curie-Skłodowska actions for research, technological development and demonstration, under grant n.721493.

# Why SMARTI ETN?

## TODAY

### Current Transport Infrastructures are:

- high-impact buildings using very limited amount of secondary materials
- passive structure subject to fast ageing and changes
- requires on-site survey and expensive and extensive maintenance
- not designed to cope with climate and traffic change

## SMARTI ETN

### SMAR experts + TI stakeholders training fellows in developing:

- TI components' prototypes of Sustainable Multi-Functional Automated Resilient Transport Infrastructure
- novel decision making frameworks, asset management methodologies and sensing technologies
- SMARTI guidelines for exploitation in EU and developing countries

## IMPACT

### Trained professional, Research products and guidelines of SMARTI:

low impact structures designed-to-last, being self-repairing and adaptable to extreme change, furthermore they will harvest energy to be self-sustaining and eventually provide energy to the surrounding buildings



**PARTNER ORGANISATIONS**  
of Infrastructure managers:  
Roads, Railways, Airports



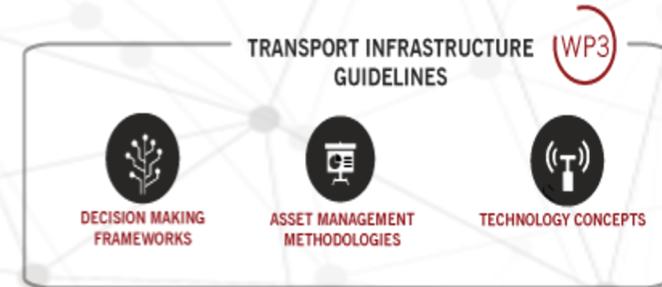
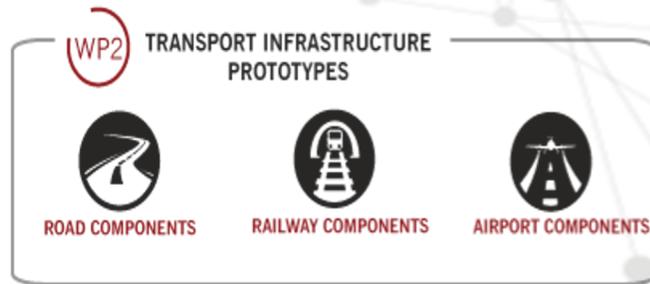
**PARTNER ORGANISATIONS**  
Experts and trainers in SMARTening of  
systems

**BENEFICIARIES**

Experts on Research and Educatuion  
Transport and Infrastructure stakehold



**15 FELLOWS AND RELATIVE INDIVIDUAL TRAINING-THROUGH-RESEARCH PROJECTS**



**SMARTI**  
Prototypes and Guidelines  
for early exploitation and dissemination



***Culture change through Innovation and Education***



- S**ustainable
- M**ulti-functional
- A**utomated
- R**esilient
- T**ransport
- I**nfrastructures

# What is SMARTI ETN?

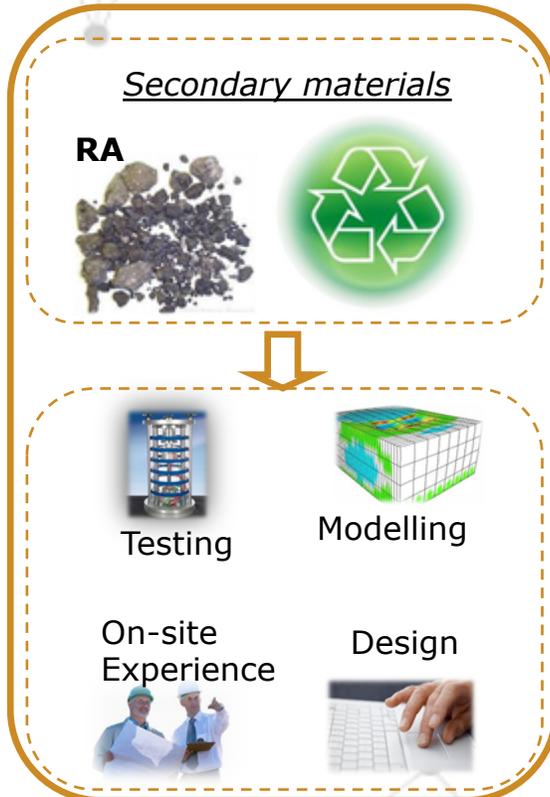


# SUSTAINABLE TI:

design to last, maximise recycling, minimise  
the impact

## How can we maximising recycling and minimises the impact?

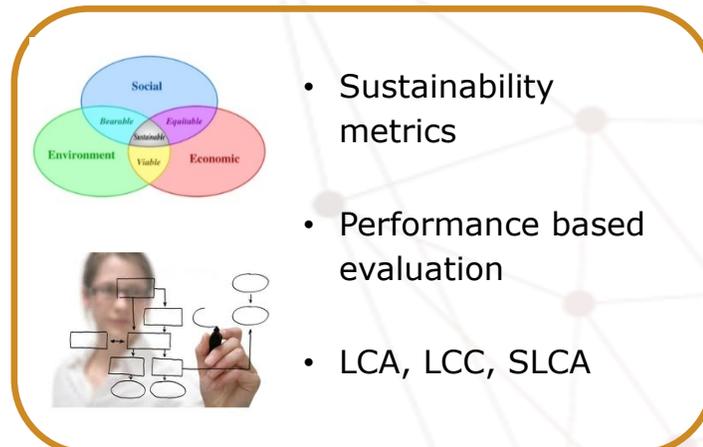
### Asphalt Technologies development



Maximise recycling



Minimise impact



Up to

# 80%



of products' environmental impacts are determined at the design phase

EU circular Economy action plan 2020  
#EUgreenddeal

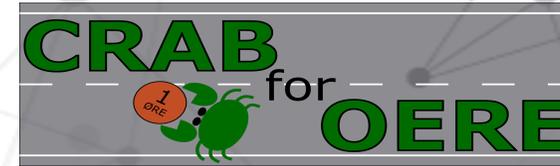
### "GreenER" Asphalt/pavement Sustainability Assessment

# SUSTAINABLE TI

## How can we maximising recycling and minimises the impact?



[allback2pave.fehrl.org](http://allback2pave.fehrl.org) AllBack2Pave



- Can we come out with a harmonized design for cold recycled base courses?

- Algoroute (FR) aims at developing a bio-binder issued from the micro-algae industry.
- Biorepavation (EU) project aims at demonstrating that the reuse of asphalt pavement materials can be facilitated by the use of bio-sourced materials.



- Eurovia (FR) built in 2018 the first 100% recycled motorway pavement.



- Plastic road (NL) aims at building roads from recycled plastics.



- Next challenge: how many times a road can be recycled?



Hautiere, 2019

Pavement carrousel Nantes – Summer 2017

Cradle

Gate

Laid

Grave

## Pavement materials SA

Product development/  
Cradle-to-Gate

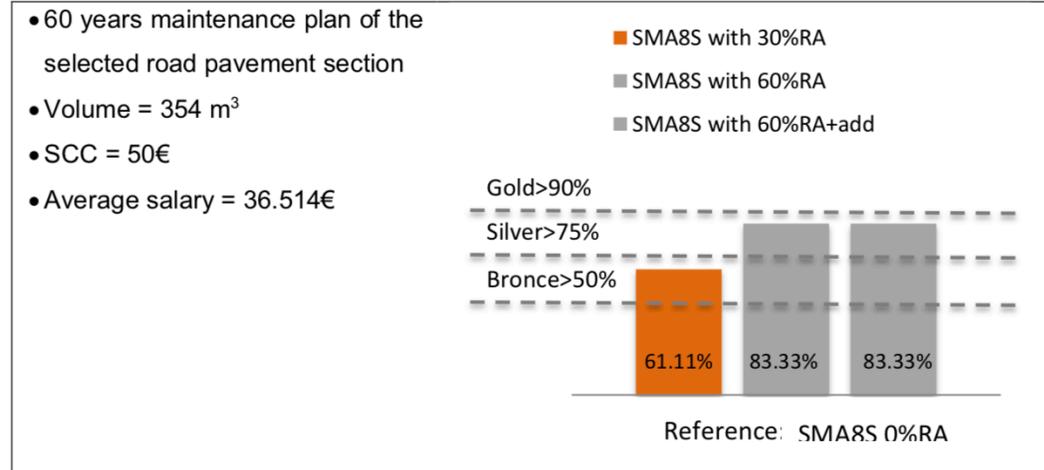
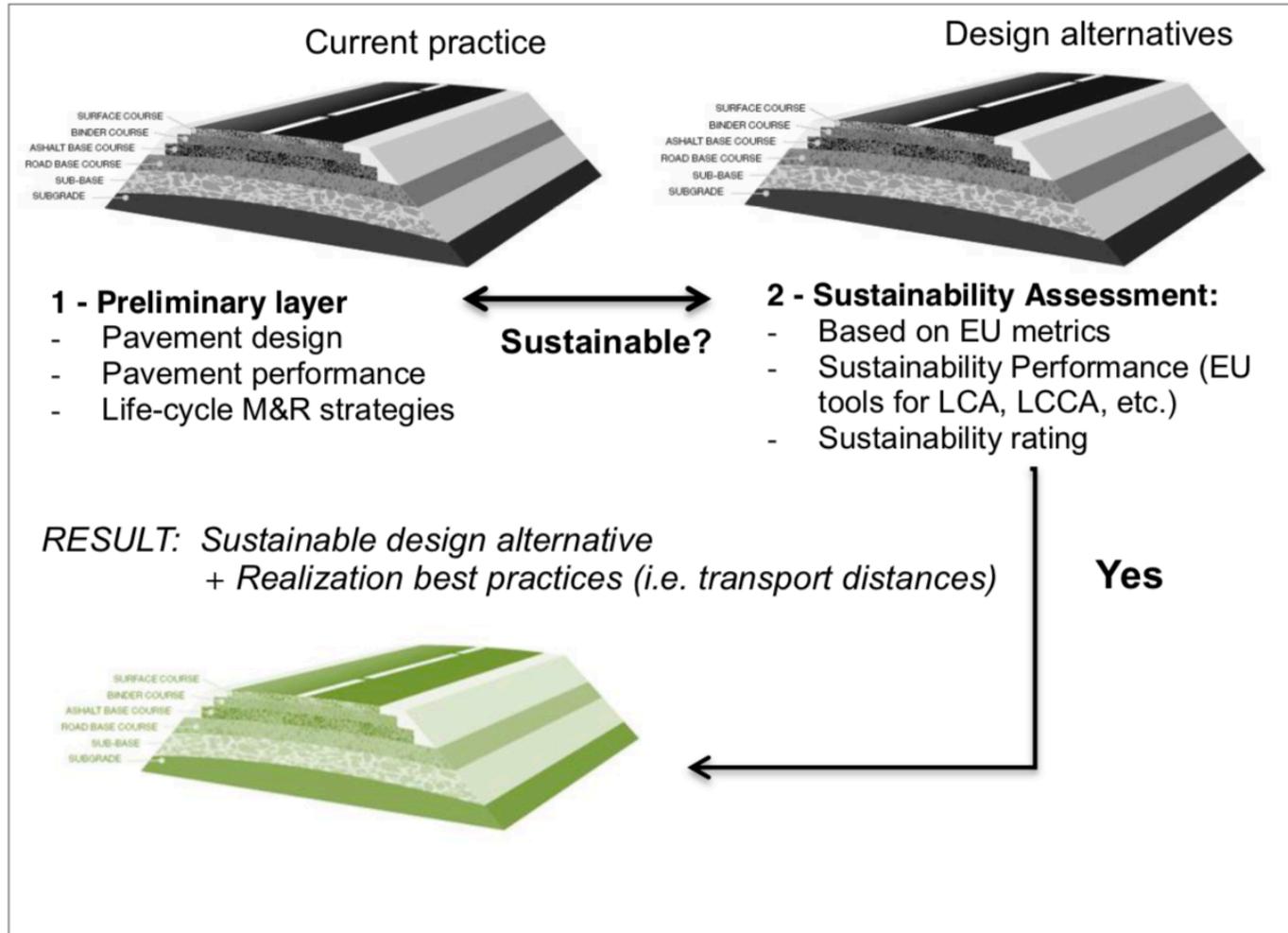
- Supporting DM in Product development (Eco-design)
- Material scientists
- Material supplier/Waste managers
- Asphalt manufacturer/contr.

