



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

Module 2: Emerging Technologies in Civil Engineering	No. of Hrs: 05
Building Information Modelling: Evolution to Object-Based Parametric Modelling, Life cycle, Building Information Modelling Dimensions, Building Information Modelling Platforms, Impact on Project Stakeholders	
Digital Twins in Construction: Overview, Building Information Modelling versus Digital Twins, Architecture, Strategic Planning for Digital Twin Implementation, Applications for Building Energy and Carbon Performance	

Evolution to Object-Based Parametric Modelling

Introduction

Civil Engineers use drawings and models to plan, design, and construct buildings, roads, bridges, and other infrastructure projects. As construction projects became larger and more complex, better modelling techniques were developed. The evolution of modelling techniques started with Manual Drafting and progressed through CAD, 3D Geometric Modelling, Object-Based Modelling (OBM), and Object-Based Parametric Modelling (OBPM), finally leading to Building Information Modelling (BIM).

Definition

Object-Based Parametric Modelling (OBPM) is a technique in which building components such as beams, columns, and slabs are modelled with defined properties, so that changes to one component automatically update related components.

Each new modelling technique improved the design and construction of buildings, roads, and bridges by providing better visualization, more detailed information, and easier design modifications. As a result, civil engineering modelling evolved from manual drawings to intelligent digital models.

The following explanation describes the evolution of modelling techniques from Manual Drafting to Object-Based Parametric Modelling (OBPM)

1. Manual Drafting

Manual drafting is the preparation of engineering drawings on paper using instruments such as drawing boards, T-squares, scales, and pencils. Before computers, all engineering drawings were prepared manually and used to communicate design and construction information.

Limitation

Any design change required redrawing, resulting in time consumption and wastage of resources.

2. Computer-Aided Design (CAD)

Computer-Aided Design (CAD) is the use of computer software to create, edit, and manage engineering drawings. Software such as **AutoCAD** is commonly used to prepare digital drawings. In CAD, building and infrastructure components are represented using lines, circles, and other drawing elements to create 2D drawings

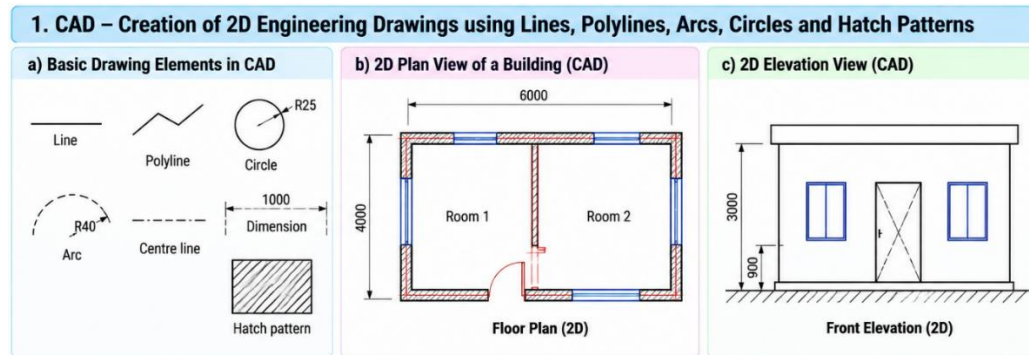


Figure 1: Fundamentals of 2D CAD drawing elements alongside a dimensioned building floor plan and front elevation view.

Limitation

Components were shown only as 2D drawings and did not include 3D models information.

3. 3D Geometric Modelling

3D Geometric Modelling is the representation of structures using three-dimensional (3D) shapes. Common shapes include cuboids, cylinders, cones, and spheres. These shapes are used to represent engineering components such as beams, columns, foundations, and water tanks.

3D modelling helps engineers visualize structures more clearly than 2D drawings by showing their length, width, and height.

