DIGITAL TWIN GUIDELINES

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Center for Buildings, Infrastructure and Public Space

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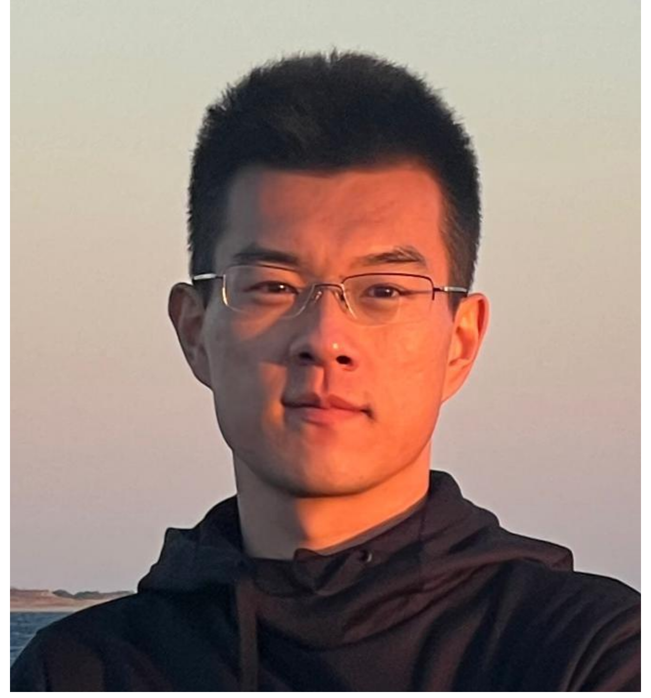

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Semester Schedule

Outline

Part 1. General Information

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Part 3. Digital Twin

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Contents

Definitions

Terminology Definitions

- Explain important terminologies, provide with detailed descriptions
- Purpose:
  - Helps readers to understand the guideline and related knowledge more clearly
- Abbreviation:
  - LEED — Leadership in Energy and Environmental Design
  - LOD — Level of Development
  - NWD — Naviswork format
  - DWF — Design Web Format

