

# DIGITAL INTERVENTION FOR THE IMPROVEMENT OF CIVIL MAINTENANCE JOBS

[Using Digital Tools to Improve Quality  
and also Proactive Maintenance]

TATA STEEL WOMEN OF METTLE SEASON 7

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TEAM  
METTLE SISTERS

Mentor  
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# EXTENT OF DIGITIZATION IN CIVIL ENGINEERING

McKinsey Global Institute industry  
digitization index; 2015 or latest  
available data

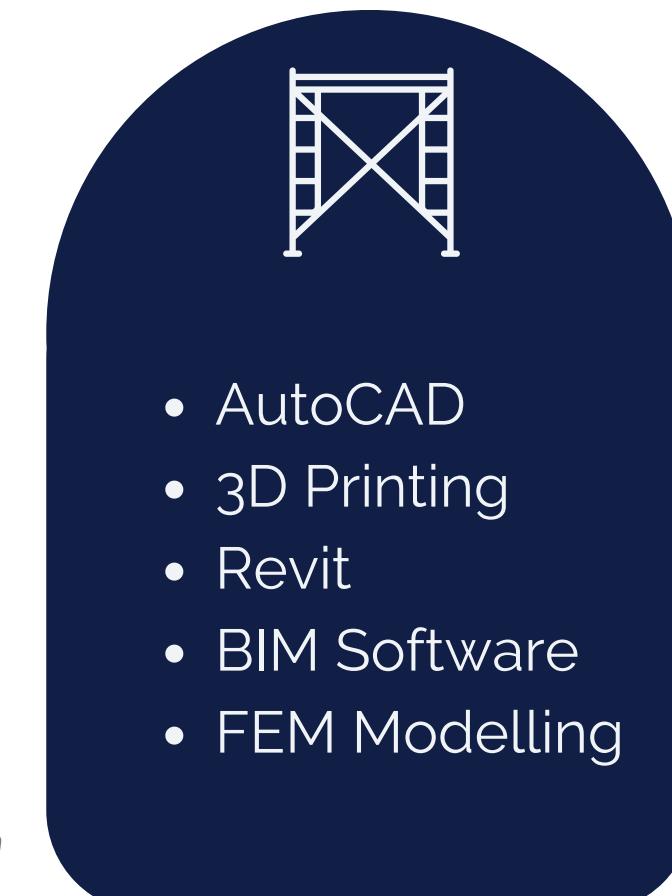
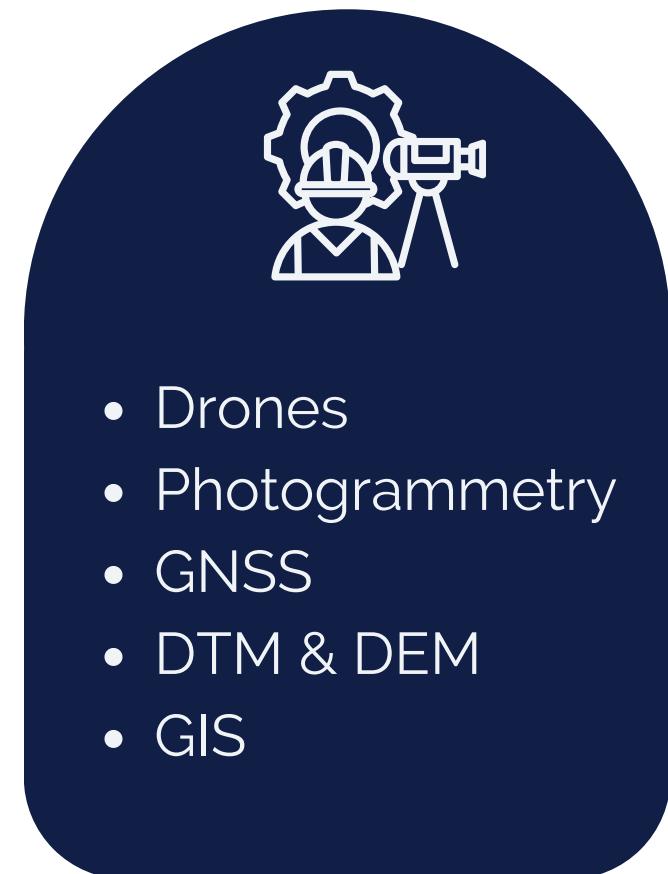
## Relatively low digitization

## Relatively high digitization

- Digital leaders within relatively undigitized sectors

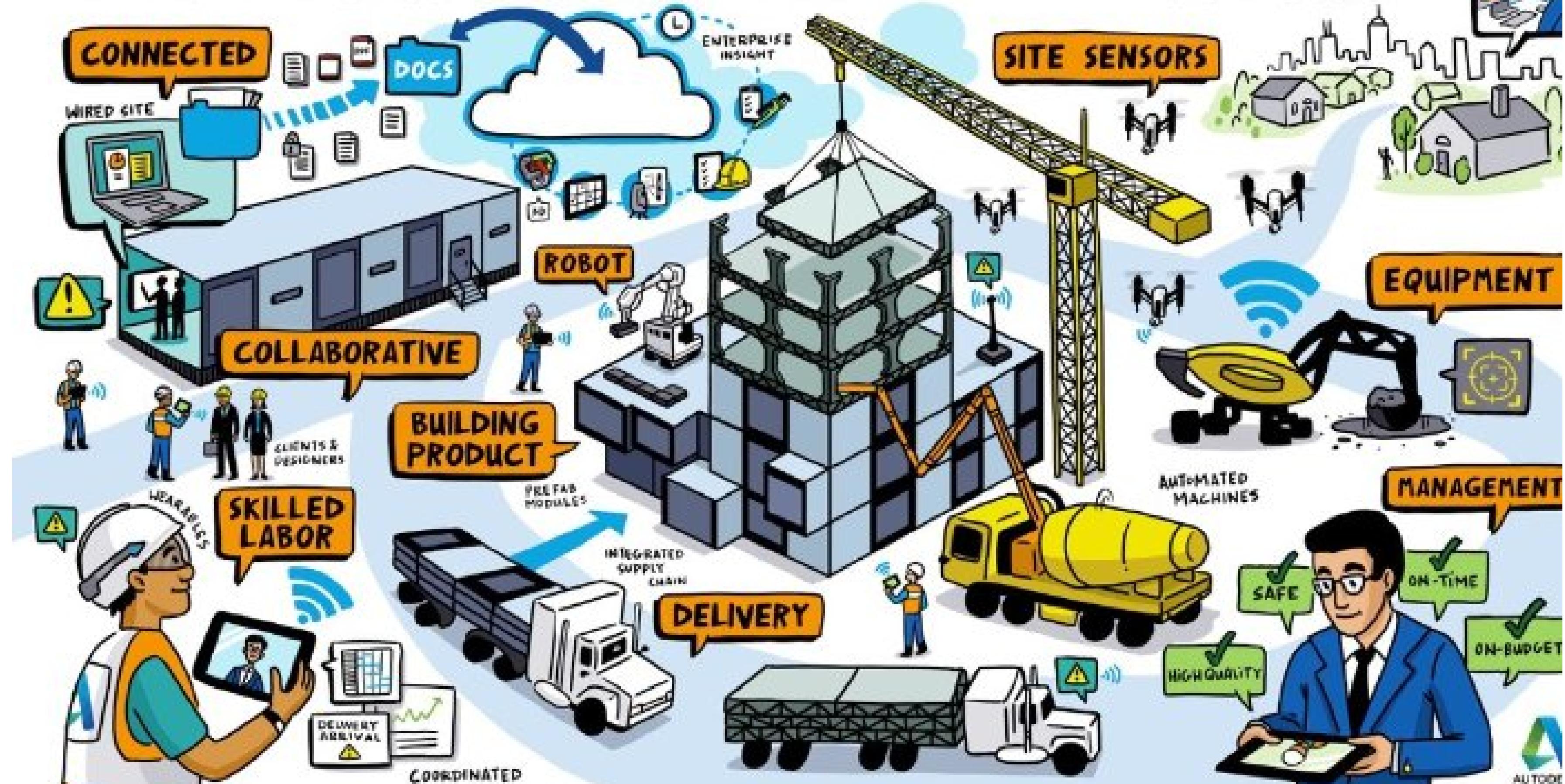


# VARIOUS DIGITAL TOOLS IN THE FIELD



**Artificial Intelligence & Machine Learning  
Cloud Based Systems**

# CONSTRUCTION SITE OF THE FUTURE



# WHY HASN'T IT BEEN IMPLEMENTED YET?

- 1 Decentralised System**
- 2 Lack of Tech Trained Professionals in the field**
- 3 Lack of Automation Philosophy**
- 4 Large Variances in Projects**
- 5 Infrastructure costs and complexity are relatively more**

# FOCUS/SCOPE OF THIS PROJECT

”  
**Applying Machine Learning for  
Structural Health Monitoring (SHM) for  
Proactive & Predictive Maintenance**

# SHM & PREDICTIVE MAINTENANCE

**Structural Health Monitoring (SHM)** is the process of using damage detection and characterization techniques for critical structures like bridges, wind turbines, and tunnels. It is a non-destructive in-situ structural evaluation method that employs several types of sensors embedded or attached to the structure.

