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Implementing Digital Twin for Enhanced Construction Management

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ABSTRACT

Building Information Modeling (BIM) is effective in design and planning, but the static nature of BIM makes it less effective in managing a construction site in real-time. To overcome this, the need for Digital Twins (DTs) with the Internet of Things (IoT) in physical site management has been emphasized. This paper proposes a DT framework for Indian construction sites, emphasizing physical and virtual environments, IoT communication, and feedback systems. The proposed framework adopts Levels of Detail (LoDs) for graphics, information, and site-related aspects such as manpower and equipment. The SLR has revealed the international research gaps in DT, which were further investigated by conducting a survey among 20 BIM experts from prominent Indian cities. The survey indicated that 70-80% of the respondents felt that DT would assist them in monitoring construction activity, increasing efficiency, increasing site safety, and utilizing LoDs. But they also cited difficulties such as fluctuating labor and high density in Indian cities. This paper proposes the combined use of DT, IoT, and BIM to overcome delays and expenses, and also proposes standardization of LoDs and the use of data fusion in DT.

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1. INTRODUCTION

Building Information Modeling (BIM) emerged as a revolutionary technology in the early 2000s, transforming the sector from 2D CAD plans to 3D parametric modeling. Over the years, BIM has evolved with additional dimensions to provide more information. However, the fact that BIM requires manual updating makes its data outdated once the project is constructed and operational. Although BIM is very effective for design purposes, it can be inadequate when handling dynamic site operations, maintenance, and facility management. This created a need for BIM to be integrated with real-time data, thus paving the way for Digital Twin solutions. A major leap ahead is required if we are talking about shifting our focus from static BIM to the more dynamic Digital Twins. Digital twins are virtual versions of the real world that are updated and changed on a regular basis. Digital Twins use real-time data to analyze changes in the real world, in contrast to BIM, which only uses data available at a particular moment in time. Teams can make better decisions, forecast when maintenance may be needed, and boost productivity throughout the construction process thanks to the information flow. The only difference between Digital Twins and advanced BIM is the integration between the digital and physical world, which has now become a necessity for the construction industry. Another advantage that Digital Twins have over BIM is the ability to perform tests using current information, enabling teams to predict possible issues and minimize losses. Embracing Digital Twins means integrating BIM with other technologies such as IoT, Cyber Physical Systems, AI, and Robotics, linking it to the broader Industry 4.0 movement. BIM is an essential tool, but it is static, and that is where Digital Twins, using real-time information, become an advantage over BIM.

1.1. Problem statement

The building industry now has the complex job of developing unifying frameworks and protocols that ease the transition from traditional BIM models to fully alive digital twin worlds. Among the challenges are integrating sensor technology and data interoperability. This dichotomy challenges us to fix technical issues, particularly in transitioning static BIM data to a dynamic, real-time environment that can integrate actual-time monitoring data and updated analytics tools.

- How much does a BIM-based digital twin improve predictability in schedules, cost control, and resource optimization compared to the conventional BIM-based method?
- In what ways do digital twins help in detecting risks and safety issues, and in controlling quality issues?

2. LITERATURE REVIEW

Research on combining BIM, IoT, and DT in construction shows these tools are becoming more important for better project management, sustainability, and efficiency. Ontology-based concepts have been proposed for overcoming interoperability problems by integrating BIM, GIS, and IoT data into integrated city models for facilitating real-time analysis and decision-making (Jianyong Shi et al., 2023). Hybrid models of the integration of DT and BIM with AI have the potential to be extremely beneficial for the construction industry. Smart model of DT focuses on the integration of BIM and IoT data through a layered system for facilitating real-time management (Heng Sun et al., 2022). Nevertheless, there exist challenges related to scaling up, data quality, privacy, and adoption, particularly in developing countries where best practices are still being developed (Marwan Abdulqader et al., 2023). For instance, in India, research is still in its infancy, but findings indicate that these technologies have the potential to reduce delays and costs by managing projects in real time using data-driven approaches (Marwan Abdulqader et al., 2023). Further research is also expected to be conducted on the development of digital twin technologies in the country, which will help address interoperability and standardization challenges observed globally (N. Megahed et al., 2022). Overall, the literature indicates an emerging trend towards the integration of digital and physical worlds in the AECO industry through the application of BIM, IoT, DT, AI, and ontology-based frameworks for the creation of smart and sustainable environments.

2.1. Building information modeling

Building Information Modeling, or BIM, came into picture in the 2000s. It was described in Autodesk's 2002 white paper as a new IT approach, with a clear distinction between 3D parametric models of buildings and traditional 2D drafting. Since then, BIM has evolved from a software application to a process and technology platform that prescribes how information is created, exchanged, and used throughout a project. Hardin and McCool highlight that the strength of BIM is in the organized and linked data that supports the visual representation, facilitating coordinated and informed decision-making among all disciplines.

The U.S. National BIM Standard defines BIM as "a digital representation of a facility and its components. It serves as a shared digital prototype, which can be accessed, viewed, and shared by all project stakeholders. Each stakeholder, whether designer, contractor, operator, or owner, can view and update information as required. The model will become progressively more detailed and accurate over time, described in Levels of Development (LOD), from conceptual to fully as-built verified data."

One could think of BIM as multidimensional. The asset lifecycle is supported by additional dimensions that add time (4D), cost (5D), sustainability (6D), and operations and maintenance data (7D). The foundation is 3D geometry. In a single information environment, these dimensions connect design (structural, architectural, and MEP), construction planning and control, financial management, environmental performance, and facilities management.

The ability of BIM to share data across applications using open standards is one of its greatest advantages. Building and infrastructure data can move easily between applications for design, construction, and facility operations thanks to Industry Foundation Classes (IFC), which offer a rich, vendor-neutral data structure. The NBIMS-US standard's COBie concept arranges asset and handover data, such as equipment lists, warranties, and maintenance details, so that facility management systems can import it directly. COBie essentially acts as a bridge between operations and construction, making sure that handover data is prepared for long-term facility management.