## Pavement activities SA

Asset management  
Cradle/laid-to-grave

- Supporting DM in development of Maintenance strategies (durability)
- Pavement engineers
- Asphalt contractors/manuf.
- Road Authorities

## How can we maximising recycling and minimises the impact?



**PavementLCM**  
pavementlcm.eu

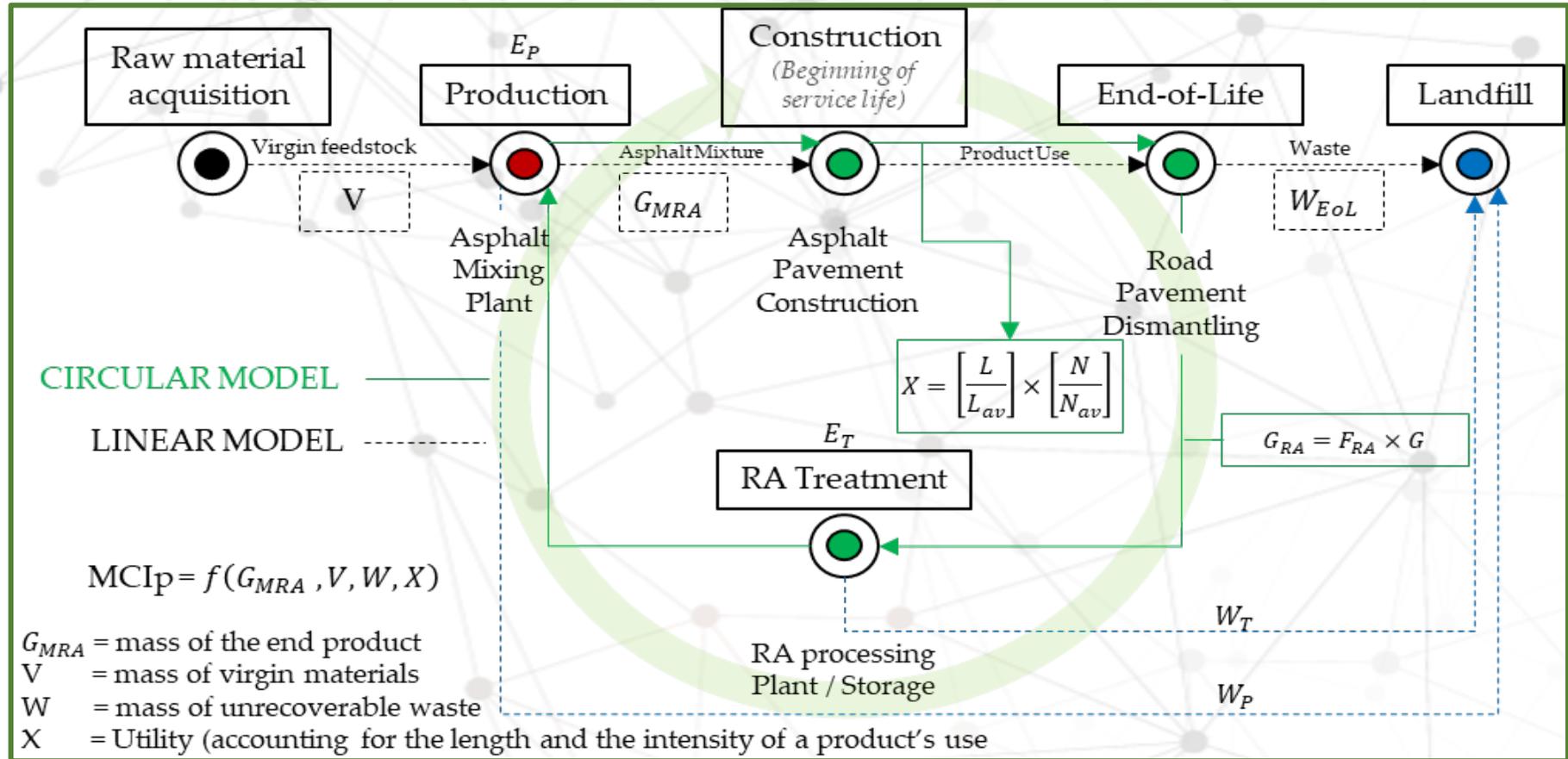
# “Sustainable and Circular Pavement Life Cycle Management”



Konstantinos Mantalovas  
ESR10



Konstantinos.Mantalovas@unipa.it



Life Cycle Sustainability Assessment + Circular Economy

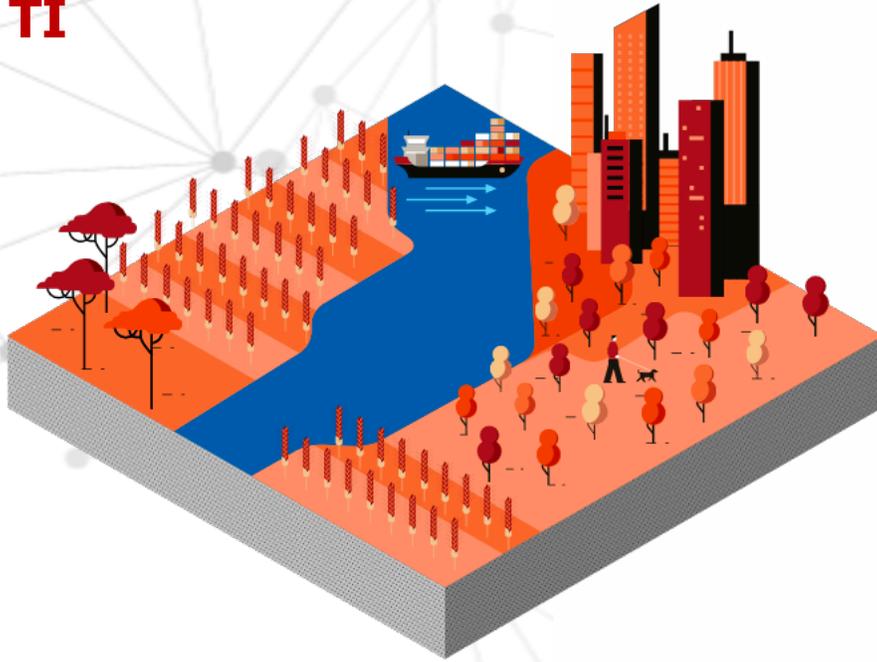
# MULTI-FUNCTIONAL TI:

*conceived not for transport purposes only  
and towards optimization of land use*

## Multi-functional TI

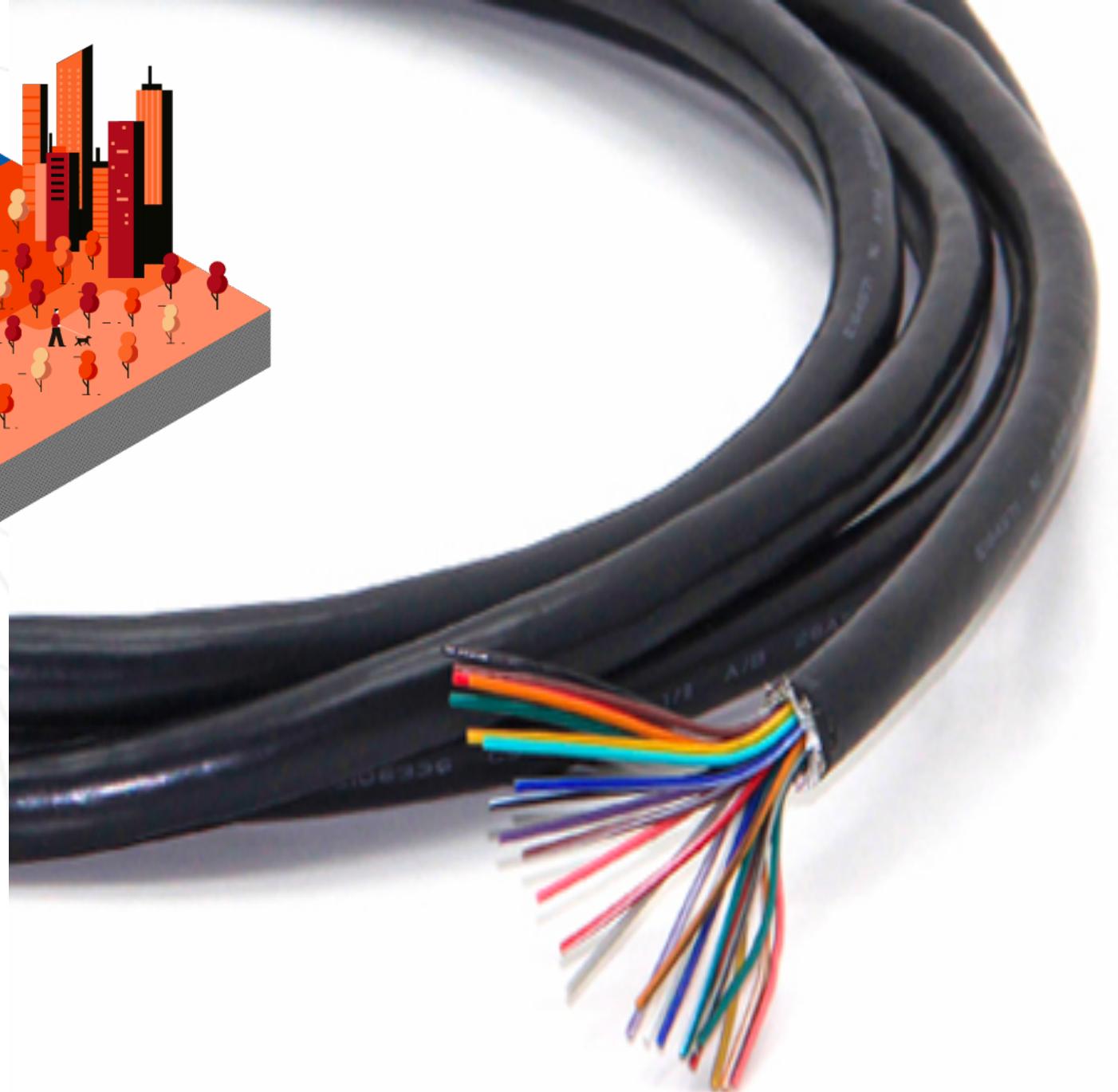
### Aim:

Optimisation  
of land use



### OPPORTUNITY:

- TI not for transport only
- TI part of ecosystem
- Energy creation/consumption
- Extended linear Sensing system network
- ✓ for the built environment
- ✓ sensing system for the planet



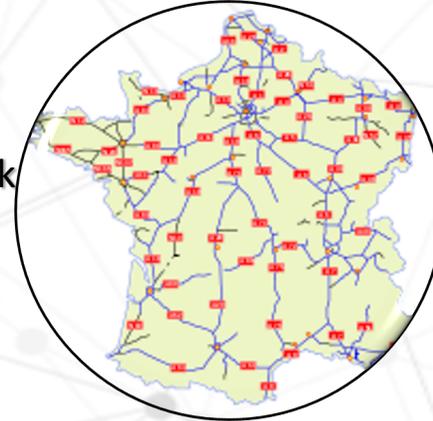
# MULTI-FUNCTIONAL TI:

Why harvest energy using the road pavement?



Exploit existing surfaces to harvest energy

Road network in France: 965446 km



50 Wh/m<sup>2</sup>



Photovoltaic road



Heat exchanger



0.2 Wh/m<sup>2</sup>

Piezoelectric road

# MULTI-FUNCTIONAL TI:

## The idea: the expected prototype

Design an hybrid system (**photovoltaic road + heat exchanger**) able to harvest energy from the sun and composed by:

Semi-transparent layer (glass + polyurethane)

Solar cells

Porous concrete layer

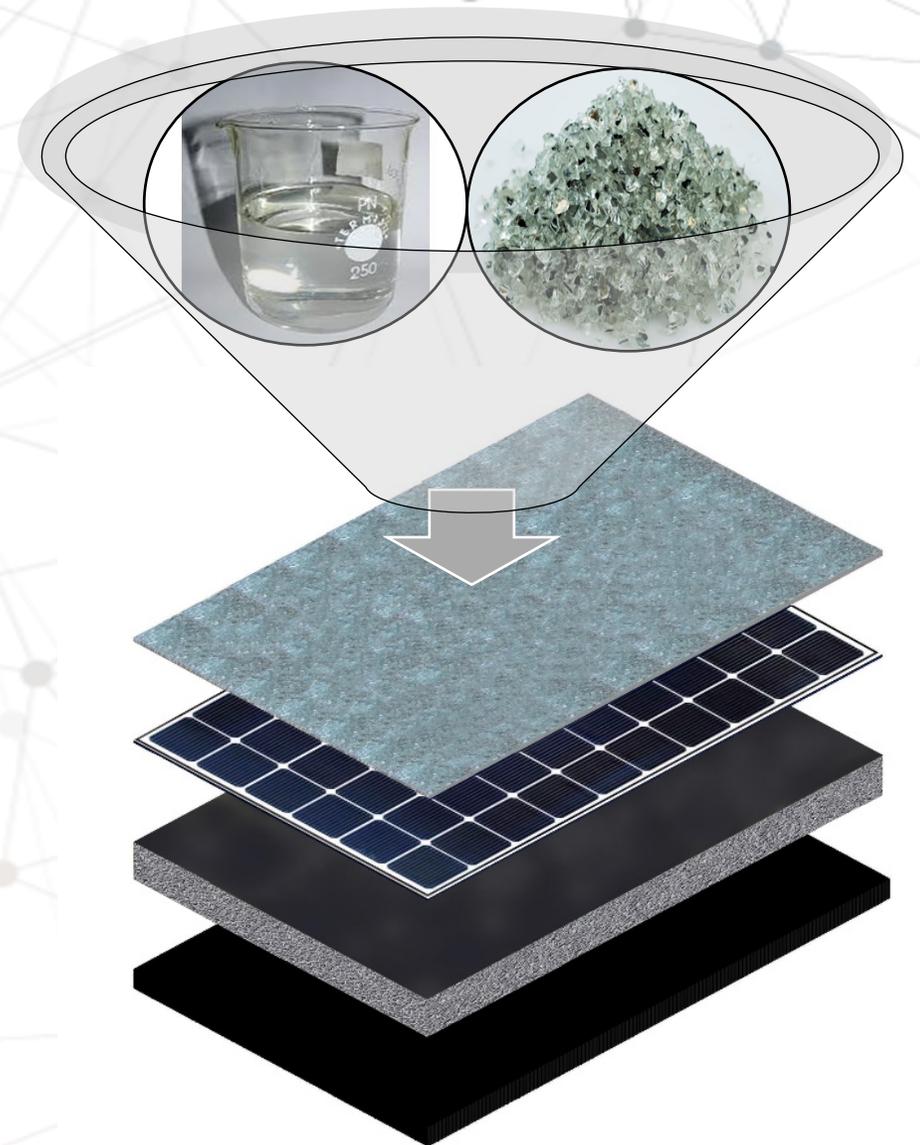
Base layer



Domenico Vizzari

ESR3

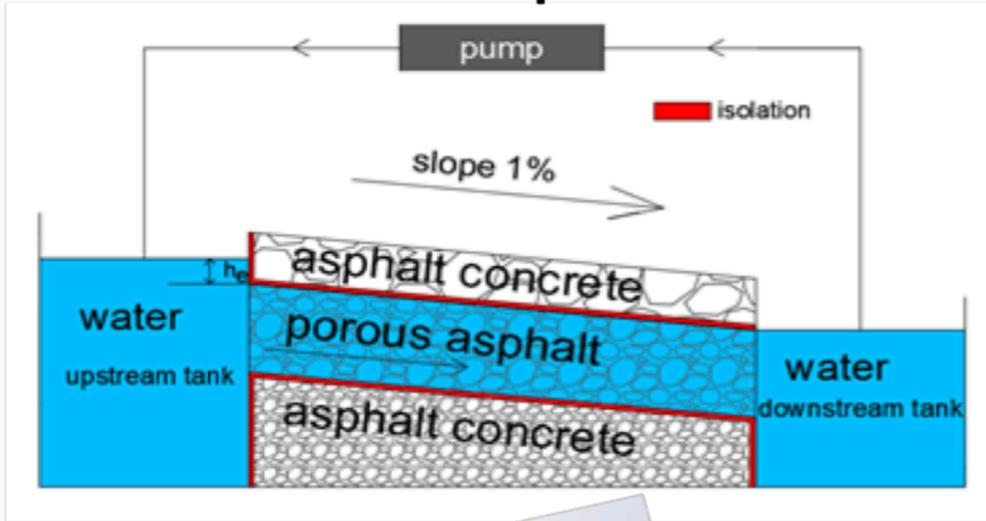
“RA2ROAD”



# Solar road

## Heating and cooling pavements

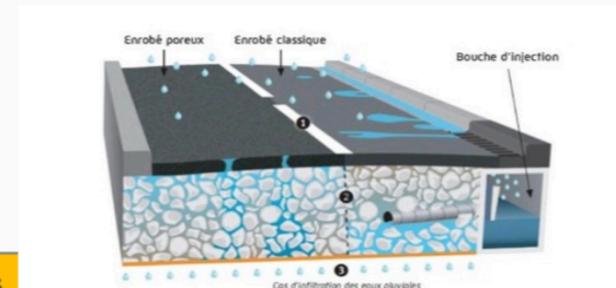
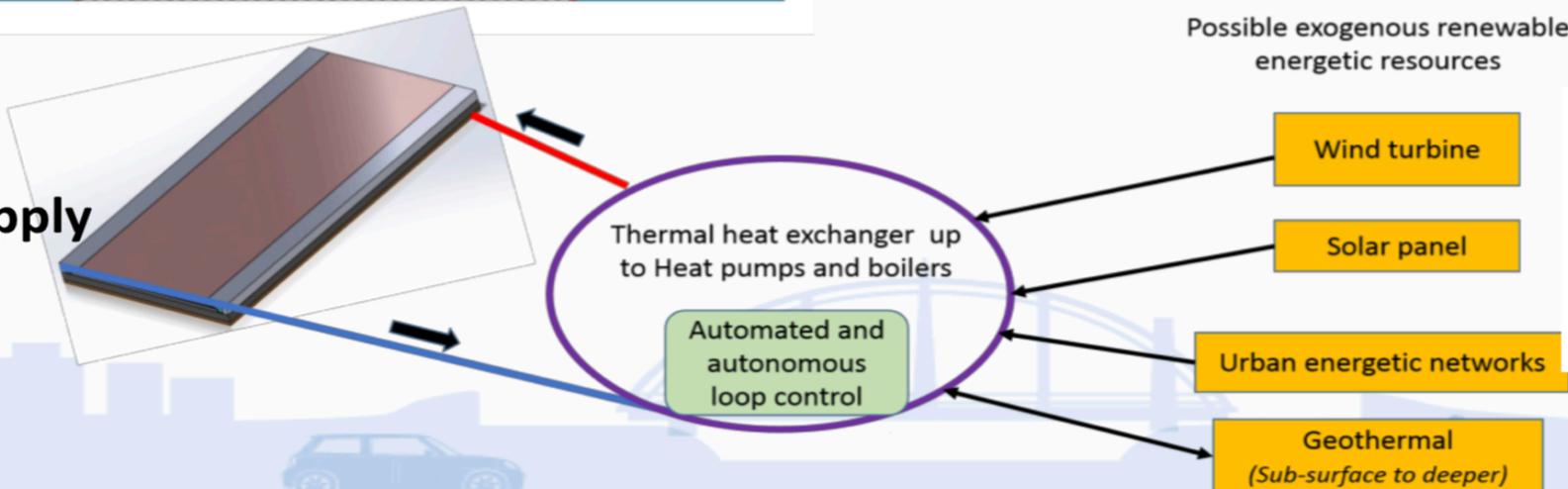
### Principle



### Demonstrator



### Energy supply system





# Road Infrastructure as a CO<sub>2</sub> Capture Factory



## CO<sub>2</sub> capture by micro-algae roadside production units

- The ANR [CANOPEE](#) project designed concepts for micro-algae production.



