ENGINEERING TOMORROW: UNVEILING GLOBAL AI TRENDS IN CIVIL ENGINEERING & PROSPECTS FOR INDIA

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ABSTRACT
Artificial Intelligence and Machine Learning have emerged as disruptive and transformative force across multiple domains and Civil Engineering is no exception. They are revolutionising various aspects and processes within this field. The Integration of AI into Civil Engineering and its practical application inevitably hinges on the overall national AI strategy of the respective country. Our article offers an in-depth analysis of the AI strategies adopted by three countries: the USA, China, and Japan. It delves into how these strategies have facilitated the integration of AI into the realm of Civil Engineering and explores the prospects within the world's largest democracy and the third-largest economy, India. While the USA & China are recognised as global leaders in integrating AI across all sectors including Civil Engineering, Japan has been deliberately included due to the dual challenges it confronts: a declining labour force exacerbated by negative population growth, and its vulnerability to natural disasters, particularly earthquakes and tsunamis, owing to its unique geographical location in a highly active seismic zone. India's AI strategy encapsulated in **#AIforAll** resonates within the Global South and our paper recommends specific 'AI Use-Case' scenarios in various branches of Civil Engineering unique to India and future prospects in the field.
Keywords—AI in Civil Engineering, NITI Aayog #AIforAll, USA AI Strategy, China-New Generation AI Development plan, AI and SHM, AI and Traffic management, AI and Construction Safety, Autonomous Excavation Systems

Introduction

AI is a rapidly advancing field that involves development of intelligent systems capable of performing tasks that typically require human intelligence. In recent times AI has become both a disruptive and transformative force across various domains, industries and Civil Engineering is no exception. Its importance lies in the ability to analyse vast amounts of data and extract meaningful insights enabling more accurate predictions and informed decision making. Integration of AI into Civil Engineering practices has revolutionised the way projects are planned, designed, constructed and maintained. This article delves into the evolution of AI in Civil Engineering with special focus on the contributions of three leading global players USA, Japan & China. It discusses current & future prospects for India.

Historical Evolution of AI in Civil Engineering

Researchers have divided the development of AI techniques into the following five periods: Incubation Period (1956 & Before), The formation period (1956 to 1965), The Dark period (1966-

1975), The knowledge application period (1975-1990) and the Integrated development period (1992-till date).

AI's involvement in Civil Engineering can be traced back to the early stages of expert systems and knowledge-based tools in the 1960s and 1970s. During this period, rudimentary AI applications were employed to assist engineers in decision-making processes related to construction materials, structural analysis, and preliminary design.

Throughout the 1980s and 1990s, AI technologies in Civil Engineering evolved with the advent of more sophisticated knowledge-based systems. These systems integrated expert knowledge, rules, and heuristics to enhance the efficiency of design processes and optimize construction methodologies but were never used at an industrial scale. The 2000s marked a significant shift as AI technologies became more intertwined with advanced numerical methods like Finite Element Analysis (FEA) and optimization algorithms. These integrations enabled engineers to tackle complex structural analysis, optimization, and design challenges more effectively.

However the real breakthrough occurred in the 2010s, as machine learning and neural networks emerged as game-changers in Civil Engineering. These technologies enabled engineers to predict structural behaviors, optimise designs, and automate various tasks by learning from historical data and patterns.

UNITED STATES OF AMERICA
Revolutionising Infrastructure : Development of AI in Civil Engg in USA

The USA has been at the forefront of R&D and adopting AI tech in all domains including Civil Engineering. The Trump administration in 2019 issued the "American AI Initiative" as an executive order that later became the "**National AI Initiative Act of 2020 (NAIIA)**" with the focused objective to keep USA the Global leader in AI through various proactive policy and incentives. The Nations focus on AI research and development has led to creation of cutting edge software tools and solutions that aid engineers in complex design and analysis tasks. Existing 'Use Case' AI tech are discussed below.
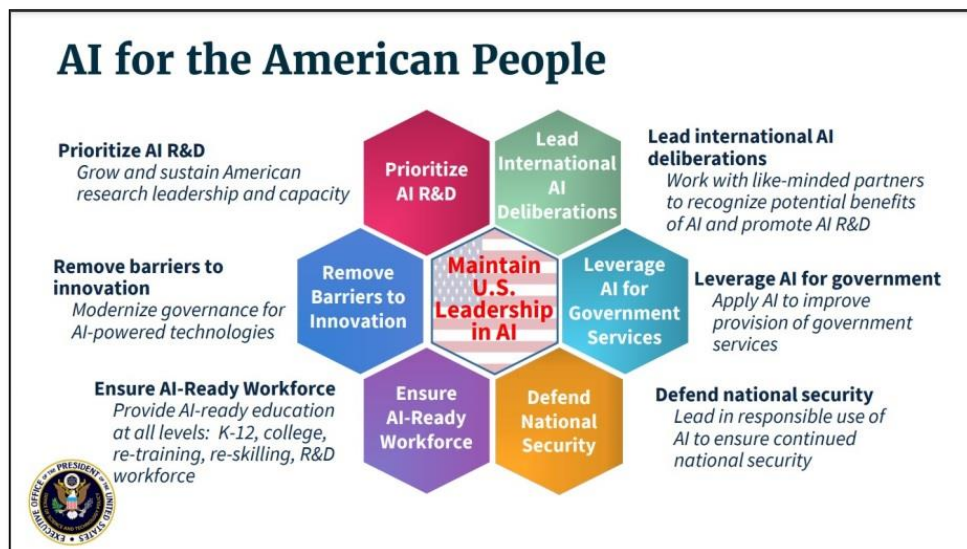

Fig 1. American AI Initiative 2019

Structural Health Monitoring(SHM) AI has made a significant impact in predictive analysis for structural health monitoring and US has commenced integrating AI models in the SHM of vital assets like tunnels and bridges. By integrating sensor networks and AI algorithms, Civil engineers can continuously monitor the health and performance of bridges, buildings and other infrastructure assets in real time. The sensors collect real time data on structural strains, vibrations and

environmental conditions which is fed into an AI driven analytics platform that performs processes and analyses data. AI algorithms analyse these data to detect unusual patterns & any sign of stress or fatigue that exceeds predefined thresholds, the system generates alerts automatically prompting investigation and further actions.