2.2. Applications of Digital Twins in Construction

A digital twin in the construction sector is basically a digital duplicate of a building or structure that is linked to the real thing from conception to completion and beyond. It is more than just a static model; it gathers and combines a range of data into a single system, including structural data, sensor data, building data, and architectural and engineering models. In order to create a model that reflects and updates itself with the asset over time, BIM is typically integrated with other elements like IoT sensors, cloud computing, and advanced data analytics.

The design, engineering, construction, and operation teams can access, evaluate, and model the asset at any stage of the project by using a digital twin. This promotes efficiency, sustainability, and safety by aiding in the early detection of issues and data-driven decision-making. Predictive maintenance and optimal building system management are made possible by real-time data and analytics, which reduce risk and make effective use of resources before issues arise. Performance and energy efficiency are enhanced as a result. Additionally, a data-driven approach facilitates better teamwork, time and cost savings, and long-term value addition over the asset's lifetime.

Real-time connectivity, analytics, and live data feeds must be added in order to transform a BIM model into a digital twin. Digital twins are most useful during the operation and maintenance phase, but BIM is most effective during design and construction. The digital twin is not created in a vacuum; rather, it is based on a solid BIM foundation. IFC-based models and digital deliverables, among other data produced during the design and construction phase, continue to be crucial and are refined to meet the demands of the operation phase. Proper information management through BIM is crucial even during the operation phase, highlighting the necessity of a robust BIM model to maintain the relevance of the digital twin.

The process of creating a digital twin involves first creating a BIM model. A BIM model includes all the architectural, civil, and systems information. After creating the BIM model, IoT devices are placed in the building to gather information about the performance of the systems. A system of communication is then created to ensure that the sensor information, BIM information, and system information can all communicate effectively. As the sensors gather information, it is then mapped to the correct information in the BIM model. This ensures that the digital twin remains updated at all times. This process helps stakeholders to make sense of all the information gathered and use it to make informed decisions. It also helps in activities such as testing new designs, exploring new strategies to reduce consumption, and improving system efficiency. For the digital twin to remain relevant, it must be updated at all times to ensure that it remains in sync with the real-time information.

2.3 Internet of Things as the Enabler

IoT is the critical bridge between static BIM information and dynamic digital twins. Various sensors are always keeping their finger on the pulse of the project, each with its own particular use:

- Environmental sensors monitor temperature and climate conditions to provide real-world data for quality control and safety.
- Structural health sensors, such as inclinometers, stress sensors, and displacement sensors, monitor for any deformations and ensure the structure is sound in real time.
- Equipment and process sensors, such as vibration sensors, temperature sensors, and gear-tracking sensors, facilitate predictive maintenance and efficient resource allocation.
- Worker safety sensors are integrated into wearable personal protective equipment (PPE) to monitor for compliance, physical safety, fatigue, and fall hazards.
- Visual and spatial solutions, such as AI-driven cameras, RFID, and video monitoring, assist with progress monitoring and unauthorized access detection.

The integration of all these different types of sensors into a cohesive whole requires a strong communication infrastructure that addresses wireless communication protocols, bandwidth, signal strength, and cybersecurity.

2.4 Level of Details (LoDs) for BIM

Some nations have established their own Level of Detail (LoD) standards in the realm of Building Information Modeling (BIM). Table 2.4.1 lists the major construction-related LoD standards, their characteristics in terms of categorization and developers' intent, and in-depth information about these standards. In these standards, LoD and LOD are used interchangeably and may refer to the level of detail in the geometric information of model elements or to the level of development, which refers to the phase of refinement and information attached to an element (BIMForum, 2013).

Trani et al. (2015) identified specifics in site design and categorized them as preliminary, clear, and execution levels. They found that an increase in detail gradually allows designers to bring different aspects of a site design in line with one another, but their study was not concerned with site management operations. Cassano and Trani (2017) extended their study to include construction site elements and identified levels of concept, development, detail, and installation that correspond to the process from drafting to contractor-driven installation design. However, their study did not include the entire process of a construction site's lifecycle.

Table 2.4.1: BIM LoD / LoI / Standards across the globe

Location / Scope	Description of LoD / LoI	Standard / Guideline (name & year)
USA (buildings)	Defines Levels of Development LOD 100–500, focusing on reliability of model elements for use (design → FM).	AIA E202-2008 BIM Protocol; AIA G202-2013; BIMForum LOD Specification (2013–2020)
UK (buildings)	Introduces "Level of Definition" = Level of model Detail (LOD) + Level of model Information (LOI) tied to project stages.	PAS 1192-2:2013 Specification for information management using BIM
UK → ISO / global	Replaces earlier "LOD/LOI" language with Level of Information Need as primary concept for specifying required information.	ISO 19650 series (from 2018); adopted and referenced in multiple national updates
Australia	Adopts AIA/BIMForum-style Level of Development (LOD); provides matrices for expected info per LOD.	NATSPEC National BIM Guide (2011, 2016); NATSPEC BIM and LOD paper; NATSPEC BIM Properties tools
New Zealand	Defines Levels of Development 100–500 (incl. 350); distinguishes Level of Detail vs Level of Development.	New Zealand BIM Handbook (BAC/NZCIC), Annex C – Levels of Development
Netherlands	National BIM information levels; extends US LOD with 7 tailored levels used via object–level matrix.	Dutch National BIM Levels of Development (Berlo & Bomhof R&D standard)
Italy (construction)	LOD scale for construction-site elements (equipment, temporary works); aligned with AIA LOD then mapped to Italian UNI scale.	UNI 11337-4 and related work on LOD for construction site elements (LOD C/D etc.)
Korea (housing corp.)	LH-LOD system for Korean housing projects; adapts foreign LOD guidelines to domestic design process.	LH Corporation BIM Design Guideline – LH-LOD (Korea Land & Housing Corp.)
Finland	"Common BIM Requirements" with content level (Level 1–3) for BIM objects, focusing on attributes.	COBIM / Common BIM Requirements (BSI references; Finnish guidelines)
Singapore	National BIM Guide with Level of Detail definitions for elements across project stages.	Singapore BIM Guide v2.0 (Building and Construction Authority, 2013)