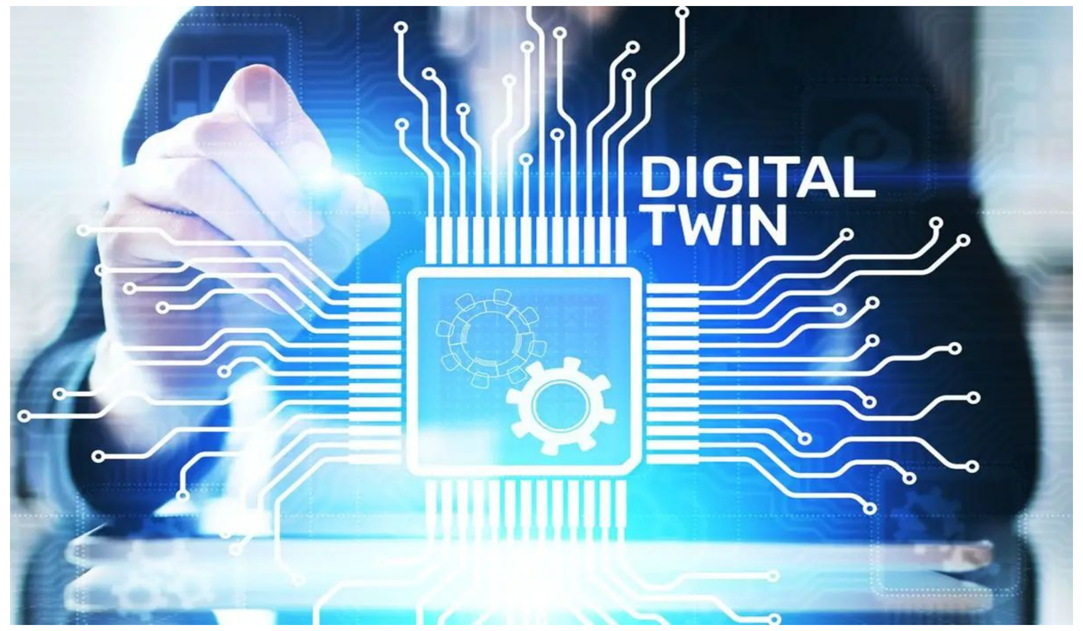
Definitions

- **Terminology Definitions**
  - Digital Twin

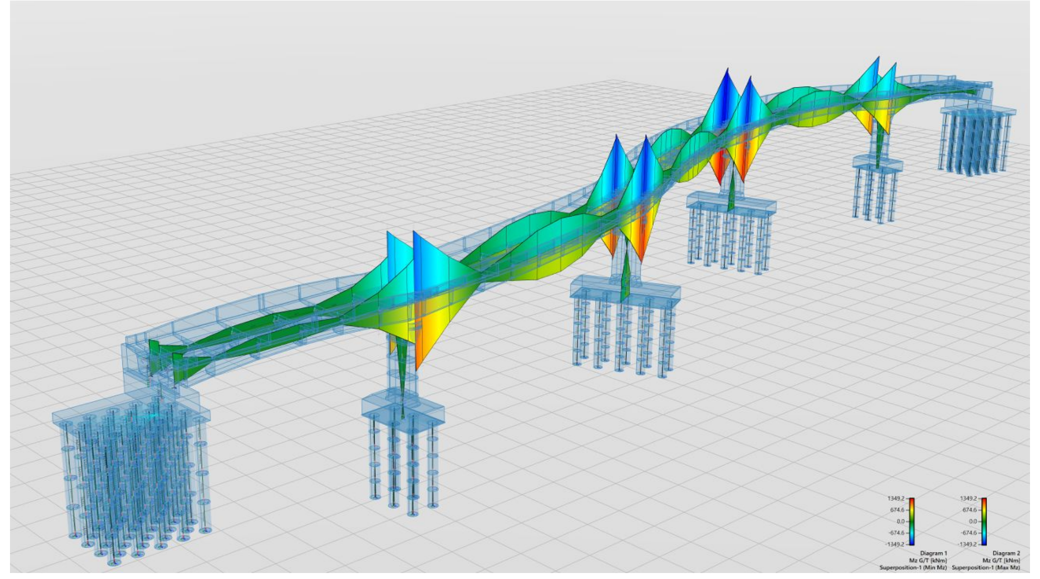
Digital twin is a digital representation of an intended or actual real-world project physical product, system, or process

  - BrIM

Bridge Information Modelling (BrIM) is a computerized technique used in the discipline of civil engineering to plan, build, and oversee projects involving bridges and other forms of transportation infrastructure.



Tech Briefly| Digital Twins, 2021



Tech Briefly| Digital Twins, 2021

Object Requirements

Component	LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
Girders	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, anchorage details	Fabrication, assembly, installation details	As-built model, inspection/maintenance data
Piers	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, bearing details	Formwork design, concrete placement	As-built model, inspection/maintenance data
Abutments	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, backfill, bearing details	Formwork design, concrete placement	As-built model, inspection/maintenance data
Bearings	Basic representation, location	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, anchorage, grouting, elastomeric pad details	Fabrication, assembly, installation details	As-built model, inspection/maintenance data
Foundations	Basic representation, location	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, pile/pier connection, soil-structure interaction details	Formwork design, concrete placement, pile installation methods	As-built model, inspection/maintenance data

