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
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EXTENT OF DIGITIZATION IN CIVIL ENGINEERING

VARIOUS DIGITAL TOOLS IN THE FIELD

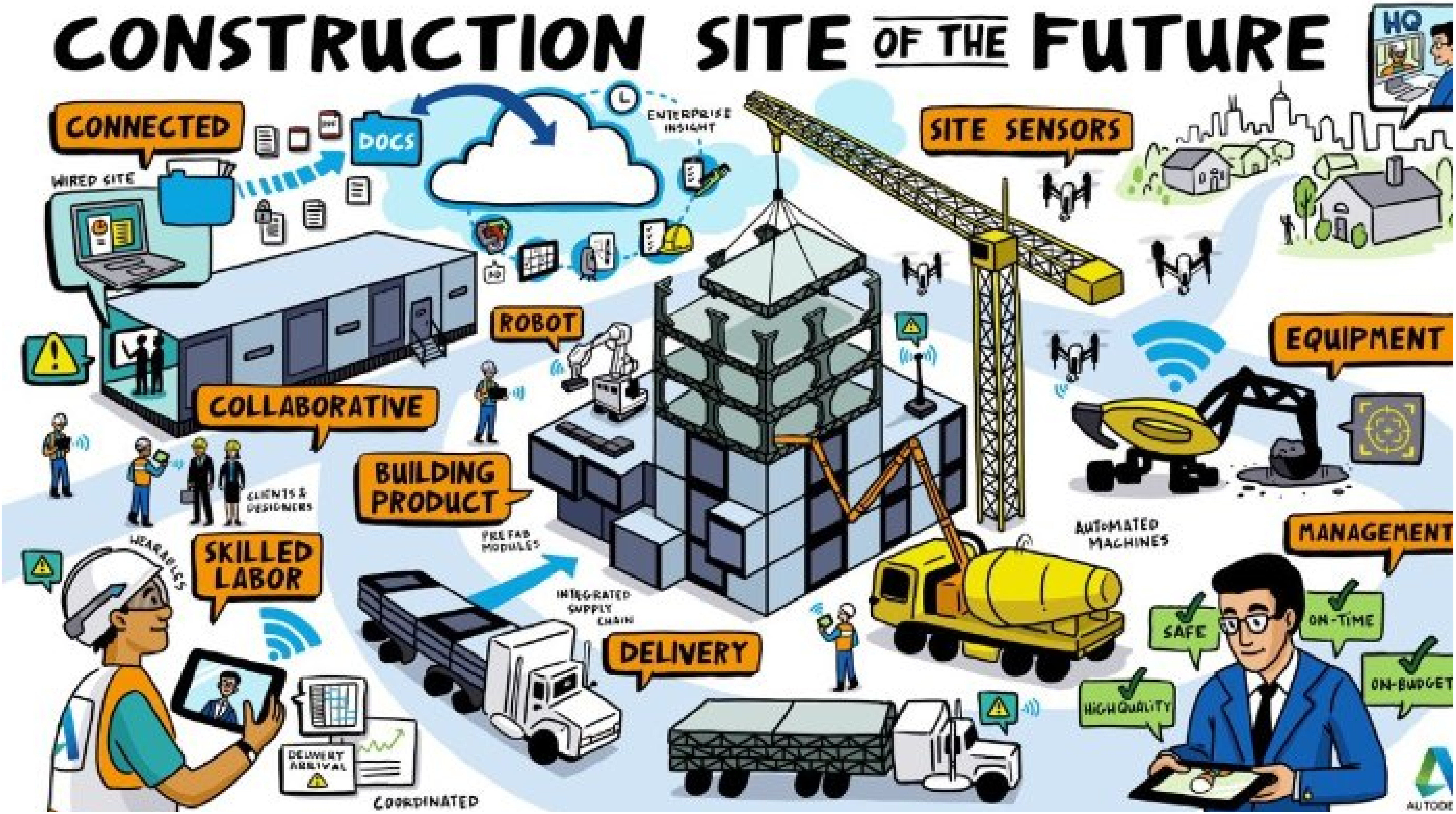
- Drones
- Photogrammetry
- GNSS
- DTM & DEM
- GIS

- Electrical Resistivity Tomography
- Ground-Penetrating Radar
- Seismic Analysis Tools

- Data Collection and Network Analysis
- Digital Tickets
- Vande Bharat
- Electric Vehicles

- AutoCAD
- 3D Printing
- Revit
- BIM Software
- FEM Modelling

Artificial Intelligence & Machine Learning
Cloud Based Systems



CONSTRUCTION SITE OF THE FUTURE
HQ
CONNECTED
WIRED SITE
DOCS
ENTERPRISE INSIGHT
SITE SENSORS
ROBOT
EQUIPMENT
COLLABORATIVE
CLIENTS & DESIGNERS
BUILDING PRODUCT
PREFAB MODULES
AUTOMATED MACHINES
MANAGEMENT
WEARABLES
SKILLED LABOR
INTEGRATED SUPPLY CHAIN
DELIVERY
SAFE
ON-TIME
ON-BUDGET
HIGH QUALITY
DELIVERY ARRIVAL
COORDINATED

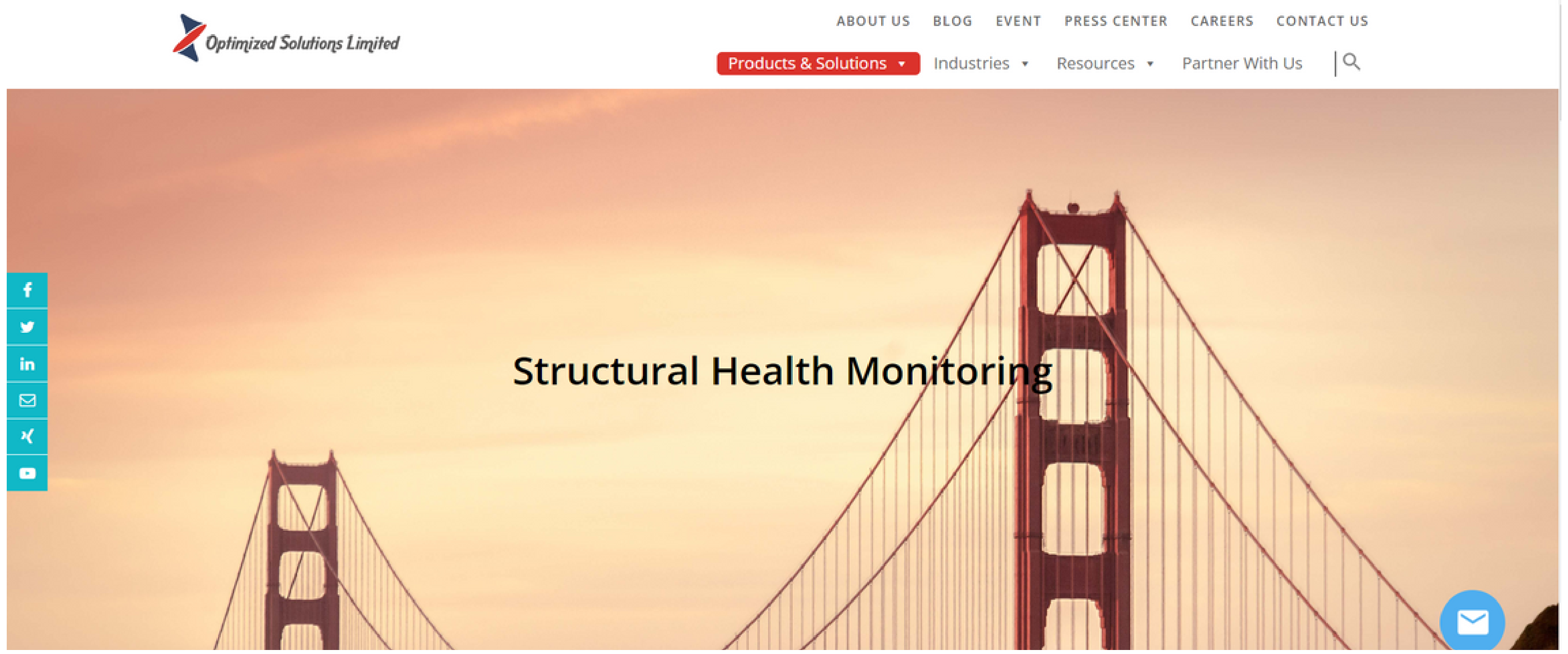
WHY HASN'T IT SCALED YET?

