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Application of the Internet of Things in the Field of Civil Engineering: A State-of-the-Art Review

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Abstract

The notion of IoT, also known as the Internet of Things, has been there for many years, but recent technical progress has elevated its prominence. The increasing need for creative ideas, approaches, and technology is driven by the fast evolution of our world today. The construction sector has enthusiastically adopted the IoT as an advanced technology to develop intelligent structures, enhance resource efficiency, and manage construction expenses. One of the main benefits of incorporating IoT into construction operations is the notable advantage of being able to gather and analyse real-time data. The use of IoT technologies in the construction industry can greatly augment productivity and efficiency. This review article examines the IoT and its applications in different fields of the civil engineering and construction industry. It investigates the advantages of IoT in this sector and explores how it is implemented.

Keywords: Internet of Things (IoT), Structural Health Monitoring (SHM), Artificial Intelligence (AI), Automation, Image Processing, Data Acquisition.

1. Introduction

Globally, the construction industry has been significantly underperforming, experiencing an annual loss of approximately $1.6 trillion due to low productivity rates. Studies indicate that approximately 57% of labor hours in the construction industry are dedicated to non-value-added activities, contrasting sharply with the 26% observed within the manufacturing sector. Innovative technologies offer solutions to address these challenges. Hence, it is imperative to tightly integrate and incorporate innovative "technology-enabled" processes through the Internet of Things (IoT) into the construction industry. This integration aims to minimize uncertainties and optimize all operations in a systematic fashion [1–4].

Although there isn't a universally accepted definition for the Internet of Things (IoT), its origins trace back to 1982 when a modified coke machine was connected to the Internet to monitor inventory. However, the term "IoT" was coined in 1999 by Kevin Ashton, particularly in the realm of supply chain management. It refers to a network of physical objects equipped with sensing, actuating, and communication abilities. This interconnectedness facilitates a unified platform for data synthesis and processing, allowing seamless access to domain-specific software and services [5–7].

The Internet of Things (IoT) is a technology crafted by humans, envisioned through intelligent virtual objects. These objects possess the ability to comprehend their surroundings and enable nearby devices to interact autonomously, free from direct human intervention. In basic terms, IoT is a system of sensors, gadgets, and appliances capable of exchanging data about their current physical state and the environment around them via the Internet. The adoption of smart devices and IoT technology is leading to the development of intelligent and sustainable infrastructure. It improves the efficiency of the construction industry across the entire process, from material production to design, construction, operation, and maintenance stages [8]. As a sector heavily reliant on labor, the construction industry offers employment opportunities with relatively low investment requirements. Consequently, it significantly contributes to mitigating unemployment rates, particularly in many low-income countries [9]. Utilizing IoT facilitates the real-time collection and sharing of data across vital resources in various industries, encompassing machinery, personnel, materials, and tasks. This inherent capability empowers IoT to create intelligent applications across a diverse array of sectors. Within the construction realm, these applications span transportation and traffic systems, fleet tracking solutions, logistics chain management, smart cities, industrial automation, collision avoidance systems in vehicles, energy efficiency measures, waste management, smart buildings, homes, and offices, as well as environmental monitoring, among others [10–12]. In the construction sector, the pace of innovation and the uptake of new technologies tend to be inherently slower compared to more technologically advanced industries like manufacturing, aviation, and electronics [13]. The increasing utilization of IoT has brought substantial benefits to various sectors, including automotive, mining, defense, agriculture, and manufacturing. These sectors are considerably ahead in adopting IoT compared to the relatively less advanced construction industry [14].

Estimates suggest that the IoT could lead to significant cost savings, ranging from 22% to 29% of total expenses in the construction sector. This translates to annual benefits of approximately $75 billion to $96 billion. The IoT promises swift reporting, thereby cutting down communication expenses while also potentially eliminating human errors or

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omissions. Moreover, it will enhance process control and optimization through advanced algorithms and artificial intelligence. These technologies can interpret data effectively, going beyond mere analysis [15]. Evidence suggests that the Internet of Things (IoT) holds significant promise for applications within the construction industry. It facilitates the capture, recording, processing, and synthesis of vast amounts of data, leading to actionable insights. Consequently, integrating IoT technologies has the potential to create new economic opportunities and enrich the data landscape, fostering future big data-driven insights [16–18]. The Internet of Things (IoT) presents compelling prospects for practitioners to enhance the industry's reputation and lead the way in leveraging advanced technologies to address its time and resource limitations. Construction activities often span extensive areas, necessitating remote collaboration among diverse departments and resources. This underscores the demand for ubiquitous, swift, and automated decision-making capabilities on the construction site [19]. The Internet of Things (IoT) employs systems like sensors and connected devices to monitor real-time parameters. It leverages the data gathered through techniques such as big data analytics and data mining to deliver visually informative outcomes [20]. For the construction industry to confront contemporary technological challenges, it must transition from traditional, primitive methods to digitalized and automated systems. This transformation represents a significant stride towards enhancing productivity, efficiency, and environmental sustainability, while also fostering dynamic planning and management capabilities [21]. This review paper provides an overview of the wireless IoT technology's applications in various fields of civil engineering infrastructure. It also delves into several case studies involving real structures and laboratory investigations aimed at monitoring the structural health of civil engineering constructions.

2. Review of IoT-based technologies used in civil engineering construction

2.1 IoT in SHM

Monitoring and evaluating the state of civil engineering infrastructure is vital for a country's economic advancement. This is because ensuring structures are well-maintained over their lifespan and timely repairs can greatly decrease the costs associated with reconstruction. Civil engineering infrastructure experiences a decline in structural performance over time due to various factors. These include immediate or short-term issues such as inadequate curing, vibration, shrinkage cracks, and workmanship during or after construction, as well as long-term effects like material degradation, weathering, rebar corrosion, water seepage, loading conditions, environmental degradation, and crack formation. Therefore, it is vital to implement structural health monitoring (SHM) throughout the entire service life of civil engineering infrastructure. This real-time, nondestructive monitoring can detect damage locations early and monitor factors that could lead to future damage, thus extending the infrastructure's service life.