Object Requirements

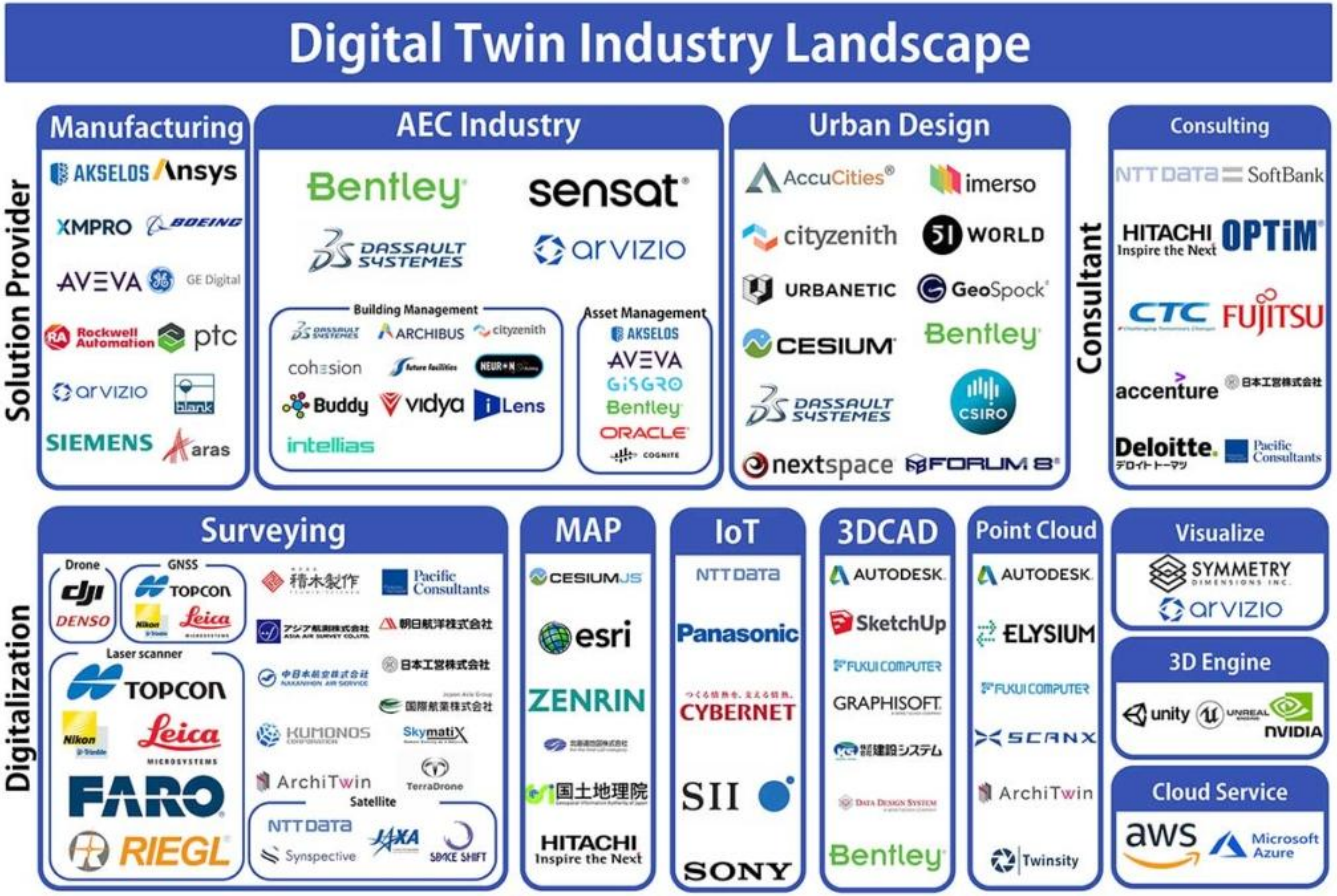
Component	LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
Deck	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, wearing surface details	Formwork design, concrete placement, surfacing installation	As-built model, inspection/maintenance data
Expansion Joints	Basic representation, location	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, anchorage, sealing details	Fabrication, assembly, installation details	As-built model, inspection/maintenance data
Parapets	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, reinforcement, anchorage details	Fabrication, assembly, installation details	As-built model, inspection/maintenance data
Drainage Systems	Basic representation, location, alignment	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, slopes, inlet/outlet details	Installation methods, slopes, and connections	As-built model, inspection/maintenance data
Lighting Systems	Basic representation, location	Approximate dimensions, material properties, connections	Accurate dimensions, material specifications, mounting details, wiring, and controls	Fabrication, assembly, installation details	As-built model, inspection/maintenance data

Softwares and Platforms

BricsCAD®
AUTODESK® REVIT®
AUTODESK® NAVISWORKS®
Bentley® Advancing Infrastructure
AUTODESK® CIVIL 3D® 2021
KREO
Tekla® Structures
AUTODESK® INFRAWORKS®

USE	Software/Platform
Surveying, Terrain Modelling	AutoCAD Civil 3D, Bentley OpenRoads
Analysis	SAP2000, CSiBridge, LUSAS Bridge(FEA software), Bentley RM Bridge
Code Validation Softwares	ETABS, AASHTOWare Bridge Design and Rating (BrDR), STAAD.Pro, Tekla Structural Designer
Design Review Softwares	Autodesk Navisworks, Autodesk BIM 360, Bluebeam Revu(for PDFs), Trimble Connect,
AR softwares, Tools	PTC Vuforia, Microsoft HoloLens
Coordination Platforms	Trimble Connect, Bentley ProjectWise, Procore, 3D Repo
VR Tools	Oculus
Clash Detection	Autodesk Navisworks, Autodesk BIM 360 Coordinate, Trimble Connect, Bentley ProjectWise,
Structural Health Monitoring	SCADAS by Siemens, ARTeMIS Modal by Structural Vibration Solutions, Oasys GSA Suite

Softwares and Platforms



Accucities Digital Twin Industry Map by Symmetry Dimensions, 22 Nov. 2020

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Thanks!