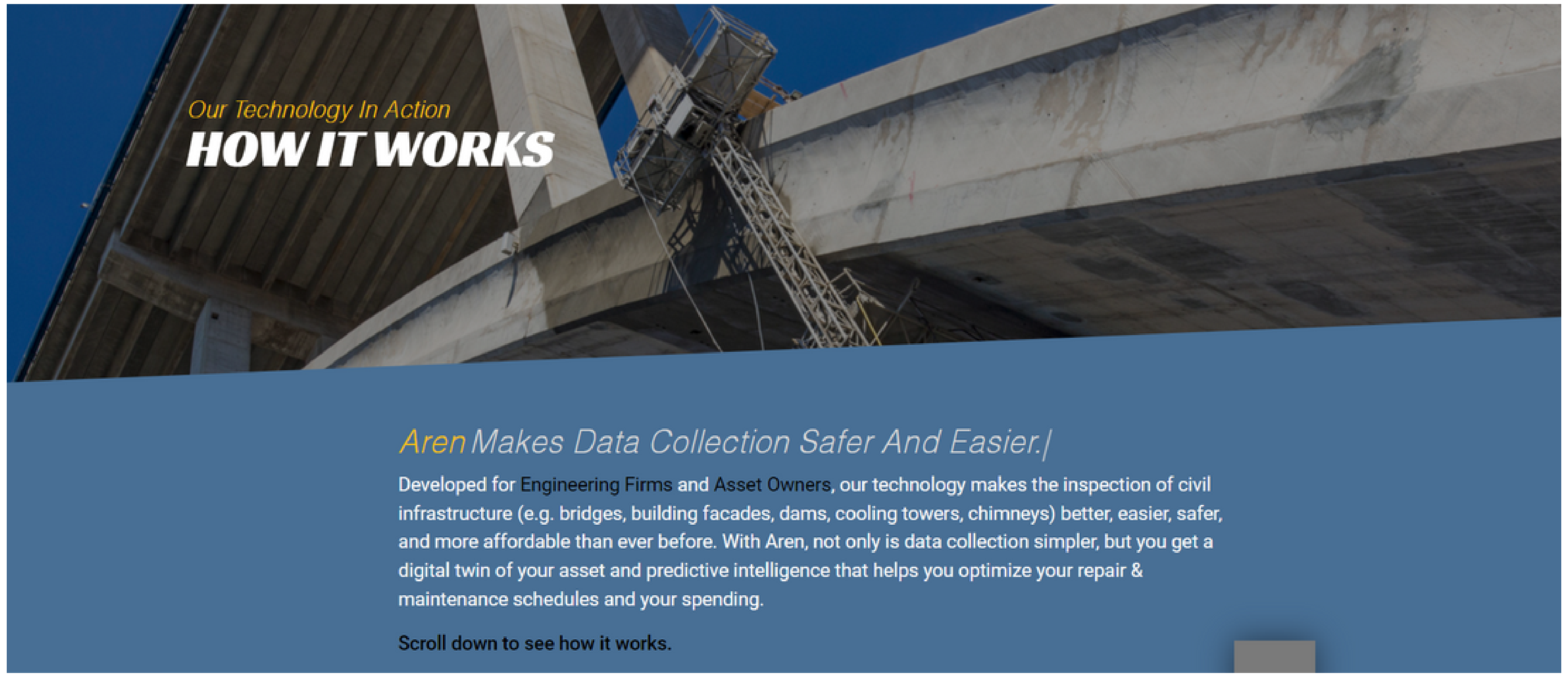
1. Decentralised System
2. Lack of Tech Trained Professionals in the field
3. Lack of Automation Philosophy
4. Large Variances in Projects
5. Infrastructure costs and complexity are relatively more

FOCUS/SCOPE OF THIS PROJECT

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

SOME COMPANIES IN THE SPACE





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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