Numerous case studies have recorded the collapses and damages of civil engineering structures resulting from inadequate structural health monitoring (SHM). For instance, formwork shoring system collapses have resulted in the fatalities of construction workers at numerous construction sites [22]. In April 1978, the collapse of a reinforced concrete (RC) cooling tower in Willow Island, Virginia, USA, resulted in 51 workers falling from the roof of the tower [23]. The assessment following the collapse suggested that the premature removal and insufficient anchoring of the scaffold, along with the failure to achieve the required concrete strength, were likely causes of the collapse. Numerous studies have underscored the importance of wireless sensors and the Internet of Things (IoT) in Structural Health Monitoring (SHM) across various engineering disciplines. These sensors, strategically positioned, can transmit data to a cloud-based platform, alerting relevant individuals and authorities to any unusual changes in monitored damage-sensitive parameters. This functionality enhances the efficiency of existing SHM systems[24–28]. IoT technologies enable real-time data transfer to cloud platforms, facilitating remote access to collected data, enhancing device connectivity, and enabling the calculation of parameters of interest. Artificial intelligence technologies augment the potential of IoT-based monitoring sensors for smart supervision and SHM applications in civil engineering, and their operation does not necessitate human involvement [29–31]. The data gathered from IoT sensors is used to foresee several structural health indices that impact the long-term health of engineering structures. IoT finds its application in SHM of civil infrastructures. IoT uses various techniques such as image processing, vibration-based analysis, crack detection, etc., to monitor heritage structures, structures of national importance, mass concrete structures, etc.

2.1.1 IoT in concrete technology

The performance of concrete structures is majorly evaluated using their mechanical and durability properties and also, they play a major role in assessing their health or performance. Improper management of the fresh concrete mixture might lead to insufficient strength growth in the latter stages of its lifespan. By using IoT-based wireless sensors, their mechanical and durability performance can be assessed in real-time. Sensors decrease the need for core-cutting procedures or the requirement to be physically present on-site for sample extraction and testing. Consequently, these sensors result in cost reduction. The service life of the structures decreases due to various factors such as a lower rate of strength gain, poor control over the quality and placing of concrete, formation of plastic cracks, improper formwork and early removal of formwork, and improper cover to the reinforcing bar, resulting in their corrosion [32].

The internal temperature of the fresh concrete mix is detected by the embedded IoT sensors, which is then correlated with the heat of hydration of concrete to estimate the early age strength of concrete using the concept of maturity index method [33–36]. Due to the smaller size of these sensors, they can easily be buried in foundations, columns, beams and slabs to monitor their rate of strength gain. Apart from the sensors, researchers have used smart aggregates made of piezoceramic material to determine the strength using wireless sensors [37–42]. An automatic water spraying system to cure concrete in one of the projects in Hunan, China, was developed by Wei et al. [43] using IoT. Perry et al. [44] did a study where they arranged eleven thermocouple sensors in a network to assess the strength of a concrete foundation using the maturity index approach.

The concept of IoT is used in several studies to determine the right time for the removal of scaffold, which majorly depends on the compressive strength of concrete. In one of the studies, the safety of the labourers was guaranteed by monitoring the slab displacements. An alarm would be triggered if the slab experienced an excessive amount of displacement [45]. It is important to determine the optimum scaffold removal time in concrete structures that are to be post-tensioned to transfer the pre-stresses [46–51]. Having said that, the presence of voids in concrete drastically affects the durability of the concrete structures, it is important to ensure proper vibration of the plastic concrete by avoiding under vibration and over vibration [52]. The vibration quality of concrete was predicted by Wang et al. [53] by combining IoT with convolutional neural networks (CNN). The parameters such as chloride ion concentration and pH of concrete can be monitored to detect corrosion in the reinforcing bars to predict the long-term performance of reinforced concrete structures by using IoT based corrosion monitoring system [54, 55]. Yang et al.[56] utilised IoT technology to monitor the temperature and relative humidity of concrete during the implementation of automated concrete curing equipment. A threshold value of 80% for relative humidity and a temperature over 45^0C were chosen to determine when to apply a fogging spray to concrete. John et al. [57] implemented an IoT system to record the atmospheric temperature, internal temperature of concrete, and relative humidity of concrete specimens. The purpose was to identify the crucial threshold at which plastic shrinkage fractures begin to form under hot weather circumstances.

2.1.2 IoT and image processing to detect cracks and damages

IoT in conjunction with image processing may be used for damage detection in structures at inaccessible locations by videography inspections using drones. The detection of damage in structures initiated by cracks and fire has to be on time as they directly affect the health of the structure [32]. Hence, to enhance the service life of the structure, and ensure its safety, it is important to detect these cracks and repair them at the earliest [58]. Rui et al. [59] used deep CNN in conjunction with images captured from video cameras to detect fire smoke in a power plant and observed that the developed model exhibited a high accuracy of 97% for the training data and 95% for the testing dataset. Mondal et al. [60] implemented R-CNN in conjunction with mobile internet to assess the extent of damage and categorise it as spalling, buckling, and the exposure of reinforcements and fractures in structures that were affected by earthquakes. To detect fractures and generate crack maps, the Laplacian of Gaussian algorithm was employed to process the captured images of a bridge deck using a real-time camera mounted on a mobile robot [61]. Using a Raspberry Pi camera to capture images, Iyer et al. [62] developed a prototype to monitor the structural health of rails. The prototype utilised ultrasonic sensors to detect fractures, squats, and corrugations of the rails. Alfarraj [63] developed an IoT system using the concept of a bio-inspired deep learning approach, to analyze the images of the road, captured by mobile camera sensor to detect cracks in the road. Unmanned aerial vehicle (UAV) was used by Feng et al. [64] to capture images of spillway tunnels to detect real-time rebar corrosion and exposure using deep learning (DL) frameworks.

2.1.3 IoT to monitor the health of heritage structures

It is important to monitor and preserve the heritage structures as they contribute to the nation's economy and GDP significantly as they flourish in the tourism sector. They serve as the cultural identities for traditional beliefs and customs. Hence, historical structures and monuments require regular inspection and damage diagnosis, failing to which reduces the importance of these structures, and lose their cultural identity and affecting the livelihood of people dependent on them [32]. It is worth noting that many of the ancient structures are at risk due to the accumulation of damage in them that would have been caused due to several environmental factors and seismic events, leading to the high vulnerability of these structures [65]. The monitoring of the heritage structures is a challenging task as these structures in the past were majorly masonry units that consisted of highly heterogeneous construction materials, complex architecture, and shapes that may fail in a complex way. One of the ancient kilns in one of the historical sites in China was restored by integrating virtual reality (VR) with IOT by Yu et al. [66]. The considerable enhancement in the accuracy of the health monitoring of heritage structures can be achieved by integrating non-destructive testing methods with machine learning techniques.