AI Enabled Drone Inspection The USA has also been at the forefront of integrating drone technology and machine learning algorithm using digital twins to achieve seamless capability in terms of visual inspection of critical infrastructure assets. This technology is being considered a game changer in the Infrastructure Inspection sector due to the versatility of drones and their ability to reach difficult areas. The technology is successfully used in inspection of offshore RCC Oil and gas platforms, Industrial chimneys, Multistorey buildings and Bridges.
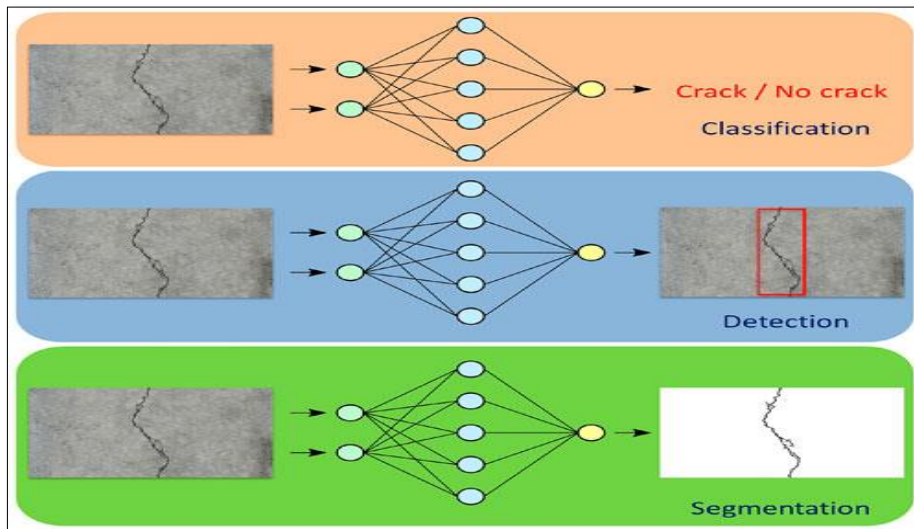

Fig 2. Three modes of CNN based Image Analysis

**Fig 3. Bridge Inspection Using AI Integ Digital Twin Platform**

JAPAN
Data to Designs: Japan's Journey in Integrating AI with Civil Engg

Japan unlike other leading AI global powers faces a twin challenge of a dwindling labour force aggravated by negative population growth and its susceptibility to natural disasters especially

earthquakes and tsunamis. The seismic resilience naturally transcends Engineering, as it's a matter of National Safety. Consequently, Japan has been a pioneer in leveraging AI technology to enhance it's disaster preparedness, safety measures and infrastructure resilience. The "**AI Strategy 2022**" of Japan outlines its principled approach towards realising Society 5.0, characterized by the integration of cutting-edge technologies, particularly AI, the Internet of Things (IoT), Big Data, and Robotics, to create a human-centric and sustainable society contributing towards sustainable development goals. Advanced AI and Robotics are expected to play a significant role in Society 5.0.
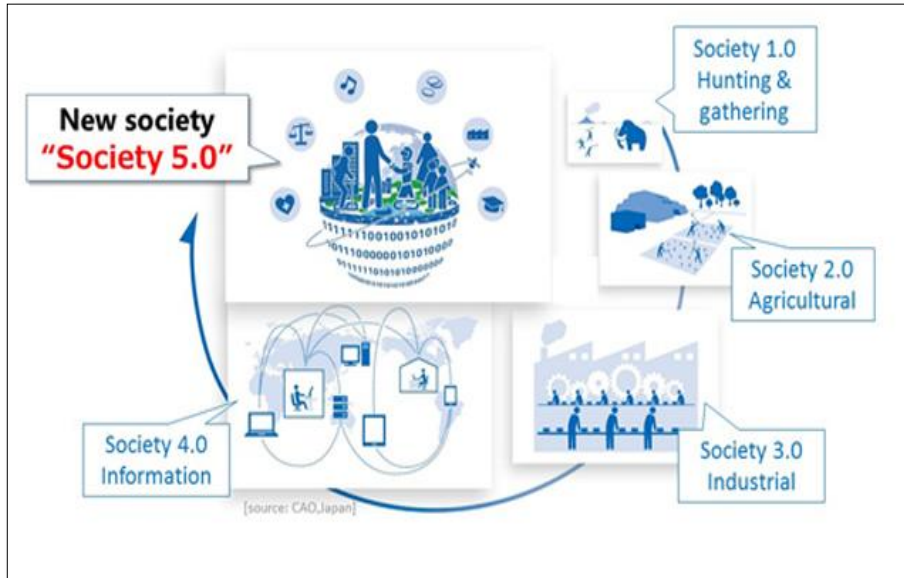
Fig 4. Evolution of Society 5.0
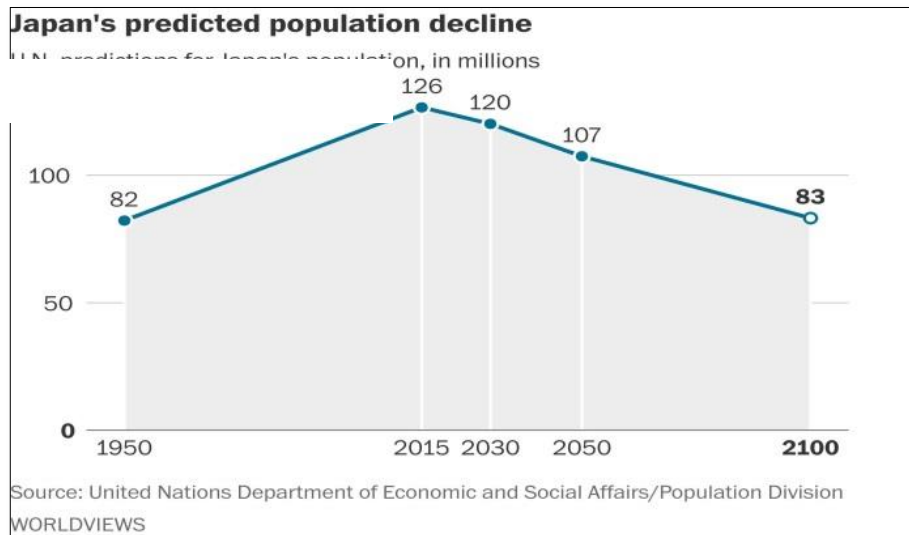
Fig 5. Population Growth Rate-Japan