Questions and Comments

Part 3: Digital Twin

Introduction

- In this section, Digital twins have been introduced and how they will be used in each phase of the project has been briefed
- Design Stage: simulate different design alternatives and evaluate their performance and cost-effectiveness.
- Construction Stage:plan and optimize construction processes, such as scheduling, sequencing, and resource allocation
- OPerations Stage :In the operations stage, digital twins shall be used to monitor the performance of bridges in real-time

3.1 Introduction

Digital twins shall be used at different stages of the bridge lifecycle, including design, construction, and operations.

In the **design stage**, digital twins shall be used to **simulate different design alternatives and evaluate their performance and cost-effectiveness**. This shall help designers to identify optimal designs that meet project requirements and minimize the risk of failures.

In the **construction stage**, digital twins shall be used to **plan and optimize** construction processes, such as **scheduling, sequencing, and resource allocation**. This shall help contractors to minimize delays and cost overruns and improve safety and quality on construction sites.

In the operations stage, digital twins shall be used to **monitor the performance of bridges in real-time** and detect potential issues before they become critical. This shall help bridge owners to optimize maintenance and repair schedules, minimize disruptions to traffic, and ensure the safety and reliability of the bridge.

Overall, the use of digital twins shall help to improve the performance, safety, and sustainability of bridges and reduce the risk of failures and disruptions. However, the implementation of digital twins shall require careful planning, collaboration, and coordination among different stakeholders and adherence to industry standards and best practices.

Digital Twin Use Cases

Predictive Maintenance

- In this section, the procedure to implement predictive maintenance has been elaborated
- Identify Critical Areas
- Install sensors to collect data
- Collect historical data and create digital twin
- AI or ML will be used to predict behavior of the bridge

3.2 Digital Twin Use Cases

3.2.1 Predictive Maintenence

To implement predictive maintenance using digital twins in bridges, several steps shall be taken. First, the critical components and systems of the bridge that require maintenance shall be identified to ensure maintenance efforts are focused on the most crucial areas of the bridge.

Next, sensors shall be installed to collect real-time data on the performance of these components and systems to generate insights that will be used to plan and schedule maintenance activities.

Thirdly, historical performance data and other relevant information about the bridge shall be collected to create a digital twin of the bridge that simulates its behavior under different conditions.

Following which, a machine learning or artificial intelligence algorithm shall be trained to compare the real-time sensor data to the predicted performance of the digital twin and generate alerts when maintenance is required, thus ensuring that maintenance activities are proactive and scheduled before a critical failure occurs.

Then, the alerts generated by the system shall be used to plan and schedule maintenance activities proactively to reduce downtime and repair costs.

After this, the performance of the bridge shall be continuously monitored, and the digital twin shall be updated as necessary to ensure accurate predictions, which will improve the accuracy of the predictive maintenance system.

Implementing predictive maintenance using digital twins in bridges shall help improve the safety, reliability, and lifespan of the bridge while reducing downtime and repair costs. However, it is crucial to have a reliable data collection and analysis system and ensure the accuracy and reliability of the digital twin to make accurate predictions. Additionally, the digital twin shall be regularly updated with new data and validated against real-world performance data to ensure its accuracy.

Digital Twin Use Cases

Performance Evaluation

- In this section, implementation of performance evaluation has been shown
- KPIs like structural integrity, structural health, load bearing capacity or traffic flow must be identified
- Sensors should be installed and real time data should be collected
- Data should be analysed and insights should be generated about the performance of the bridge
- AI and ML should be used to compare predicted and actual performance

3.2.2 Performance Evaluation

To conduct performance evaluations of bridges using digital twins, the following steps shall be taken. Firstly, the key performance metrics that need to be evaluated, such as the structural integrity and load-bearing capacity of the bridge, shall be identified. Next, sensors shall be installed on the bridge to collect real-time data on its performance.In addition to these key indicators, other performance indicators such as structural health, energy efficiency, environmental impact, safety, and traffic flow shall also be monitored using digital twins. By analyzing real-time data on these factors, it is possible to optimize performance indicators and improve overall efficiency.