Hautiere, 2019

## CO<sub>2</sub> storage by recarbonation of recycled concrete aggregates

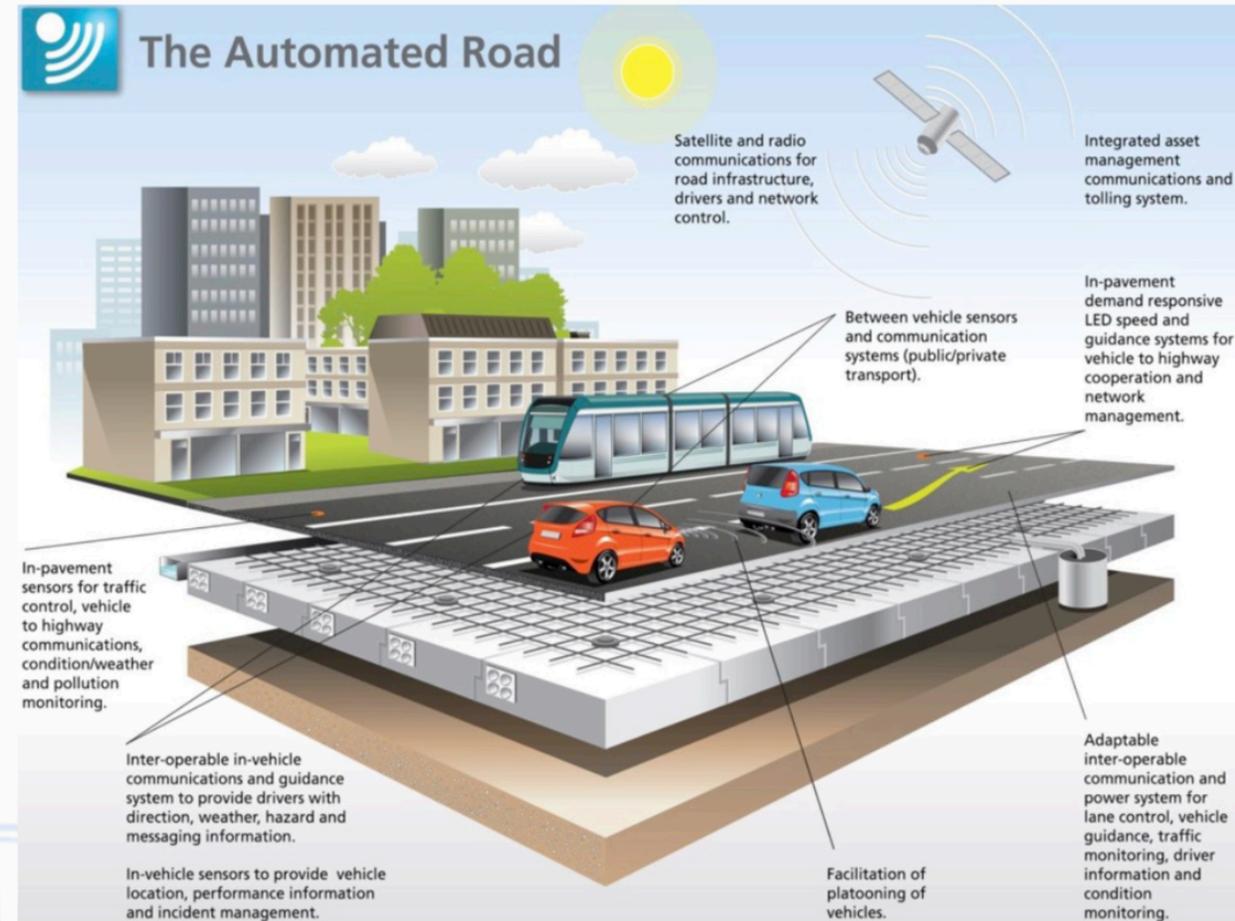
- The IREX [FastCarb](#) project aims at storing CO<sub>2</sub> using concrete aggregates



# AUTOMATED TI:

*equipped with sensors to allow pro-active communication towards a more intuitive use and a simplified management*

- Fully integrated with the user, vehicle, services and operations
  - Will incorporate a fully integrated information, monitoring and control system;
  - Will support a co-cooperative vehicle-highway system that will manage travel demand and traffic movements.
  - Will ensure the co-existence of autonomous, connected and conventional vehicles
  - Will measure, report and respond to its own condition, providing instant information on weather, incidents and travel information.



# AUTOMATED TI:

## CROWD MONITORING + SMART DATA ANALYSIS

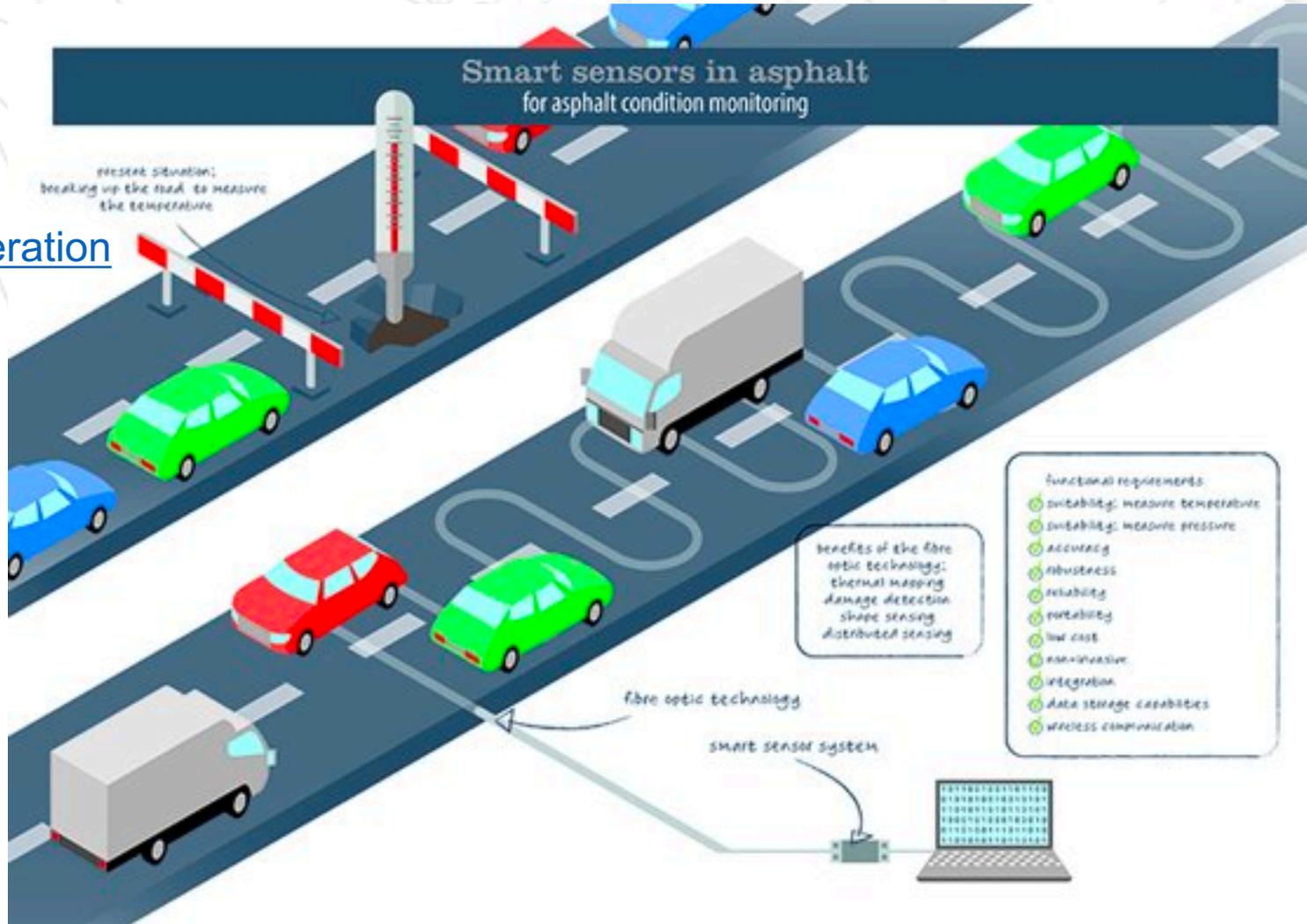
- Mobile phones
- Vehicles

## EMBEDDED TECHNOLOGIES

- Piezo-electric sensors + electronics
- Fibre Bragg Gratings (FBG) technology
- Wireless systems

## AIMS:

- Enable communication for Managers/Users
- Predictive maintenance
- Pavement design



## WHAT DO WE WANT TO MEASURE?

# Mechano-Mutable Materials

Conventional AM + Magnetic particles + Magnetic Field  
**= SMART MATERIAL (MAM)**

Aggregate (coarse)

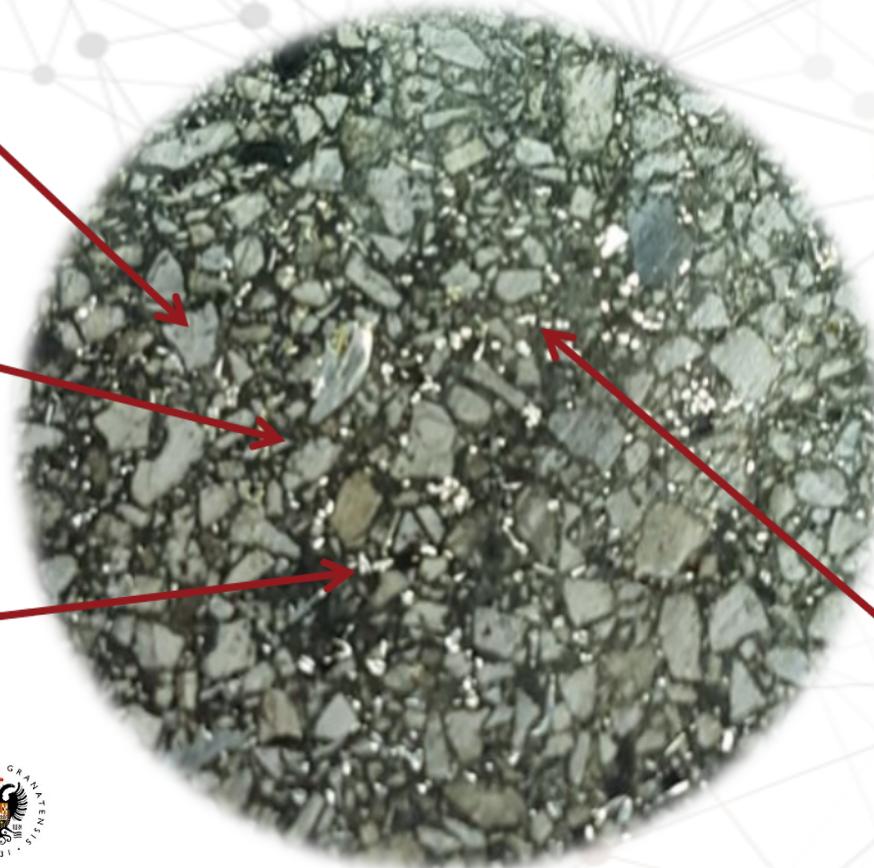
- Mechanical performance: lineal-elastic.