**Predictive Maintenance** is based on processing the operation data sent via sensors using data analytics techniques. It is a subset of SHM whereby faults are predicted based on data trends and maintenance is done before the fault occurs

**How is it more effective than traditional methods?**

- quick detection and diagnosis,
- robustness
- classification error estimation
- adaptability
- real-time computation and storage handling
- multiple fault identifiability

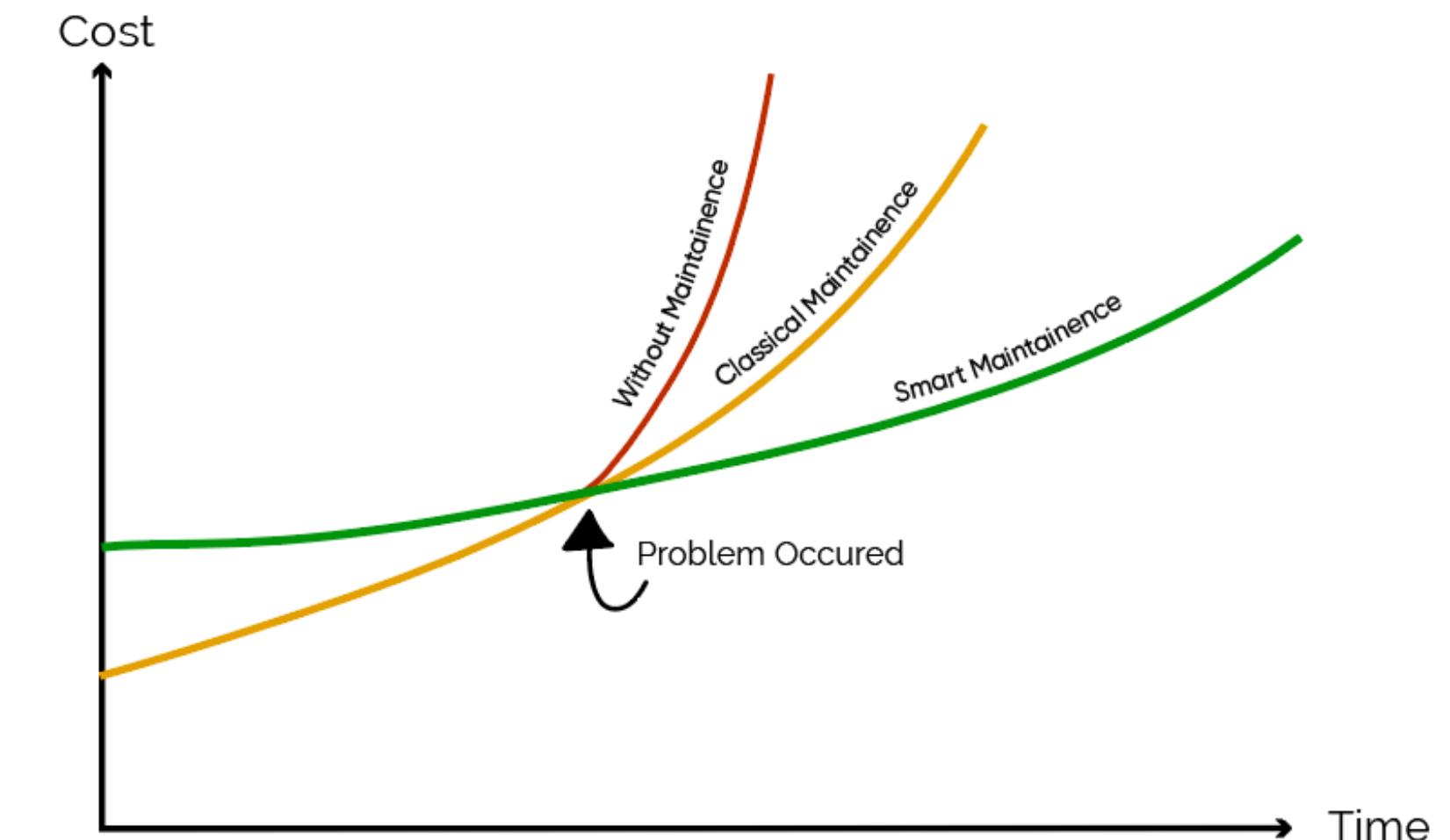
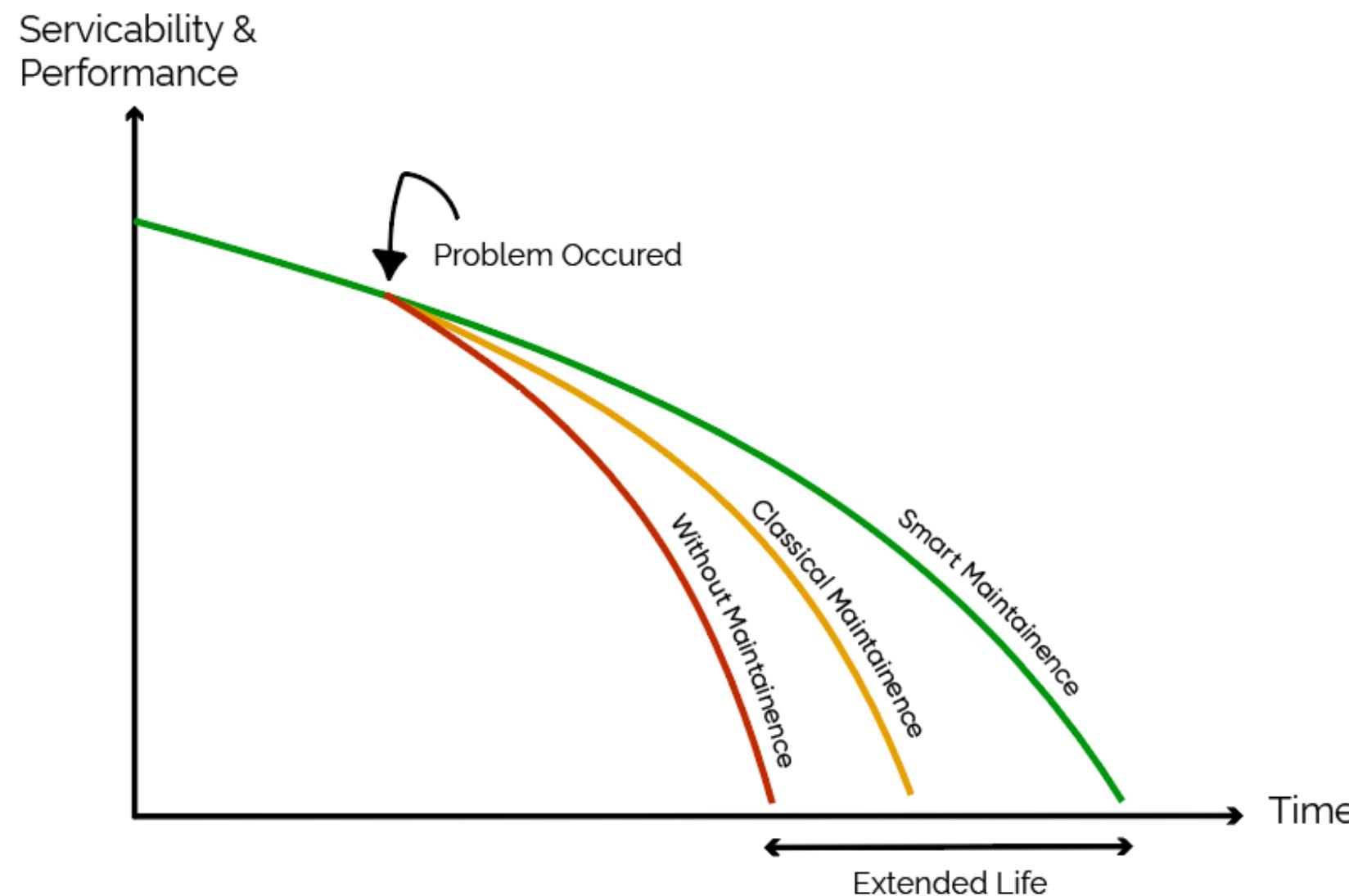
## ADVANTAGES

- 1 Root cause of problem is easier to find
- 2 Longer lifespan of structure
- 3 Less downtime
- 4 Lowers maintenance costs by up to 20-30%