The data collected from the sensors shall then be processed and analyzed to generate insights into the performance of the bridge. Based on this information, a digital twin of the bridge shall be created to simulate the behavior of the bridge under different conditions. The insights generated by the digital twin shall then be used to make informed decisions on maintenance, repairs, and upgrades.

To ensure accurate predictions, a machine learning or artificial intelligence algorithm shall be trained to compare the real-time sensor data to the predicted performance of the digital twin. The algorithm shall then identify areas where performance is suboptimal or deteriorating.

It is important to continuously monitor the performance of the bridge and update the digital twin as necessary to ensure accurate predictions and recommendations. Therefore, the owner or operator shall ensure that the digital twin is regularly updated with new data and validated against real-world performance data to ensure its accuracy. By conducting regular performance evaluations using digital twins, bridge owners and operators shall be able to monitor the health of their assets, make data-driven decisions, and improve the overall performance of the bridge.

However, to ensure the accuracy and reliability of the digital twin, a reliable data collection and analysis system shall be established. Additionally, proper measures shall be taken to ensure the accuracy and reliability of the digital twin to make accurate predictions.

Digital Twin Use Cases

Risk Assessment

- In this section, using DTs for risk assessment has been elaborated
- All assets of the bridge, including its components and systems, shall be identified,
- The identified risks shall be evaluated based on their likelihood of occurrence and potential consequences using risk matrices
- A digital twin of the bridge shall be created based on the data collected in step one to simulate the bridge's behavior under different conditions and assess the impact of identified risks on its performance.
- Risk mitigation strategies shall be developed based on the results of the risk assessment using the digital twin
- he performance of the bridge shall be monitored in real-time using data collected from sensors and the digital twin to identify any changes that may indicate the emergence of new risks and promptly address them

3.2.3 Risk Assessment

To implement risk assessment using digital twins in bridges, expertise in risk assessment techniques, data analytics, and bridge engineering shall be required.

The first step in implementing risk assessment shall be asset identification. All assets of the bridge, including its components and systems, shall be identified, and data on their age, condition, and maintenance history shall be gathered. This information shall be used to identify potential risks associated with each asset using techniques such as fault tree analysis or failure mode and effects analysis.

The second step shall be risk evaluation. The identified risks shall be evaluated based on their likelihood of occurrence and potential consequences using risk matrices. The goal shall be to prioritize risks and identify those that require immediate attention.

The third step shall be digital twin creation. A digital twin of the bridge shall be created based on the data collected in step one to simulate the bridge's behavior under different conditions and assess the impact of identified risks on its performance. The digital twin shall provide a virtual representation of the bridge that can be used to analyze and optimize its performance and identify potential issues before they occur.

The fourth step shall be risk mitigation. Risk mitigation strategies shall be developed based on the results of the risk assessment using the digital twin. These strategies shall be designed to reduce or eliminate the risks identified in step two and shall be consistent with industry standards and best practices.

Digital Twin Use Cases

Design and Construction

- In this section, using DTs for Design and Construction of bridges
- Design options shall be tested and optimized using the digital twin.The digital twin can also be used to simulate the bridge's performance under various loads,
- Construction plans and simulations shall be generated using the digital twin to ensure safe and efficient construction.
- During construction, the digital twin shall be used to monitor the project's progress

3.2.4 Design and Construction

The use of digital twins in the design and construction of bridges shall involve the creation of a digital model that contains all relevant design and construction information. This digital twin can be used to simulate various scenarios and evaluate the bridge's behavior under different conditions. Potential issues or design flaws can be identified early on before construction begins.

Design options shall be tested and optimized using the digital twin. Engineers can test different materials, optimal shapes of the bridge, and placement of supporting pillars to determine the most efficient and cost-effective design. The digital twin can also be used to simulate the bridge's performance under various loads, including traffic, wind, and earthquake scenarios.

Construction plans and simulations shall be generated using the digital twin to ensure safe and efficient construction. The digital twin can help engineers identify potential construction challenges and plan accordingly, resulting in a smoother construction process and fewer delays.

During construction, the digital twin shall be used to monitor the project's progress and detect any potential issues or delays. Early intervention can help prevent costly and time-consuming delays.

By implementing these steps, engineers and construction teams can utilize digital twins to optimize and streamline the design and construction process, resulting in a more efficient and safer construction of bridges.