The Japanese AI strategy lays emphasis on integration of AI in those fields where it has existing strengths and to address challenges unique to it especially in infrastructure, disaster prevention, transportation and logistics. It promotes R&D for utilisation of AI tech in material science, upgrading and improving the efficiency of maintenance and management through automatic identification of abnormalities in infrastructure facilities using AI. Japan embraces AI as an agent of sustainability. With a landscape characterized by seismic challenges and a commitment to sustainable development,

Japan has harnessed the power of AI to pioneer a new era of smart and sustainable infrastructure as enumerated in succeeding paras.

Infrastructure Planning and Smart Cities AI is being integrated into the planning and construction of new infrastructure especially smart cities with seismic resilience. A No of smart cities have come up, the renowned ones are 'Panasonic: **Fujisawa City, Kanagawa'**, Accenture: **Aizuwakamatsu, Fukushima** and Plug and Play: **Osaka City**, **Osaka**. The major emphasis on these cities are monitoring of energy consumption of various buildings using AI for analytics.

Seismic Retrofitting and Structural Analysis AI algorithms are being increasingly used to scrutinize seismic data, historical earthquake records, and structural properties to assess existing structures, identify vulnerabilities and recommend tailored seismic retrofitting measures thus aiding structural engineers to implement appropriate retrofitting strategies. Historical seismic data converges with AI algorithms to yield predictive models. The fusion of human wisdom and AI's analytical prowess culminates in engineering marvels that confidently endure seismic tests, defying the tremors that would challenge their integrity.

Disaster Response and Damage Assessment AI-driven technologies play a pivotal role in post-disaster response and damage assessment. Drones equipped with AI algorithms conduct surveys of affected areas, assess infrastructure damage, and provide real-time information to emergency responders. AI-powered image recognition and ML algorithms help identify damaged structures, road blockages, and areas requiring immediate assistance, streamlining rescue and relief operations.
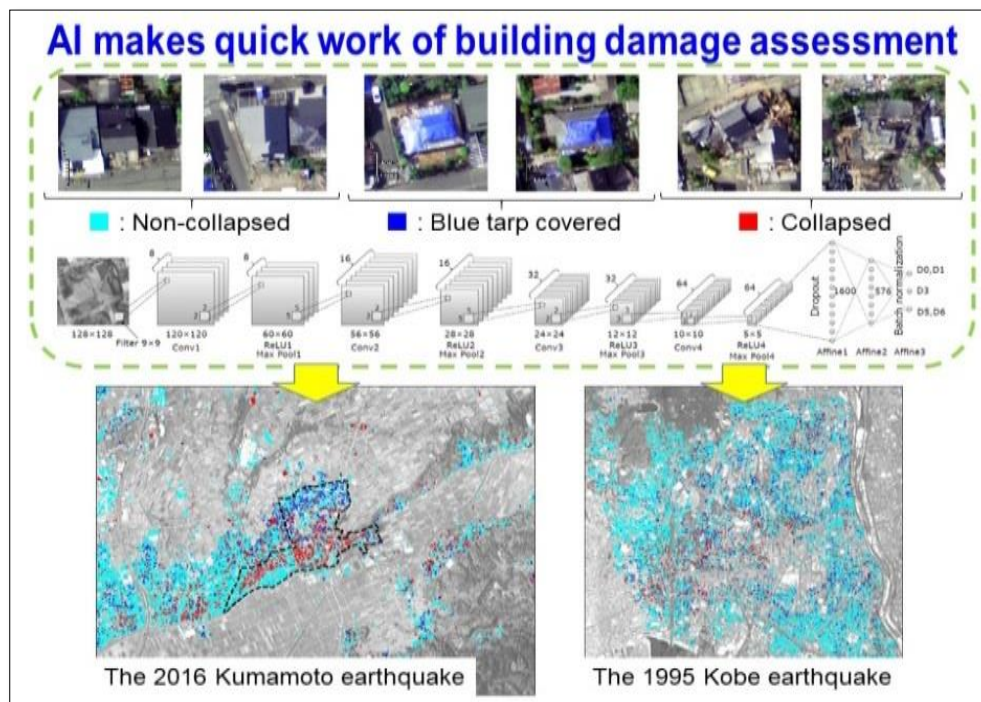

**Fig 6. DL Algorithm for Post Disaster Assessment using Visualisation**

CHINA
**Sculpting Tomorrow: China's Multi-Faceted Strategy for AI and Infrastructure Advancements**

The Chinese central government publicly released its '*New Gen AI Development Plan*' on 8 July 2017, an year after Google's DeepMind AlphaGo defeated the world champion in the strategic Chinese board game Go, which is known as the most challenging classical game for Artificial Intelligence because of its complexity. This game with simple rules has an astonishing 10 to the power of 170 possible board configurations - more than the number of atoms in the known universe. The

event is considered a milestone in AI development as the system learnt and mastered the game playing with itself.