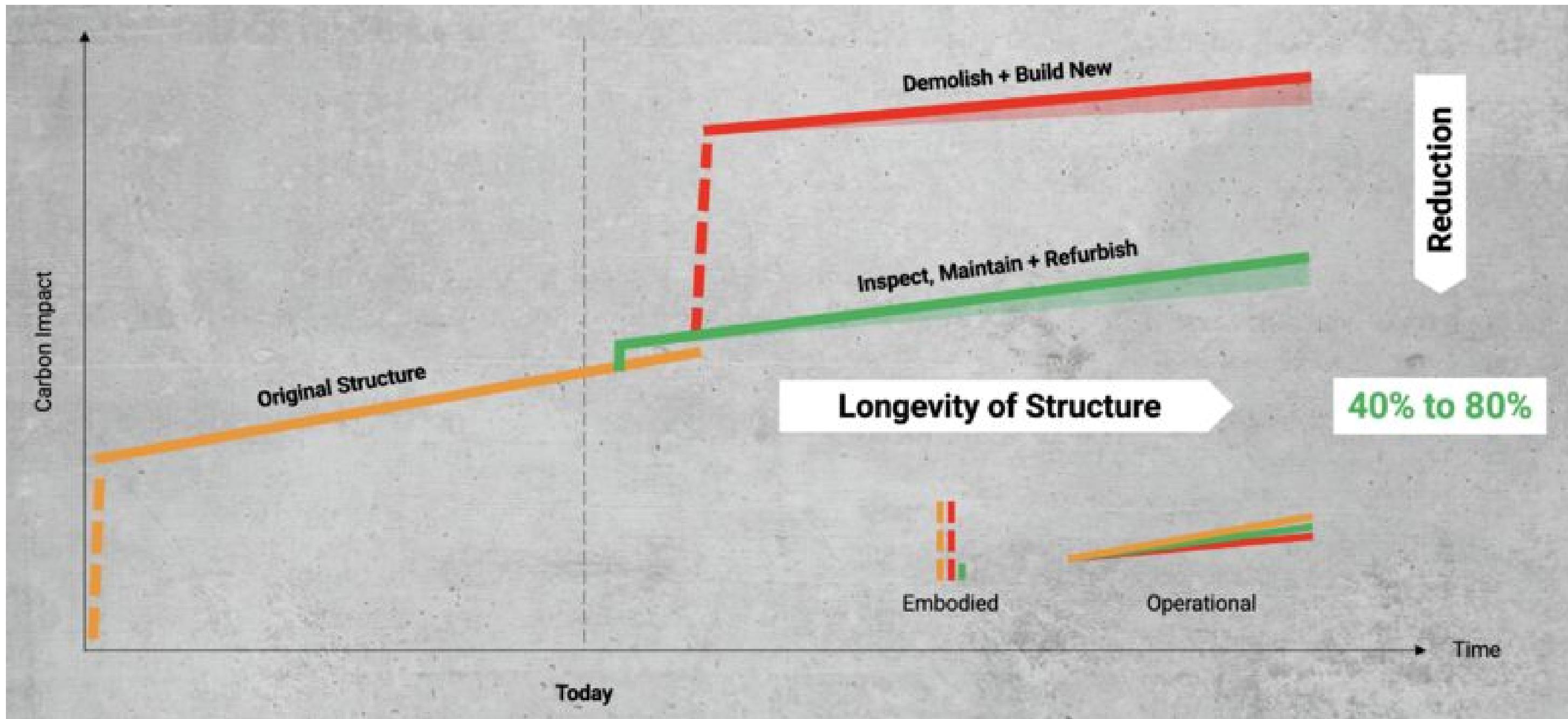
## CHALLENGES

- 1 Hard to bring agreement among the different stakeholders
- 2 Not legally compulsory

# PERFORMANCE VS TIME VS COST



# HOW IS IT RELATED TO THE THEME



# SOME COMPANIES IN THE SPACE

The screenshot shows the homepage of Optimized Solutions Limited. At the top left is the company logo with the text "Optimized Solutions Limited". The top navigation bar includes links for ABOUT US, BLOG, EVENT, PRESS CENTER, CAREERS, and CONTACT US. Below the navigation is a secondary menu with "Products & Solutions" (highlighted in red), Industries, Resources, and Partner With Us, along with a search icon. The main visual is a photograph of the Golden Gate Bridge against a warm, orange sunset sky. Overlaid on the bridge is the text "Structural Health Monitoring". On the far left, there is a vertical column of social media icons for Facebook, Twitter, LinkedIn, Email, and YouTube. A blue circular button with a white envelope icon is located in the bottom right corner of the main image.

The screenshot shows the homepage of Aren.ai. The top portion features a large image of a bridge under construction with a yellow overlay containing the text "Our Technology In Action" and "HOW IT WORKS". Below this, a blue banner contains the text "Aren Makes Data Collection Safer And Easier." followed by a detailed description of the service: "Developed for Engineering Firms and Asset Owners, our technology makes the inspection of civil infrastructure (e.g. bridges, building facades, dams, cooling towers, chimneys) better, easier, safer, and more affordable than ever before. With Aren, not only is data collection simpler, but you get a digital twin of your asset and predictive intelligence that helps you optimize your repair & maintenance schedules and your spending." At the bottom of the banner, there is a link "Scroll down to see how it works.".



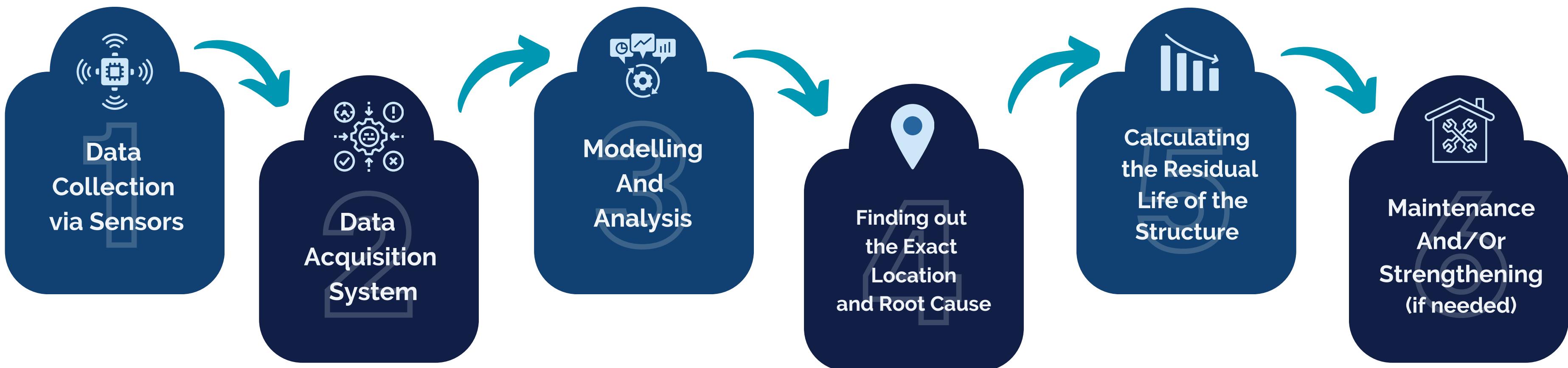
Optimized Solutions Ltd

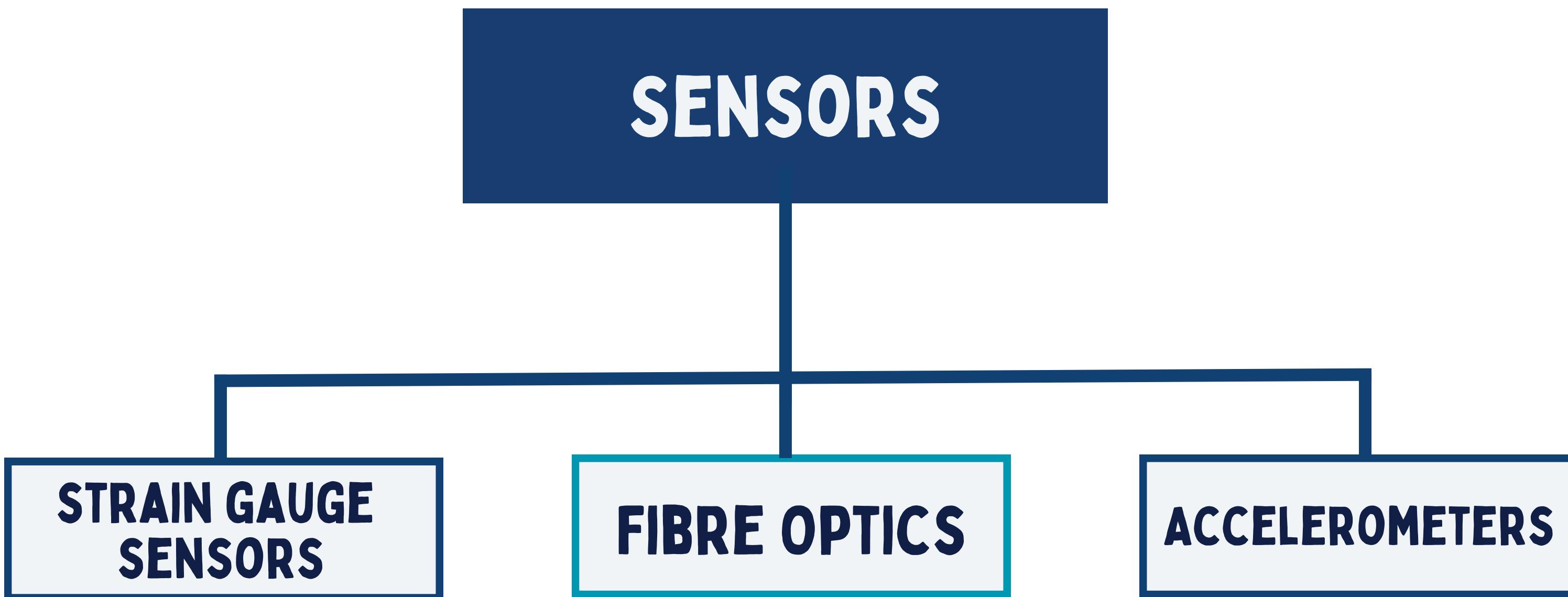
vs



Aren.ai

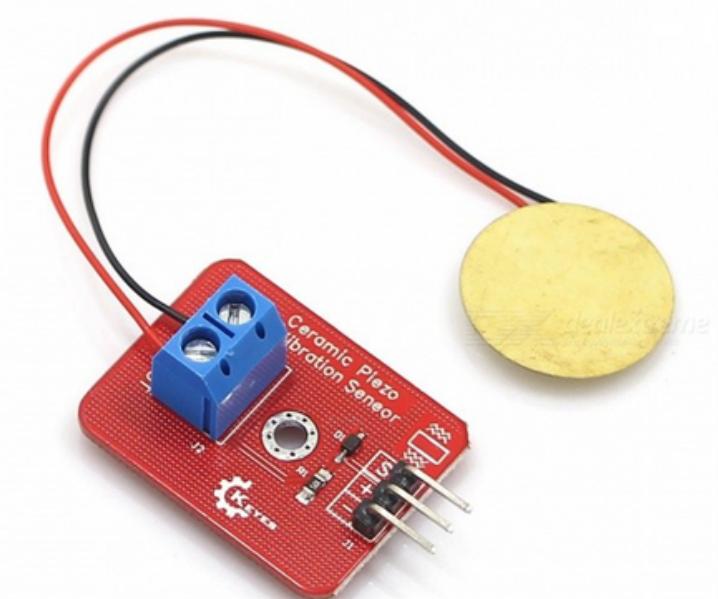
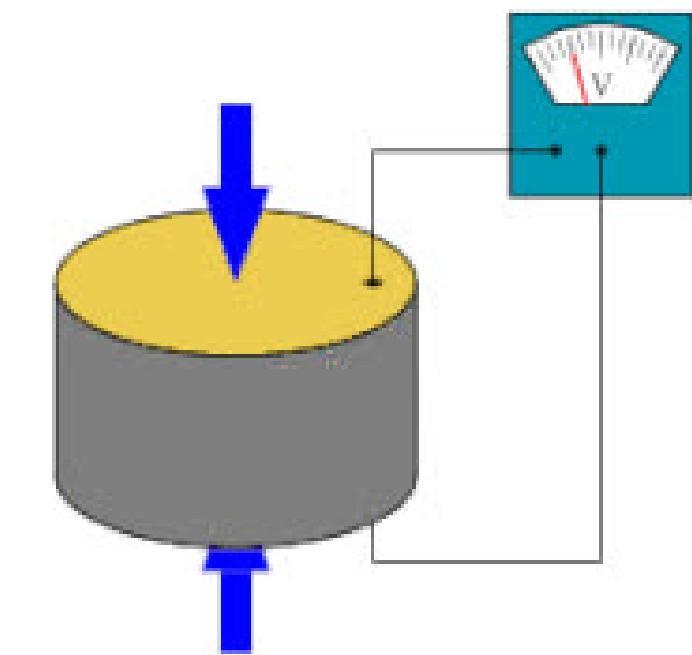
# THE PROCESS