Filler (fines)

- Mechanical performance: lineal-elastic.

Asphalt binder

- Mechanical performance: viscoelastic

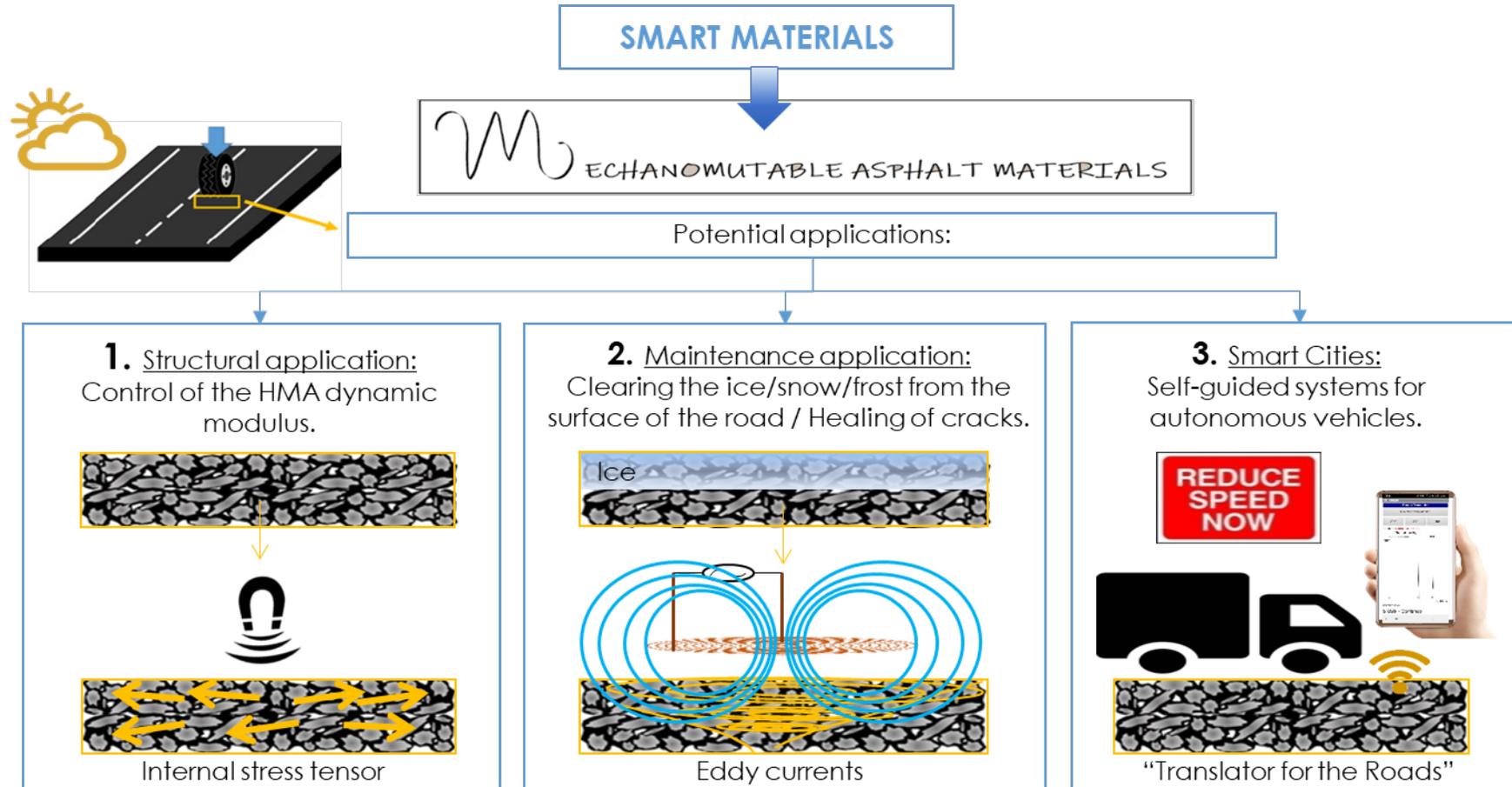


Magnetic particles

- Mechanical performance: magnetic (under activated fields).

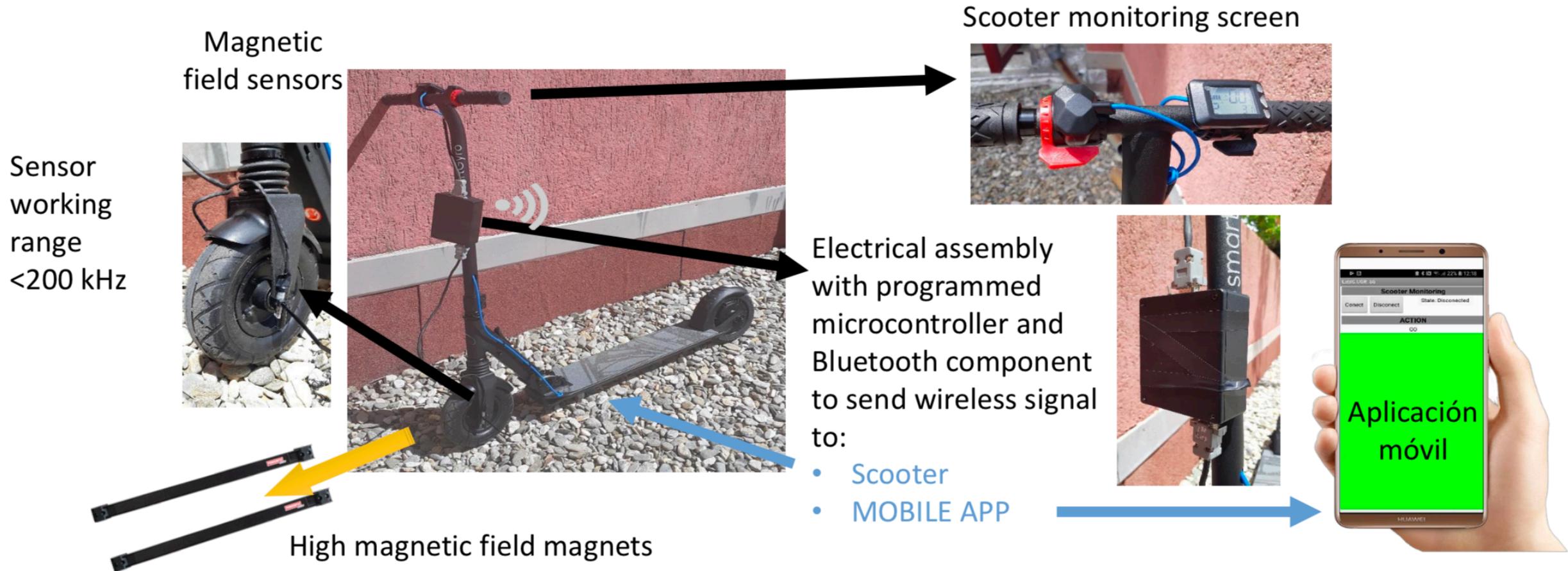
# Mechano-Mutable Materials

**ROADS OF FUTURE:** SMART structures that require of:



# Mechano-Mutable Materials

## Scooter Concept test 1

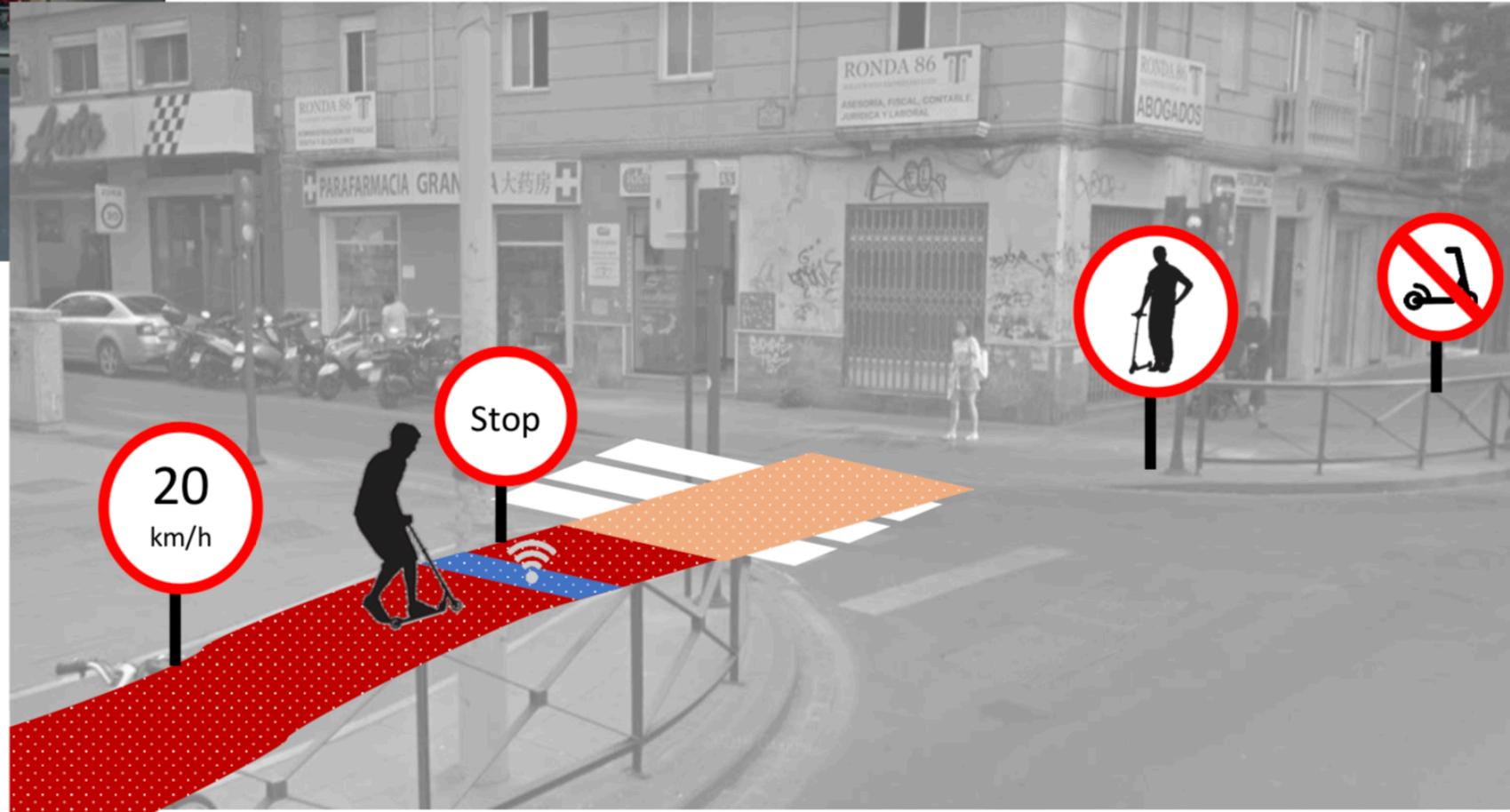


# Mechano-Mutable Materials

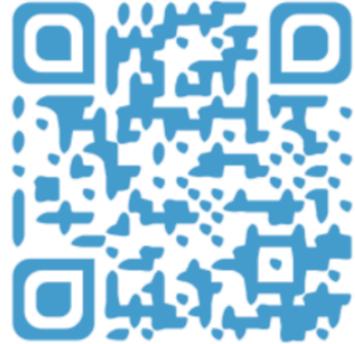
---



# Mechano-Mutable Materials



Thank you very much!