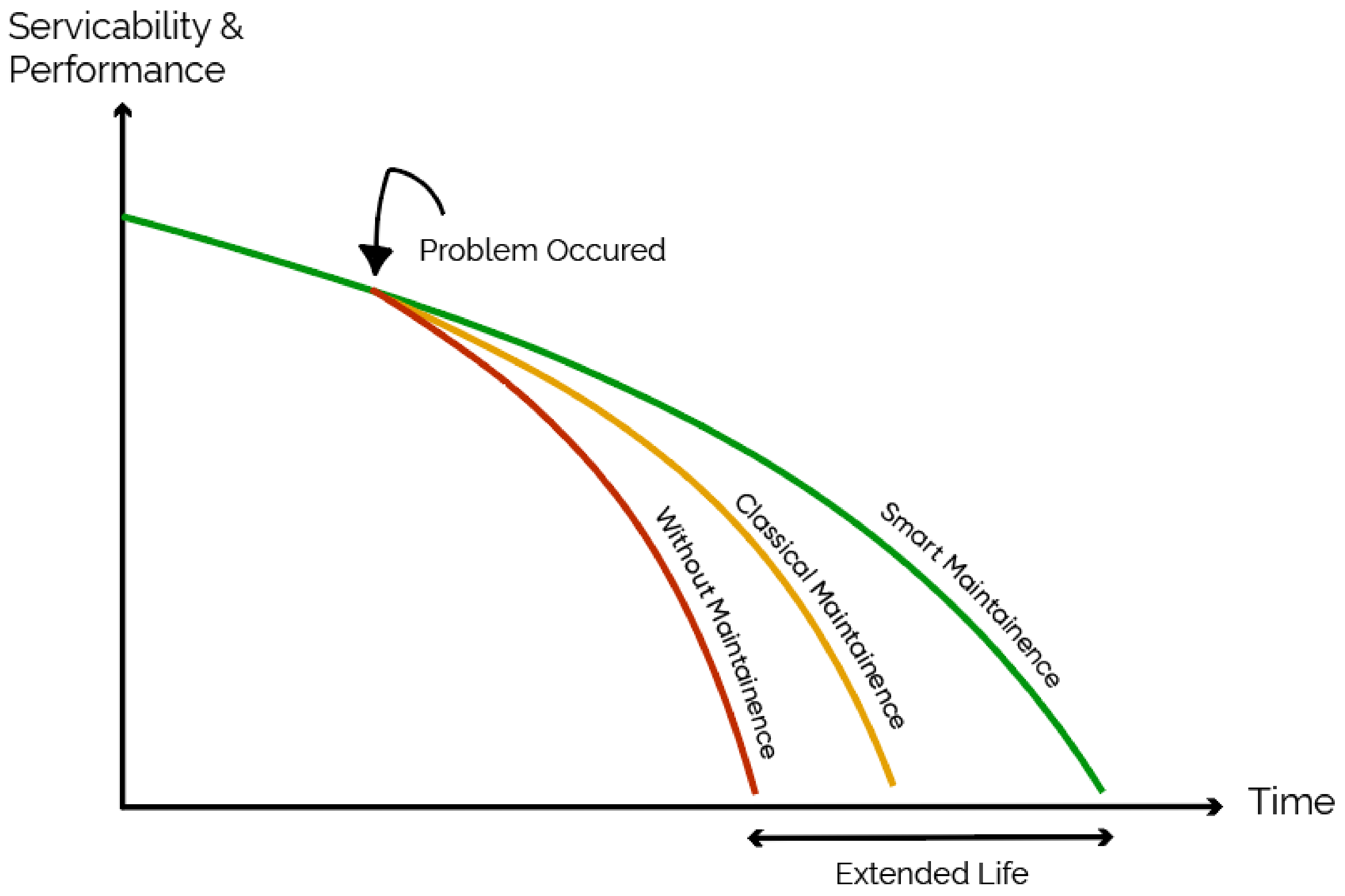
ADVANTAGES

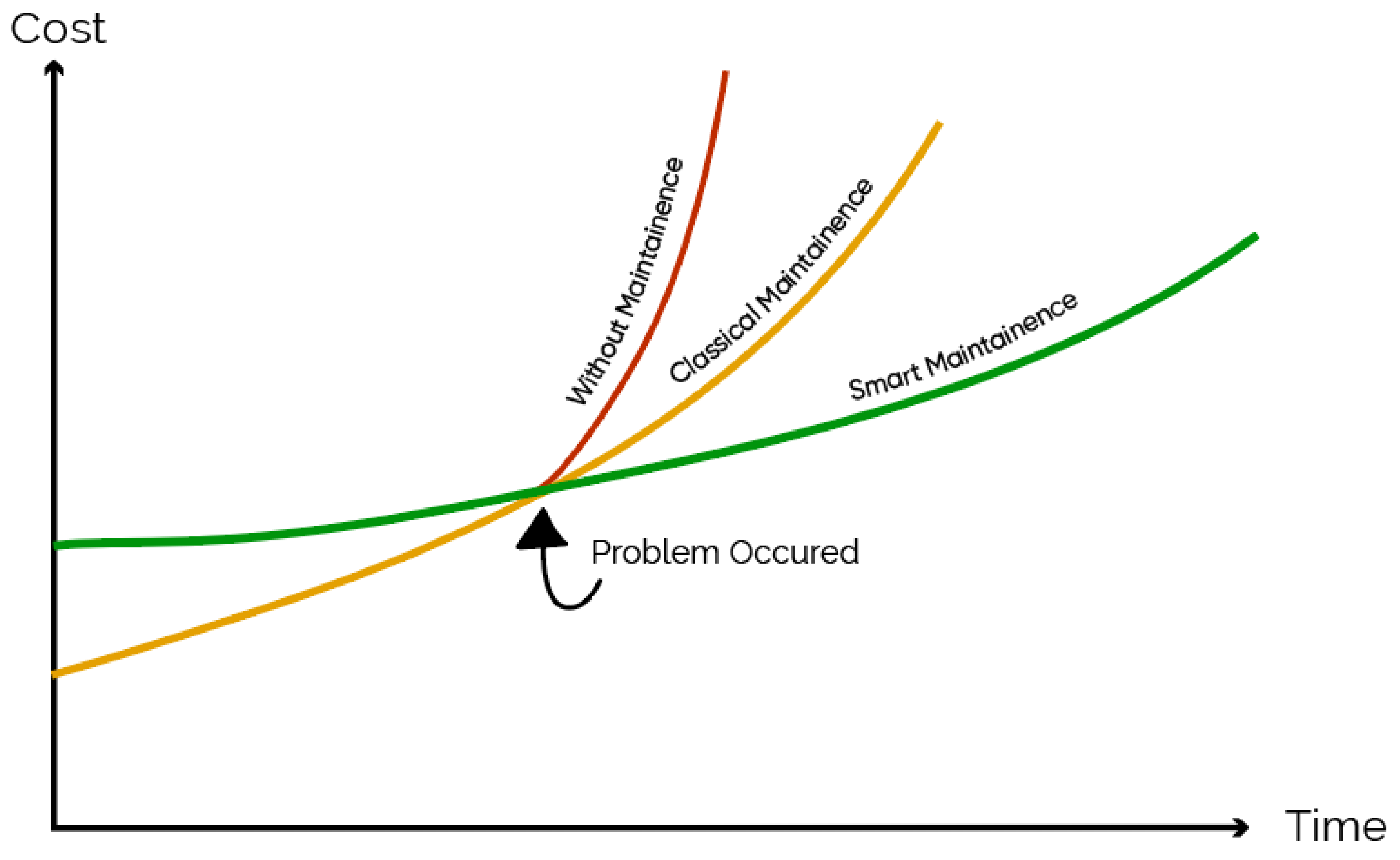
1. Root cause of problem is easier to find
2. Longer lifespan of equipment
3. Less downtime
4. Lowers maintenance costs by up to 20-30%

CHALLENGES

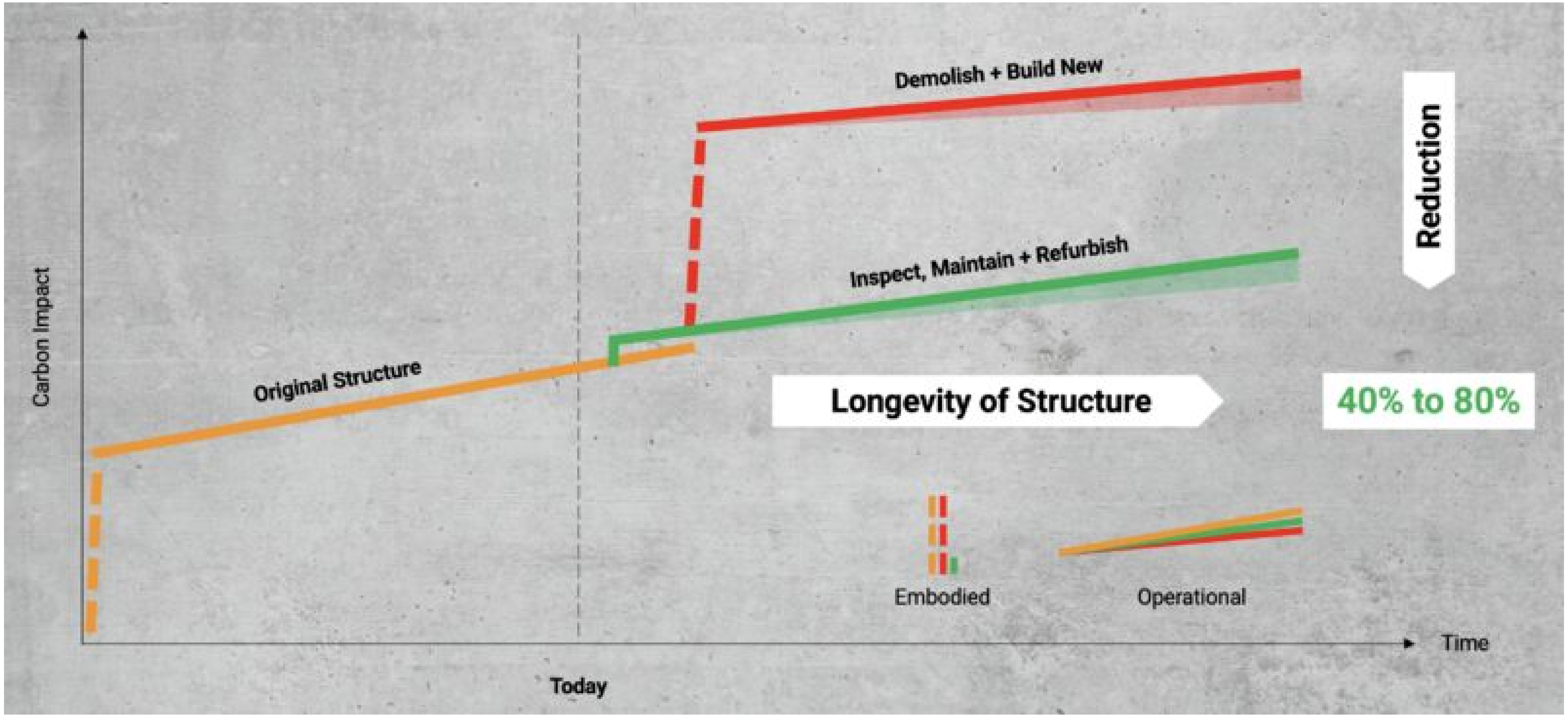
1. Hard to bring agreement among the different stakeholders
2. Not legally compulsory