# PIEZO SENSORS

- Piezoelectric materials are capable of **transforming mechanical strain and vibration energy into electrical energy**.
- Piezoelectric sensors boast benefits such as compact size, light weight, cost-effectiveness, and high sensitivity.
- **Cost about Rs 50-100 /sensor**
- Electro-Mechanical Impedance (EMI) sensors can be **attached to the surface** of the structure or **embedded into the structure**, such as smart aggregates
- EMI sensors **convert electric signals to mechanical stress and vice versa**. Feedback signals, processed using algorithms, aid in damage detection, localization, and characterization.
- These can be strategically positioned on **critical areas prone to damage**, such as bolted joints or adhesive joints as the its detection areal range is quite small
- EMI sensors are **sensitive to high frequencies** ( $>30$  kHz) for immunity against ambient noise.



Piezoelectric Vibration Sensor

# PIEZOELECTRIC SENSORS - WORKING

- A strong PZT - lead-zirconate-titanate

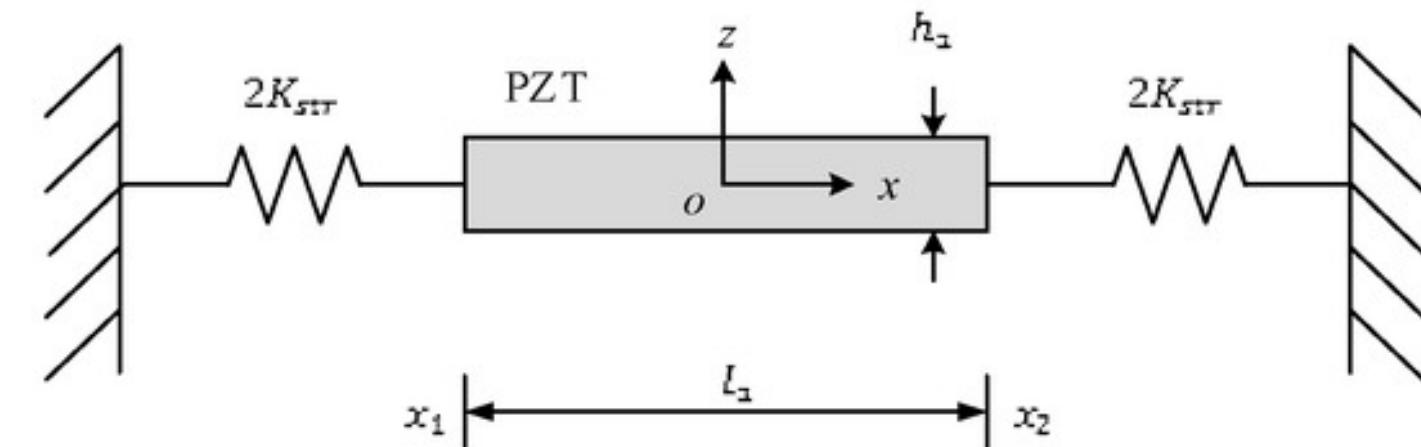
## Piezoelectric Admittance

$$Y(\omega) = i\omega C \left[ 1 - \kappa_{31}^2 \left( 1 - \frac{1}{\varphi \cdot \cot(\varphi) + K_{str}/K_{PZT}} \right) \right]$$

$$\frac{dY}{d\omega} = iC \left[ 1 - \kappa_{31}^2 + \kappa_{31}^2 \frac{1 + \frac{K_{str}}{K_{PZT}} + \frac{l_a^2}{12c^2}\omega^2}{\left( 1 + \frac{K_{str}}{K_{PZT}} - \frac{l_a^2}{12c^2}\omega^2 \right)^2} \right]$$

$$\omega_n^2 = 6c^2 \frac{3 + 2K_{str}/K_{PZT} - \sqrt{9 + 8K_{str}/K_{PZT}}}{l_a^2}$$

When a crack occurs and propagates in the host structure, the local stiffness of the host structure will reduce. While the local stiffness of the host structure decreases, the peak frequency in the piezoelectric admittance signature also decreases



Capacitance

$$C = l_a b_a \tilde{\epsilon}_{33}^T h_a^{-1}$$

Stiffness of the PZT patch

$$K_{PZT} = A_a / (s_{11}^E l_a)$$

Angle

$$\varphi = \gamma \cdot l_a / 2,$$

Wave Number

$$\gamma = \omega/c$$

Wave Speed

$$c = \sqrt{1/\rho s_{11}^E}$$

Electromechanical Coupling Factor

$$\kappa_{31}^2$$

Stiffness of Host Structure

$$K_{str}$$

Dielectric Constant at Zero Stress  
mechanical compliance at zero field

$$\tilde{\epsilon}_{33}^T$$

$$s_{11}^E$$

# LOW COST SENSOR DEVELOPMENT IN INDIA

REINVENTING THE WHEEL

## IIT-D develops low-cost sensor for monitoring concrete health

Is there anything common to a concrete bridge, a human foot and the flow of traffic? When it comes to a low-cost sensor developed at the Indian Institute of Technology, Delhi, (IIT-D), to measure vibration patterns in structures, there may be a strong link.

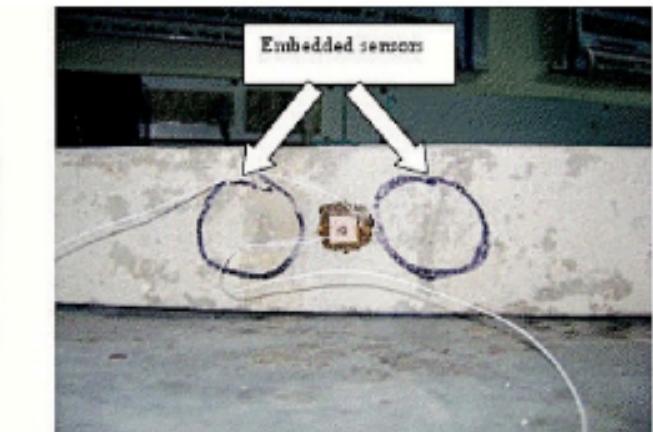
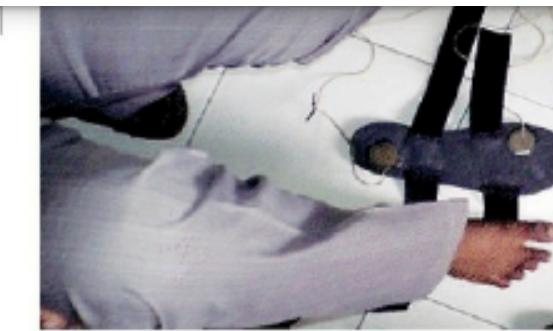
The piezo-based sensor designed by the institute's civil engineering department was primarily aimed at structural health monitoring, but its potential applications could extend to mapping foot-sole pressure for clinical applications or as a traffic monitoring sensor buried in the carriageway.

A sensor made of a piezoelectric material such as quartz, responds to mechanical stress by developing surface charges, a phenomenon called 'direct effect'. Conversely, an electric field causes it to undergo a mechanical strain. The prefix piezo is derived from Greek, which means 'squeeze' or 'press'.

In a recent research paper, a team led by associate professor of the civil engineering department Suresh Bhalla demonstrated that a piezoelectric ceramic (PZT) patch can complement existing techniques of measuring the vibration response of a concrete structure, such as a bridge, by playing the double role of determining strain for the structure as a whole and also at a local level. This can serve as a viable alternative to expensive accelerometers, which are widely used to carry out the health monitoring of such structures, the team says.

Bhalla, who heads IIT-D's Smart Structures and Dynamics Laboratory, has come out with a ready-to-use composite piezoelectric sensor especially for reinforced concrete structures. "The cost of such a sensor would be less than one-tenth of the cost of an accelerometer," he says, adding that the sensor practically becomes part of the structure and can serve it for very long periods without any fear of accidental damage.

Their research paper, published in the Journal of Intelligent Material Systems and Structures, notes that the performance of surface-bonded patches like the piezo electric sensor have been shown to be as good as accelerometers and can capture frequencies as low as 1 hertz (Hz). "The sensor has been tested in the laboratory environment successfully," says Bhalla, adding



**The sensor was primarily aimed at monitoring structural health, but its potential applications could extend to mapping foot-sole pressure for diabetics or for monitoring vehicular traffic**

that further laboratory trials and pilot studies are in progress.