In 2020, China surpassed the USA in the share of AI paper citations. The **'Stanford University AI Index 2023'** annual report states that China continues to lead in AI journals publications and citations. Nine of the top 10 institutions in the world in 2021 by virtue of rank by number of AI publications in all fields are all Chinese.
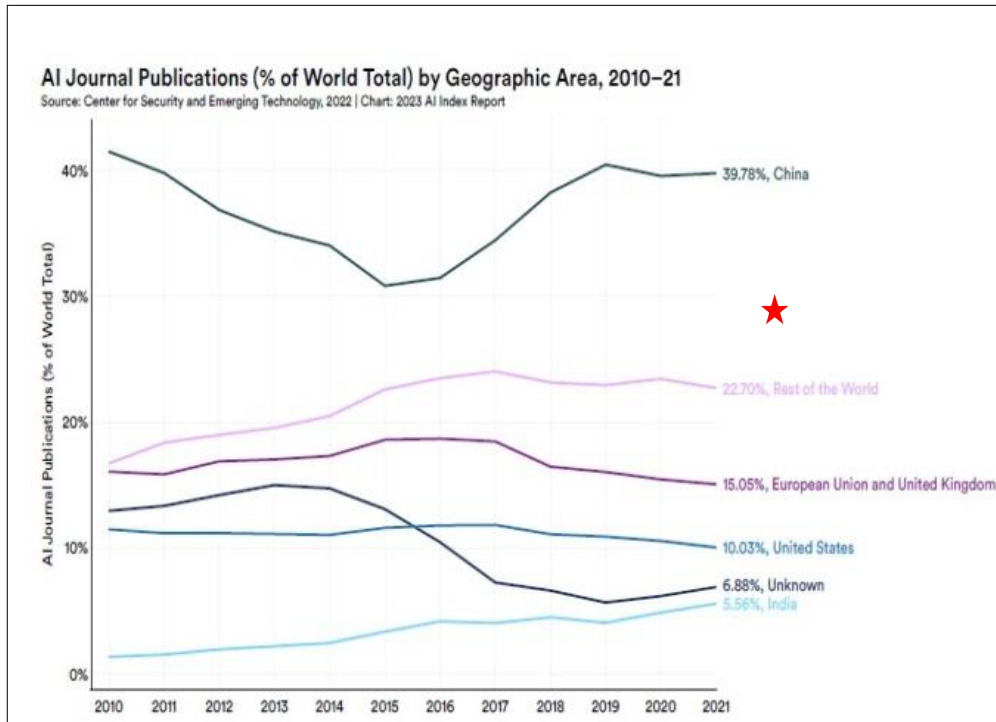
**Fig 7. Total AI Journal Publications by Area**
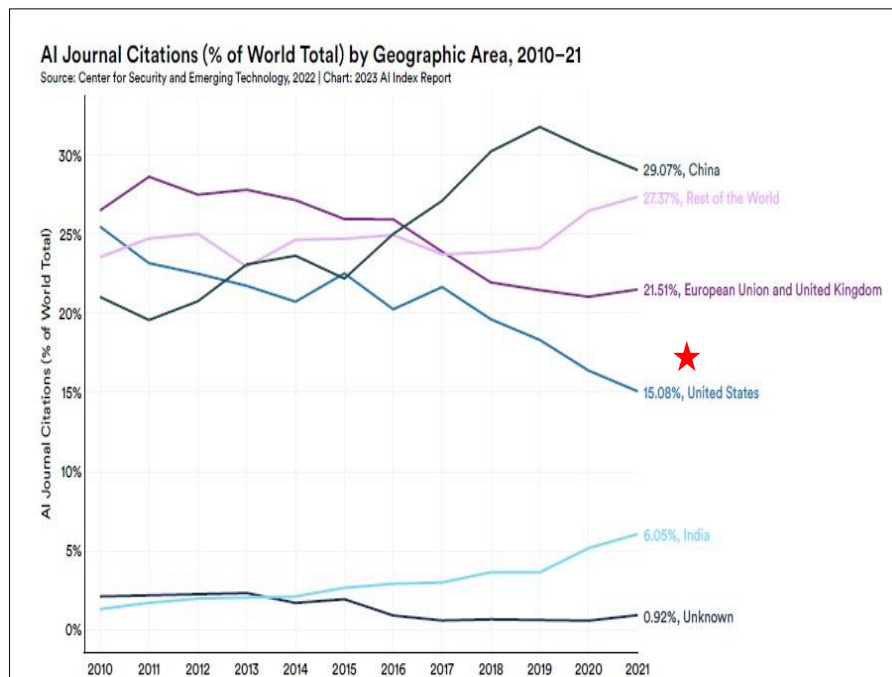
Fig 8. Total AI Journal Citations by Area
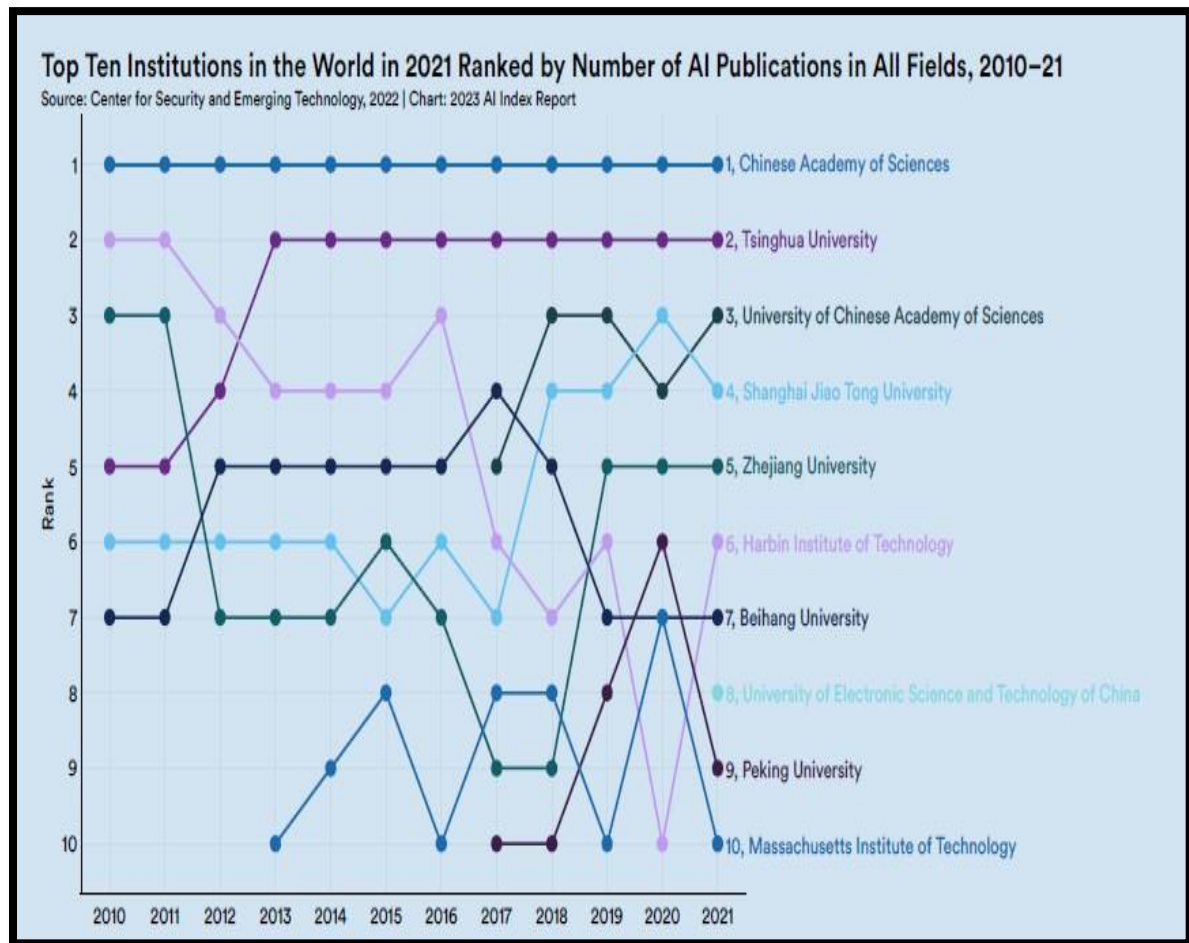
Fig 9. Top Ten Institutions by No of AI Publications