PERFORMANCE VS TIME VS COST

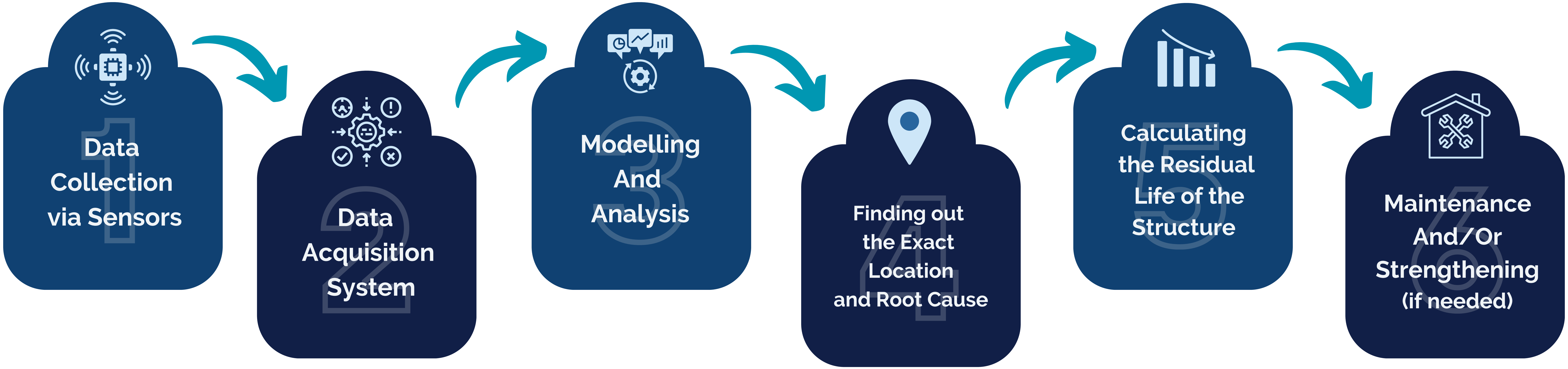


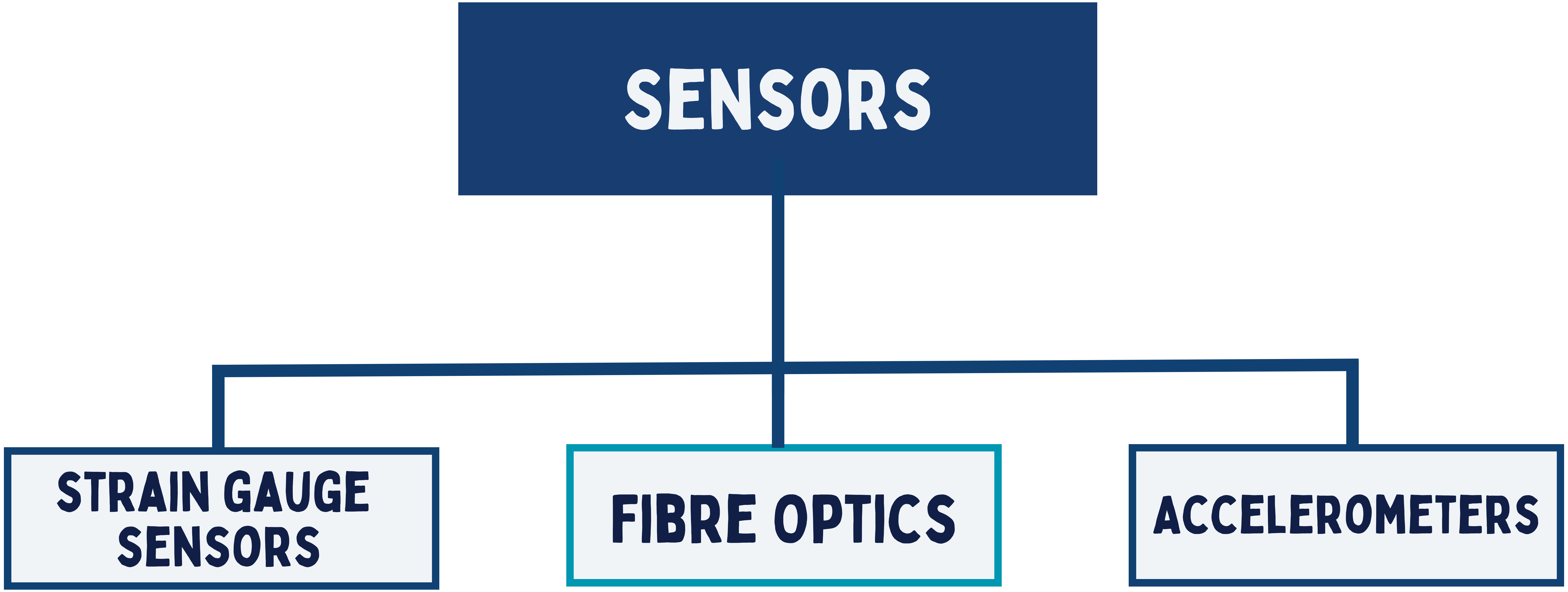


HOW IS IT RELATED TO THE THEME



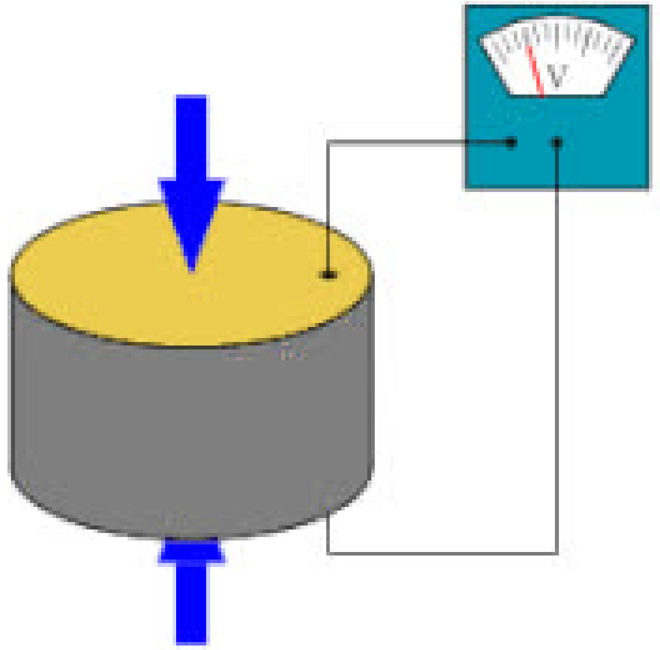
THE PROCESS

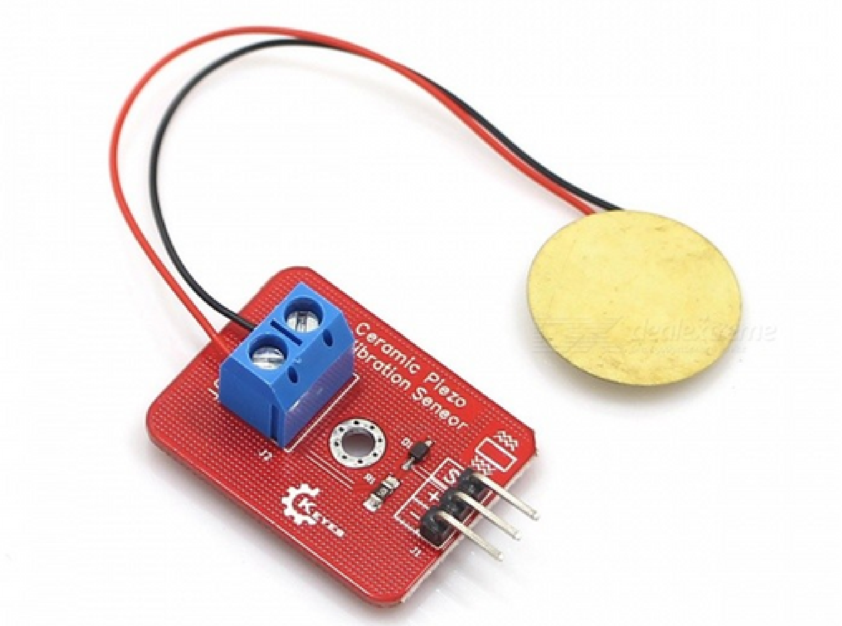

1
Data Collection via Sensors
2
Data Acquisition System
3
Modelling And Analysis
4
Finding out the Exact Location and Root Cause
5
Calculating the Residual Life of the Structure
6
Maintenance And/Or Strengthening (if needed)