Piezo composites have been in use as sensors and actuators in aerospace applications for over two decades though their entry into civil engineering is more recent. Currently, the types of sensors widely used for global structural health monitoring (SHM), or monitoring a structure as a whole, include electrical resistance strain gauges, fibre-optic sensors, piezo-electric accelerometers and ultrasonic pulse transducers.

"PZT is currently used for active sensing at an extremely local level to detect flaws and damages. The jury is still out on structural global level SHM using PZT, as the performance are used for local-level response," says IIT Rourkela director Pradipta Banerji. He is also on the executive council of the International Society for Health Monitoring of Intelligent Infrastructure.

In a subsequent paper published in the journal *Experimental Techniques*, Bhalla's team demonstrated the use of the piezo sensors for monitoring traffic flow by embedding it below the carriageway. "Compared with other traffic sensors available in the market, the proposed sensor is very cost-effective and warrants minimal data processing efforts and hardware costs," the paper noted. The sensor had successfully passed tests under different traffic types and

it could be calibrated for action under real situations, it said.

The team also collaborated with the Centre for Bio-Medical Engineering at IIT-D to adapt the same piezo sensor for biomedical applications such as mapping the foot-sole pressure and its distribution. "This is specially relevant for diabetic patients whose foot pressure distribution is sometimes of concern. Such patients tend to lose their sensation on the sole and are prone to exerting very high foot pressures leading to foot ulcers," he says.

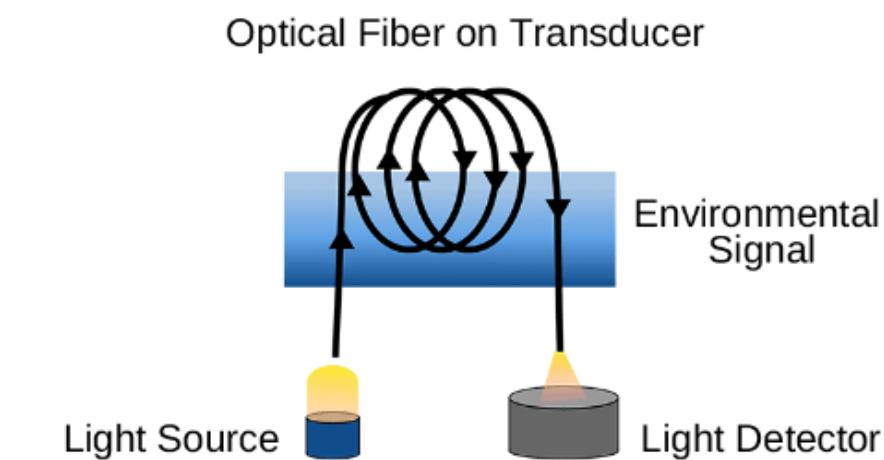
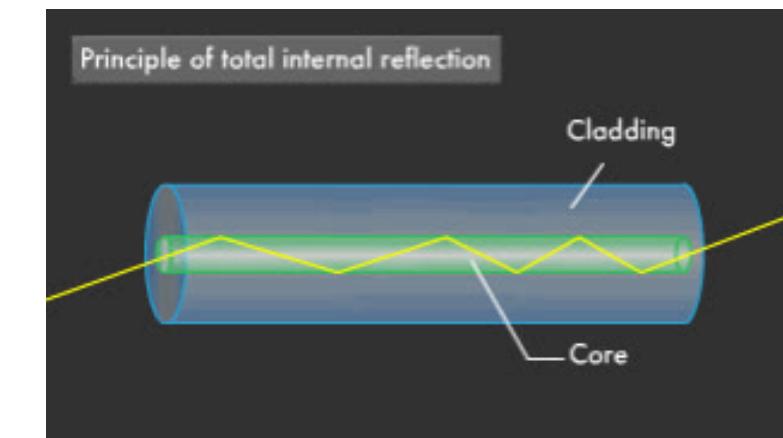
The team has submitted proposals for transfer of the technology to a few companies under IIT-D's Foundation for Innovation and Technology Transfer. Bhalla says the sensor has an edge because it can be used with minimum intervention and is less expensive.

Over the past few years, the quest for better sensors for SHM has driven research into areas such as wireless sensor networks and system identification techniques to interpret data and assess the condition of structures and for life extension of old structures. According to Banerji, some of the key challenges currently are to develop substantive and automated interpretation of online SHM data that can provide alerts when a structural or functional deterioration occurs in a structure, and the integration of data from various sources.

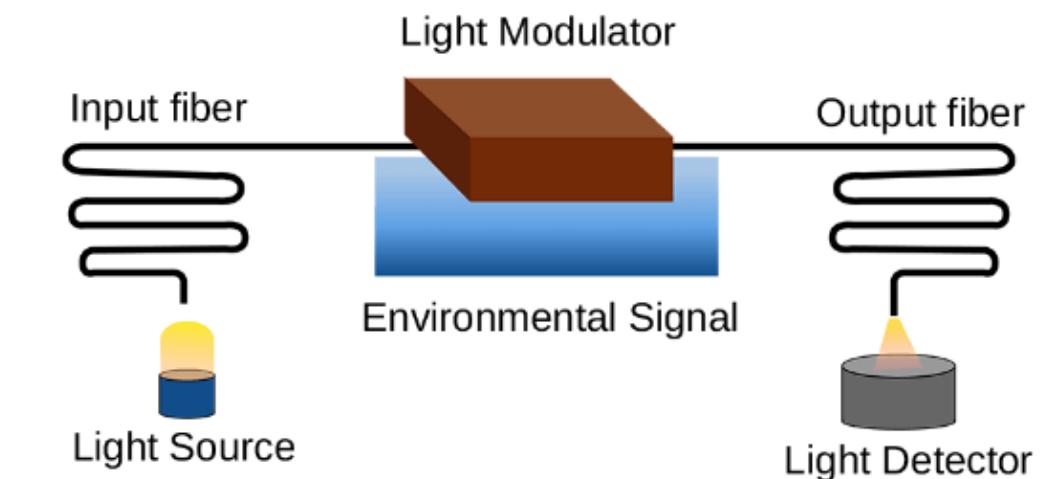
— Ajay Sukumaran

# FIBER OPTICS

- Works on the principle of "**total internal reflection**"
- An optical fiber is comprised of a light-carrying core in the center, surrounded by a cladding that acts to traps light in the core. Glass fiber is covered by a plastic buffer coating that protects it from the environment and allows easy handling for splicing or termination.
- **Cost varies from Rs 8 -10 to Rs 40+ per metre**
- Can be used for detecting and **measuring many different properties** like corrosion, strain, force, vibrations (like seismic), etc
- Extrinsic FOS are better for SHM as easier to calibrate and most of the factors to be sensed and monitored can be done by this sensor more effectively.

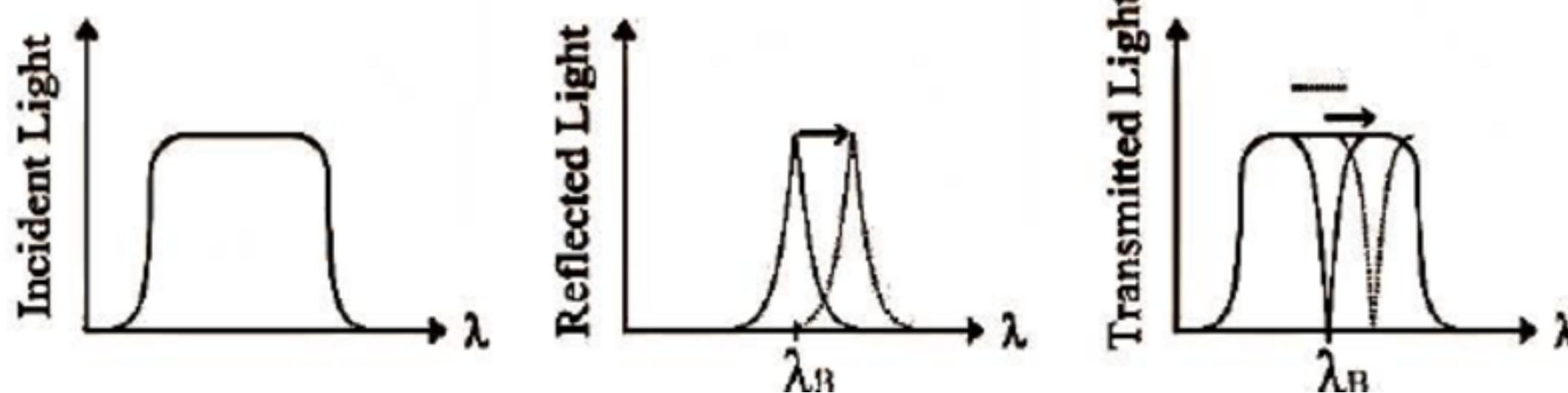
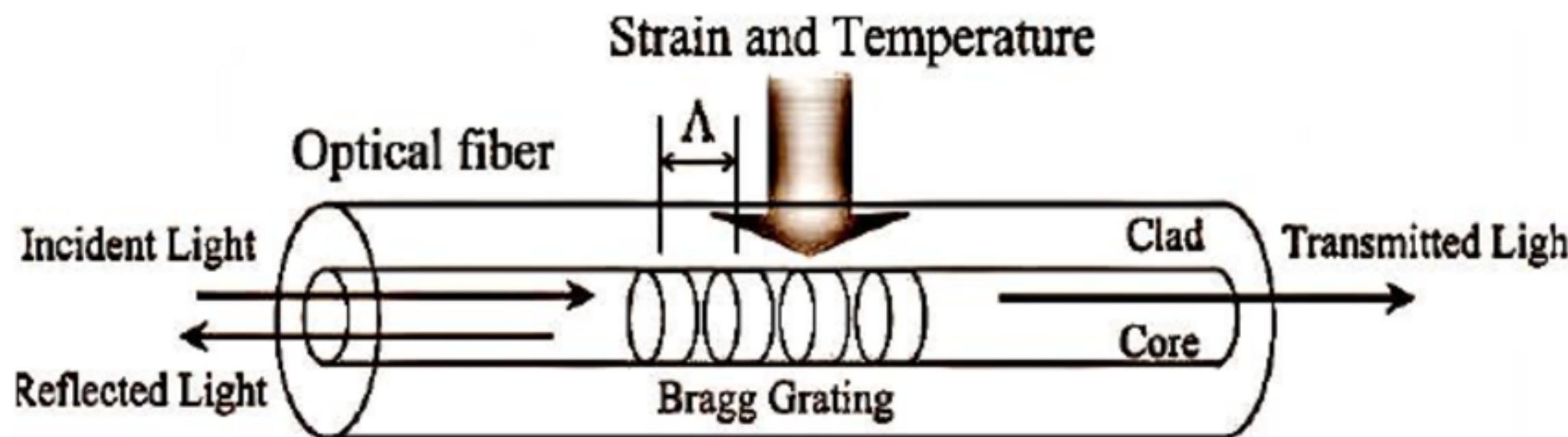