As one decodes the Chinese '*Next Gen AI Development Plan'*, two distinct things emerge, firstly China considers AI as a new focus of International competition, and hence evolved a guiding ideology that emphasizes on development of smart economy, build smart society, maintain national security and to build an ecosystem that interacts and integrates knowledge groups, technology groups and industry groups which support each other with talents, system and culture. Secondly it also stresses on following the "*law of coordinated development of economic construction and National Defence construction, by promoting two way transformation and application of military & Civilian scientific and technology achievement, joint construction and sharing of military & Civilian innovation resources*". It clearly states that *"All types of platforms should promote Military-Civilian sharing and sharing in accordance with requirements and relevant regulations for deep Military-Civilian integration"*.

Recently, the China Academy of Information and Communication tech (CAICT), a think tank under the PRC Ministry of Industry and Infotech (MIIT) published a '*White Paper on Artificial Intelligence*' in 2022 which has been translated into English by Centre for Security and Emerging Tech (CSET). The paper discusses the '3D Development of AI' namely Technology Innovation, Engineering Practices & Trust Worthiness and Safety as the new coordinates for AI development.
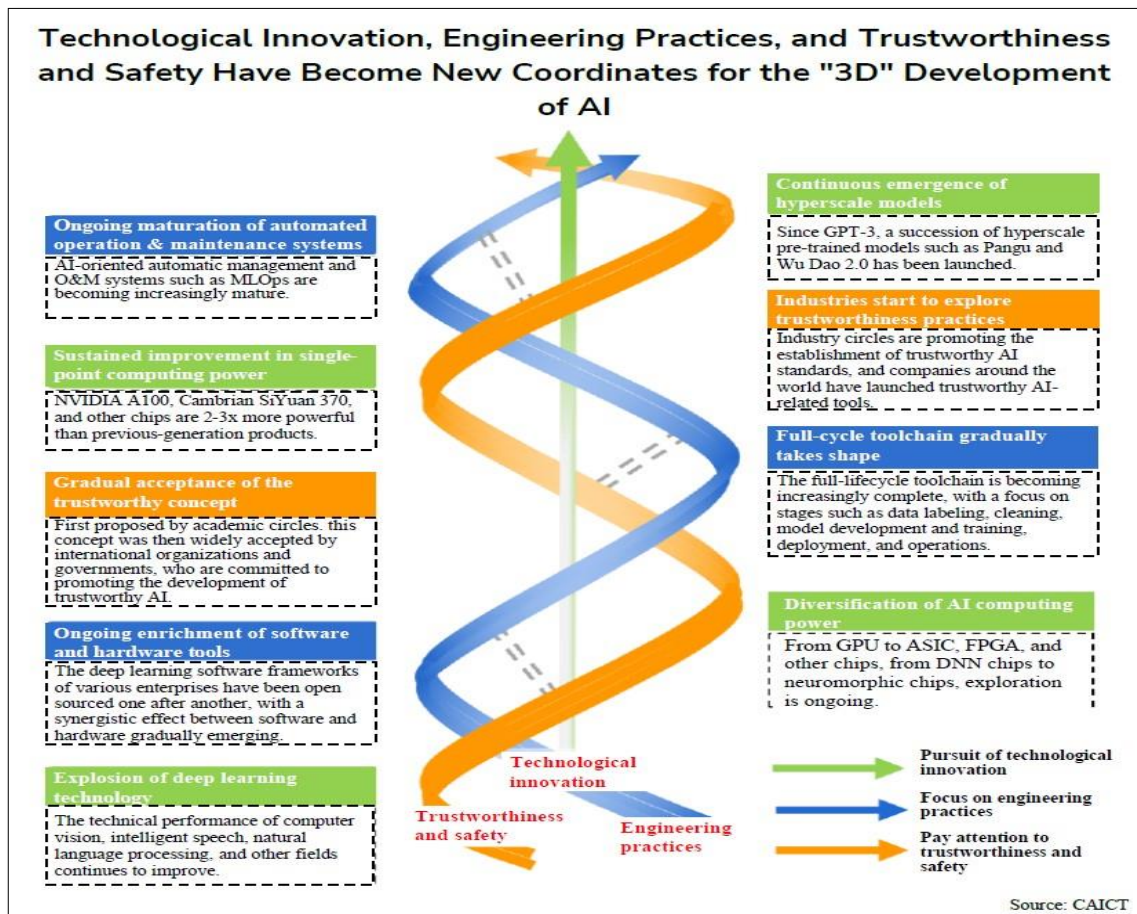
Fig 10. Extract from White Paper on AI- CAICT