SENSORS
STRAIN GAUGE SENSORS
FIBRE OPTICS
ACCELEROMETERS

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

PIEZO SENSORS - WORKING

- A strong PZT - lead–zirconate–titanate

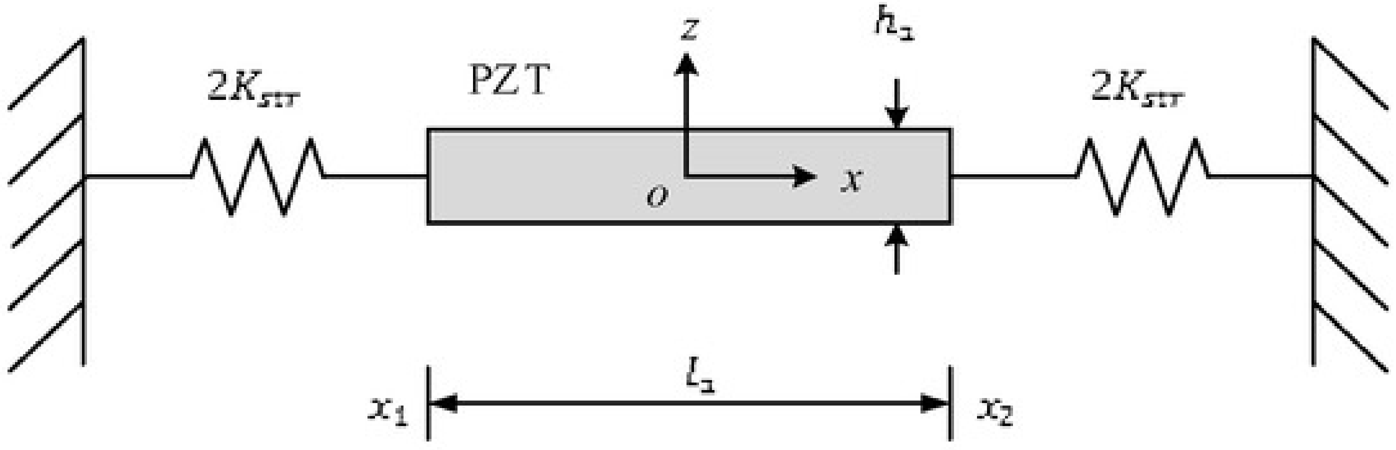
Piezoelectric Admittance

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

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

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

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

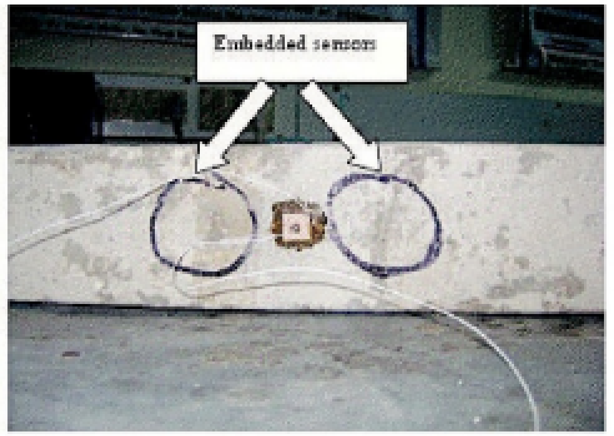


Capacitance	$C = l_a b_a \tilde{\varepsilon}_{33}^T h_a^{-1}$
Stiffness of the PZT patch	$K_{PZT} = A_a / (s_{11}^E l_a)$
Angle	$\varphi = \gamma \cdot l_a / 2$
Wave Number	$\gamma = \omega / c$
Wave Speed	$c = \sqrt{1/\rho s_{11}^E}$
Electromechanical Coupling Factor	κ_{31}^2
Stiffness of Host Stucture	K_{str}
Dielectric Constant at Zero Stress	$\tilde{\varepsilon}_{33}^T$
mechanical compliance at zero field	s_{11}^E

LOW COST SENSOR DEVELOPMENT IN INDIA

REINVENTING THE WHEEL

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



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

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 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 perforce are used for local-level response," says IIT Rourkee 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.

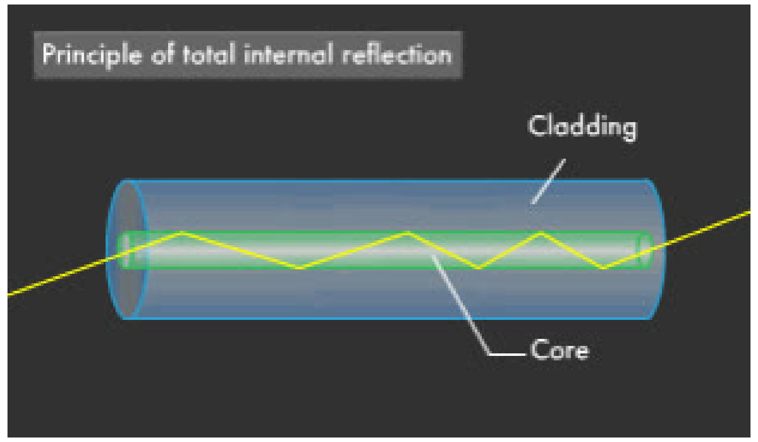
The team has submitted proposals for transfer of the technology to a few companies under IIT-D's Foundation for Innovation and Technology Transfer. Bhalla says the sensor has an edge because it can be used with minimum intervention and is less expensive.

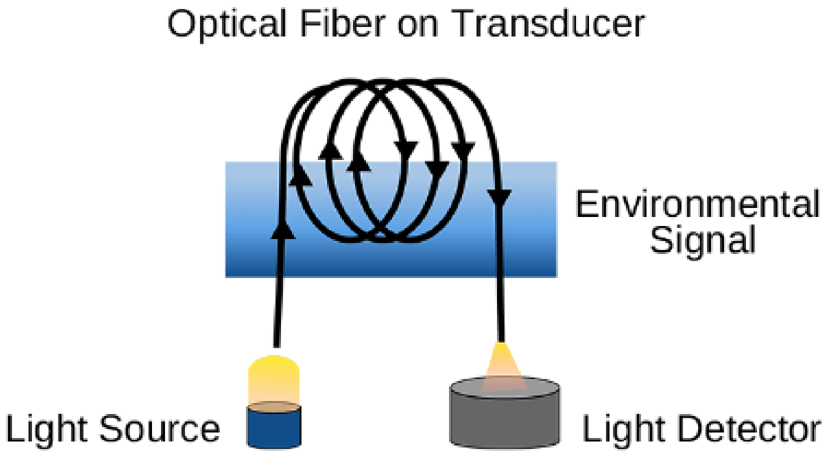
Over the past few years, the quest for better sensors for SHM has driven research into areas such as wireless sensor networks and system identification techniques to interpret data and assess the condition of structures and for life extension of old structures. According to Banerji, some of the key challenges 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

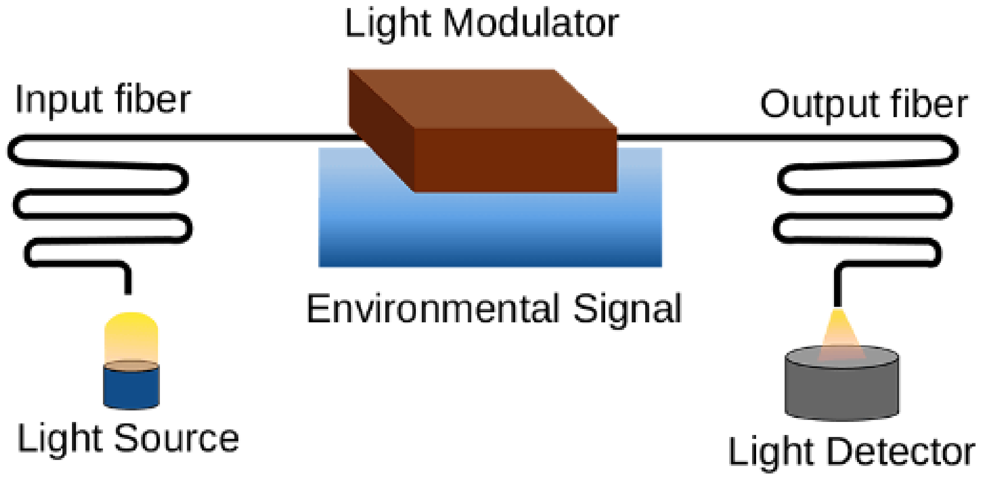
FIBER OPTICS

- 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 caliberate and most of the factors to be sensed and monitored can be done by this sensor more effectively.