A deep learning technique was used by Wang et al. [67] for automated on-site damage detection by images captured using a mobile phone. Accelerometer sensors were used by Lamonaca et al. [68] to collect data to develop a calibrated finite-element model to detect damages in the Castle of San Fili, Italy. An IoT framework was used by Uva et al. [69] to evaluate the seismic vulnerability of the masonry churches by employing [quality detection platform (QDP)] and mobile phones to collect data. Researchers have highlighted the importance of maintaining the optimum indoor climatic conditions of heritage structures to ensure an enhanced life span of these structures and the elements present inside these structures such as wall paintings etc [70–74]. Several factors such as internal temperature, moisture migration, relative humidity, UV radiation, pests and rodents, etc., combinedly affect the durability of these structures. The internal air quality, internal temperature, and internal humidity of one of the museums in Portugal were monitored by Tse et al. [75] using a self-adaptive system, which automatically controls the indoor parameters and turns them off when the museum is not in use. Studies have developed systems that provide colour codes to easily interpret the health of structures by a layman [76, 77]. Low-cost sensors were used to determine temperature, humidity, and carbon dioxide concentration values of the interior of churches in Portugal to monitor their internal environment, where Silva et al. [78] used the Arduino platform. The same approach was followed by Perles et al. [79] to identify the damaged objects present inside the church in Span by monitoring the interior temperature and relative humidity. The deterioration of Saint Domenico Church in Matera, Italy caused by environmental effects was detected using a cloud-based IoT platform by Lerario and Varasano [80]. These obtained data may be used to create a digital twin of the structure in the future to monitor the health of the structure [81].

2.1.4 IoT to detect damages using vibrations

Apart from determining the damages through image processing techniques, damages in any structure can be determined and monitored by vibration-based analysis by observing changes in natural frequencies and mode shapes of the damaged structures. For instance, any change in the mass of the structure, stiffness of the structure, or change in the damping can be used to identify the damages in the structure [32]. Researchers in the past have detected damages in various structural members such as space trusses, multi-story buildings, flat plates, cantilever beams, and masonry structures using the concept of dynamics i.e., changes in the natural frequencies and mode shapes [82–87]. Shukla and Lingaraj [88] used different types of sensors to sense temperature, moisture, and vibrations to detect damages in dams by monitoring them continuously using an IoT-based approach developed by them. Excessive deflections and inclinations in various load-carrying members of RC structures were monitored by Paul et al. [89] using a portable structure analyzer mounted on the RC members to ensure safety and safe evacuation during an emergency event. Apart from the laboratory-scaled models, monitoring of real-time structures such as vibrations in bridges, and story drifts in multistorey buildings, etc., are monitored using vibration-based techniques [90, 91].

2.2 IoT in Intelligent Transport Systems

The current surge in urbanization is a significant and multidimensional global issue that necessitates a comprehensive solution. Such concerns include pollution, traffic, and resource depletion, among others. Transportation networks are critical components of the daily lives of individuals. As a consequence of the expanding urban population, there will be a rapid proliferation of automobiles worldwide. This development will lead to various challenges such as congestion on the roads, nuisance noise, and fatal crashes on the roads, among others [92]. Intelligent transport systems reduce petroleum consumption and travel durations while increasing safety and traffic flow. Smart transportation applications possess considerable promise in mitigating the challenges posed by the continuous movement of people to urban regions and providing a more secure way to travel through extensive coordination among diverse traffic control systems from various domains, large-scale operation, and processing of substantial volumes of data collected from multiple sources [93].

Pham et al. [94] presented an innovative algorithm that increases the efficacy of the present stored in the cloud smart-parking system and develops an Internet-of-Things-based network structure. The researchers proposed an approach that aids users in autonomously locating an unoccupied space for parking at the most economical price, utilising novel performance indicators to calculate the user parking fee. These metrics would take into account both the distance travelled and the overall quantity of vacant spaces in each parking garage. Based on the model's outcomes, it can be inferred that the method decreases user waiting time and increases the probability of successful parking.

Deeplaxmi et al. [95] created the Smart Vehicle Assistance and Monitoring System (SVAMS), an innovative intelligent transportation system, utilising the Internet of Things. SVAMS is an intelligent transport system (ITS) designed to tackle a multitude of traffic-related obstacles. It is a solution for traffic management, monitoring, and optimisation that utilises Zigbee to connect all vehicles and is supported by a data centre for centralised monitoring. All system information is stored in the clouds for processing, evaluation, and future use. SVAMS is a sleek, affordable system that monitors air quality, collects tolls automatically, identifies violations of traffic regulations, and tracks vehicles, among other features. Adoption of SVAMS will facilitate the creation of C-3 (Clean, Corruption-Free, and Crime-Free) municipalities.

In order to manage real-time transport data, Jan et al. [96] developed a framework for assessing transport data utilising Hadoop and Spark. The proposed data networking system is utilised to implement the suggested architecture and selection process for data distribution to the intelligent transportation system. As soon as possible, processing of data and real-time distribution to citizens are disclosed in the peer-reviewed evaluation results of the proposed method.

In addition, Khazaei et al. [97] put forth an approach for analysing big data in the context of public transportation statistics in order to gain an understanding of traffic patterns. On account of its cloud-based and cluster-based architecture, the platform offers online and offline analysis dependability, scalability, and flexibility in response to fluctuating operating conditions. Several use cases were employed to validate the system, such as identifying congested portions of main roadways and the median speed in the Greater Toronto Area.

A variation-based online trip duration estimation method was proposed by Yu et al. [98]. The method utilised clustered neural networks (CNN) as variables for input and utilised traffic vectors that were produced using raw sensing data. In order to evaluate the efficacy of the proposed method, this study employed simulated data from the microscopic simulator CORSIM to conduct rigorous computational experiments.

Wang et al. [99] developed a methodical approach to intelligent transit management on bus corridors in their study. A three-tiered strategy is recommended to facilitate the execution of managerial responsibilities by urban planners, technicians, and administrators. The system's configuration capitalised on the capabilities of Big Data. Brazil is currently operating this system, which calculated the demand for passengers and the time it takes for buses to travel using Big Data techniques.