Capitalising on its rapid economic growth and commitment to advance in Engineering capabilities, China with its extensive infrastructure development initiative continues to provide ample opportunities to integrate AI into Construction, Transportation and Urban Planning projects. Few 'Use Case' sectors are discussed as under.

Smart Infra China has successfully embraced the concept of Smart Infrastructure where AI and Internet of Things (IoT) converge to monitor health and performance of Bridges, Roads, Railways and Buildings in real time. For instance in the city of **Hangzhou**, the '**City Brain**' project uses AI, Big Data analytics & Cloud computing to optimise urban traffic flow, manage congestion and reduce travel times by integrating data from multiple sources such as traffic cameras, GPS devices and public transportation.

AI & Robotics in Construction China has been investing heavily in AI driven construction robotics to improve efficiency and precision in construction projects. Robotic systems equipped with AI algorithms are being used for tasks like Bricklaying, Concrete pouring and 3D printing of building components. These robots can work faster, more accurately than traditional manual labour, leading to cost savings and faster project completion. The South China morning post in an article titled *"China's robot built 3D-printed dam ready in 2 years : Scientists"* has claimed that China is using AI to effectively turn a dam project on the Tibetan Plateau into the World's largest 3D printer. The 180 metre (590 feet) high Yangqu hydropower plant will be built slice by slice using unmanned excavators (Autonomous Excavation System), trucks, bulldozers, pavers and rollers, all controlled by AI in the same additive manufacturing process used in 3D printing. China's implementation of AI technology in various Infrastructure projects showcases its commitment to embracing cutting edge innovations to drive economic growth and sustainable development. As AI continues to evolve, its integration into China's construction sector is expected to play a crucial role in advancing the vision of Chinese Communist Party to be a global AI power in all fields.
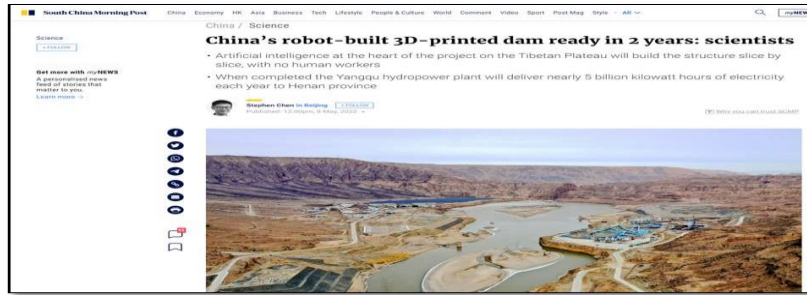
Fig 11. South China Morning Post dated 08 May 2022

INDIA
Engineering Evolution: Unleashing AI's Power to Transform India's Construction Sector