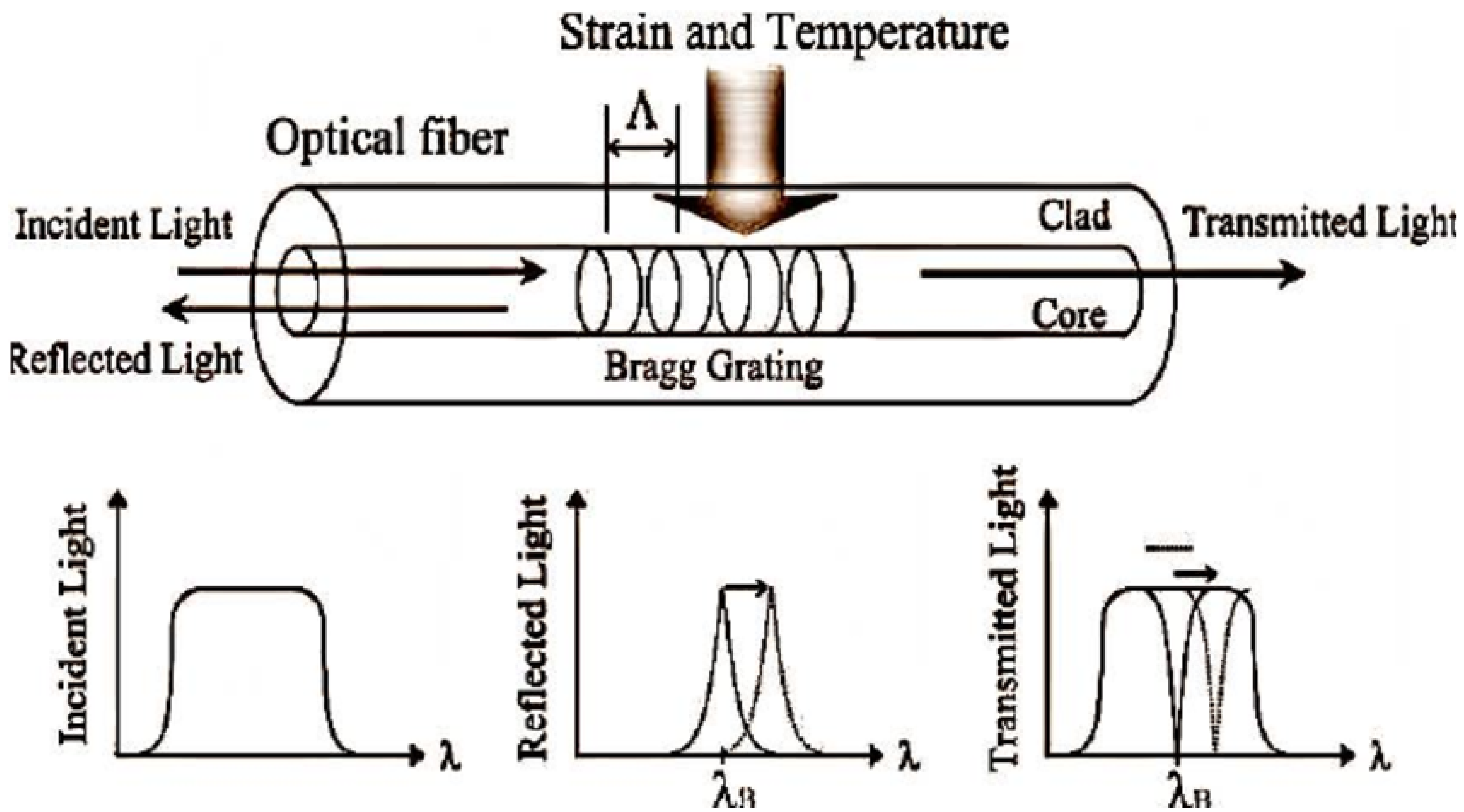


Intrinstic Fiber Optic Sensor



Extrinsic Fiber Optic Sensor

FIBER BRAGG GRATING



Bragg wavelength

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

Variation with Strain

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

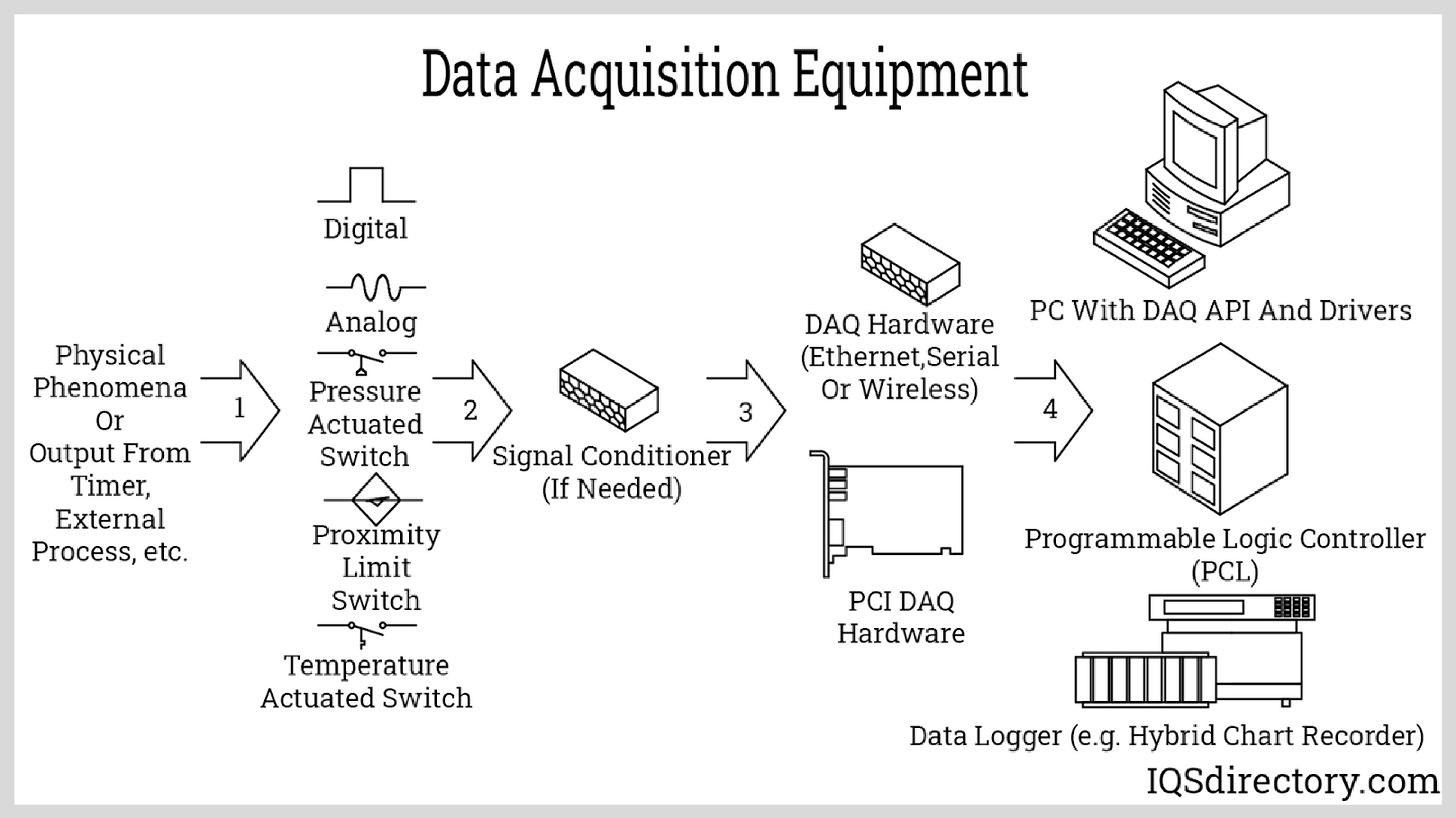
Variation with Temperature

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