Intrinsic Fiber Optic Sensor



Extrinsic Fiber Optic Sensor

# FIBER BRAGG GRATING



Bragg wavelength

$$\lambda_B = 2n_{eff}\Lambda_B$$

Variation with Strain

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - \rho_e)\varepsilon$$

Variation with Temperature

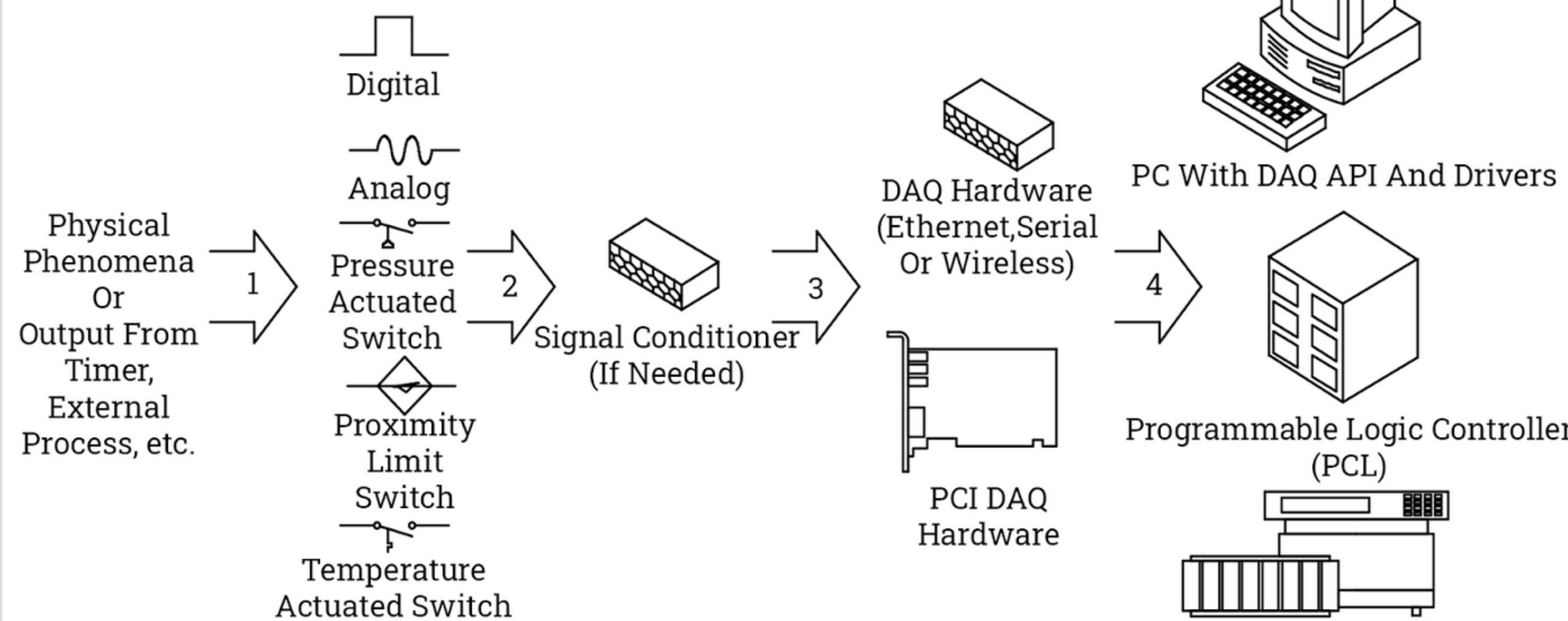
$$\Delta\lambda_B = 2\left(n_{eff}\frac{\partial\Lambda_B}{\partial T} + \Lambda_B\frac{\partial n_{eff}}{\partial T}\right)\Delta T$$

Photo-Elastic Coefficient

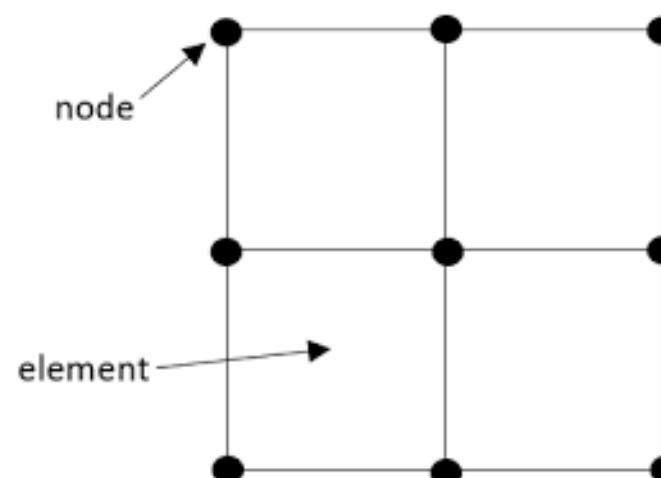
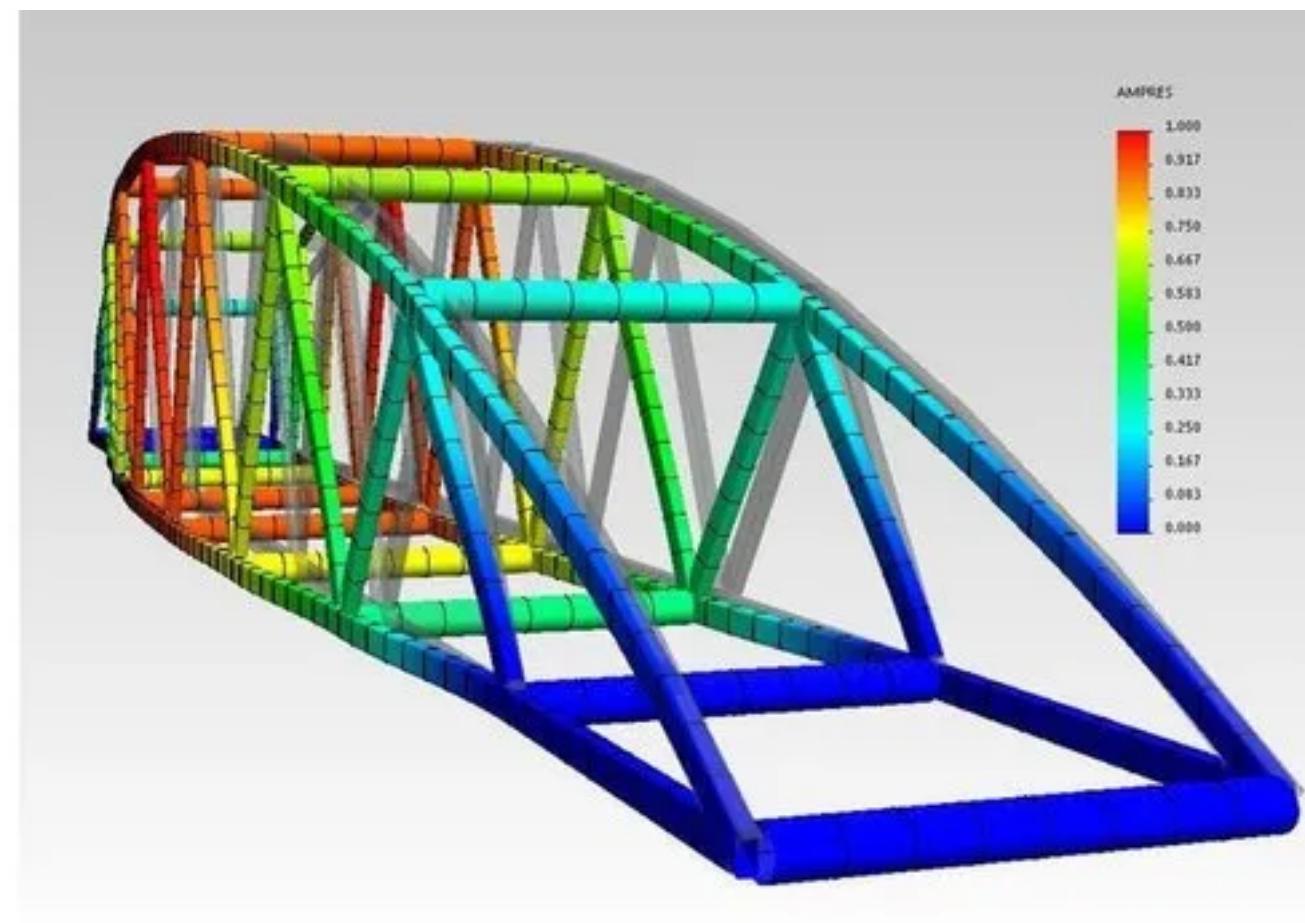
$$\rho_e = \frac{n_{eff}^2}{2} [p_{12} - \nu(p_{11} + p_{12})]$$