India is at the cusp of a technological revolution, rising as a startup Powerhouse with a booming Infrastructure Industry, with a large number of Highway projects, Smart City projects with focus on last mile connectivity and housing for all. India ranks second only to China in the number of new STEM graduates being added into the economy. The national AI strategy promulgated by NITI-Aayog has focused on AI for all with emphasis on Responsible AI. It states that India's approach to AI implementation is to be guided by optimisation of social good rather than maximisation of topline growth. At a global level, the 'Current AI adoption and Future AI Investments' graph clearly shows that the construction sector is lagging behind other sectors especially in terms of future AI investments. The inference being that opportunities for growth of AI in this sector would depend on innovation and integration of new ideas and new 'Use Case' scenarios wherein India can emerge as a leader in this field. The No of Indian users using the GitHub platform for AI projects shows an increasing trajectory reflecting India's strengths.
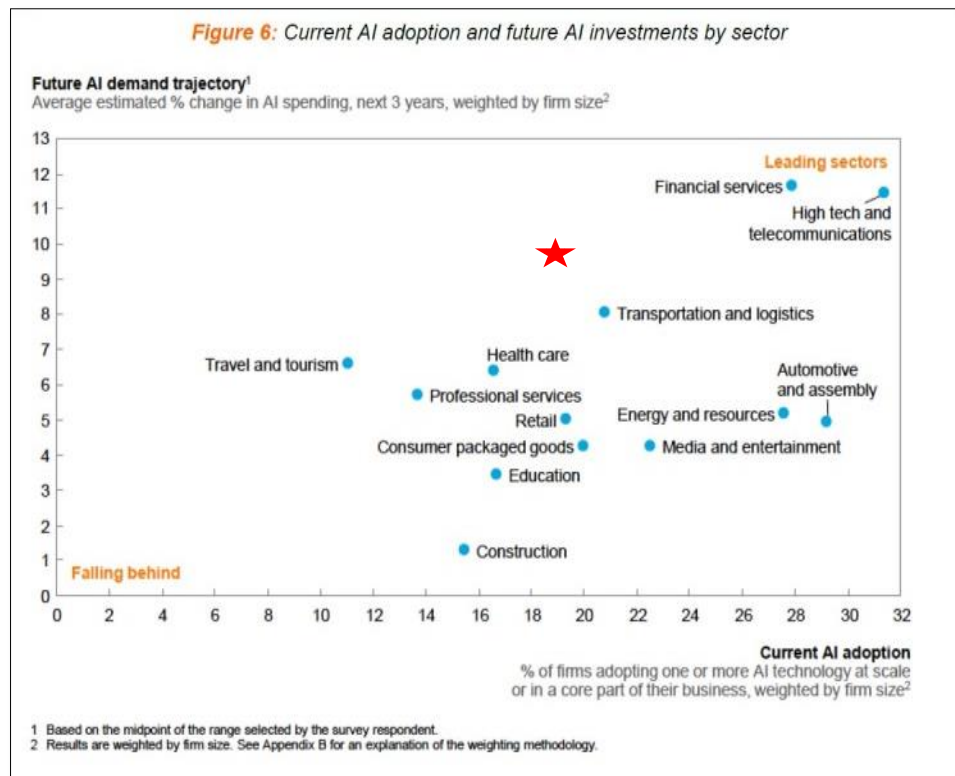
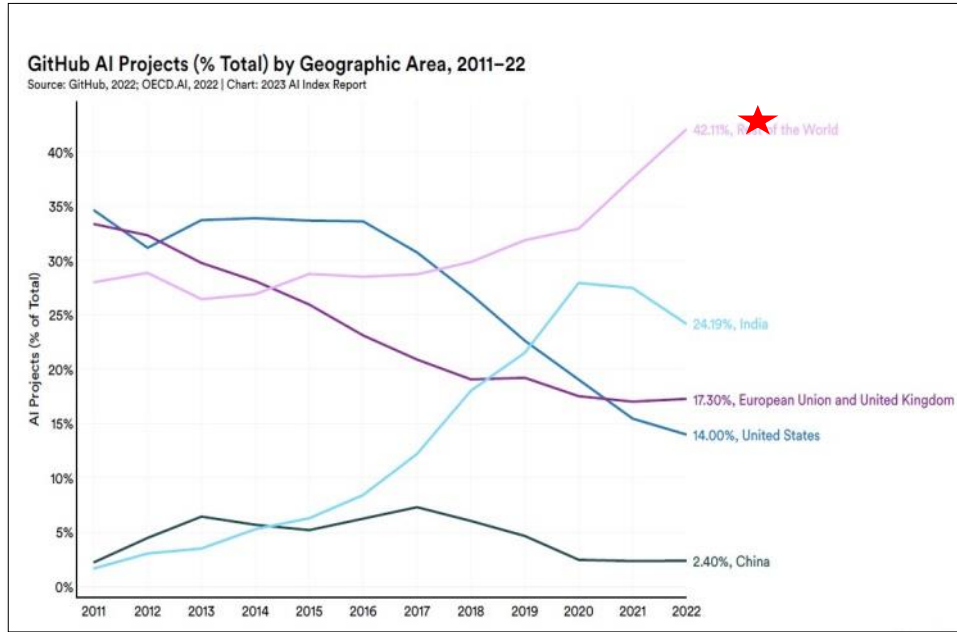**Fig 12. AI Adoption & Future AI Demand trajectory : Sector Wise**
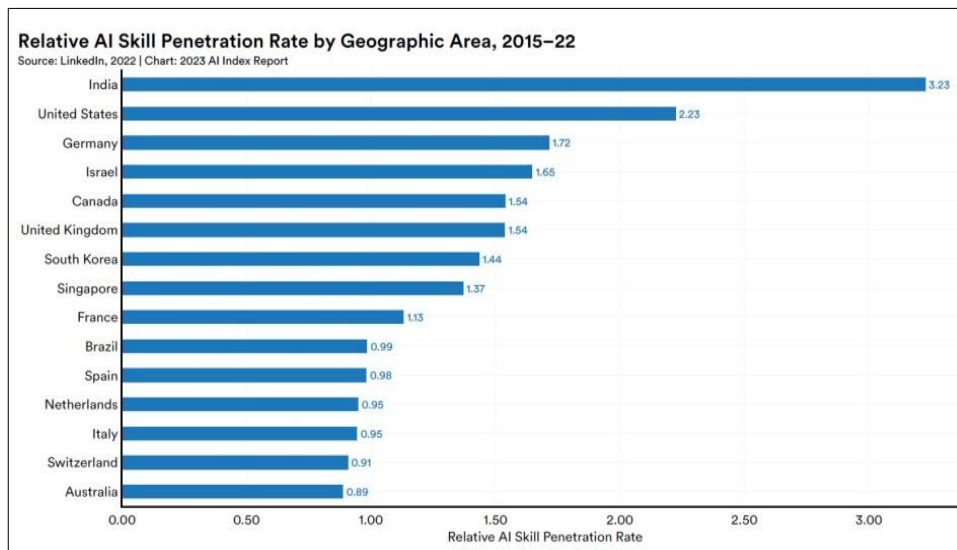
Fig 13 AI Projects in GitHub : Area Wise

Fig 14 AI Skill Penetration Rate (Based on LinkedIn) - 2023 AI Index Report

AI Prospects in Civil Engg for India

The recommended 'Use Case' AI tech for various subfields within Civil Engineering in India are discussed below.