Digital Twin Use Cases

Training and Simulation

- In this section, using DTs for Design and Construction of bridges has been shown
- Digital twins in bridges can simulate and train for a range of scenarios such as emergency response drills, maintenance and repair operations, and disaster preparedness simulations.
- Emergency responders can use digital twins to plan their response to different scenarios.
- he digital twin can also be utilized to provide virtual training and simulation environments for engineers and construction workers.
- Trainees can practice their skills and techniques in a safe and controlled environment, which can help to improve their performance and reduce the risk of accidents during actual construction.

3.2.5 Training and Simulation

Digital twins in bridges can simulate and train for a range of scenarios such as emergency response drills, maintenance and repair operations, and disaster preparedness simulations. Emergency responders can use digital twins to plan their response to different scenarios. Maintenance and repair teams can use digital twins to ensure they have the necessary tools and equipment. Disaster preparedness simulations can identify potential weaknesses in the bridge's design and construction and plan mitigation strategies. The use of digital twins in training and simulation can help improve safety, efficiency, and preparedness in bridge operations.

The digital twin can also be utilized to provide virtual training and simulation environments for engineers and construction workers. Trainees can practice their skills and techniques in a safe and controlled environment, which can help to improve their performance and reduce the risk of accidents during actual construction.The digital twin shall be integrated with various sensors and monitoring systems to provide real-time data on the bridge's behavior and performance. This can help engineers and trainees to monitor the bridge's response to various loads and environmental factors and evaluate the effectiveness of different training and simulation strategies.

Digital Twin Use Cases

Asset Management

- In this section, implementation of DTs in asset management has been shown
- The implementation of digital twins in asset management for bridges shall involve the creation of a comprehensive digital model of the bridge.
- This model shall contain all essential information regarding the bridge's design, construction, and operational data.
- Using the data collected a digital twin of the bridge shall be created.
- Once the digital twin has been created,it should be used to analyze and simulate different scenarios, such as potential maintenance needs and repair strategies. As the bridge ages and conditions change, agencies shall continue to monitor and update the digital twin.

3.2.6 Asset Management

The implementation of digital twins in asset management for bridges shall involve the creation of a comprehensive digital model of the bridge. This model shall contain all essential information regarding the bridge's design, construction, and operational data. This information can then be used to monitor the bridge's performance and identify potential issues or defects that require attention. Additionally, the digital twin can be used to simulate different scenarios, such as changes in traffic patterns, environmental conditions, or maintenance and repair work, to help bridge managers make informed decisions and optimize operations. Overall, the use of digital twins in asset management can help to improve the safety, efficiency, and lifespan of bridges.

Digital twins technology opens up new avenues to improve condition monitoring, streamline maintenance, and increase occupant comfort, driving considerable savings along the way.

3.2.7 Digital Twins For RFI

RFI (Request for Information) is a standard construction project procedure that involves seeking information from stakeholders such as architects, engineers, contractors, and suppliers. Digital twins can be utilized to expedite the RFI process and promote stakeholder participation.

- Centralized RFI management
- Real-time collaboration
- Project data visualization
- RFI routing automation
- Analytics and insights

3.5 AI and ML in Digital Twins

AI and machine learning can play a significant role in developing and maintaining digital twins for bridges. Digital twins are virtual replicas of physical assets that enable engineers and technicians to simulate, monitor, and analyze the performance of the asset in real-time.

- Identify the problem
- Collect data
- Preprocess the data
- Select the appropriate AI and machine learning algorithms
- Train the models
- Validate the models
- Implement the models
- Monitor and update the models
- Evaluate the outcomes

3.6 Blockchain Integration

Blockchain technology may be used to build bridges in digital twins to increase data security, transparency, and accountability.

- Identify the problem
- Define the scope of the digital twin
- Choose the appropriate blockchain platform
- Create the smart contracts
- Develop the blockchain infrastructure
- Implement the blockchain solution
- Test and verify the solution
- Train the stakeholders
- Monitor and maintain the solution

Digital Twin Platforms

- **It provides more opportunities and creativities to the construction management**
- **Vertex Software: create 3D-powered digital twin applications for industry**

Digital Twin Platforms

3.7 Digital Twin Platforms

Digital twin technology has been widely used in the field of urban planning development and construction industry. Especially for the smart city movement, this technology was devoted as a comprehensive platform to exchange all kinds of information and real-time data, which provided a proper space for all engineers to communicate with each other. Similarly, as a huge system or platform, digital twin technology provides more opportunities and creativities. In this case, digital twin can be considered as a platform to serve engineers, which greatly increases the working efficiency.