# DATA ACQUISITION SYSTEM

## Data Acquisition Equipment



# FINITE ELEMENT MODELLING



- Basically divides a structure into a discrete small interconnected elements , hence the name and connected via nodes and/boundaries.
- An extension of the spring equation  $F = -kx$ , except here the quantities are represented as matrices as they are easier to compute, especially by a computer

$$[K]\{u\} = \{F\}$$

Global Stiffness Matrix  
 Nodal displacements (unknowns)  
 Nodal forces

$$\varepsilon = \frac{\Delta u}{L}$$

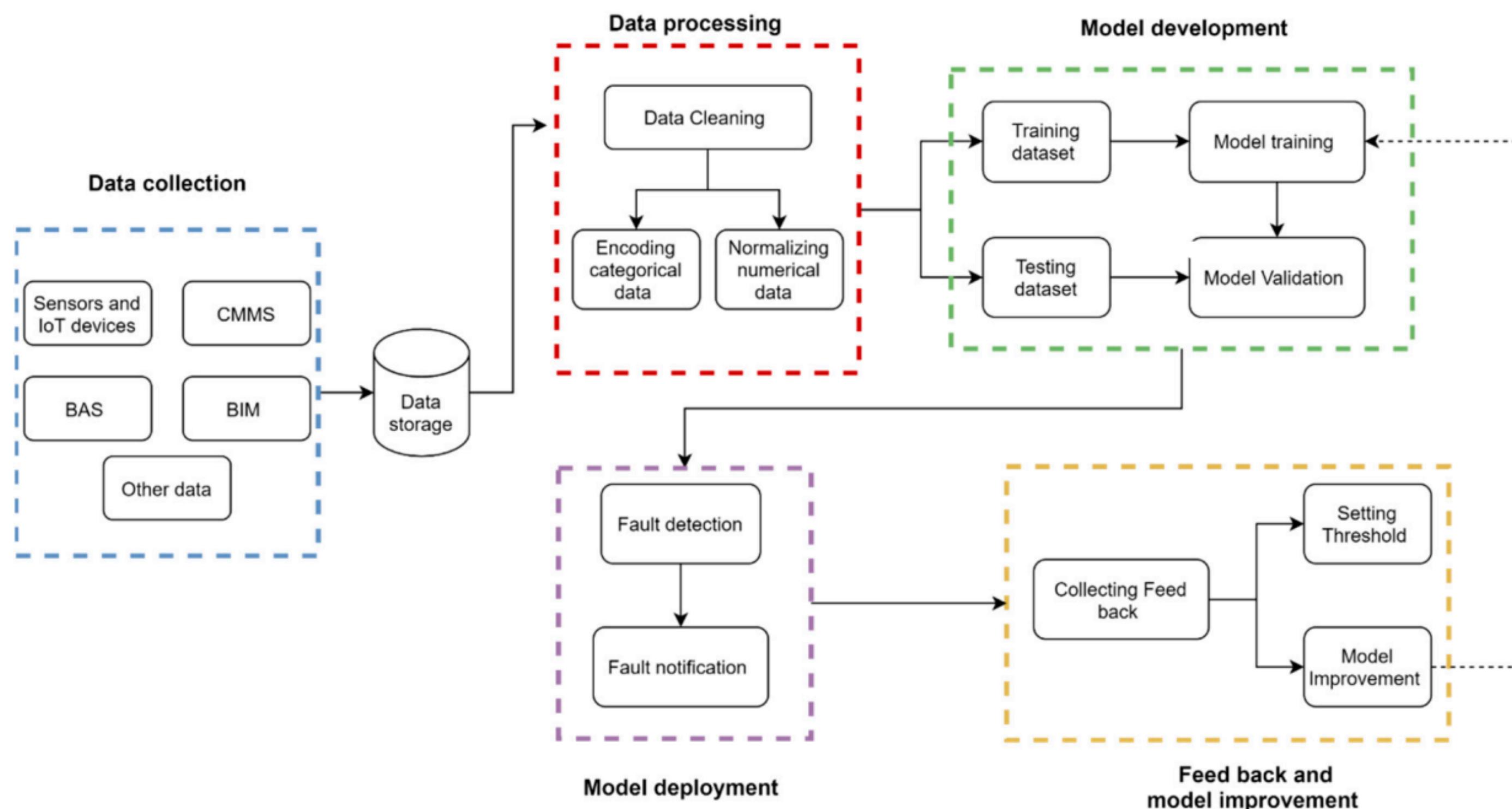
$$\sigma = E \cdot \varepsilon$$

and  $FOS = \frac{\sigma_y}{\sigma}$

## Global Stiffness Matrix

- Singular
- Symmetric
- Superposition of the individual element stiffness matrices

# MACHINE LEARNING MODELLING



# CRACK DETECTION

Cracks serve as **vital indicators of structural behavior**, reflecting distress within a material due to incompatible stress or deformation.

## Types of Cracks

- Superficial
- Structural

These fissures are categorized based on factors such as width, length, orientation, location, etc.

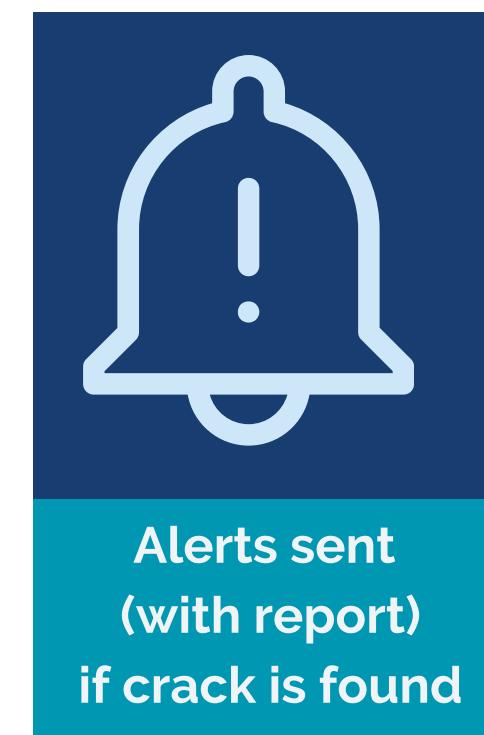
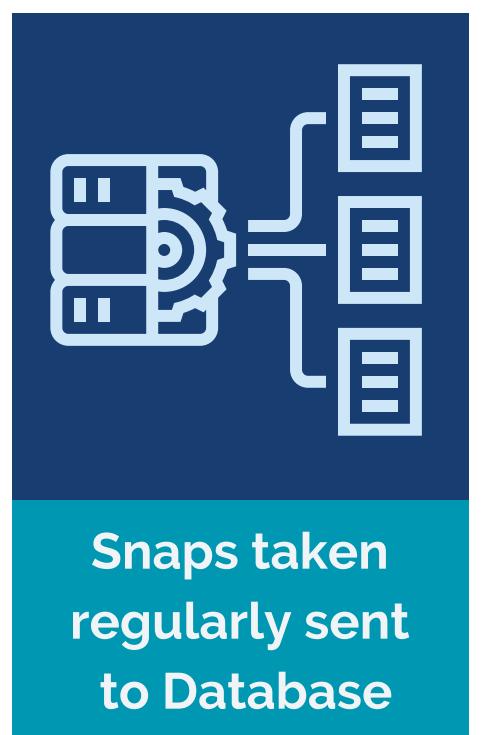
## Traditional Manual Monitoring

- lack reliability
- hindered by limited observations and accessibility => data is not continuous

## Solutions

- Fiber optic and laser scanner systems, offering higher accuracy but demanding substantial resources.
- Alternatively, **image-based crack inspection** provides an objective and accurate approach. Advanced models can identify crack dimensions with high precision, quick recording, and archiving of crack patterns, enabling permanent observations and offline measurements.

# CRACK DETECTION USING ML



# CRACK DETECTION USING ML

① http://localhost:8501

Design Elements Coding Civil Engineering Cl... Digital Marketing N... Main Page - Algorit... goldmine DTF Supplies Order... final clu...

## Crack Detection

This CNN model detects cracks from concrete surfaces to monitor the health of buildings and even roads.

It can be connected to a DAQ or programmed inside drones as well, and is cost effective

Check out the Model [Here](#)

### About the Model

Total Dataset: 15000 images of each Positive and Negative Images

Dataset used for training: 12000 images selected randomly from the entire set, because it was overfitting

[Dataset Source](#)

No. of CNN layers = 3

No. of epochs: 12

Choose an image...