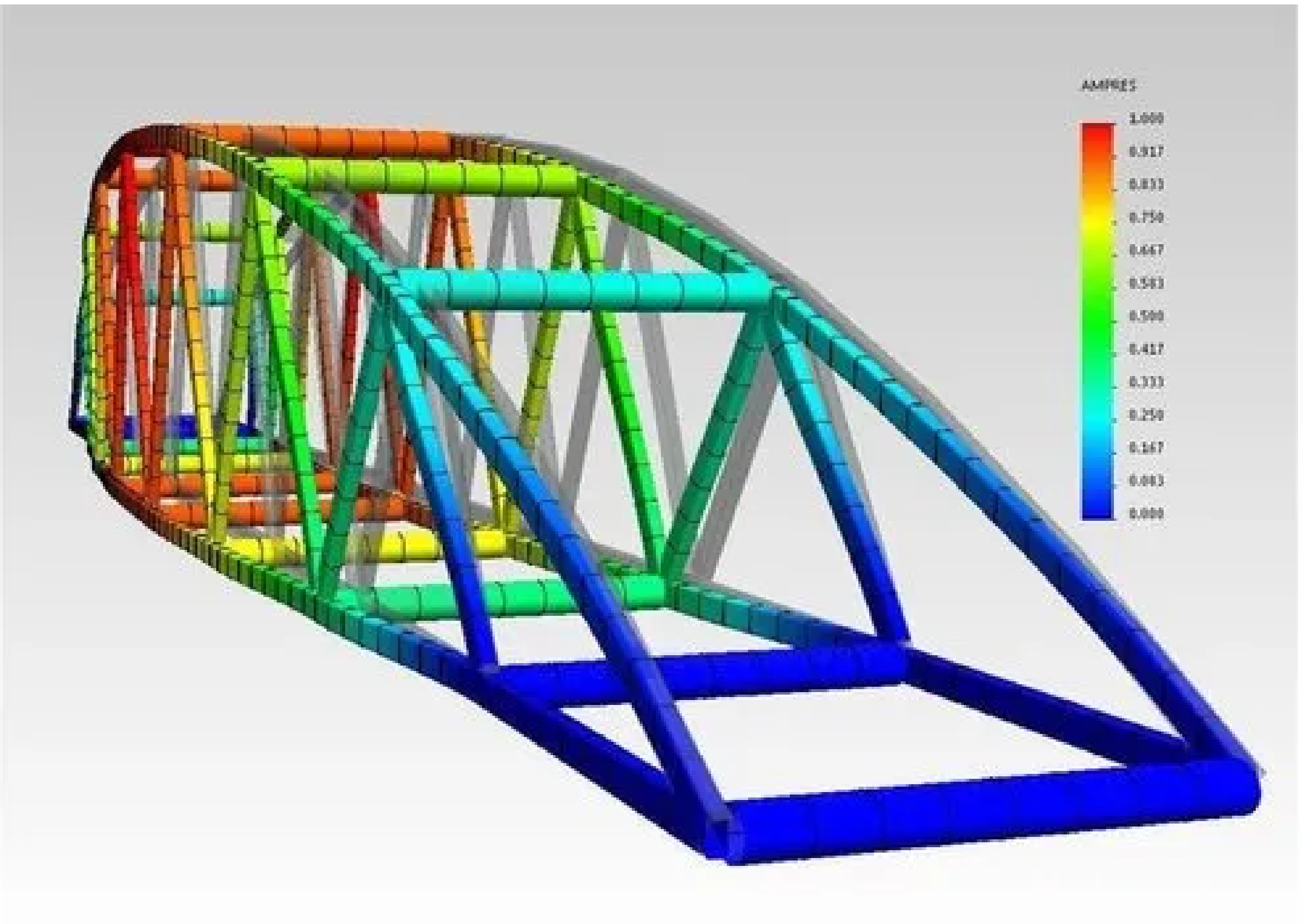
Photo-Elastic Coefficient

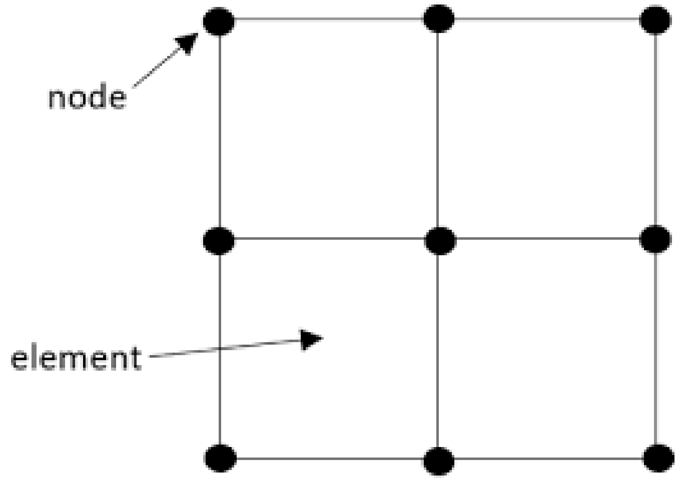
$$\rho_e = \frac{n_{eff}^2}{2}[p_{12} - \nu(p_{11} + p_{12})]$$

DATA ACQUISITION SYSTEM



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

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

Global Stiffness Matrix

Nodal displacements (unknowns)