Source: Researcher's Compilation (2026)

2.5. Limitations of BIM in Construction

According to the literature review , Building Information Modeling (BIM) has yet to receive significant attention for its potential in the design and pre-construction phase, as this phase is already standardized in many countries. However, researchers are more interested in exploring the shortcomings in Building Information Modeling in terms of implementation in the life cycle of buildings, from construction to demolition. Even if advanced Building Information Models and data bases are used, limitations exist (Honghong et al., 2023). According to researchers, Building Information Modeling performs best in terms of planning, design, and construction but fails during operation and maintenance (O&M) and life cycle management (Rafsanjani & Nabizadeh, 2023; Honghong et al., 2023). Some of the limitations in Building Information Modeling are data incompleteness, data being outdated or in pieces, which affects decision-making even if data is correctly entered during construction but is not updated on a regular basis (Deng et al., 2021). Although IFC is a standard data exchange protocol for Building Information Modeling, it is optimized for static data exchange and is unable to manage real-time data exchange and synchronization (Radzi et al., 2023). It is also unable to integrate sensor data and real-time monitoring (Hosamo, Imran, et al., 2022). Building Information Modeling limitations are also experienced during predictive maintenance, as Building Information Modeling is based on static geometry (Coupry et al., 2021). Poor facility management standards also create problems in integration with maintenance systems (Lu, Xie, Parlikad, et al., 2020). Inadequate software integration also creates problems in collaboration among various parties (Zhao et al., 2022). Problems are also experienced in terms of integration between 3D models and IoT data, which does not allow smooth integration between the physical and digital worlds (Villa et al., 2021). Building Information Modeling is static in nature, which limits its ability to be more adaptable to operation and maintenance (Radzi et al., 2023). This is where the necessity for Building Information Modeling evolution to digital twin (DT) arises.

2.6. Advantages of DTs in Construction

Digital Twins (DTs) are digital copies of physical systems that enable us to control them in real time using IoT. DTs help us optimize the management of our resources. It gives the opportunity for the development of a much more intelligent form of energy management. Digital Twins help us understand how we utilize our energy resources. Additionally, they assist us in making real-time decisions regarding maintenance, which ensures that our resources do not fail. Having real-time information about our resources, energy, and comfort enables us to lead better. It has reliable diagnoses that assist us in identifying the problems. Additionally, it provides with simulations that assist us in identifying the conflicts in the construction of buildings, optimally allocating resources, and avoiding errors. With DTs, we have the ability to monitor the occupancy of buildings through image recognition and computer vision. This enables us to optimally allocate resources, reduce energy consumption, and improve comfort. In summary, DTs have the potential of revolutionizing the construction industry through the improvement of monitoring, visualization, occupancy, and urban analysis, as well as collaboration.

2.7. Gaps in Transitioning from BIM to DT

However, there is a growing trend in digital twin cities (DTC), but most of the research is still at the theoretical or application-oriented level. This is holding back the full potential of DTC in practical applications. However, the way forward in the successful implementation of DTC is still being held back by some challenges, including the integration of massive data streams from Building Information Modeling (BIM) and Internet of Things (IoT) technology, the lack of standardized data integration processes, and concerns about data privacy and security in cloud computing. These observations are shared by Abugu et al. (2024), who note costs and limitations as factors that hinder the adoption of DTC in the construction industry. The availability of data is another issue that keeps being mentioned, as noted by Jacobellis and Ilbeigi (2022), who note the significance of intensive data collection in the successful implementation of effective digital twin technology in smart city management. From the literature, it can be seen that integrated systems have not gained much attention in the construction industry. However, a comprehensive digital twin city system integrating space, design, and construction could provide great benefits. In this context, this research proposes, tests, and demonstrates a new approach to digital twin cities, integrating BIM and IoT for the real-time monitoring of construction processes. This new approach aims to provide solutions to some of the challenges identified in the existing literature.

3. METHODOLOGY

In this research, different approaches have been used to develop and test the framework. A detailed literature survey, development of a guiding framework, and questionnaire surveys have been used to test the research.

3.1 Search approach

The first stage was to establish the literature using through a number of databases. A systematic search was carried out on ScienceDirect and Google Scholar. The search terms used were: “BIM” AND “DT” OR “DIGITAL TWIN” AND “BIM”, AND “CONSTRUCTt” industry OR “BIM AND SITE” OR “construction sector” OR “Built* Environment”. This resulted in the retrieval of 1,857 documents from ScienceDirect, 416 from Web of Science, and 132 from Google Scholar.A systematic approach was established to select which papers would pass the criteria for content analysis. The search on ScienceDirect was conducted broadly,

and this reflects the extent to which digital twin (DT) technology has applications in many fields. To ensure that the search results are valid and reliable, we restricted the search to papers published after 2019, when the UNI EN ISO 19,650 standard was published. This standard formalized project information management during the asset lifecycle in the construction industry. As can be seen from the annual distribution of articles, there has been a tremendous increase in academic interest in integrating BIM, modeling, and DT in the construction industry in the past few years (2021-2023). Although DTs have applications in aerospace and robotics, their revolutionary impact in the construction industry has only recently gained attention (Madubuike et al., 2022).