Drag and drop file here  
Limit 200MB per file • JPG, PNG, JPEG

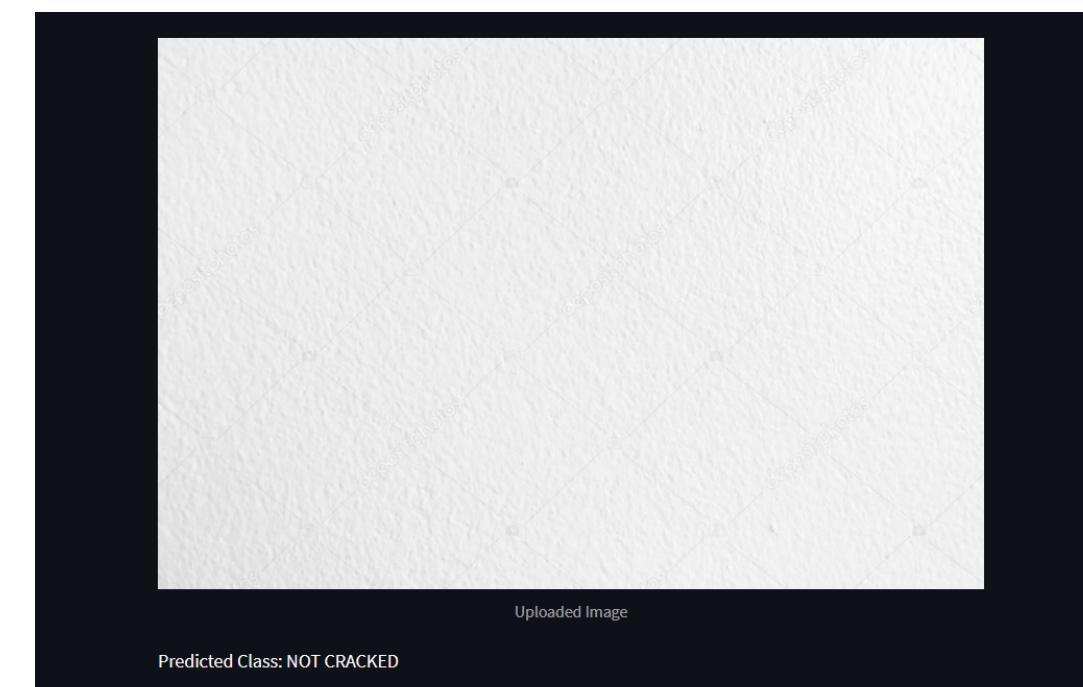
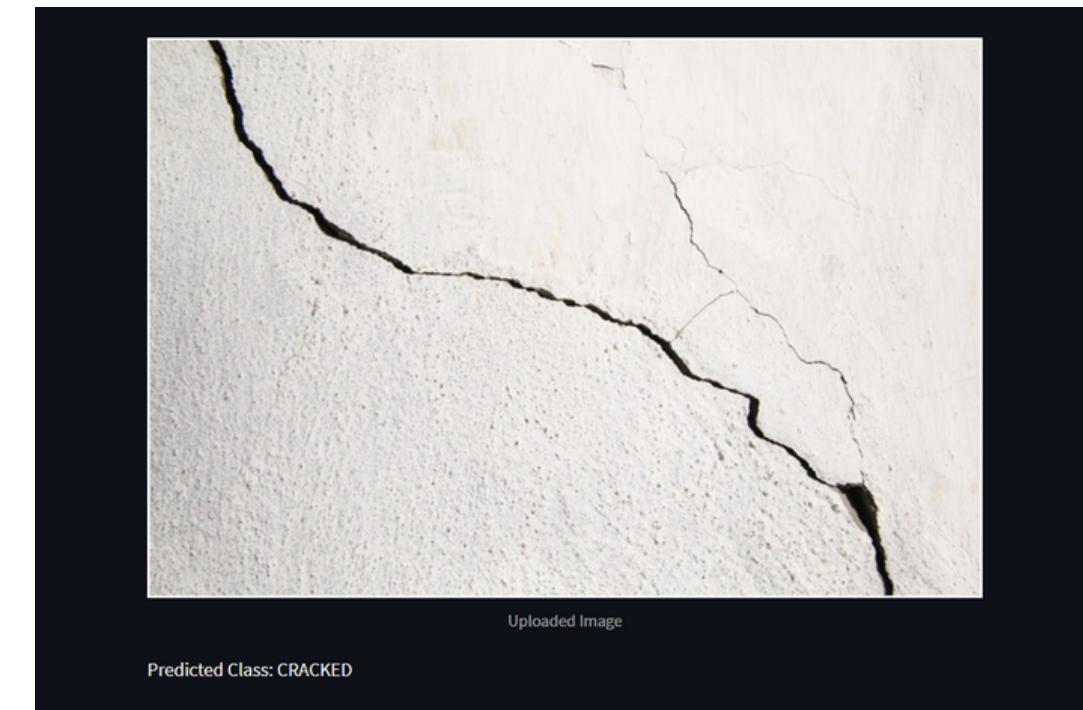
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### Evaluation Results

Test Loss: 0.12

Test Accuracy: 97.44 %

R2 Score: 0.90



# FINDING LOCATION AND ROOT CAUSE

## Location

- It can easily be done by connecting the data to the 3D model of the structure along with the sensor network.
- As the sensors are deployed in a network, if the data from a particular one shows anomalies, we can easily track the source/location of the sensor and we will immediately get to know the location of the fault.

## Root Cause

- Root cause can be found out comparing the FEM models of the actual stress and strains to the theoretical ones.
- It can also be found by looking at the construction history to cross check whether the construction was in compliance of IS Codes

## Non Destructive Tests (NDT)

- X Rays, Ultrasonic Tests, etc

# RESIDUAL LIFE OF A BUILDING

**Depends on many factors like:**

- 1 Corrosion
- 2 Difference between actual and theoretical loading
- 3 Constant Wear
- 4 Service Life
- 5 Mechanical Properties

*By Poisson Distribution, for short term life*

Description	Formula
overall damage assessment	$\varepsilon = \frac{\alpha_1 * \varepsilon_1 + \alpha_2 * \varepsilon_2 + \dots + \alpha_i * \varepsilon_i}{\alpha_1 + \alpha_2 + \dots + \alpha_i}$
relative evaluation of damages	$\gamma = 1 - \varepsilon$
constant wear	$\lambda = \frac{-\ln \gamma}{t_\phi}$
service life	$T = \frac{0,16}{\lambda}$

Various methods are used, depending the use case

# RESIDUAL LIFE OF A BUILDING

*For Static Strength*

Description	Formula
Residual resource by the criterion	$T_k = \frac{\sigma_b(t) - [\sigma]}{\alpha_\sigma}$
rate of decrease of mechanical properties	$\alpha_\sigma = \frac{\sigma_b - \sigma_b(t)}{t}$

*For Dynamic Loads*

Description	Formula
resource cyclic performance	$T_e = \frac{T_e * [N]}{N_e}$
resource of residual capacity	$T_{ost(c)} = T_c - T_e$

# SMART MAINTAINENCE -SELF HEALING CONCRETE

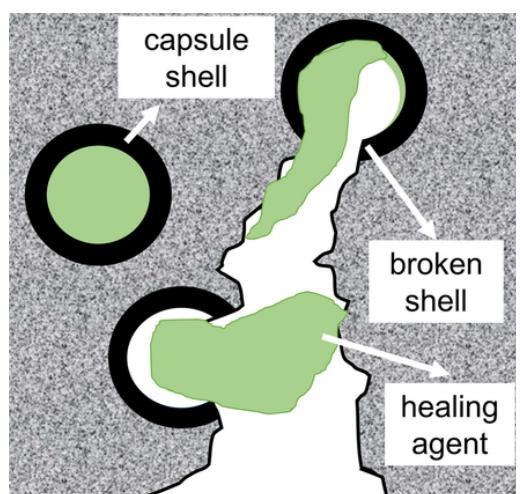
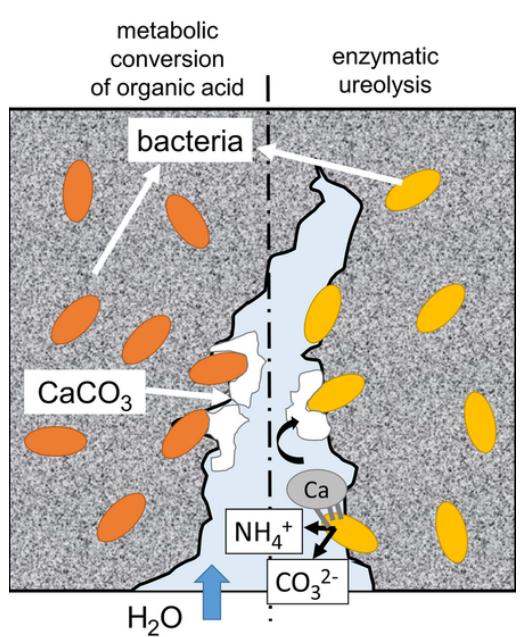
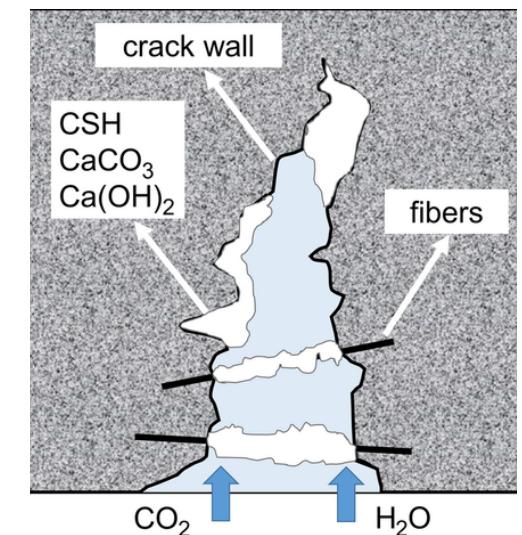
Self Healing Concrete is a class of smart material that has the structurally incorporated ability repair damages caused by mechanical usage over time.

## Biotic Concrete

- Uses acid producing bacteria mostly from the bacillus family, which acts as a catalyst
- It is preferred when the concrete structure have access to water or moisture.
- When cracks appear, the water seeps in and the spores of bacteria germinate and feed on the calcium lactate converting it to insoluble limestones, which starts to harden and fills the crack

## Abiotic Concrete

- Uses chemical compounds like epoxy, methyl methacrylate(MMA), dicyclopentadiene(DCPD), Na<sub>2</sub>SiO<sub>3</sub>
- Used when access to moisture is limited
- **Direct method :** Healing agents are directly added to the mix design while making in a proper ratio according to the cement used.
- **Encapsulation :** A self-healing agent is encapsulated using a different type of shell material and geometric properties of capsule. The shell material should be able to endure the hydration heat and a highly alkaline environment.



Thank you!

# REFERENCES



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