Vertex software could be a good digital platform for team collaboration by showing 3D data and achieving agile visual transformation between different sides. More importantly, this software can provide very personal service to customers. For example, it can build solutions to fit any model on different devices. For another, it can also connect data to a single 3D visual source if the customer wants to extend the enterprise. Thus, not only to align the business data to 3D-model, but also to show visualization to any devices or users, Vertex software plays a key role as a digital-twin platform.

Real-Time Monitoring

- Record the continuous movement of the network performance
- Show every detailed change and update of the system
- There are a couple of real-time monitoring softwares:

  Nagios, SignalFX, and Cisco AppDynamics

3.9 Real Time Monitoring

Firstly, real-time monitoring can record the continuous movement of the network performance. It can show every detailed change and update of the system, which is very helpful to review and improve itself. To be more specific, it can avoid a list of safety issues at construction sites. For example, when workers are using ladders or scaffolds, monitoring will supervise them to operate correctly, which greatly reduces risks of injury. At the same time, a real-time monitoring system can also help to collect data periodically, in order to observe the changes at each given interval. In addition, there are a couple of real-time monitoring softwares, such as Nagios, SignalFX, and Cisco AppDynamics.

AR & VR for Digital Twins

- AR (Augmented Reality): Technology which overlays digital layer on the real physical world.

  “AR = Real World + Virtual World”

- VR (Virtual Reality): Computer-generated simulation of a three-dimensional fully virtual world

- They allow users to immerse themselves in the environment of the bridge’s digital twin

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AR & VR Implementation

AR & VR may be implemented in digital twins in the following ways:

- Visualization: provide realistic 360-degree views of the digital twins
- Data Visualization: Users can inspect critical information, using AR
- Training: develop training simulation for workers to learn and practice processes
- Remote Collaboration: enable remote communication among team members

AR & VR Implementation

3.10 AR and VR for Digital Twins

The reason to make an almost identical digital twin of a bridge to the one that already exists is to create an environment where adjustments and updates can be made quickly and less costly with almost identical results in the physical space. Yet, when AR and VR are combined users and stakeholders may envision and explore the digital twins in a more realistic and engaging way. AR and VR, combined with highly advanced machine learning technology, enable the development of a digital twin of the bridge where experimentation and adjustments can be made without affecting the real, physical structure.

Augmented Reality, or AR, is a technology that overlays digital information or images onto the real environment world to improve them with digital details, typically using a camera or other sensors on a mobile device such as an iPad or a specialized AR headset such as Microsoft HoloLens. A digital layer is superimposed on the real physical world, allowing users to observe and interact with digital content while still being in their physical environment. Users can clearly distinguish between the actual and virtual world. Augmented Reality is basically "Real World + Virtual World. VR, or Virtual Reality, on the other hand, is a computer-generated simulation of a three-dimensional environment that can be interacted with through the use of specialized hardware such as Head-Mounted Displays (HMDs) such as the Oculus Rift, VR headsets, and controllers. The technology employs advanced graphics, audio, and other sensory input to provide the user with a realistic, immersive experience.

Before the merging of AR or VR technology with digital twins, the digital twins have been 3D models of the bridge represented on 2D screens. However, VR allows users to immerse themselves in the environment of the digital twin of the bridge. Users can "walk" around the bridge, inspecting each component in detail and identifying any problems. This creates a more intuitive impression, which helps to understand the digital twin's dynamics (and so also of its physical counterpart). AR has a place here as well. AR can be used to overlay information and data onto a digital twin of the bridge, allowing users to see extensive information about the structure and its components.

Depending on the application and use case, AR and VR may be used in digital twins in a variety of ways, including the following:

1. Visualization: VR and AR may be utilized to provide highly realistic and immersive visualizations of digital twins. This may enable users to explore and interact with the virtual replica in a way that closely resembles the physical environment. It also enables the bridge's digital twins to have an uninterrupted 360-degree free-flowing view.

2. Data visualization: With AR, users may see critical information and key performance indicators in context by overlaying real-time data onto a digital twin.

3. Training: VR and AR may be used to develop interactive training simulations for a wide range of applications. For instance, maintenance employees may be trained using VR simulations of the digital twin, allowing them to practice processes and learn in a safe, controlled environment. This may be particularly useful for monitoring complex systems or processes.

4. Remote collaboration: AR and VR may be used to enable remote collaboration and communication among teams working on the digital twin. For example, engineers in various locations can use VR headsets to interact with the same digital twin and discuss design modifications in real-time.