In order to test the hypothesis that digital twins can help in the analysis and control of construction activities at the site in India, a questionnaire survey was conducted among BIM professionals. The research was based on the benefits that can be achieved by integrating digital twins, IoT, and BIM in the management of construction site activities. A total of twenty questionnaires was sent between January 1 and February 20, 2026

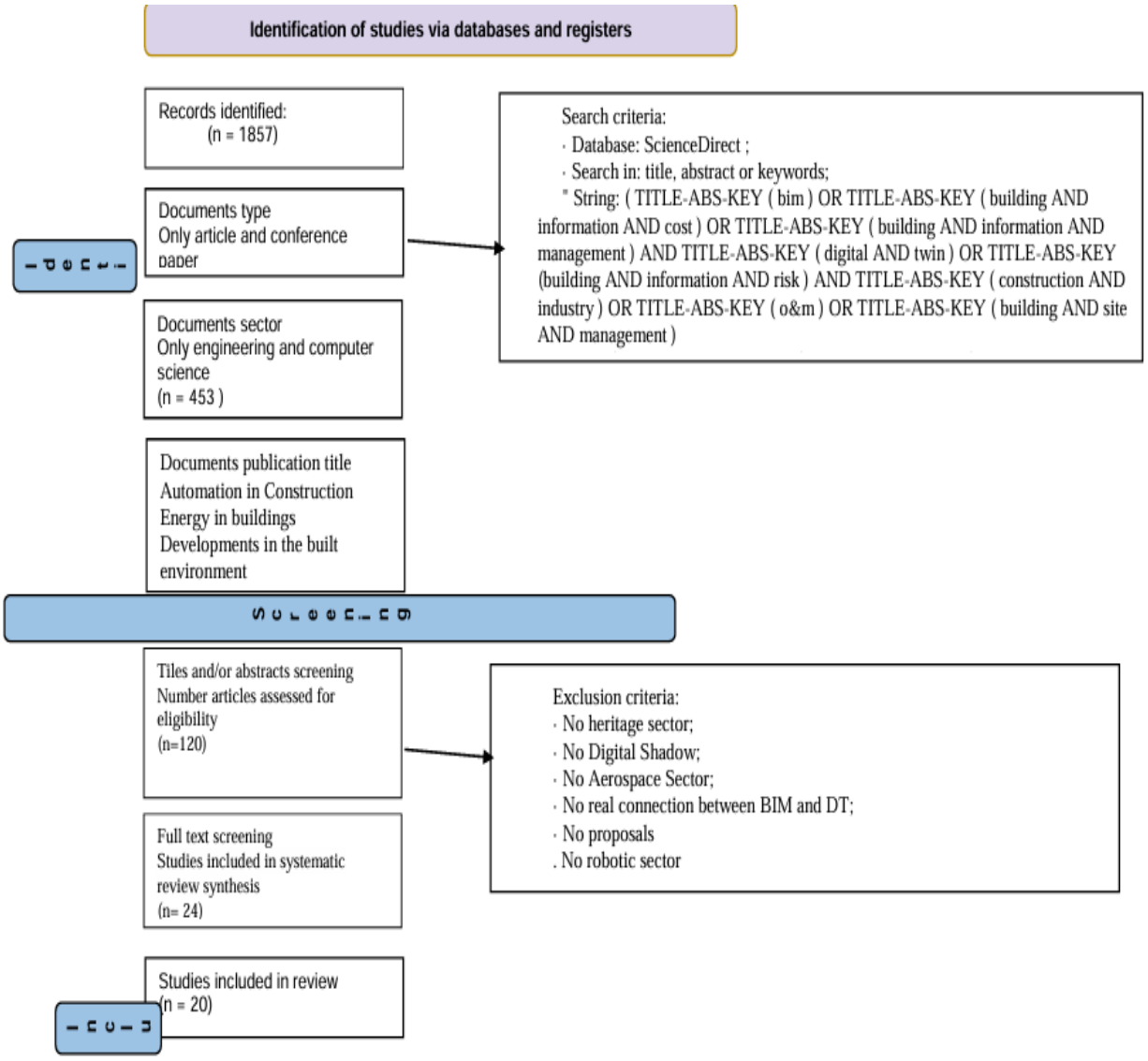


Figure 3.1: Summarisation of the literature review (based on the PRISMA model)
Source: PRISMA model output

4. DATA ANALYSIS AND DISCUSSIONS

A digital twin establishes a living and dynamic connection between the physical world and its cyber representation. In the context of construction site management, this concept is based on four interrelated pieces:

- The physical world.
- A cyber world that comprises a 3D representation of the key characteristics of the live aspect, along with a data-driven representation that extracts knowledge from various sources of data. This allows a real-time view of the live aspects, translating raw data into useful knowledge to inform decision-making and facilitate various activities. The need for standards is important in specifying information models for various live aspects.

- An integrated system that enables the exchange of data in both directions between the digital and physical twins, with live updates via the Internet of Things (IoT).
- Feedback systems that function in the physical world.

The data monitoring module is the core of the digital twin. It extracts knowledge from various types of data and enhances understanding of raw data through several processing steps. It identifies the process of data processing into three broad phases: acquisition, integration, and utilization. It identifies the process of raw data to the digital twin's actionable inputs, describing the key challenges in each phase, along with possible solutions and recommendations.

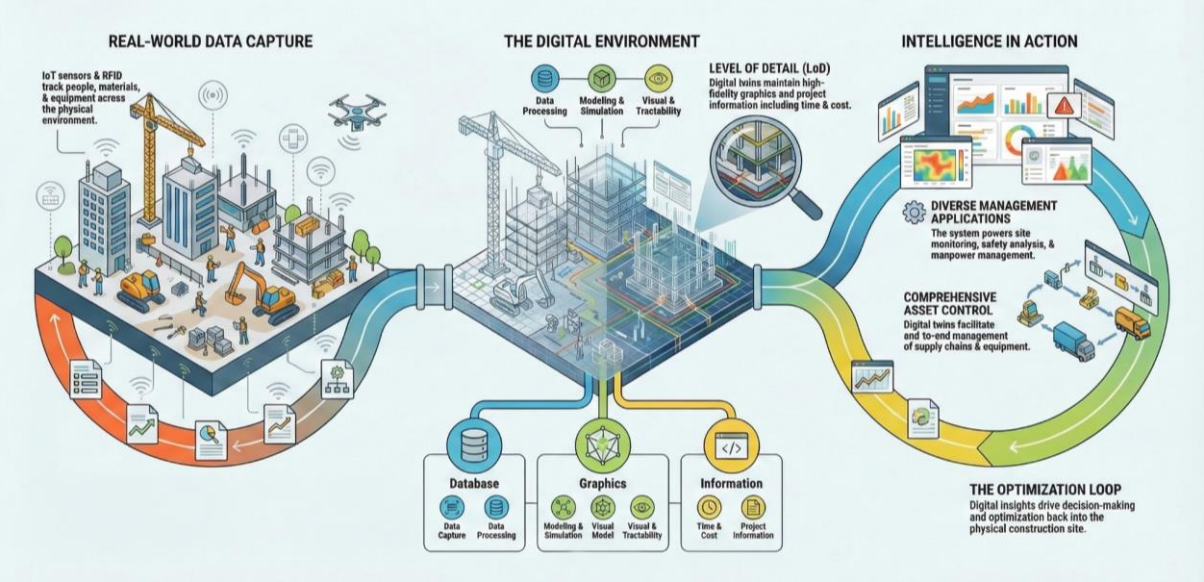


Figure 4.1: Conceptual Framework of DT in Construction Sites
Source: Researcher's infographic