A model employing a computerised learning forecasting scheme was devised by Keller et al. [100] for Advanced Driver Assistance Systems (ADAS), which aid vehicles in critical manoeuvres. They presented a unified step-by-step solution to an organising and supervision issue that was capable of operating in real time. By integrating a naturalistic model with a model forecasting controller, their method eliminates the requirement for a precalculated reference indication, specifically a line of travel. Instantaneous functionality is achieved through a rudimentary differentiation of the components, which enables the prediction of the state trajectory of the plant for every conceivable combination of discretized input values.

2.3 Smart agricultural and irrigation techniques using IoT

One among the fields most susceptible to the impacts of the climate change is agriculture. A rise in mercury, alterations in patterns of precipitation, and potentially more frequent occurrences of floods and drought are anticipated to have an impact on the farming industry [101, 102]. Concurrently, with a worldwide expected population of 10 billion individuals by 2050 requiring agricultural output to expand by 40%, this growth is critical [103, 104]. The application of ICT (Information and Communication Technology) to perceive, track, and regulate the agricultural atmosphere, machinery, and technology utilised by farmers is referred to as "smart farming." It is one of the potential solutions suggested to address the difficulties posed by the environment while simultaneously improving the standard of living for farmers [103, 105]. Smart farming enabled by the

Internet of Things is regarded as the next generation of agriculture for a number of reasons, including the fact that it provides numerous advantages for all parties involved, from the individual farmer and the agricultural system to the worldwide environment perspective [106, 107]. Intelligent agricultural activities enabled by the Internet of Things encourage optimised crop treatment, such as precise usage of pesticides, water, and sowing, which could significantly boost the output of farms. Consequently, the enhanced level of efficacy or productivity may result in increased income for the agricultural practitioners [108, 109].

An additional sophisticated endeavour, as detailed in the research paper by Mondal and Rehena [110], was centred on the construction of a system for tracking that could transmit and analyse data in instantaneously. It is proposed that the threshold-based self-control algorithm reduces the necessity for personal involvement. However, it would be hampered by insufficient Wi-Fi coverage. Study by Carlos et al. [111] introduced a surveillance system that utilised LPWAN networks (Sigfox) to improve the adaptability of monitoring systems in practical situations. The researchers took into account the characteristics of a wide variety of farming environments. The system's functionality is to some extent limited in scope as a result of the requirement for broad network connectivity and the introduction of a subscription charge. An advanced irrigation control system was proposed by Goap et al. [112] which utilised free software and machine learning technologies. Regardless the utilisation of Internet of Things (IoT) functionalities to optimise the monitoring and regulation of irrigation procedures, it is imperative to recognise that inconsistencies might emerge between the assessments derived from experimental trials conducted on a small scale and their practicality in real-life situations. Furthermore, predictive modelling has a restricted capacity to process data with multiple dimensions. Kashyap et al. [113] devised DLiSA, an IoT-enabled intelligent irrigation system designed for precise farming that incorporates machine learning as well as deep learning methods using neural networks. The objective of the whole thing is to generate forecasts regarding irrigation by integrating current and past information. It is crucial to note that the proposed methodology has yet to undergo validation in operational agricultural systems. Complicated ties introduced by the constantly evolving and changing nature of farming operations may affect the precision and dependability of the forecast tool. Premkumar et al. [114] introduced an edge-based irrigation system that significantly transforms the approach taken in determining watering routines. By continually modifying the system's forecasting algorithms in response to changing conditions, the system guarantees punctual and precise irrigation. It enhances versatility and reduces lag by transferring real-time duties to the periphery. It is imperative to acknowledge that the energy consumption, data loss, and response time of the system remain undetermined and necessitate more research. Diedrichs et al. [115] designed an agricultural frost prevention prediction system that incorporates thermal conditions, as opposed to exclusively depending on temperature and restricted data from sensors. Enhancing data using the Synthetic Minority Oversampling Technique (SMOTE) enhanced frost sensing. However, the complex nature of predicting future patterns and the multitude of elements in the data contribute to the ongoing challenge of making accurate predictions. Evaluation of the general efficacy of the framework and actual testing are required to enhance generalizability and practical applicability. Smart farming was implemented using an in the cloud IoT framework developed by Khattab et al. [116]. This architecture facilitates the acquisition and transfer of agricultural information to a back-end platform hosted in the cloud, where it is processed and analysed. A theoretical server for the cloud comprising the requisite elements for the implementation of this structure is introduced. The initial findings of the proposed study are inconclusive, and in order to address the complexities of enormous scale agricultural conditions, the prototype requires enhanced instantaneous decision-making abilities.

Advocating for integrating Internet of Things (IoT) technology to tackle issues such as environmental degradation and the excessive depletion of non-renewable resources is vital for advancing sustainable agricultural growth.

2.4 IoT in environmental engineering

2.4.1 IoT-based IAQ

Recent studies have shown that indoor environments harbor various pollutants, leading to increased health risks for occupants. Given that the majority of people spend more than 85% of their time indoors, indoor air quality (IAQ) has a significant impact on overall well-being. Both short-term and chronic exposure to air pollutants have been associated with higher morbidity rates in cardiovascular and respiratory diseases, as well as inflammation, ultimately leading to increased mortality rates [117–119]. The specific sources of indoor and outdoor pollution can vary between different buildings. Additionally, the impact of these pollution sources on indoor air quality (IAQ) can change over time. Moreover, it is crucial to acknowledge that building ventilation significantly influences indoor air quality (IAQ) [120]. These observations highlight the variety of factors that influence indoor air quality (IAQ), resulting in a process characterized by significant uncertainty and randomness. It is opportune to explore whether commercial indoor air quality (IAQ) sensors and IoT technology can improve the daily monitoring of IAQ. This investigation has the potential to enhance energy efficiency, demand flexibility, and resilience of the ventilation system. This field holds significant promise for advancement. Another notable advantage of the IoT-based indoor air quality (IAQ) platform is its ability to enable long-term IAQ monitoring with a large number of samples. This feature facilitates the gathering of comprehensive real-time indoor air quality (IAQ) data from diverse buildings in their actual operating environments. Utilizing the vast data from the IoT platform, machine learning (ML) models can effectively predict indoor air quality (IAQ).