Paulina Leiva-Padilla  
ESR14 - SMARTI ETN

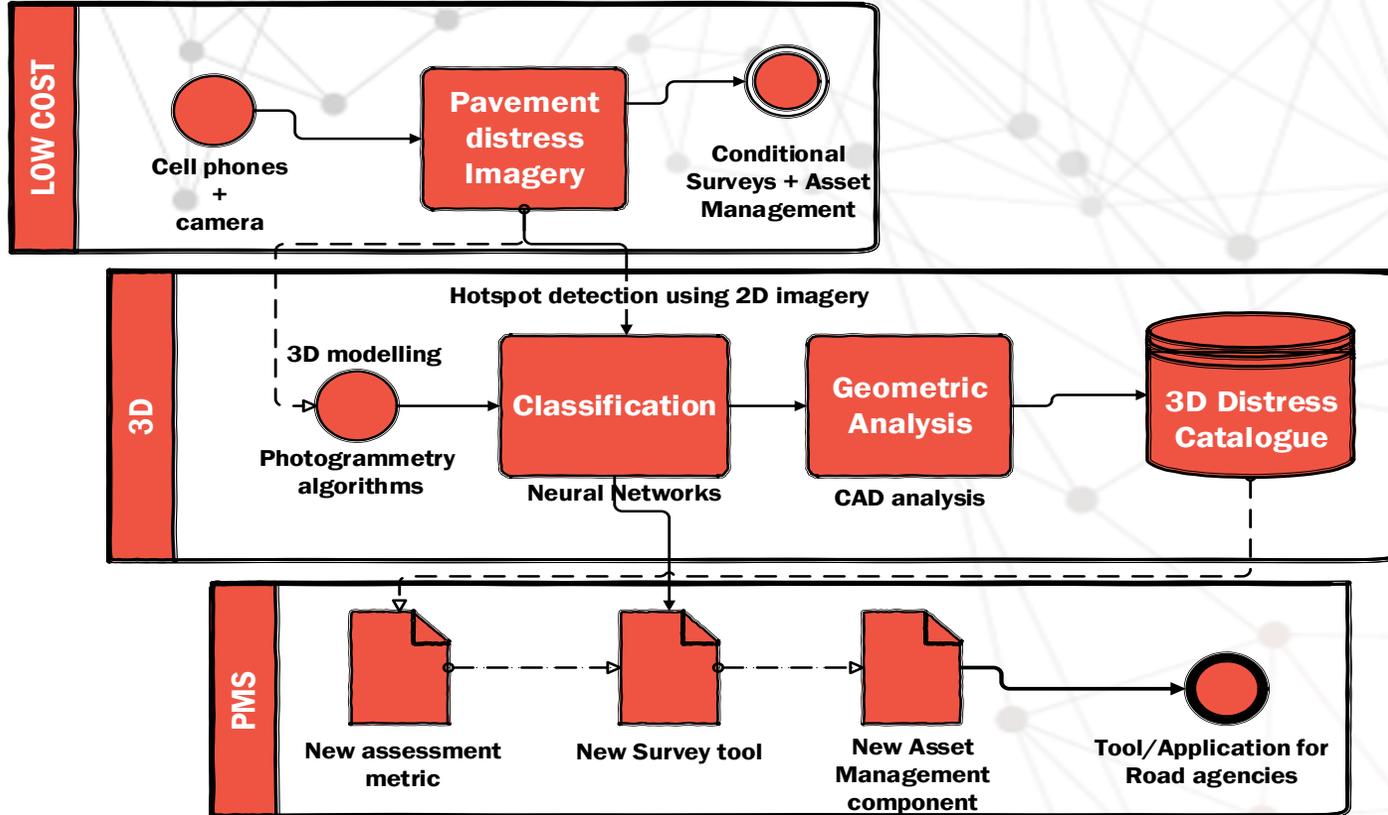
[pleiva@ugr.es](mailto:pleiva@ugr.es)

<https://esr14smartietn.blogspot.com/>

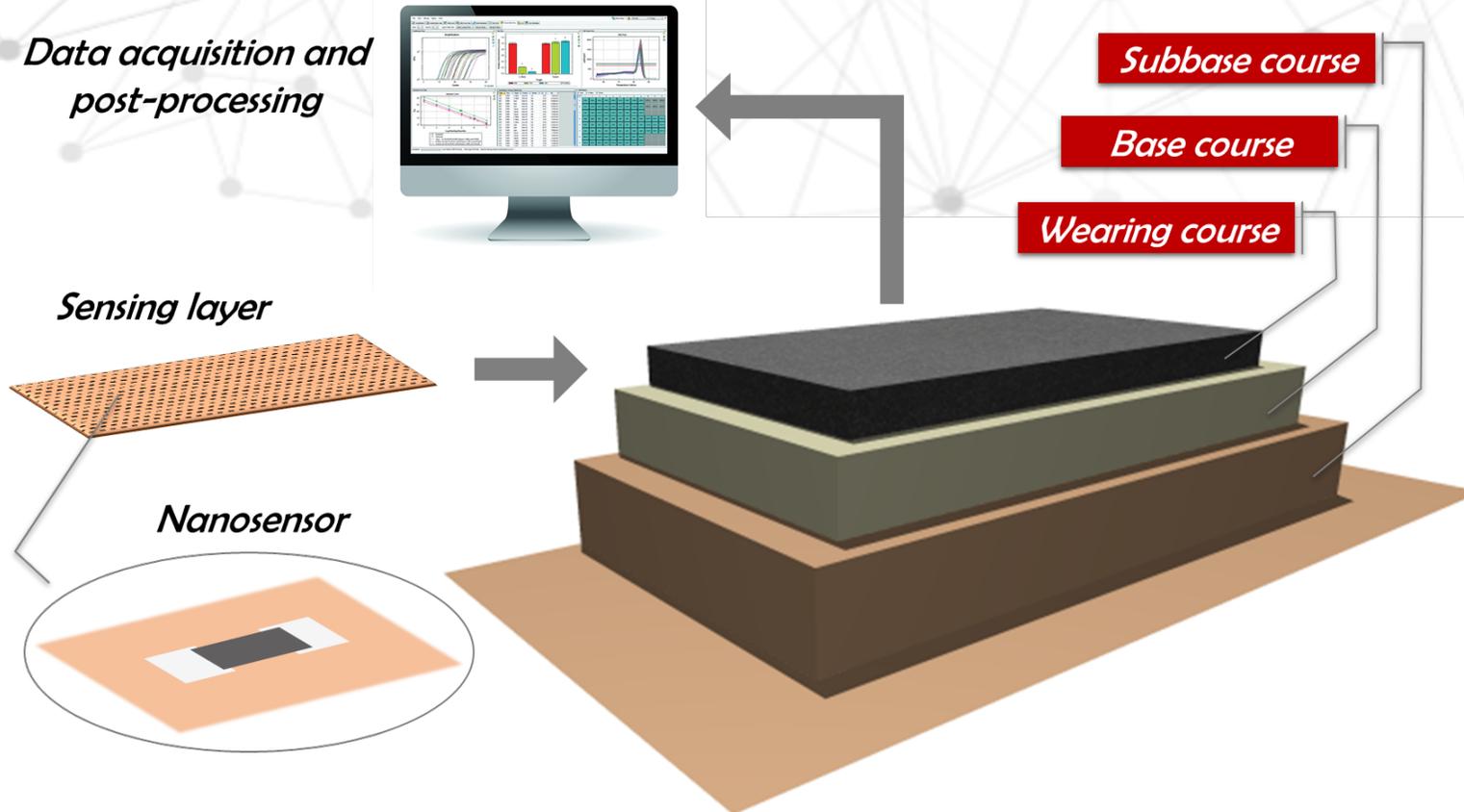


The SMARTI ETN project has received funding from the European Union's Horizon 2020 Programme under the Marie Skłodowska-Curie actions for research, technological development and demonstration, under grant n.721493.