4.1. Data Acquisition

DT usually acquires data from sensors using two major approaches, both of which rely on real-time data from multiple sources. However, challenges such as sensor compatibility and large data sets require the application of solutions such as standard protocols and edge computing (Lu et al., 2020).

4.2. Data Integration

Data integration is a process that occurs in three phases: mapping, duplicate detection, and fusion. A common problem arises from the use of different terms, formats, systems, tools, and standards in multiple sources, which most management software cannot handle. The objective is to enhance data quality by adding new sources, define data attributes, and simplify access for humans and computers by eliminating duplicates (Bleiholder & Naumann, 2009).

The first level of integration, data mapping, is aligning the different models of the data. The second, duplicate detection, involves identifying if the data refer to the same physical object (Ramya et al., 2017). This data is then integrated into a single view, improving it with the most relevant information in a way that helps to form digital twins.

4.3. Data Usage and Analytics

Finally, data interpretation (Kaur et al., 2020) is done using information fusion methods in the last stage of these pipelines. This results in more accurate signals, improved model performance, better predictions and beneficial decision making (Liu et al., 2018). Information fusion approaches have been proposed for optimizing the workload of workers on construction sites by synthesizing worker workload information from management information systems and sensor information to create dynamic models.Decision support systems utilize such fusion of data for daily optimized allocation of workers and better trade planning with predictive models (Wang et al., 2019).

4.4. Interaction with the Real World

A digital twin is a bridge between the physical world and the virtual world through continuous data exchange. This implies that any changes in the physical world will have a corresponding impact on the virtual world in near real-time. This is done through the help of computing, which have the ability to create a closed-loop system that monitors activities and allows interaction between the physical and virtual worlds. This is more than data fusion; it provides a very strong connection between the physical and virtual worlds, which includes device-to-device interactions as well as human/object-to-device interactions.

4.5. Data Acquisition

DT acquires data from sensors through two primary approaches, both of which are grounded in real-time data inputs from diverse sources. However, issues such as sensor compatibility and the sheer volume of data make the application of standard protocols and edge computing prominent (Lu et al., 2020c).

4.6. Data Integration

Data integration occurs through three steps: mapping, duplicate detection, and fusion. The common problem in this process is the use of different terms, formats, systems, tools, and standards in diverse sources, which most management software is not capable of handling. The aim is to improve data quality by introducing new sources, assigning attributes to data, and facilitating human and machine access by eliminating duplicates (Bleiholder & Naumann, 2009).

The first step in data integration is data mapping, which involves synchronizing different data models. The second step is duplicate detection, which identifies data that corresponds to the same physical entity (Ramya et al., 2017). Data fusion merges this data into a unified record that contains the most valuable information, which is a critical process in creating digital twins.

4.7. Data Usage and Analytics

In the final phase, information fusion methods analyze raw data (Kaur et al., 2020). This results in more distinct signals, improved model performance, more precise predictions, and more intelligent decision-making (Liu et al., 2018). In the construction environment, fusion methods combine worker workload information from management systems with sensor information to develop dynamic models. Predictive models in decision support systems rely on fusion to assign workers more accurately on a daily basis and to improve trade planning (Wang et al., 2019).

4.8. Interaction with the Real World

The digital twin establishes a connection between the physical and virtual worlds through continuous data flow. Changes in the physical world update the virtual world in near real-time, and changes in the virtual world can impact the physical world. This is made possible by a closed-loop computing environment that monitors, manages, and enables two-way interactions (Guan et al., 2016). This is more than data fusion; it establishes strong connections between the physical and virtual worlds, including machine-to-machine interactions and human/object-to-machine interactions.

4.9. Practical Contributions

Engagement with the physical world translates to concrete benefits for construction sites. Live status site monitoring offers real-time views of the system, aiding in easier analysis, enabling comparisons parallel to multiple dimensions, and informing fast, data-driven decisions—particularly in emergency situations.

- Regarding equipment, status-tracking dashboards initiate maintenance notifications, aid in identifying problems with models, and record data on usage and maintenance to inform leasing, buying, and adjustment changes.
- The asset management benefits from the visualization through the direct control of the asset's data, which assists in decision-making.
- The supply chain management benefits from the simulation analysis of the routes, which assists in the testing of the routes' feasibility, leading to the adjustment of the logistics, equipment, and labor.
- The workforce management benefits from the workload analysis, which assists in the allocation of the workload on a daily basis, adjustments at a low cost, and the adjustment of the decisions regarding the scaffolding
- Safety analysis focuses on the integrity of the load-bearing capacity in the design, and the sensors help in the structural health monitoring and failure analysis (Hackmann et al., 2013). Personnel tracking reduces the risks associated with proximity to hazards.
- Emissions and energy management utilize sensors to record carbon and energy information for modeling, prediction, and improvement.

4.10. Levels of Detail (LoDs) for Digital Twins on Construction Sites

The concept mapping begins with a hierarchical classification of site components.Figure 4.11.3.1 shows the site components during construction. Construction site elements encompass work, living, and business spaces, as well as boundaries, roads, landscapes, facilities, equipment, prefabricated parts, materials, and personnel.