Semiconductor sensors commonly include a sensing layer composed of metal oxide material, positioned on an alumina substrate and connected to the sensor chips. The sensor's conductivity increases when it is exposed to detectable gases. This change in conductivity produces an output signal that corresponds to the gas concentration [121]. However, these sensors are sensitive to environmental fluctuations, as the conductivity of semiconductors is affected by changes in temperature and humidity [122]. Using multiple semiconductor sensors in combination is an effective approach to improving the reliability of pollutant identification [123]. In order to calibrate a formaldehyde sensor, constructed a 10-layer convolution network and, for complex compounds, attained an uncertainty of approximately 11 ppb [124]. For instance, another team conducted an additional comparison of PM2.5 and CO2 concentrations in residential areas of Xi'an across a variety of ventilation mechanisms. Based on the monitoring results, they offered suggestions for the operation of mechanical ventilation systems to decrease indoor PM2.5 and CO2 concentrations. [125]. Dai et al. [126] installed IAQ sensors in 117 residences across five climate zones in China and monitored PM2.5 and CO2 for more than a year. There were four prevalent ventilation systems in China that were represented by the housing samples. The researchers were able to compare the indoor air quality (IAQ) across a variety of seasons and ventilation modes through extensive and long-term surveillance. They presented an exceptional summary of the indoor air quality (IAQ) in urban Chinese residences by leveraging this advantage. [126]. In Tianjin, Zhao et al. [127] compared the indoor air quality (IAQ) of residences with various ventilation modes and evaluated the efficacy of PM2.5 purification devices in real-world operation. The researchers reached the conclusion that while the mechanical ventilation system can reduce the frequency of elevated particle pollution levels indoors, its ability to increase the frequency of healthy pollution levels is limited [127]. In another work conducted a comparative analysis of the indoor PM2.5 and PM2.5–10 estimation effectiveness of MLR and ANN in naturally breathable schools. The ANN model had an RMSE of 7.41%, i.e., 19.35% less than the MLR model [128]. Li et al. [129] estimated the indoor PM2.5 concentration utilizing a random forest model and building characteristics and the outdoor environment as inputs. Through an examination of the model's variable importance, it was ascertained that the type of dwelling, air conditioning usage, and window condition are significant determinants in the estimation of indoor PM2.5 concentrates [129].

2.4.2 IoT in water quality analysis

Monitoring and evaluating the safety and health of water sources is a critical function of water quality analysis. Water quality monitoring systems have historically been established using lab-based approaches, wherein samples of water are collected from different places and subsequently transferred to a testing facility for assessment. Time-intensive and expensive, lacking monitoring in real time capabilities, conventional lab-based water quality monitoring systems are unreachable to remote locales. Five contributing variables were incorporated by Nampak et al. (2014) using a GIS approach: lithology, drainage, land cover/land use, lineaments, seepage, and slope. The results indicated that approximately 1.2% of the evaluation area was deemed to have significant room for groundwater to recharge [130]. In their study, Almetwally et al. [131] devised and constructed an automated decision-control device to monitor determining water's quality metrics. A cloud-based repository stored historical measurements from the various water quality sensors that determined acceptable levels. This public health-related system prevents the discomfort that is typically encountered during remote laboratory evaluation of acquired specimens [131]. According to Roseela et al., IoT-enabled immersed remote communication equipped with a microcontroller and Wi-Fi constituted a groundbreaking invention. The distance between the articles, turbidity, and temperature were determined by employing sensors connected to the transmitter and monitoring them at the receiving end. This was accomplished over various time intervals utilising IoT technology [132]. To obtain satellite-derived spectral indices, Wang et al. [133] developed a machine learning approach utilising WQI and fractional derivative algorithms. A support vector regression model was employed to assess the precision of the approach [133]. An investigation conducted utilised six models of machine learning methodologies to forecast water quality for use in irrigation [134]. The findings demonstrated that A.I. models are effective approaches for obtaining an accurate understanding of the characteristics of water systems [134]. In general, the numerical results obtained from the application of WQI sensor technology, IoT, machine learning, deep learning, and GIS technologies to forecast water quality are promising. The potential of these tools to generate accurate water quality models for forecasting has been demonstrated in several previous studies.

2.4.3 IoT-based waste management system

The complete process starting from the collection of waste from the source, their transportation, storage, disposal, and recycling is termed waste management. The term waste mentions is majorly generated by humans and industries [135]. IoT has become progressively more significant in waste management operations at every level over the past decade [136]. Ultrasonic sensors are mostly used to monitor the fullness levels of waste bins and alert the waste management personnel once they are full by eliminating the timely manual checks of these bins by humans [137, 138]. Barth et al. [139] analysed the trade-offs between the cost reduction and the quality of the service provided by using a bin sensor module. Kerdlap et al. [140] proposed an agent-based model that could simulate various waste management steps such as non-biodegradable waste generation, their collection layouts, sorting and their recycling under different scenarios. In a study, the waste bins were assigned certain identification codes to track and monitor their conditions by using an IoT based garbage management system [141]. Effective waste management by applying the principles of deep learning and IoT was shown by Rahman et al.[142]. Ramos et al. highlighted the importance of integrating the sensors with optimization algorithms to achieve maximum garbage quantity collection with reduced transportation costs and optimized collection routes [143]. The author of another study proposed optimised collection routes for an optimised collection system in Al-Mostakbal city. This was achieved by selecting the most suitable pick-up and container locations [144]. Tran et al., utilised a mixed-integer nonlinear programming method to develop improved agricultural waste collection systems and transportation networks, in addition to municipal waste collection [145]. Chance-constrained programming was used to develop a stochastic optimization model by Shah et al. to maximize the value of the recovered waste with minimal transportation cost [146]. Optimized waste collection was achieved by the ICT-based smart waste categorization and collection system (SWCCS) proposed by Lu et al. [147]. GIS-based models were used by researchers to optimize waste collection and collection routes for advanced waste collection methods [148]. An automated waste bin allocation system and collection route system with a centralized monitoring system were achieved by IoT-based algorithms by Roy et al. [149].

2.5 IoT in Forensic Civil Engineering

Frequently for legal purposes, forensic engineering investigates defects or failures in performance through the application of engineering principles. Forensic engineering is different from other traditional engineering principles as the former focuses on detecting the causes of failure of various civil engineering structures post their occurrence whereas the latter focuses on the design and maintenance of civil infrastructures [150, 151]. Majorly, forensics finds its applications in medicine, criminology, etc., but with the development of IoT and AI, forensic methods have been extended to investigate the causes of failures in the field of civil engineering [152–155]. In a broader sense, forensic civil engineering involves various aspects such as inspection and investigation in failure sites, data, and evidence collection. Regular inspections and monitoring also fall in the subsets of forensic civil engineering as these practices prevent the actual failure of civil infrastructures [156]. In recent days, forensic engineers have been inclined towards the use of unmanned aerial vehicles (UAV) as they foster the engineers to inspect and collect accurate data sets for further investigation. UAVs are usually robots that can fly without a pilot i.e., drones, etc., which can collect data and evidence from the locations which are inaccessible by humans [157]. With exponential development in the sensor and UAV technology and by integration of both of them, the use of in-situ data collection, manual inspections by humans, and satellite-based monitoring can be eliminated as the UAVs integrated with sensors provide accurate data with very few missing data and higher resolutions measurements [158].