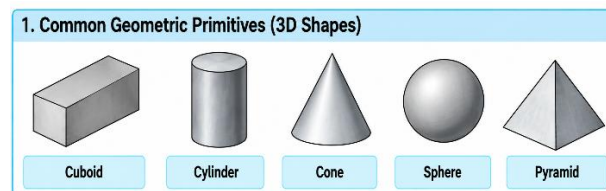


Figure 2: Representation of 3D geometric shapes

Limitation

Models showed only the 3D shape of components but did not contain information to identify them as beams, columns, walls, or slabs.

4. Object-Based Modelling (OBM)

Object-Based Modelling (OBM) is a modelling technique in which building components such as beams, pillars, and walls are represented as actual building elements instead of simple 3D shapes.

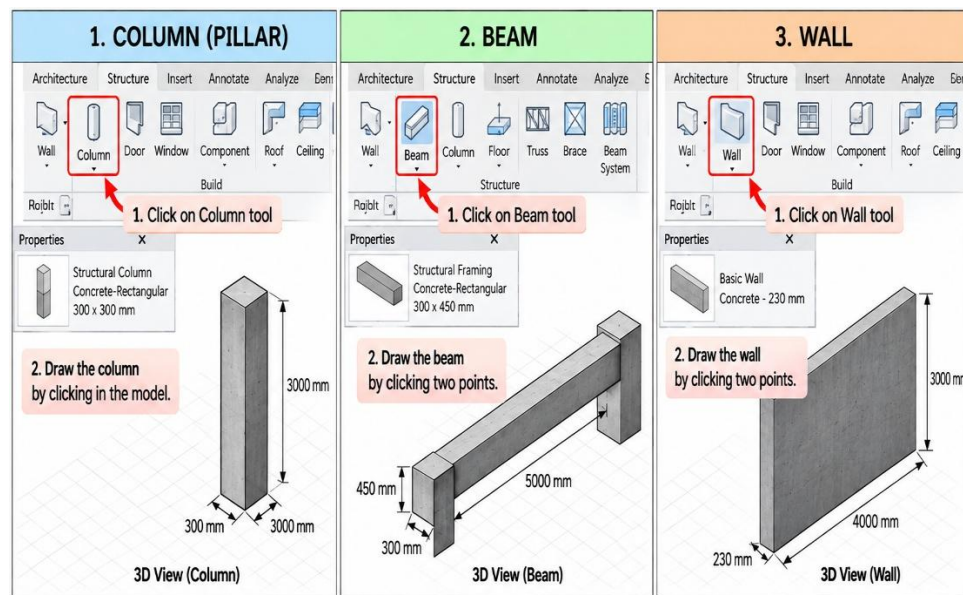


Figure 3: Illustration of Object-Based Modelling (OBM), where changes made to a Beam Object do not automatically update related in plan, elevation and beam schedule.

Limitation

If the size of a beam is changed, the beam drawings and material quantities also need to be changed. In OBM, these changes may not happen automatically.

5. Object-Based Parametric Modelling (OBPM)

OBPM is a modelling method where building and infrastructure components are created as smart digital objects instead of simple shapes. These objects contain information such as size, material, and properties. These objects can be controlled and modified using parameters, constraints, and relationships.



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

- **1. Parameters:**
Defines the details of the pillar, such as size, shape, and material.
Example: Pillar height = 3 m, size = 300 mm × 300 mm, shape = square, material = concrete.
- **2. Constraints:**
Defines the rules that control the pillar design.
Example: The pillar should be vertical, straight, and follow the required design shape.
- **3. Relationships:**
Defines the connection of the pillar with other building components.
Example: The pillar is connected to the foundation below and supports the beam and slab above.

Example: Pillar Object in Object-Based Parametric Modelling (OBPM)

Consider a pillar object with a size of 300 mm × 300 mm and height of 3000 mm. If the height is changed to 4000 mm, the pillar size is automatically updated in the model and related drawings.

Parameters (Details of the pillar):

- Size = 300 mm × 300 mm
- Height = 3000 mm (changed to 4000 mm)
- Material = Concrete

Constraints (Rules for the pillar):

- Pillar should be vertical and straight.
- Pillar size should follow design requirements.