Nodal forces

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

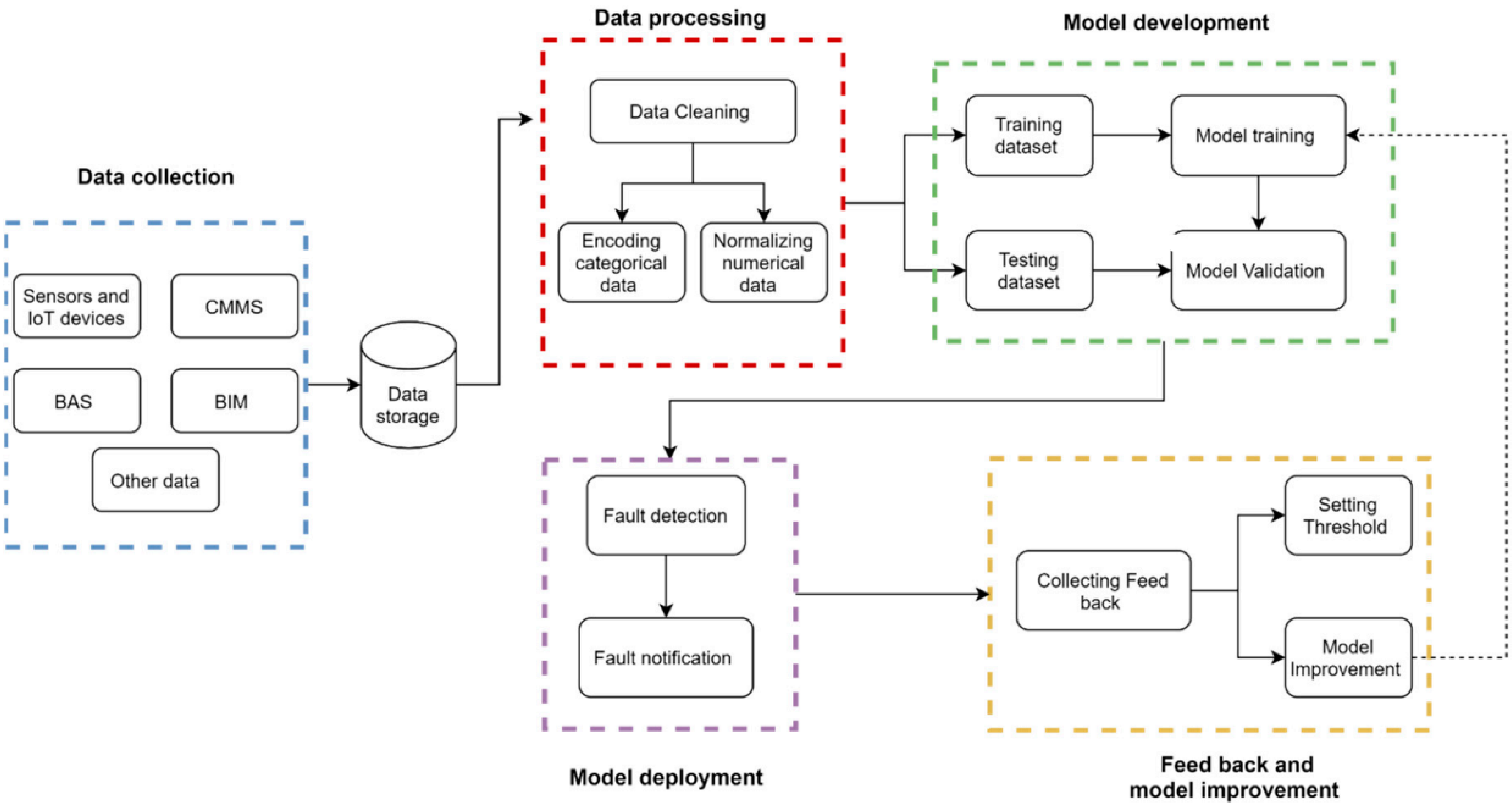
$$\sigma = E \cdot \varepsilon$$

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

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

Monitoring via CCTV Cameras

Snaps taken regularly sent to Database

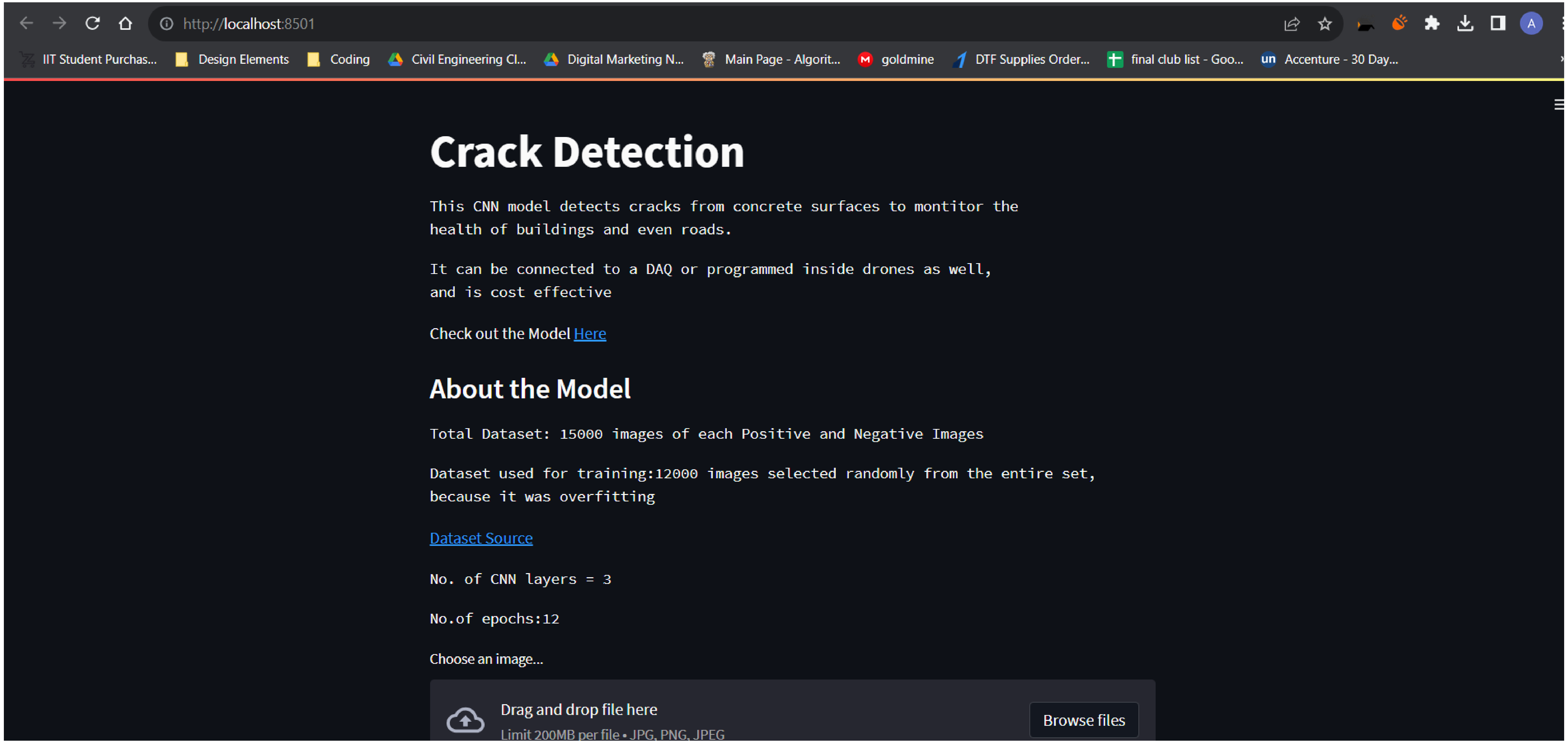
Images sent to CNN model

Model analyses images

Regular reports are made

Alerts sent (with report) if crack is found

CRACK DETECTION USING ML



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 fwhether the constuction 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 Posisson Distribution, for short term life

Description	Formula
overall damage assessment	$\varepsilon = \frac{\alpha_1 * \varepsilon_1 + \alpha_2 * \varepsilon_2 + \cdots + \alpha_i * \varepsilon_i}{\alpha_1 + \alpha_1 + \cdots + \alpha_i}$
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

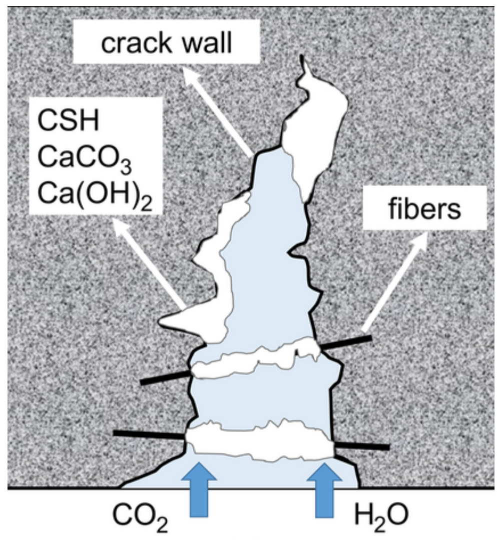
Self Healing Concrete is a class of smart material that has the structurally incorporated ability repair damages caused by mechanical usage over time.

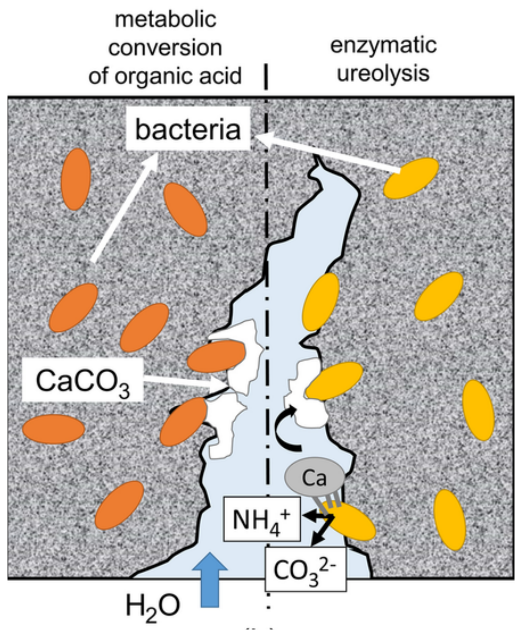
Biotic Concrete

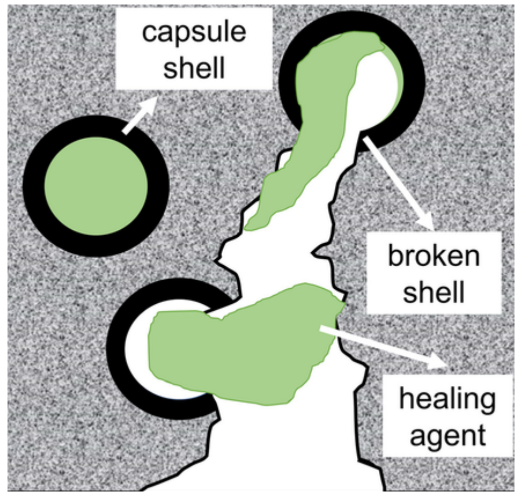
- Uses acid producing bacteria mostly from the bacillus family, which acts as a catalyst
- It is preferred when the concrete structure have access to water or moisture.
- When cracks appear, the water seeps in and the spores of bacteria germinate and feed on the calcium lactate converting it to insoluble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

Abiotic Concrete

- Uses chemical compounds like epoxy, methyl methacrylate(MMA), dicyclopentadiene(DCPD), Na2Sio3
- 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 capsulated 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!

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