4.10.1. LoD-Graphics concept

The proposed concept for construction on sites defines the core principles and required components at each subdivision stage. Additionally, LoD-Graphics for individual components specify the progression of detail levels, from conceptual to submission.

4.10.2. Basic LoD Requirements

These specifications clarify the relationship between the overall site graphics and their individual components. They explicitly define the included elements and establish LoD thresholds, such as the required components and detail levels for LoD 300.

4.10.3. LoD-Information Requirements

LoD-Information encompasses essential project details, temporal data, and cost information to ensure the digital twin's accuracy and completeness.

4.11. Defining Framework

LoD-Graphics for construction sites use a step-by-step approach with five levels:. Here is what each level means:

- LoD 100: Modeled elements appear as simple 3D shapes.
- LoD 200: Basic site areas are separated, and the main framework is shown in the graphics.
- LoD 300: Detailed site plans and preparation elements are easy to identify.
- LoD 400: Represents the site as a 3D geometric model
- LoD 500: Provides the 3D model in harmony with real-time conditions.

4.11.1. Progressive Refinements

The information at LoD 100 is still approximate. At LoD 200, space allocations for operation and maintenance are defined. LoD 300 introduces mounting details beyond LoD 200. LoD 400 introduces more detail and autonomy of components than LoD 300, allowing the retrieval of time and cost data. BIM 4D modeling helps in understanding project time, component relationships, and construction sequencing by providing details of the construction order. BIM 5D modeling advances further by integrating databases that monitor metrics such as area, volume, unit costs, and totals, and also generates reports for management. Since the independence of components is necessary to prevent errors in calculation that impact material costs, such as multi-layer wall panels, pipe sizes in networks, or precise numbers of sprinkler systems (BIMForum, 2013)—components that are not clearly independent may cause errors in material costs, such as multi-layer wall panels, pipe sizes in networks, or precise numbers of sprinkler systems (BIMForum, 2013)—this independence is critical.

4.11.2. Component-Specific LoD-Graphics

LoD-Graphics for individual site components illustrate subdivisions using uniform principles, summarized and illustrated in Figure 4.11.3.1. Some components, such as equipment and landscape, are introduced later, not at the beginning.

4.11.3. Minimum LoD Requirements

LoDs record the history of development from concept to delivery. To advance to a particular LoD, all criteria must be met and the cumulative minimums defined, according to AIA standards, where higher levels include all lower levels (BIMForum, 2013). To qualify for LoD 300, for instance, one must satisfy all criteria for LoD 100, 200, and 300.

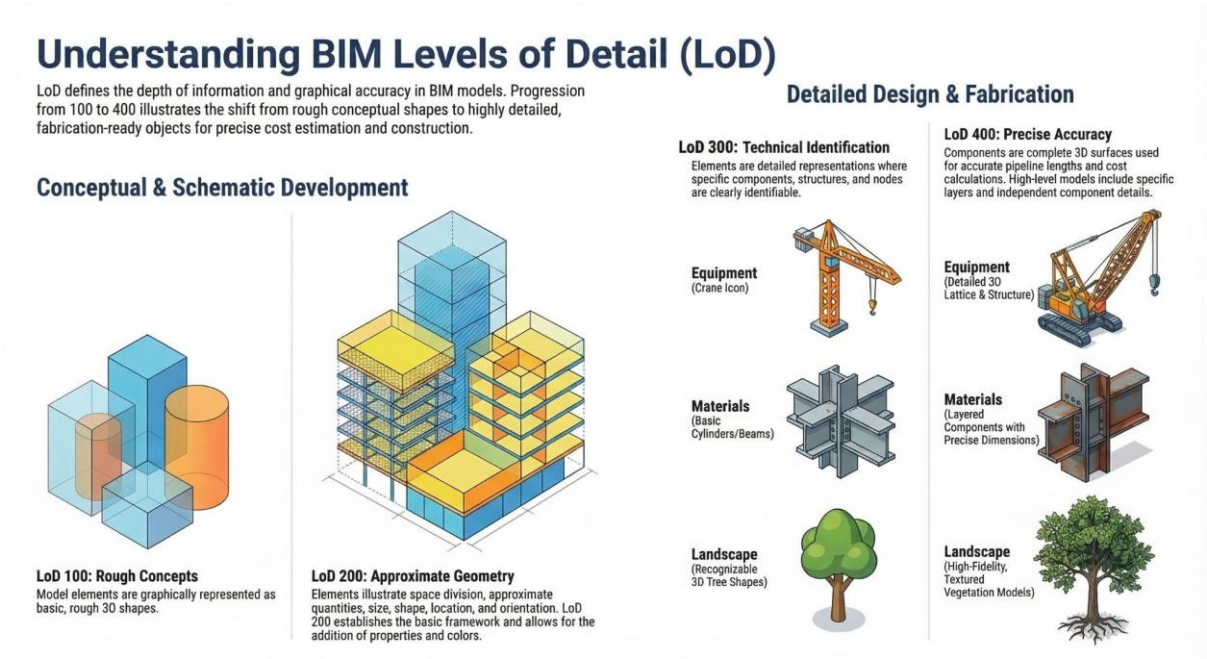


Figure 4.11.3.1. : LoD-Graphics for construction site components
Source: Researcher's infographic

4.12. Defining Information

The key information needs that are relevant to construction sites include information related to the specifics of the project, information related to time (which is often referred to as 4D), and information related to cost (which is often referred to as 5D). As discussed in the progression model by the LoD-Graphics team, LoD-Information progresses from the approximate (LoD 100), to basic, to detailed, to complete, and finally to verified (LoD 500), and the criteria for this can be seen in Figure 4.12.1