“SuRoMa”




# ESR2 project - Nanoasphalt



# Contacts



Fellow: ***Maria Barraiera***

Host institution: ***EIFFAGE (Lyon, France)***

Doctoral School: ***Ecole Polytechnique (Paris, France)***

Contacts:

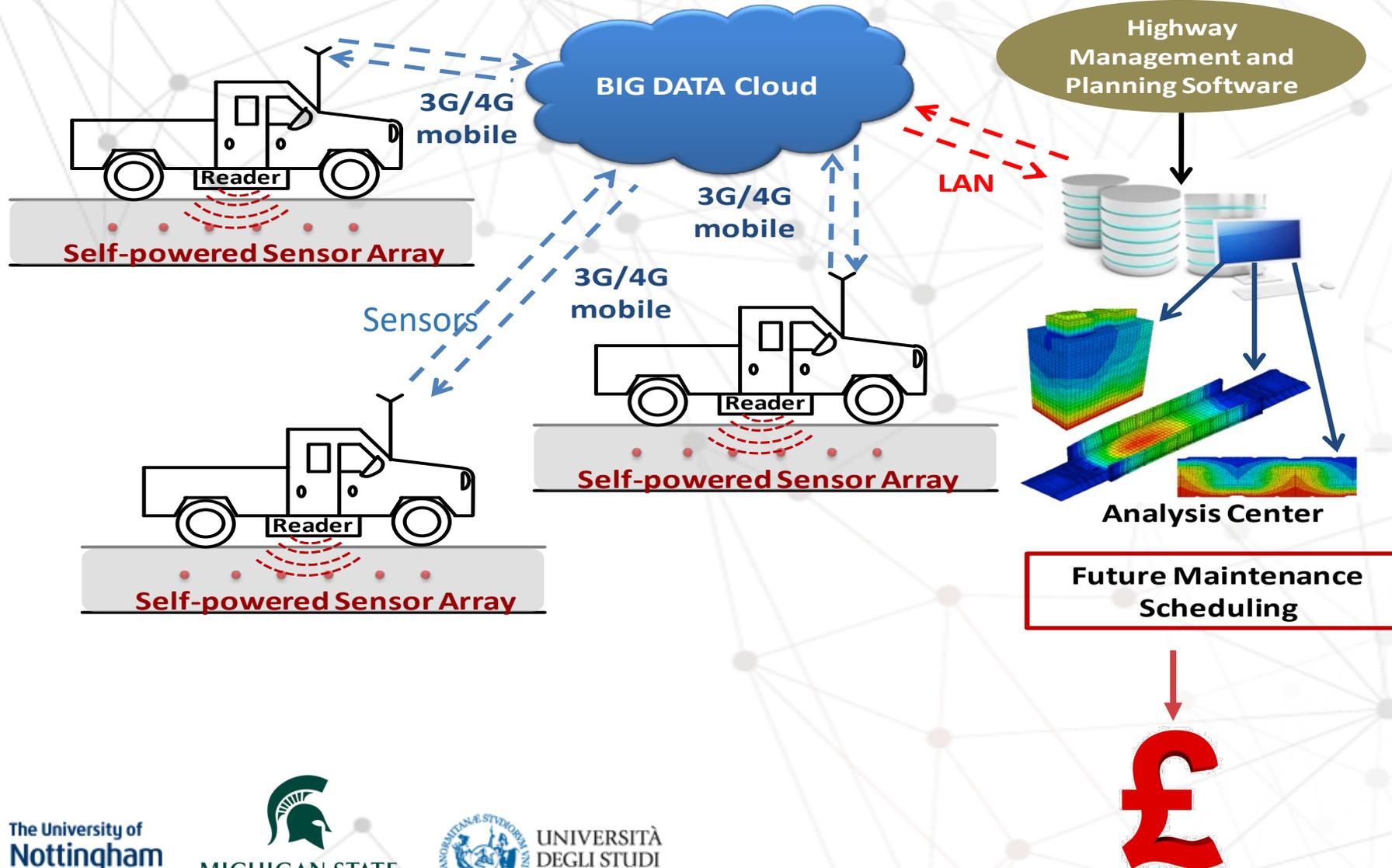
Email: maria.barraiera@eiffage.com

Blog: <http://esr2smartietn.blogspot.com/>

Social media:



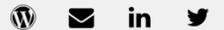
# SmartEcoPave/Track – ESR 5/7



**Mario Manosalvas Paredes**

ESR 7

“SMARTECOPAVE”



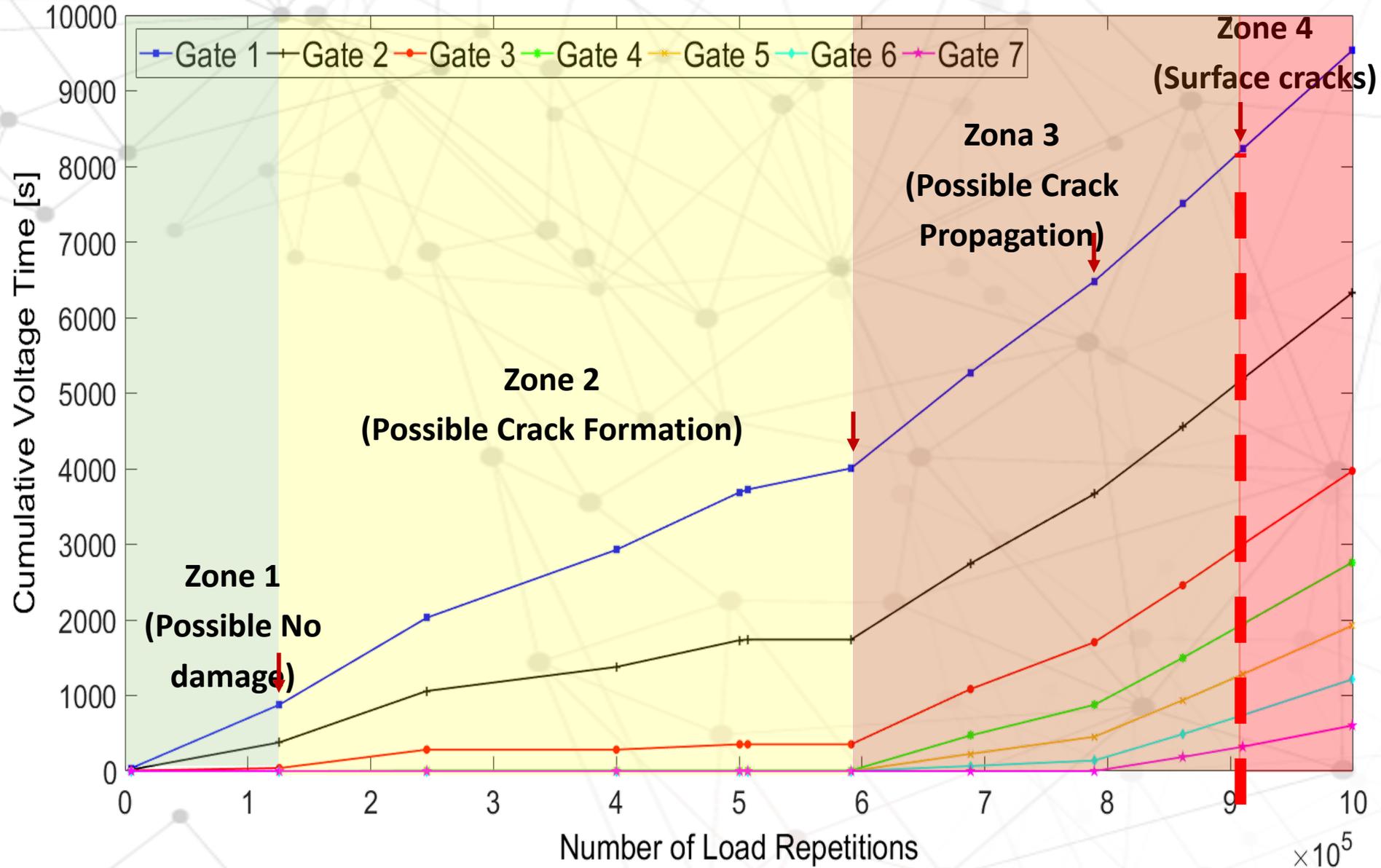
**Rufus Adjetey Nii-Adjei**

ESR 5

“SMARTECOTRACK”



# W-PFG Sensor – Validation Study



# Conclusions for AUTOMATED pavements

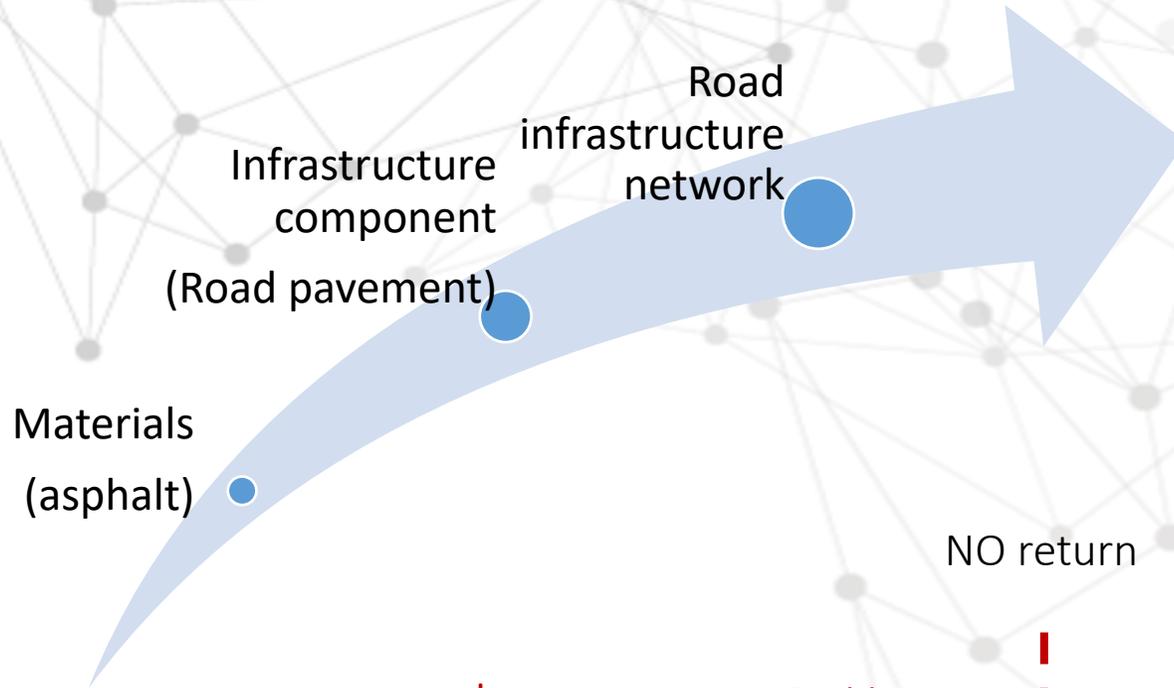
---

- **Data-driven approach** is needed for better design of materials and pavement and management of the asset
- **Pavement Monitoring should move from STATIC to DYNAMIC (real time?)**  
current monitoring solutions relies only on external monitoring equipment and current sensing system are too expensive for a wide-spread use.
- **Embedded pavement sensing systems will allow to**
  - Improve paving material response models – short term
  - Improve pavement design procedures (shift factors) - medium term
  - Finally potentially help in asset management – long term
- **SMART data analysis** of existing/crowd data should be considered as a smart(er) solutions