Relationships (Connection with other components):

- Pillar is connected to the foundation below.
- Pillar supports the beam above.
- Pillar details are shown in drawings and quantity calculations.

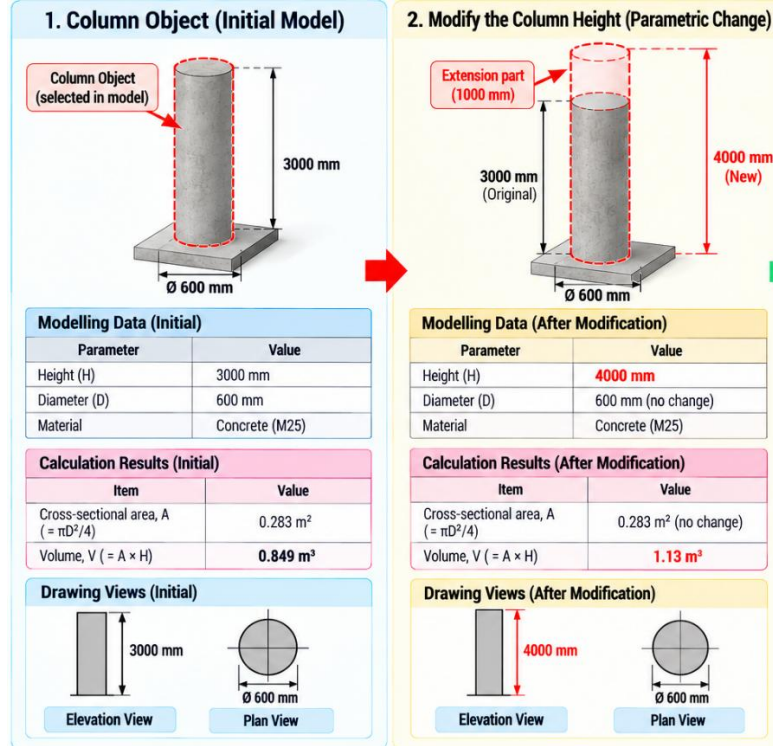


Figure 4: Illustration of Object-Based Parametric Modelling (OBPM), where changes made to a column will automatically update related in plan, elevation and column schedule