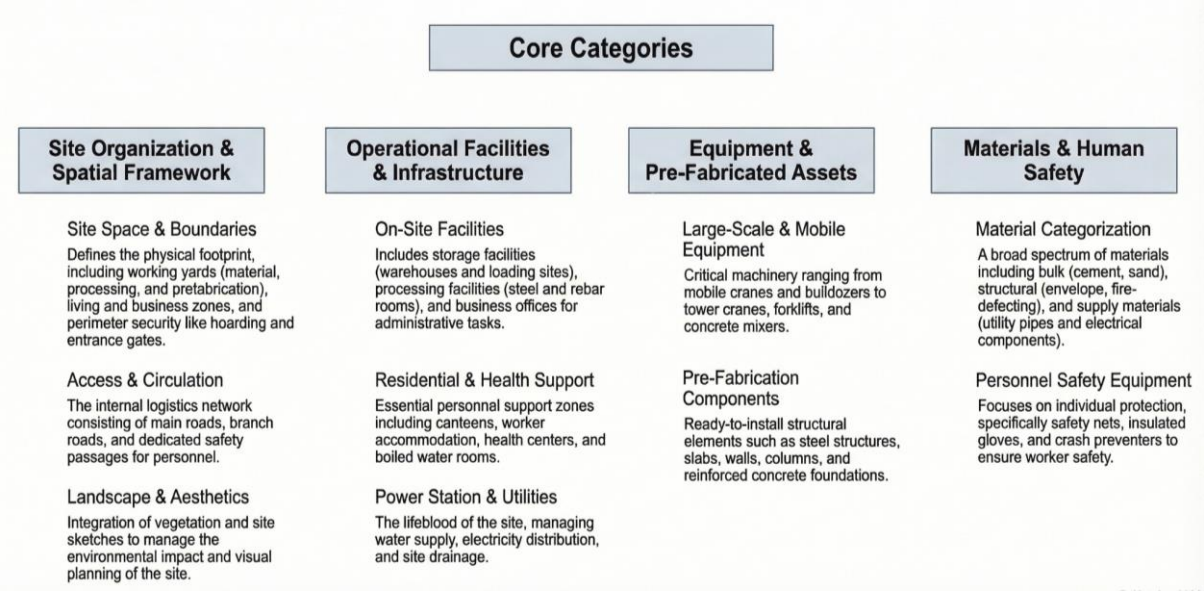


Figure 4.12.1: Construction site components
Source: Researcher's infographic

4.13. Data Management

Managing data in construction sites is a difficult task. It involves integrating data from various stakeholders, managing complex technical information, developing data-sharing protocols, and maintaining data confidentiality and privacy. Construction sites are complex and chaotic, and hence require a lot of information to flow in and out during the entire process. Traditional methods, which involve the use of papers, are likely to result in inefficiency, data loss, and even creation of false data (Chen & Kamara, 2011).

4.13.1. BIM as a Solution

Building Information Modeling (BIM) addresses data management challenges in the construction industry. BIM offers complete information, open information flows, enhanced interactions, and digital visualization (Ma & Ma, 2017). BIM integrates and standardizes data, thus limiting data fragmentation. BIM helps in data sharing, reuse, and coordination (Ozturk, 2020).

4.13.2. Barriers to Collaboration

Traditional data management practices, which involve the use of papers, do not allow data sharing because changes occur at every stage, and organizations operate independently. Traditional data management practices result in data fragmentation, isolated data, and repetition of tasks (Tao et al., 2018). BIM helps in data integration, and hence, data moves and is accessible to everybody. However, integrating various expertise and different kinds of technical data in BIM is another challenge that faces the industry.

4.13.3. Security and Access

For construction projects to be successful, there is a need to enhance collaboration and data sharing. When data is sensitive, as in the case of data in the construction site, there is a need to establish data access protocols. Access protocols help in avoiding waste and limiting risks due to human factor changes.

5. RESULTS AND DISCUSSION

The results of the questionnaire survey were satisfactory, as all twenty questionnaires received a response. It was within the time frame to complete the research. The respondents had experience ranging from 1 year to over 15 years in the construction industry. They were involved in planning, designing, approval, procurement, construction, and research. This helped to inject objectivity into the research. They came from Delhi, Gurgaon, Noida, Pune, Mumbai, and Bangalore. This helped to inject reliability into the research.

The research was based on key questions:

Q1: Digital twins facilitate real-time monitoring at Indian construction sites even when weather changes or the workforce varies.

Q2: Digital twins can improve construction site management in India by optimizing the management of the workforce, equipment, assets, and supply chain.

Q3: Digital twins facilitate quality improvement in Indian construction projects while allowing precise detection of defects and code compliance.

Q4: Digital twins can improve efficiency at Indian construction sites in crowded cities.

Q5: Digital twins can improve site safety in India by providing real-time alerts for hazards, there by eliminating the use of informal labor.

Q6: How can BIM integration in digital twins address problems like cost overruns and delays in site management in Indian construction?
Q7: What benefits do IoT sensors offer in Indian construction site management, including the remote monitoring of large-scale construction projects?
Q8: How can cloud-based databases facilitate multi-party collaboration in Indian construction while ensuring GST compliance?
Q9: Are the present definitions of LoD applicable to Indian construction sites for integrating digital twins?
Q10: Are the present requirements of LoD applicable to Indian construction sites for integrating IoT and BIM?
Q11: Do the present requirements of LoD provide a clearer vision for BIM integration in digital twins in Indian project plans at different stages of the project lifecycle?