# RESILIENT TI:

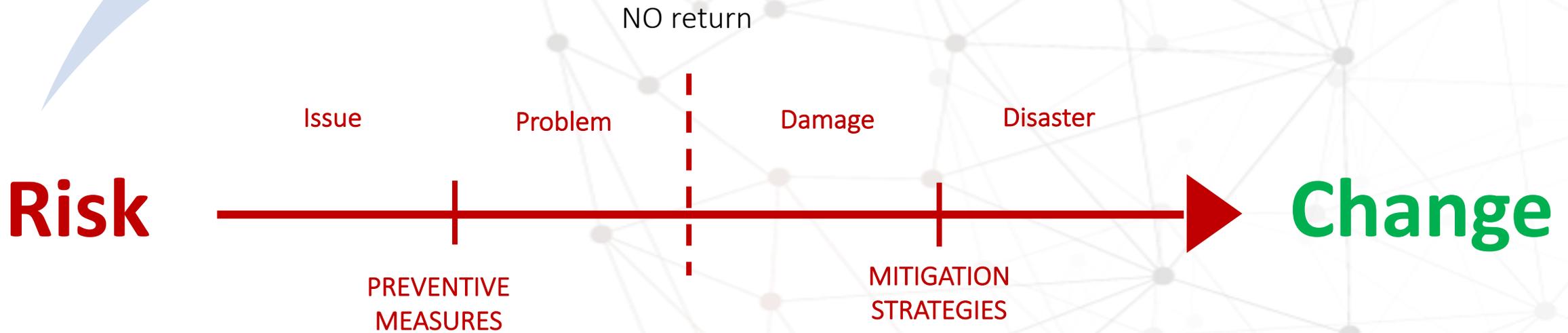
*conceived to self-repair and be adaptable to changes due to natural and anthropogenic hazards*

# RESILIENT TI



**Resilience:**  
the capacity of a system to recover from difficulties (change), by managing risk

*Personal statement adapted from Oxford dictionary*



## WHY?

- RISK/CHANGE - We live within a DYNAMIC system with constant changes: Nature
  - Human resilience
  - If nature evolves/adapts why don't we adapt to it?
- RISK/CHANGE - Anthropogenic changes (caused by Human)
  - Human population + traffic
  - Terroristic attack
  - Period of drastic/ exponential changes (weather and climate change)
- SYSTEM - Infrastructures are built to be run
  - Increased ageing of existing infrastructure
  - Scarcity of non-renewable resources
  - Durability and perpetual pavement concept
  - Sustainability calls for cost-effective intervention, reduced maintenance
  - Guarantee Transport => connecting people



## HOW?

### - MATERIALS (Asphalt technologists)

- POLYMER MODIFIED BITUMEN (weather, UTI)
- RECYCLING and BIOBINDERS (scarcity natural resources)
- PHASE CHANGING MATERIAL (changing mechanical properties)
  - Mechano-mutable Asphalt Materials
  - Heat dissipating materials
  - Self-healing materials (metal fibers or capsules)
- VIRTUAL MATERIAL/LABORATORY (predicting mechanical properties)
  - Computational capacity of our machines is increased
  - Complex materials could need adaptation of testing

### - INFRASTRUCTURE COMPONENT/ROAD PAVEMENT SECTIONS AND NETWORK (Contractor and Asset managers)

- ASSISTED CONSTRUCTION PROCESS (IC,IR, etc..)
- PREVENTIVE MAINTENANCE (Smart data analysis)
  - Responsive pavement (sensors)
  - Big data harvesting from vehicles (mobile phones)
  - Smart analysis of existing data
- ROAD NETWORK Guarantee traffic flow (planning)



<http://smartienn.eu>



[www.foreveropenroad.eu](http://www.foreveropenroad.eu)



[www.ifsttar.fr/en/research-expertise/major-projects/r5g-5th-generation-road](http://www.ifsttar.fr/en/research-expertise/major-projects/r5g-5th-generation-road)

# WHERE?

## The Pre-Fabricated Road

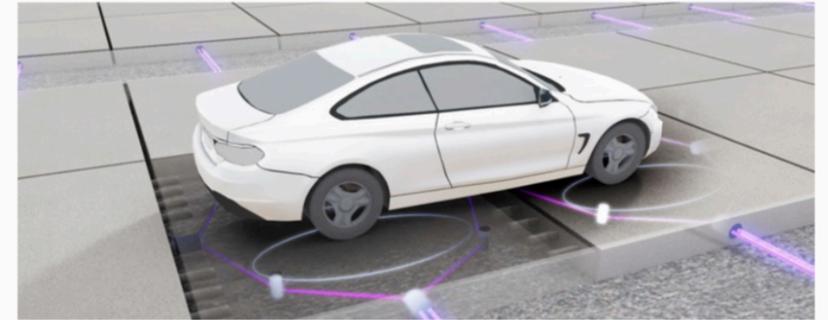
### CUD-FR

- Urban pavement for smart city planning



### INTEGRATED ROADWAYS - USA

- Durable, precast concrete sections embedded with digital technology and fiber optic connectivity to transform ordinary roads into smart roads.



### MODIESLAB - NL

- Integrated motorway pavement



**INTEGRATED  
ROADWAYS**



# WHERE?

Removable urban pavement: RUP



More information: [thierry.sedran@ifsttar.fr](mailto:thierry.sedran@ifsttar.fr)

## WHERE?

- INFRAVATION PROGRAMME
  - SELF-HEALING pavement (EU, UK)
  - Post-fossil fuel society pavement
- CLIMATE CHANGE
  - Thermochromic lines
- DECISION FRAMEWORK
  - SMARTI
- RESILIENT PLANNING
  - the "route du Littoral" in La Réunion Island:  
<http://www.nouvelleroutedulittoral.re>

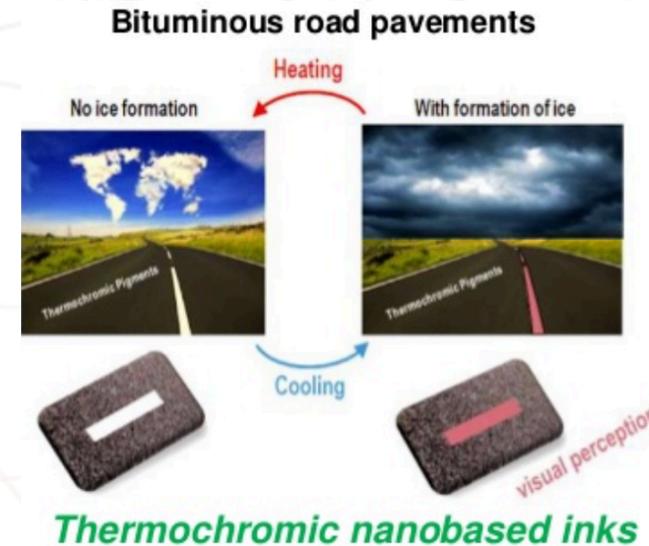


<http://www.infravation.net/>

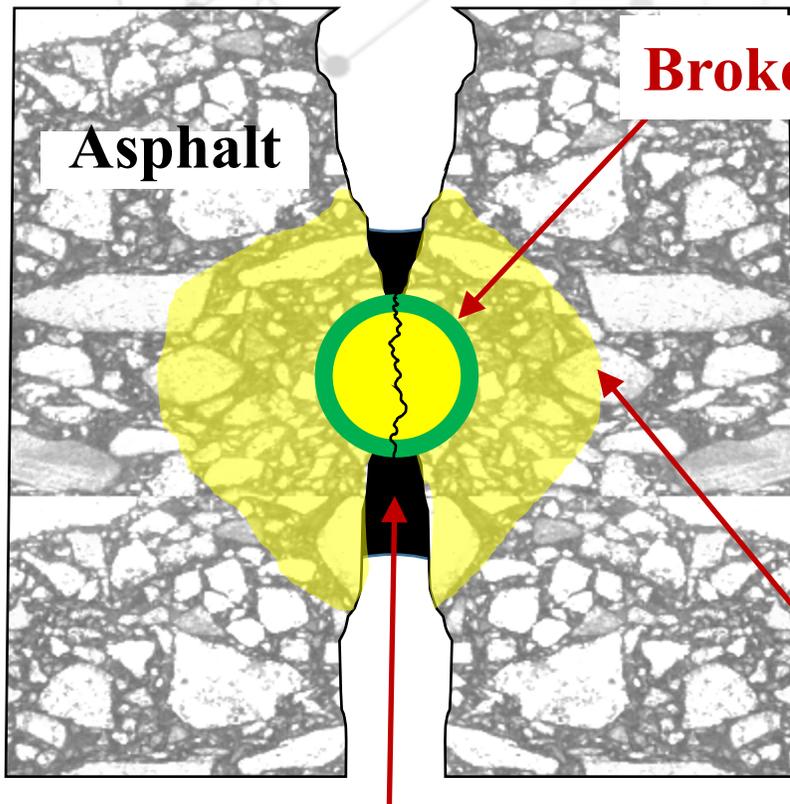


<http://biorepavation.ifsttar.fr>

<http://healroad.eu>

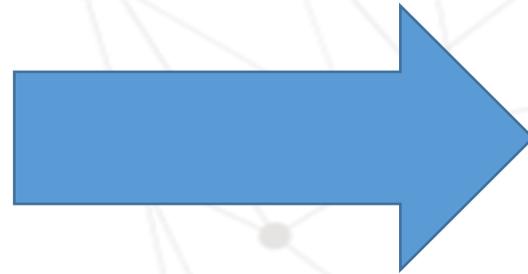


**Mechanical loading degrades the capsules that release the oil wherever it is more needed**



**Broken capsule**

**Asphalt**



**SELF - HEALING  
ASPHALT**

**Healing material**

**Local reduction of bitumen viscosity**  
*(This promotes the drainage of bitumen into the cracks)*



Philippe Sohounou - ESR9



philippe.sohounou@nottingham.ac.uk



@p\_sohounou



linkedin.com/in/philippe-sohounou/en

WEB: [smartietn.eu/research/smarti-guidelines/esr9/](http://smartietn.eu/research/smarti-guidelines/esr9/)



# SMARTi

European Training Network

For more information check [smartietn.eu](https://smartietn.eu)



SMARTI ETN has received funding from the European Union's Horizon 2020 Programme under the Marie Curie-Skłodowska actions for research, technological development and demonstration, under grant n.721493.



*sustainability*

an Open Access Journal by MDPI

IMPACT  
FACTOR  
2.592

## Smart Solutions for Sustainable Transport Infrastructure

### Guest Editors

Dr. Davide Lo Presti, Prof. Dr. Fernando Moreno-Navarro, Dr. Kamilla Vasconcelos Savasini, Prof. Dr. Cesare Sangiorgi, Prof. Dr. Daniel Fresno Castro

### Deadline

31 December 2020

# Special Issue

[mdpi.com/si/47710](https://mdpi.com/si/47710)

Invitation to submit



***Engineering has no better choice than investing in its sustainable development embracing innovation and new technologies to effectively support healthy society and respecting the environment***

***(Lo Presti, 2018)***



University of  
Nottingham

UK | CHINA | MALAYSIA



University of  
Nottingham

Nottingham Transportation Engineering Centre

<http://nottingham.ac.uk/ntec>  
[@NTECcomms](#)

# Thanks for your attention

davide.lopresti@nottingham.ac.uk

davide.lopresti@unipa.it

R<sup>G</sup>



*@DrLoPresti @SMARTIETN*



UNIVERSITÀ  
DEGLI STUDI  
DI PALERMO



dipartimento  
di ingegneria  
unipa