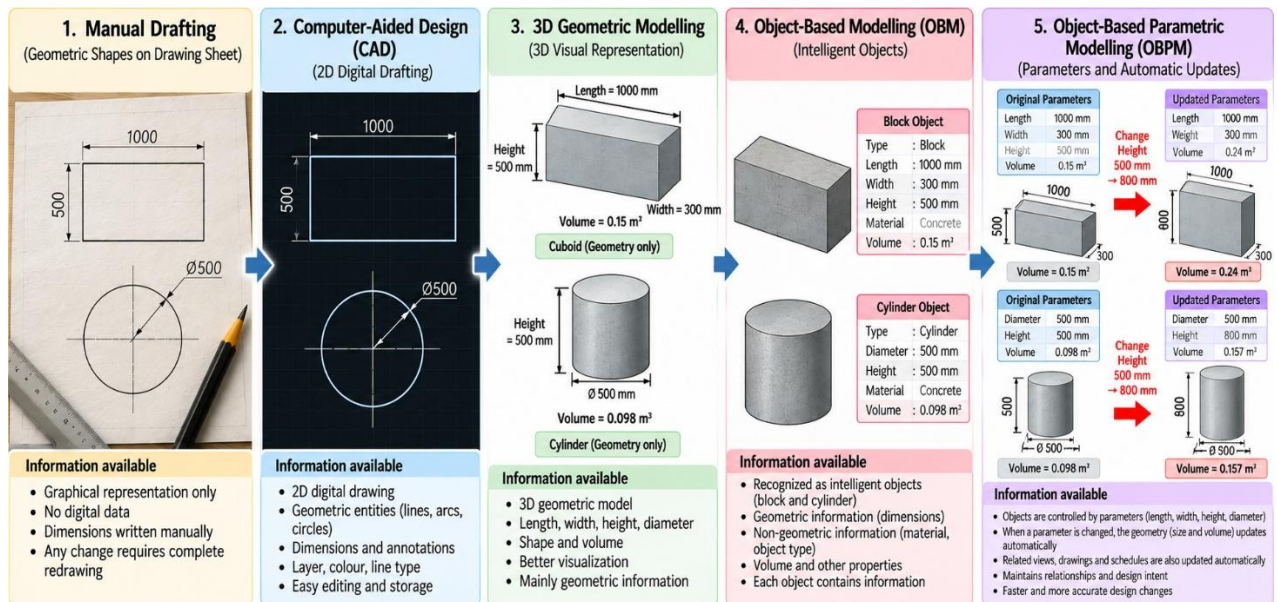


Figure 5: Evolution from Manual Drafting to Object-Based Parametric Modelling (OBPM).



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

Following Table 1 shows the summary of Evolution of Modelling Techniques from Manual Drafting to Object Based Parametric Modelling

Table 1: Summary of the Evolution of Modelling Techniques from Manual Drafting to Object Based Parametric Modelling

Sl. No.	Stage	Representation of Components	Primary Application	Limitation
1	Manual Drafting	Hand-drawn engineering drawings on paper	Preparation of plans, elevations, sections, and schedule of opening details	Modifications required manual erasing and redrawing of drawings
2	Computer-Aided Design (CAD)	2D lines and shapes	Creation and editing of engineering drawings in digital form	Difficult to understand the drawings for customers
3	3D Geometric Modelling	3D shapes such as cuboids, cylinders, cones, and spheres	Visualization of engineering structures in three dimensions	Can not identify in drawing whether a component is a beam, pillar, wall.
4	Object-Based Modelling (OBM)	Objects like beams, columns, and pillars	Creation of intelligent engineering components with properties	Changes made to an object will not change overall drawings automatically
5	Object-Based Parametric Modelling (OBPM)	Intelligent objects controlled by parameters, constraints, and relationships	Automatic updating of drawings, schedules, and quantity calculations	Difficult to share project information among all people involved in the project.

Note: Evolution to Object-Based Parametric Modelling

1. **Manual Drafting** = Drawings on Paper
2. **CAD** = Digital Drawings
3. **3D Geometric Modelling** = CAD + 3D Shapes and Visualization
4. **OBM** = 3D Geometric Modelling + Engineering Information (Objects)
5. **OBPM** = OBM + Parameters + Constraints + Relationships + Automatic Updates
6. **BIM** = OBPM + Collaboration + Information Management Throughout the Project Lifecycle



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

Building Information Modelling

Definition

Building Information Modelling (BIM) is a digital process used by civil engineers to create and manage a 3D model of a building or infrastructure project, including information about its components, dimensions, materials, quantities, and cost throughout its design, construction, operation, and maintenance.

Building Information Modelling- Life Cycle

Definition:

The BIM life cycle refers to the stages of a construction project, from initial planning and design through construction, operation, and maintenance to final renovation or demolition.

Stages of Building Information Modelling (BIM) Life Cycle

A construction project involves different activities at different phases, such as planning, design, construction, operation, and maintenance. To manage these activities effectively, the project is divided into different stages throughout its life cycle.

In a construction project, BIM supports the facility from its initial concept and planning through design, construction, operation, maintenance, and finally renovation or demolition.

Accordingly, the Building Information Modelling (BIM) Life Cycle consists of the following five stages:

1. Planning Stage
2. Design Stage
3. Construction Stage
4. Operation and Maintenance Stage
5. Renovation or Demolition Stage

1. Planning Stage

The **Planning Stage** is the stage where engineers decide what to build, where to build, and how much it may cost. BIM helps visualize the proposed building, study the site, and estimate the approximate project cost before design work begins.