Structural Engineering   As India continues on the path of sustainable economic development with a positive growth rate, the upcoming years will usher in more urbanization, the construction sector will continue to flourish with No of new Multistorey projects, Flyovers, Bridges and Tunnels including Metros coming up across all cities with special emphasis on tier 2 & 3 cities. The border regions will see more investments in Smart Villages/Towns and Strategic assets including roads will continue to be built in forwards areas (Seismic Zone V). The McKinsey report on effect of Automation on various sectors emphasis the tremendous potential for the construction sector in the coming years. Integrating AI in construction of Smart Cities offers unique opportunities to achieve energy efficiency reduce carbon footprint and achieve sustainable development goals. In the field of Structural Health monitoring, the construction of Metro Rail that includes construction of both tunnels and bridges offers immense opportunities to industries to come up with an indigenous low cost

solution based on cloud computing thereby integrating Digital India mission with **#AIforAll**. Structural Damage assessment and employing drone-based AI algorithms for inspection for Water tanks, Multistory buildings, Industrial structures and Bridges have huge potential for cost & time effectiveness.
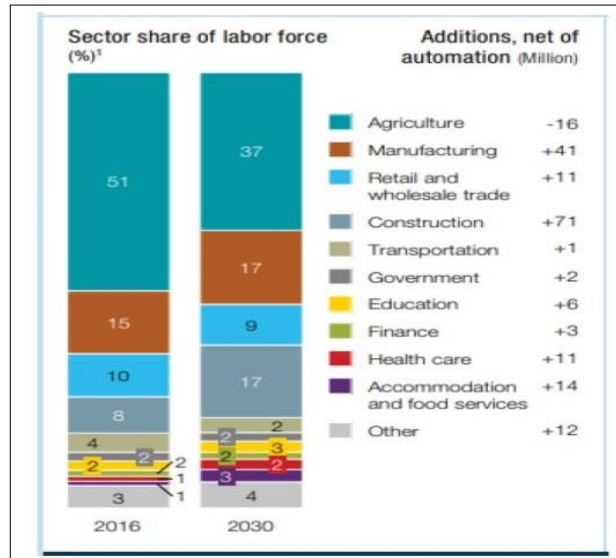
Fig 15. McKinsey Report on Automation

Transportation Engineering   In the transportation sector, India continues to invest in increasing the No of highways and overall connectivity. The Year-end review 2022 published by MoRTH shows a tremendous 47.85% growth in length of National Highways. The real time evaluation and monitoring of road conditions especially both in Tier-1 cities and border areas through AI enabled detection & identification of potholes, AI monitored traffic management that can integrate vehicle movements and traffic signals, identify peak traffic hours and bottle necks are few of the 'Use-Case'. AI and ML tools can help in planning maintenance schedule with prioritisation in allocation of resources for repair by integrating sensory data and GIS. For Border Road projects in forward locations the integration of AI & Autonomous Excavation System can be a game changer in enhancing efficiency and faster completion of strategic connectivity.
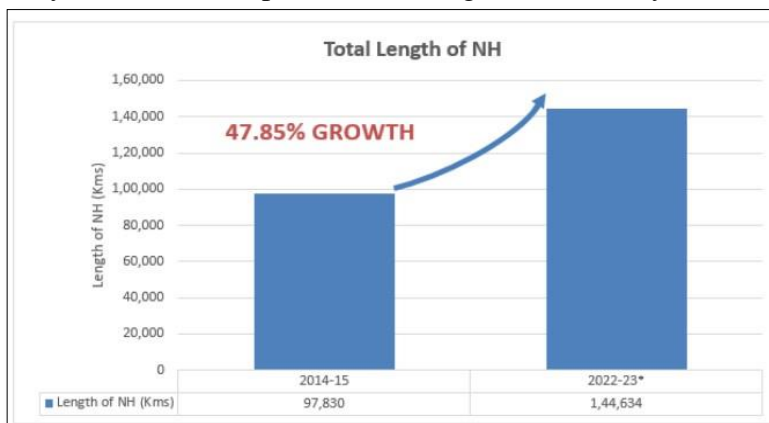
Fig 16. MoRTH- Year End Report 2022

Construction Site Safety   The construction industry in India despite being the second largest after agriculture accounts for quarter of all work place accident fatalities. Such challenges in site safety

require technology driven and innovative solutions. It states that falls, electric shock, collapsing walls and scaffolding at construction sites are the leading cause of work related death. AI driven ML systems that use image identification & object classification can monitor the sites in real time and provide warning alerts to site engineers reducing avoidable fatalities.

Fig 17. AI-Monitored Construction Site

Conclusion   AI and Machine Learning have emerged as pivotal tools in Civil Engineering globally, revolutionising various aspects of the field. This paper covers its integration by three major global powers namely the USA, Japan and China by analyzing their respective National AI strategy. The United States continues to lead in sheer volume of AI investments, China has emerged as the world leader in AI research & education with a Top-down driven AI implementation strategy. Japan due to its susceptibility to natural disasters has embarked on Society 5.0 with AI & Robotics at the forefront. The NITI-Aayog report points out that India's thriving startup ecosystem and abundant STEM graduates offer a fertile ground for AI innovation across various sectors, including Civil Engineering with immense entrepreneurial ingenuity, a supportive ecosystem and government policies that can nurture their ambitions. Leveraging AI in the construction sector holds immense potential to revolutionize processes, enhance efficiency, and drive sustainable growth. AI in Civil Engineering is more than a technology it's a driving force which when harnessed with Synergy amongst all stakeholders can open up new possibilities for the Industry and the end user alike. These are no longer distant visions but tangible realities reflecting our nations unwavering commitment to becoming a global leader in technology, entrepreneurship and development with the **#ResponsibleAI** and **#AIforAll** as it's core strength as envisaged in our National AI Strategy.

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