2.5.1 Forensic engineering in the field of structural engineering

In the field of structural engineering, failure may be broadly classified as failure due to stability and failure due to durability. In the event of any disaster, UAVs are used for the inspection of structures and to judge their vulnerability [159]. Various methodologies such as computer vision techniques, artificial intelligence, and photogrammetry are used by UAVs to inspect damaged structures [160, 161]. Evident structural damages are detected and 3D maps are developed using RGB cameras with advanced DL and CNN algorithms to analyse the damages [162–164]. Researchers have shown diverse applications of UAVs by proposing a virtual reconstruction of archaeological sites using photogrammetry and SfM/MVS algorithms and acquiring hazardous situations at the site of construction [165, 166]. Complex 3D models were developed by Rodriguez-Gonzalvez et al. [167] to analyse extreme and complex situations by acquiring image-based data from UAVs. Weng at al. [168] estimated the maximum dynamic displacements of physical structures by employing a tomography-based UAV.

2.5.2 Forensic engineering in the field of water technology

Being said that water bodies serve as lifelines for humans and aquatic animals, it is highly important to keep a continuous vigilance on the quality of water and ensure that they are free of potential threats such as algal blooms, oil spills, and other types of contamination. Employing UAVs to detect contaminations, and practice emergency response protocols during an emergency can enhance the safety and ensure the safe functioning of these freshwater bodies by preventing hazards [151]. UAVs in conjunction with sensors, have also proved to be rapid in action and economical in monitoring the health of fresh water bodies. UAVs are fitted with RGB and IR thermal cameras to detect oil spills, as they pose a danger to the well-being of humans by bioaccumulation, hamper integrity, and render the water bodies polluted. Multispectral sensors were used by Olivetti et al. [169] to map the total suspended solids concentration in water bodies, as they had advanced spatial and temporal resolution. Using a hyperspectral fine-resolution camera, Shang et al. [170] monitored the chlorophyll concentrations and intensity of phytoplankton blooms in inaccessible locations. Isgro´ et al. [171] utilised electrochemical sensors to estimate the concentration of heavy metals in freshwater bodies by comparing spectral and actual data using image data.

2.5.3 Forensic engineering in the field of geotechnical engineering

As the failure is unexpected, continuous monitoring of vast regions and mapping them based on the various types of failure such as slope failure, excessive ground deformation, seepage, etc., is crucial in forensic engineering [172]. By interpreting the spatial data collected from UAVs, researchers have developed photo-based 3D models to interpret and analyse the dangerous and inaccessible slopes, and build virtual archives of geotechnical data [173]. An accurate and flexible landslide monitoring system was developed by researchers in the past by using UAV photographs and SfM algorithms to build a 3D model that was correlated with DEMs and orthophotos [174]. The mapping method was used to monitor ground deformations such as deposition, erosion, etc., rather than developing 3D models. UAVs were used to inspect and monitor the geotechnical deformations by mapping methods, caused due to excavations, underground coal mining, etc., in geological discontinuities in inaccessible locations and hazardous areas [175–177]. Using UAVs to investigate a catastrophic landfill failure in China, revealed an insufficient compaction and higher pore-water pressure as the cause of the failure [178]. UAVs also find their application in surface thermodynamics to monitor surface heat flows in highly volcanic and inaccessible terrains [179].

2.6 Integration of IoT and smart buildings

From an operational standpoint, the present advancement towards creating intelligent buildings, communities, and cities may be characterised as fragmented and divided in terms of incorporating technology and developing applications. This is mostly due to the existing constraints of IoT applications and sensor networks in buildings, cities, and infrastructures are not effectively integrated [180, 181]. The idea of smart buildings emerged from the growing incorporation of sophisticated technology into buildings and their systems. This allows for the remote operation and management of the whole life cycle of structures, resulting in convenience, comfort, and cost- and energy-efficiency. In recent years, the Internet of Things (IoT) has begun to make its way into the construction industry. Researchers and practitioners are actively investigating the advantages and disadvantages of IoT via real-world implementation. The widespread consensus is that the utilisation of modern technologies is an essential requirement for the successful implementation of smart buildings, also referred to as intelligent buildings. This encompasses various aspects such as the deployment of sensors, engineering and analysis of large datasets, utilisation of cloud and fog computing, development of software engineering, and the implementation of algorithms for human-computer interaction. For instance, prominent firms such as IBM and Intel have already introduced their smart building solutions to the global market, showcasing their competitive advantage and reflecting the future trend of the Internet of Things (IoT) [182].

Indoor localization is very valuable for enhancing building performance. For example, those who are not acquainted with a building may be given directions to their desired location. The occupancy data obtained via localization information could then be used to allocate resources in a fair and equitable manner. Furthermore, determining the location of residents will aid in comprehending their behaviours and forecasting distinctive occurrences inside structures. One exciting aspect of the Internet of Things (IoT) is the advancements in micro-location technologies, which have the potential to accurately find any object with a high degree of precision, potentially within a few inches. Micro-location refers to a very accurate geo-fence that allows for the precise positioning and tracking of objects inside a building. This technology is used to enhance service provision, such as improving thermal comfort, lighting, and offering preference-based services [183]. Alletto et al. [184] developed a location-aware system that was specifically designed for an Internet of Things (IoT) museum. This system functions as an intelligent tourist guide, offering travellers assistance. The visitor possesses a wearable device that combines the capabilities of location awareness and image recognition. When a visitor arrives at a location with a particular historical context or artwork, a wearable device employs a Bluetooth Low-Energy (BLE) infrastructure to track the individual. Subsequently, the processing centre employs this data to engage the user and communicate with them.