2. Design Stage

The **Design Stage** is the stage where engineers prepare the building design. BIM is used to create digital models of foundations, columns, beams, slabs, walls, and services so that all parts of the building can be coordinated before construction starts.



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

3. Construction Stage

The **Construction Stage** is the stage where the building is physically constructed on site. BIM helps engineers obtain quantities of concrete, steel, bricks, and other materials, plan construction activities, and monitor project progress.

4. Operation and Maintenance Stage

The **Operation and Maintenance Stage** begins after the building is completed and occupied. BIM helps engineers keep records of the building and plan inspection, repair, and maintenance activities during its service life.

5. Renovation or Demolition Stage

The **Renovation or Demolition Stage** occurs when the building becomes old and requires modification, expansion, or demolition. BIM provides information about the existing structure, helping engineers carry out renovation or demolition work safely and efficiently.

Building Information Modelling Dimensions

BIM Dimensions (D) are different types of information added to a BIM model. Each dimension provides additional details about the project, such as shape, time, cost, and maintenance information.

BIM dimensions help engineers and other project members to plan, design, construct, and manage a building effectively.

The following BIM dimensions show how additional information is progressively added to the BIM model to support different stages of a project.

- **3D** → Geometry (3D representation of building components using length, width, and height)
- **4D** → Geometry + Time
- **5D** → Geometry + Time + Cost
- **6D** → Geometry + Time + Cost + Sustainability
- **7D** → Geometry + Time + Cost + Sustainability + Maintenance

Thus, each BIM dimension (D) represents an additional layer of information integrated into the BIM model, enhancing its functionality throughout the project life cycle.



Figure 6: Role of BIM Dimensions (3D–7D) in Developing an Integrated BIM Model Throughout the Project Life Cycle.

Building Information Modelling Platforms

BIM software platforms are used to **create, manage, and share building information digitally**. Different software tools are used for **3D modelling, time planning, cost estimation, sustainability analysis, and facility management**.

The table below shows BIM dimensions (3D–7D), their features, and commonly used BIM software in the AEC industry.

Table 2: BIM Dimensions and Software Platforms Used in the AEC Industry

SL NO	BIM Dimensions	Features	Building Information modelling Software Platforms
1	3D BIM	3D model with size and shape information	- Autodesk Revit - Graphisoft Archicad
2	4D BIM	Time and Construction Schedule Information	- Oracle Primavera P6 - Microsoft Project
3	5D BIM	Cost and Quantity Information	- CostX - Autodesk Revit Schedules
4	6D BIM	Sustainability and Energy Information	- Autodesk Insight - Autodesk Green Building Studio
5	7D BIM	Building operation and maintenance information	- Autodesk Tandem - Archibus

Impact of BIM on Project Stakeholders

Project stakeholders are people involved in a construction project, such as owners, architects, engineers, contractors, and field engineers. BIM helps all stakeholders to share information, coordinate work, and complete the project efficiently.

- 1. Owners/Clients:** Provide project requirements, budget, and objectives.
- 2. Architects:** Create the building design and BIM model based on the owner's requirements.
- 3. Structural Engineers:** Design foundations, columns, beams, and slabs to ensure structural safety.
- 4. Mechanical, Electrical, and Plumbing (MEP) Engineers:** Design air-conditioning, electrical wiring, water supply, and drainage systems.
- 5. Project Managers:** Coordinate project activities, schedules, and resources to ensure timely completion.
- 6. Contractors:** Use the BIM model to guide construction activities and estimate material quantities.
- 7. Field Engineers:** Use BIM models to virtually inspect the project, check dimensions, verify site work, and ensure construction follows the design.

Thus, BIM acts as a common platform that connects all stakeholders by enabling efficient information sharing, coordination, and collaboration throughout the project life cycle.