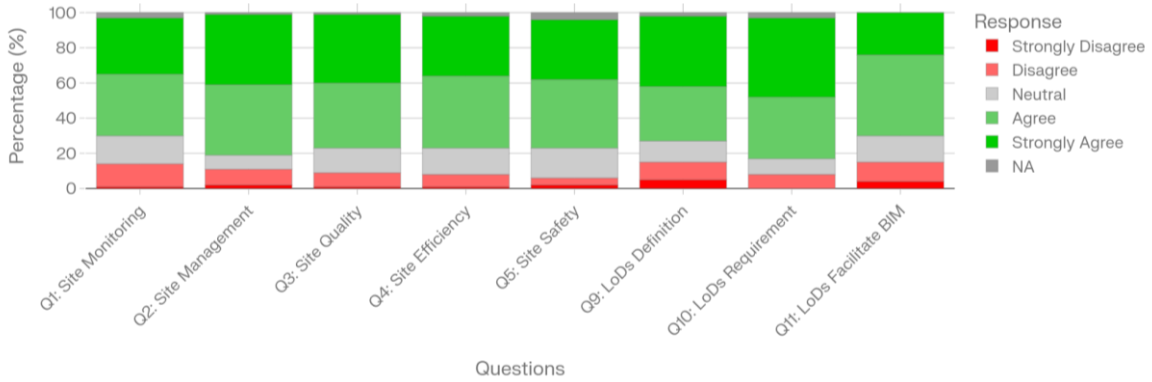


Figure 5.1. : Survey Analysis
Source: Questionnaire Survey Output

In Q1-Q5, the majority of the respondents were inclined positively towards digital twins (DTs) in various domains. Approximately two-thirds to four-fifths of the respondents agreed or strongly agreed that real-time monitoring (Q1, 67%), management of sites including workforce, equipment, assets, and supply chain management (Q2, 80%), improvement in quality through defect detection and code compliance (Q3, 76%), optimization of efficiency through predictive scheduling in urban projects (Q4, 75%), and safety optimization aligned with informal labor patterns (Q5, 73%) were important. For LoD-specific questions (Q9-Q11), there was consistent agreement at an average of 72% for clarity of definition (Q9), IoT-BIM integration requirements (Q10), and extensibility for lifecycle planning (Q11).
There was a remarkable level of agreement on Q2 (80%), which emphasizes the applicability of DTs in the labor-intensive Indian environment. The level of neutral responses was modest, ranging from 10% to 15%, with a peak for LoD specifics (approximately 12% on Q9). The level of disagreement remained low at a maximum of 5-10%. These findings are in favor of the application of DT/IoT-BIM frameworks to address the Indian construction industry's challenges of delays and cost escalation.

5.1.1. Case Studies and Applications

These case studies demonstrate that by integrating BIM, IoT, and Digital Twin, construction project management can be improved with real-time monitoring, detection of problems, increased safety management, and predictive maintenance, among other benefits. However, it has also been noted that there are some challenges, such as data interoperability, sensor data quality, cybersecurity, and the complexity of integrating multiple technologies, especially by construction practitioners, who note that on-site management can be improved, along with the management of standardized protocols and smarter handling of large, diverse data sets. The research, therefore, concludes that BIM, IoT, and Digital Twin frameworks are very promising for improving construction processes, provided that technical integration issues are addressed and that organizations are ready to adapt to the technologies.

Table 5.1.1.1. : Case Studies and Applications

Case Study / Project	Methodology	Inferences
Digital twin of RC cast-in-place office building	Used multiple sensors and laser scanners feeding data into a knowledge-graph DT dashboard for structural monitoring, material supply chain tracking, and progress analytics.	Demonstrated productivity and safety monitoring benefits but revealed challenges in technology readiness and integration complexity.
Smart site DT visualization (BIM+GIS+IoT)	Combined BIM, GIS, and IoT data streams into a 3D engine platform for multi-dimensional supervision (time/space/business) by site managers.	Supported enhanced decision-making through comprehensive real-time visualization of personnel, equipment, environment, and progress.

Source: Researcher's compilation (2026)

6. CONCLUSION

The move from BIM to digital twins appears to be a major milestone for the construction industry, offering potential to enhance all aspects of the industry, including pre- and post-completion activities, through the use of real-time information, sophisticated analytics, and predictive capabilities. It might also revolutionize the way construction management is done (Omrany et al., 2023). However, there are certain impediments to the adoption of digital twins at the industry level. These impediments include the cost of setting up digital twins, the lack of universal standards, and the unwillingness of people to adopt new technology (Visartsakul and Damrianant, 2023; Jahangir, Schultz, and Kamari, 2024; Kaveh and Alhajj, 2025). Future research might focus on addressing these impediments to ensure the cost of setting up digital twins is minimized, universal standards are established, and training programs are designed to ensure that the industry has enough human resources to manage digital twins (Sadri et al., 2023; Cespedes-Cubides and Jradi, 2024). Nonetheless, improving the accuracy, availability, standardization, and integration of data appears to be vital to the effective use of digital twins to update information in real time (Wang et al., 2024). There appears to be a need to develop better techniques to utilize data from IoT technology and other sources to ensure effective information sharing and updating (Kookalani et al., 2026). The implications of these technologies on employment and education might also be considered, as these are vital to the long-term success of the industry (Badenko et al., 2024; Tran, Tran, and Nguyen, 2024).

Lean principle approach, when applied to digital twins, can improve information flow, collaboration, and site productivity in the construction industry (Araújo et al., 2022). However, the large volumes of data generated by digital twin-based systems, particularly in critical infrastructure, have serious privacy and security implications. To address these challenges, robust countermeasures, including data encryption and access control, are necessary (Homaei et al., 2023; Musonda et al., 2023). To achieve this, addressing these challenges is critical to ensure that digital twins can create actual operational and productivity benefits to all stakeholders in the construction industry ("Digital Twin Production in the Architecture, Engineering, Construction and Operation Industry: Organizational Attributes and Strategies," 2023).

6.1. Future scope

Research into BIM, IoT, and Digital Twins in India is underway, though it has not been as rapid as it has been in other countries. Research into the applications of BIM, IoT, and Digital Twins has been carried out, revealing that they have the potential to enhance the management of construction projects by improving data collection, visualization, and analysis in real time. There has also been research into the potential of integrating BIM, DT, and AI to enhance resource efficiency in construction. However, challenges to the applications of BIM, IoT, and Digital Twins in India include integrating different data sources, the absence of standardized frameworks, and their low adoption rates. There is also growing interest in the use of ontology to integrate data from BIM, GIS, and IoT in smart cities, which can be of great value to India in the development of smart cities. In the future, research in India is expected to focus on building digital twin technology, resolving technical issues, and encouraging the use of sustainable building with the use of BIM, IoT, and DT.

India has made great strides in the use of BIM, and the need to incorporate IoT and Digital Twin in construction and smart building has been growing. There is, however, a need to work harder to overcome the challenges facing the applications of IoT and Digital Twin in India.

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