Given that buildings account for 40% of global energy consumption, building energy efficiency is one of the most important research subjects to date, not only in the construction of smart buildings [185]. However, it is important for a smart building to not sacrifice the quality of service provided to its users or inhabitants in order to achieve this objective. This requires finding a solution that can meet the needs of both parties. The condition of both the environment and the people inside the building is crucial in determining the optimal functioning of a smart building. For instance, the HVAC system must be adjusted based on the occupancy of the space, while the lighting system should monitor the external illumination intensity and adjust the inside lighting accordingly. Wei and Li [186] introduced an energy consumption monitoring and conservation system for intelligent buildings, using the Internet of Things (IoT). The system is comprised of the conventional three levels, equipped with sensors for all the subsystems inside the building. The application layer is responsible for supervising fault investigation, energy management, and equipment monitoring. The main drawback of the research is the absence of practical execution of testing scenarios. Pan et al. [187] first investigated the statistical correlation between overall energy consumption, heating and cooling energy consumption, and environmental factors/occupancy status. The conclusion was reached that energy is being squandered, despite its intended "green" design. In order to address this issue, the researchers developed a location-based automatic energy control framework. A Dutch business [188] has introduced a platform that includes an application and data centre for storing sensor data on CO2 levels, temperature, occupancy, humidity, light intensity, and activity in buildings.

Kelly et al. [189] developed an Internet of Things (IoT) system to monitor interior environmental conditions and energy use in residential buildings. This system uses ZigBee Wireless Sensor Network (WSN) technology, specifically using XBee-S2 modules to create the sensing network. The gateway plays a crucial role in facilitating the exchange of information between the ZigBee network and the IPv6 network. The primary contribution of this system is to showcase its capacity to link with both WSN (Wireless Sensor Network) and IPv6 (Internet Protocol version 6). This allows for the integration of IoT (Internet of Things) with home monitoring systems, providing a cost-effective and adaptable solution. It is important to note that occupant comfort and building energy efficiency might sometimes be in conflict with one other. Therefore, it is always relevant to consider both concerns simultaneously when constructing intelligent solutions for buildings. Indeed, it has been discovered that this equilibrium might be attained by the use of IoT. Piscitello et al. [190] introduced a Danger-System that can identify safety-related emergencies and provide alarm and rescue measures for individuals in a building. The system used the application put on users' cell phones to identify events such as user running or loud noise, and consolidate all the data to create possible emergency activation. In order to facilitate the use of smart metres, alarm systems, lighting controls, and other home automation devices, Kovac et al. [191] installed a smart home gateway. Through this method, homeowners have the ability to remotely oversee all related communication systems collectively. The open Home Automation Bus (openHAB) platform functions as the central component of the system, serving as an integration hub for various devices. As the number of connected devices continues to expand exponentially, the security hazards associated with IoT systems have also increased. There are numerous components of IoT systems that are susceptible to vulnerabilities, such as web interfaces, network services, backend systems, software, and physical hardware. As a result, the IoT system [192] requires security measures to be implemented at each layer to withstand assaults on the various layers, which are connected smart devices that contain sensitive data.

2.7 Automation of construction techniques using IoT

From the primitive mud shelters of early human history to the modern innovation of 3D-printed buildings, the construction industry has seen significant changes in its methods and techniques. The construction industry is now facing several problems due to the growing complexity of building projects. These challenges include issues related to quality control, worker safety, productivity, and environmental performance. With the development of the Internet of Things (IoT), many industries are endeavouring to use this technology effectively to enhance their productivity. The construction sector, too, must implement this technology efficiently to overcome the obstacles it now faces [193]. The lack of infrastructure in developing nations is a significant obstacle to continued economic expansion, particularly in achieving equitable growth. This includes deficiencies in waste disposal systems, roads, as well as the need for new bridges and world-class airports. Hence, the need for sustainable assets is now of the highest importance. This difficulty, which arises due to restricted financial resources, requires a successful and effective utilisation of the Internet of Things in the building sector.

Jeevana and Kulkarni [194] introduced a system that uses real-time sensor monitoring to reduce the interruptions caused by inadequate site administration at job sites. The researchers identified the primary reason for the delay via an extensive survey conducted in 30 building firms. The sensors are continuously monitored in real-time. As soon as a problem is detected, the site manager is promptly notified, enabling them to promptly address the situation. Xu et al. [195] introduced a cloud-based Internet of Things (IoT) platform for prefabricated building initiatives. This framework is designed to provide small and medium-sized enterprises (SMEs) with economic and adaptable advantages. They first clarified the fundamental concept of their platform and subsequently implemented it in a tangible prefabricated building project in Hong Kong. Furthermore, they employed numerous LEGO building models that were situated in a laboratory to illustrate the effectiveness of their proposed platform. Based on their analysis, it was determined that the prefabricated building sector would benefit significantly from the automation of their operations through the implementation of their proposed platform. Mega building projects may benefit from smart construction, according to a theoretical framework put forward by Zhou et al. [196]. The researchers employed a case study on the "Hong-Kong-Zhuhai-Macao-Bridge" to substantiate the practicality of their proposed framework. The application of a variety of IoT technologies, such as BIM during the remote manufacturing phase for prefabricated product production and the integration of GPS, Sonar, and weather systems during the shipping and installation phase, was demonstrated in their framework. They concluded that the integration of IoT in the construction sector is still in its early stages. Marks and Teizer [197] used Radio Frequency technology as a live proximity warning system to enhance worker safety at building sites. The researchers determined that their technology is effective in identifying the presence of large-scale construction machinery. Once the system detects any equipment, it promptly notifies both workers and equipment operators of the potential danger of being in close vicinity, which may pose a risk. Teizer et al. [198] proposed the idea of combining Internet of Things (IoT) with Building Information Modelling (BIM). They performed two case studies to illustrate their idea. The initial case investigation included tracking the workers' whereabouts, whereas the subsequent case investigation focused on collecting information about the environment, such as the light level at the workstations and the duration of exposure to high or low temperatures. The authors further created a Dynamo script to display all of the sensor information in actual time inside Autodesk Revit. They determined that their idea has the capacity to be implemented in facility administration and construction operations procedures. The use of IoT in the construction sector is now in its nascent phase. Extensive study is required to examine the different possibilities for the building sector to effectively use this technology.