Figure 7: Impact of BIM on Project Stakeholders

Digital Twins in Construction

Traditionally, civil engineers used manual drawings and later Computer-Aided Design (CAD) to represent buildings and infrastructure. Building Information Modelling (BIM) further improved this process by creating intelligent 3D models containing detailed project information. **Digital Twin technology builds on BIM** by connecting the digital model with data from the actual structure to monitor its real-time condition and performance throughout its life cycle.

Definition of Digital Twin

A Digital Twin is a virtual representation of a real building that uses data collected from the physical building to monitor its progress, condition, and performance during construction and throughout its operation and maintenance.

Digital Twin in Buildings

A Digital Twin is a virtual representation of a real building that uses data collected from the physical building through sensors and other data sources. This data is transferred to the digital model to help engineers monitor building performance, identify potential problems, and plan maintenance. Digital Twins can be used during construction and throughout the building's operation and maintenance. They help monitor structural components such as foundations, columns, beams, and slabs, as well as building systems such as HVAC, electrical, and plumbing. Civil engineers, structural engineers, architects, and facility managers use Digital Twins to monitor buildings and make informed decisions.

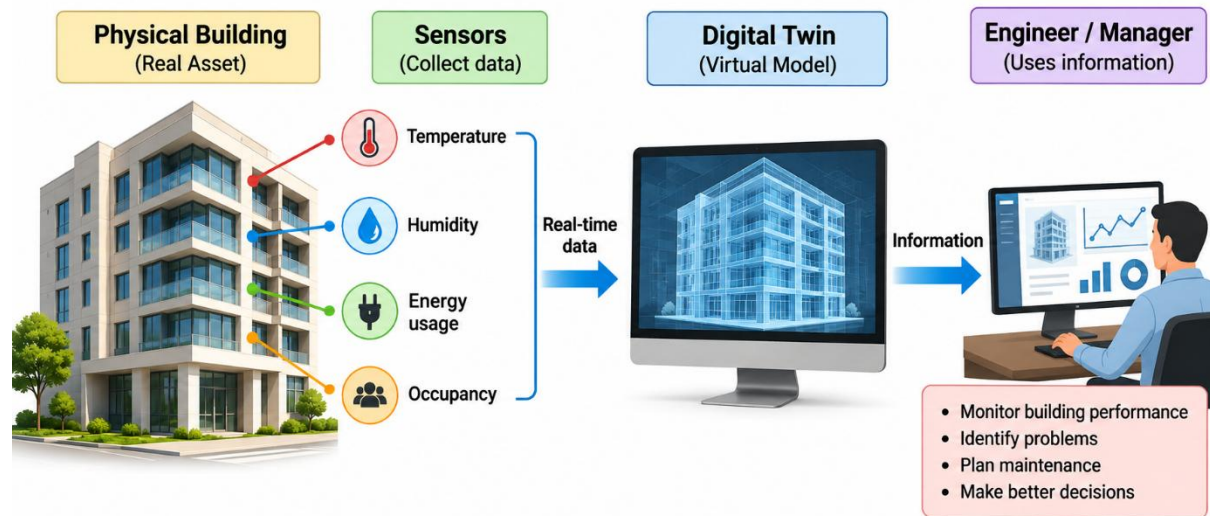


Figure 8: Digital Twin of a Building Showing Real-Time Data Flow from the Physical Building to its Virtual Model.

Figure 8 shows how sensors collect data from a physical building and transfer it to a Digital Twin model, which helps engineers monitor building performance, identify problems, and plan maintenance.



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

Building Information Modelling (BIM) versus Digital Twins

Purpose: Both BIM and Digital Twins are used to digitally represent buildings and infrastructure.

BIM: Before construction, engineers create a digital model to plan and design the building, coordinate components, and estimate quantities. The model can also be used to monitor construction progress.

Digital Twin: During construction and after completion, data collected from the physical building through sensors and other sources is connected to its digital model to monitor actual conditions, performance, and maintenance needs.

The following table 3 shows the differences between BIM and Digital Twins.

Table 3: Difference between BIM & Digital Twins

Sl. No.	Activity	Building Information Modelling (BIM)	Digital Twin
1	Model creation	Creates a detailed digital model to plan, design, and construct a building.	Connects a digital model to the actual building to monitor its condition and performance.
2	Building Visualization	Shows the planned shape, dimensions, layout, and building components.	Shows the building model along with its actual condition and performance data.
3	Construction planning	Helps plan construction activities, quantities, schedules, and coordination.	Helps monitor actual construction progress and compare it with the planned progress.
4	Building monitoring	Provides building information and supports checking during design and construction.	Monitors actual building performance using connected sensors and updated data.
5	Energy monitoring	Cannot show actual energy consumption of the building.	Shows actual energy consumption using sensors
6	Identifying problems	Helps detect design clashes and coordination issues before construction.	Helps detect abnormal conditions and potential performance problems using actual data.
7	Maintenance management	Provides basic information for building maintenance	Helps to find problems early and plan maintenance before failure
8	Decision-making	Supports design and construction decisions.	Supports operation and maintenance decisions.



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

9	Stage of use	Mainly used during planning, design, and construction.	Mainly used during and after construction, operation and maintenance.
10	Example	A 3D BIM model of a college showing classrooms, columns, beams, quantities, and building services.	A connected digital model of a college showing actual energy use, room temperature, occupancy, and equipment condition.

Architecture of a Digital Twin

Digital Twin architecture shows how different components work together to monitor a real building or infrastructure. Sensors collect data from the structure, the communication network transfers it, and the digital model and processing system analyze and display the information. This helps engineers and other stakeholders monitor the structure and make decisions during construction and operation.

The architecture of a Digital Twin consists of the following main components:

1. **Physical Structure:** The actual building being monitored.
2. **Sensors and Data Acquisition Systems:** Sensors attached to the building measure vibration, temperature, structural movement, and energy consumption.
3. **Communication Network:** Wi-Fi or other networks transfer sensor data to the digital system.
4. **Digital Twin Model:** BIM software such as Autodesk Revit provides the 3D model of the building.
5. **Data Storage and Management System:** Databases or cloud platforms store building information and sensor data.
6. **Data Processing and Analytics System:** Software such as Microsoft Azure Digital Twins helps process building data and identify unusual changes or performance problems.
7. **Visualization and User Interface:** Software such as Autodesk Tandem displays the digital building model, sensor readings, and equipment status on a computer screen.
8. **Users and Stakeholders:** Civil engineers and facility managers use the information to monitor the building and plan maintenance.