2.8 IoT and smart cities

A smart city employs information and communication technologies (ICT) to improve city operations and the well-being of its residents. It also provides solutions to specific issues, such as recycling waste to create compost or treating sewage water for construction or cleaning purposes. The notion of a smart city is to optimise the utilisation of public resources and improve the quality of services offered to people. The implementation of smart cities yields several advantages, including but not limited to enhanced transportation, surveillance, maintenance, and healthcare services. The advancements in artificial intelligence (AI) and the development of Internet of Things (IoT) technology are crucial factors that have been essential in making smart city efforts possible. Based on statistical data and projections, it can be confidently said that the Internet of Things (IoT) will emerge as a very valued technology in the smart service and applications market. This technology is expected to provide several opportunities, as well as present various obstacles and concerns [199]. From a technological perspective, smart cities may be defined as cities that extensively use information and communication technology to establish, sustain, and enhance essential services and infrastructure [200, 201]. The smart city employs a multitude of sensors, actuators, cameras, and gadgets in cars, buildings, and dwellings to oversee their physical structure and seamlessly connect with other relevant applications [202–205]. The components of a smart city may be categorised into primary groups such as smart structures, intelligent transportation systems, smart living, smart environment, smart industries, etc. It may be said that sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6 and section 2.7 in the present manuscript put together, facilitate the development of a smart city as a smart city in itself is not a single component. A smart city is made up of several smart components as explained above.

3. Role of data analytics in IoT-based civil engineering projects

Data analytics is essential in IoT-based civil engineering projects since it converts unprocessed data into practical insights that enhance efficiency, safety, and decision-making. Internet of Things (IoT) devices, such as sensors and actuators, gather up-to-the-minute data on the condition of structures, environmental factors, and the functioning of equipment. The data is used to forecast possible malfunctions, enabling prompt maintenance and minimising operational interruptions. For instance, in the context of bridge monitoring, data analytics can identify stress patterns that may serve as indicators for necessary repairs prior to a potential failure. Analytics aid in the optimisation of resource allocation, waste reduction, and task scheduling improvement. Through the analysis of data collected from construction sites, including information on equipment utilisation and material consumption, project managers have the ability to optimise and improve operational efficiency. By utilising past data, predictive models can accurately anticipate cost overruns and delays, enabling proactive modifications to project plans. Internet of Things (IoT) devices are capable of monitoring various factors such as vibrations, temperature, and load-bearing capacity. Data analytics has the capability to detect hazardous conditions and promptly notify engineers to implement necessary corrective measures. Analytics systems utilise historical data and real-time inputs to evaluate the likelihood of natural catastrophes, such as floods or earthquakes, and provide ways to reduce their impact. Analytics platforms offer visual dashboards and reports, facilitating the comprehension of intricate data for engineers, architects, and stakeholders. Predictive and prescriptive analytics facilitate decision-making by modelling multiple situations and recommending the optimal course of action. Through the utilisation of data analytics, civil engineering projects that incorporate IoT technology can attain elevated levels of efficiency, safety, sustainability, and overall project success.

4. Challenges in the use of IoT-based technologies in civil engineering

Integrating IoT-based technologies in civil engineering comes with several challenges, including:

- Data Security: Ensuring the security and privacy of data transmitted by IoT devices is crucial, especially in critical infrastructure projects.
- Interoperability: Different IoT devices and systems may use different protocols and standards, making it challenging to ensure seamless communication and data exchange.
- Scalability: As projects grow in size and complexity, managing a large number of IoT devices and the data they generate can become difficult.
- Reliability: IoT devices must be reliable and operate continuously, especially in harsh environmental conditions common in civil engineering projects.
- Power Consumption: Many IoT devices are battery-powered, so managing power consumption and ensuring long battery life are essential.
- Data Management: Handling large volumes of data generated by IoT devices requires efficient data management strategies, including data storage, processing, and analysis.
- Cost: Implementing IoT technologies can be costly, especially for large-scale projects, requiring careful budgeting and cost management.
- Regulatory Compliance: Civil engineering projects must comply with various regulations and standards, which may pose challenges for the deployment of IoT technologies.
- Addressing these challenges requires careful planning, collaboration between stakeholders, and the use of innovative solutions to ensure the successful integration of IoT technologies in civil engineering projects.

5. Conclusions

This review paper demonstrates the implementation of the IoT in real-world environments. The IoT revolution is anticipated to expand the utilisation of the IoT in the field of civil engineering. Furthermore, as IoT applications continue to develop, they may necessitate incorporation into building design codes. In addition, advancements in image processing and virtual reality would enhance the IoT-based monitoring of civil engineering structures. Further advancements in data analytics, automation, and sophisticated sensors are expected to be implemented in the construction industry in the coming years. These developments are expected to enhance the efficiency, safety, and cost-effectiveness of the construction process. In addition, workers may need to adjust to the evolving construction industry caused by the Internet of Things (IoT), which has led to debates regarding job displacement and the need for additional training prerequisites. This is anticipated to lead to enhanced building procedures, heightened safety measures, and decreased expenses. The impact of technology on the workforce remains uncertain, however, concerns have been raised about loss of employment and the need for acquiring new training and skills. The ongoing deployment of IoT will continue to prioritise cybersecurity as a crucial issue. The utilisation of IoT data in predictive analytics will result in a reduction of downtime and an extension of the lifespan of infrastructure. Civil engineers will increasingly utilise AI models based on sensor data to predict the timing and location of repairs, hence reducing expenses and minimising interruptions. Utilising real-time energy usage data will enable engineers to optimise the design and retrofitting of structures, ensuring they adhere to more stringent environmental requirements and achieve greater sustainability. The utilisation of digital twins, which are virtual representations of physical assets that simulate and forecast performance, will increase. The Internet of Things (IoT) data will consistently update these models, allowing engineers to analyse different situations and enhance designs at every stage of infrastructure projects.

Further it is recommended that civil engineering firms ought to allocate resources towards the development of infrastructure that is compatible with Internet of Things (IoT) devices and platforms. This involves ensuring that new projects are equipped with the required connectivity, data processing capabilities, and cybersecurity safeguards. To properly exploit IoT data, engineers should acquire expertise in data science and analytics. Having a thorough comprehension of how to analyse and implement this data will be crucial for enhancing designs and maintenance plans. Collaborating with IoT-focused technology companies helps expedite the implementation of intelligent solutions. Collaborative endeavours have the potential to result in the creation of personalised Internet of Things (IoT) apps that are specifically designed to address certain civil engineering obstacles. Civil engineering professionals may optimise the effectiveness, security, and environmental friendliness of their projects by proactively anticipating and adapting to these changes. In summary, the Internet of Things (IoT) has brought about significant and revolutionary changes to the construction sector, presenting a positive and encouraging outlook for the future.

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