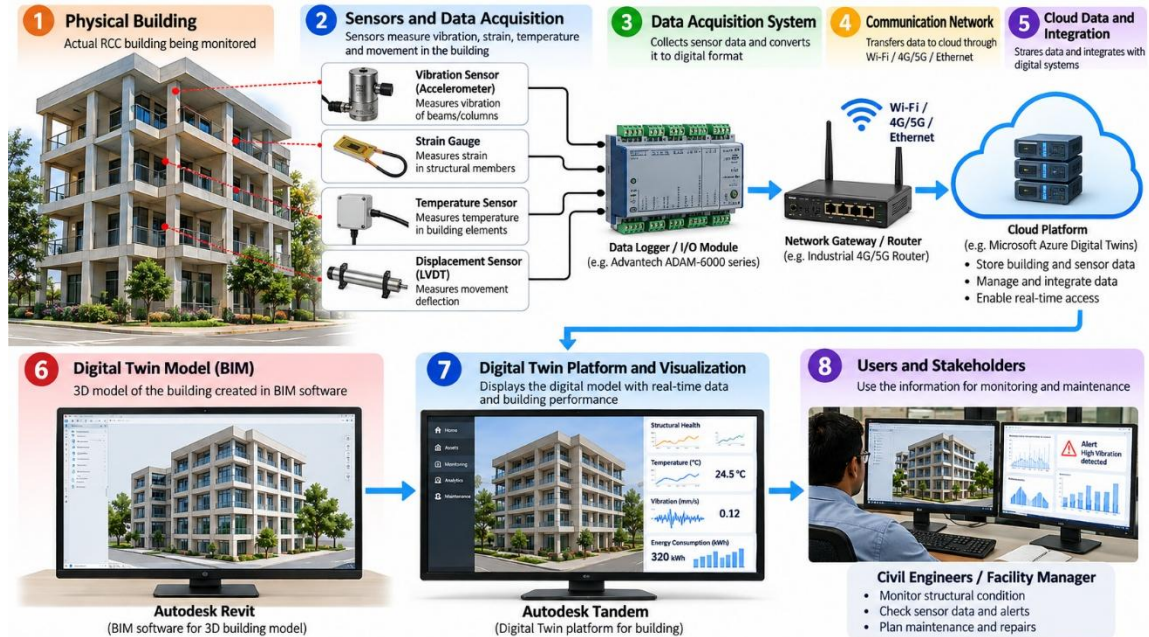


Figure 9: Architecture of a Digital Twin

Strategic Planning for Digital Twin Implementation

A Digital Twin cannot be created by simply installing sensors on a building. Proper planning is needed before implementation. Strategic planning helps to decide the purpose of the Digital Twin, required data, technologies, and responsibilities of different people.

It ensures that the Digital Twin is developed and used effectively throughout the life of the project.

Key Steps in Strategic Planning

- 1. Project Selection** → The first step is to select the building, bridge, road, or facility for which the Digital Twin will be developed.
- 2. Project Objectives** → After selecting the project, the objectives of the Digital Twin are defined, such as monitoring performance, managing energy, or planning maintenance.
- 3. Information Requirements** → Based on the objectives, the required information such as progress, energy use, and structural condition is identified.
- 4. Digital Model Development** → Using the project information, a BIM model is developed, which acts as the base model for creating the Digital Twin.
- 5. Sensor and Technology Planning** → After developing the model, suitable sensors, communication systems, and software are selected to collect and transfer data.
- 6. System Integration Planning** → The BIM model, sensors, and software systems are integrated to create a complete Digital Twin environment.



MANGALORE INSTITUTE OF TECHNOLOGY & ENGINEERING

(A Unit of Rajalaxmi Education Trust®, Mangalore)

Autonomous Institute affiliated to VTU, Belagavi, Approved by AICTE, New Delhi

Accredited by NAAC with A+ Grade & ISO 9001:2015 Certified Institution

7. **Stakeholder Coordination** → Once the system is developed, the roles and responsibilities of owners, engineers, contractors, and facility managers are defined.
8. **Operation and Improvement Planning** → Finally, procedures are established to monitor, update, and improve the Digital Twin throughout the life cycle of the facility.

Applications of Digital Twins for Building Energy and Carbon Performance

Building Energy Performance refers to how efficiently a building uses energy.

Building Carbon Performance refers to the amount of carbon emissions produced due to energy use.

Digital Twins help to monitor energy use, reduce energy consumption, and lower carbon emissions in buildings.

Applications of Digital Twins for Building Energy Performance

1. Monitoring Building Electricity Consumption → Monitors real-time electricity use.
2. Reducing Unnecessary Lighting Usage → Identifies unnecessary lighting in empty areas.
3. Improving HVAC Efficiency → Reduces energy use of HVAC systems.
4. Monitoring Building Equipment Energy Use → Tracks energy use of lifts, pumps, and fans.
5. Reducing Building Energy Costs → Helps reduce energy consumption and costs.

Applications of Digital Twins for Building Carbon Performance

6. Estimating Building Carbon Emissions → Calculates carbon emissions from energy use.
7. Identifying High Carbon Systems → Finds systems producing high carbon emissions.
8. Supporting Energy-Saving Measures → Evaluates energy-saving methods.
9. Evaluating Renewable Energy Systems → Analyzes solar and other renewable systems.
10. Supporting Sustainable Building Operation → Helps reduce emissions and improve building performance.