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Sensors and Use Cases

Sensors monitor structural health, environmental condition, and traffic pattern for digital twins of bridges.

Types of sensors:

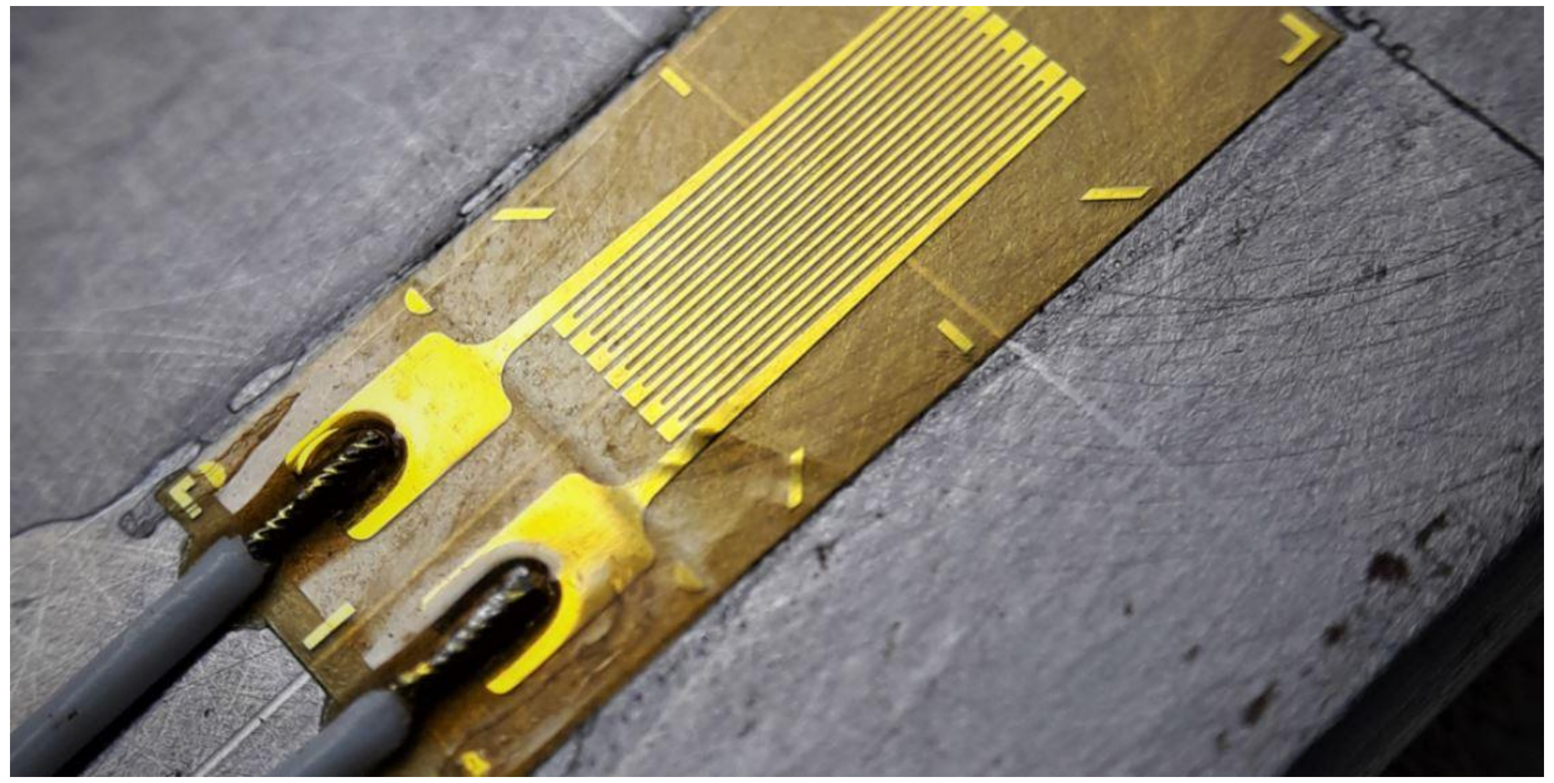
- Strain Sensors: measure deformation
- Accelerometers: measure vibration
- Temperature Sensors: measure effect of temperature change
- Environmental Sensors: measure effect of environmental factors
- Traffic Sensors: measure issues caused by traffic

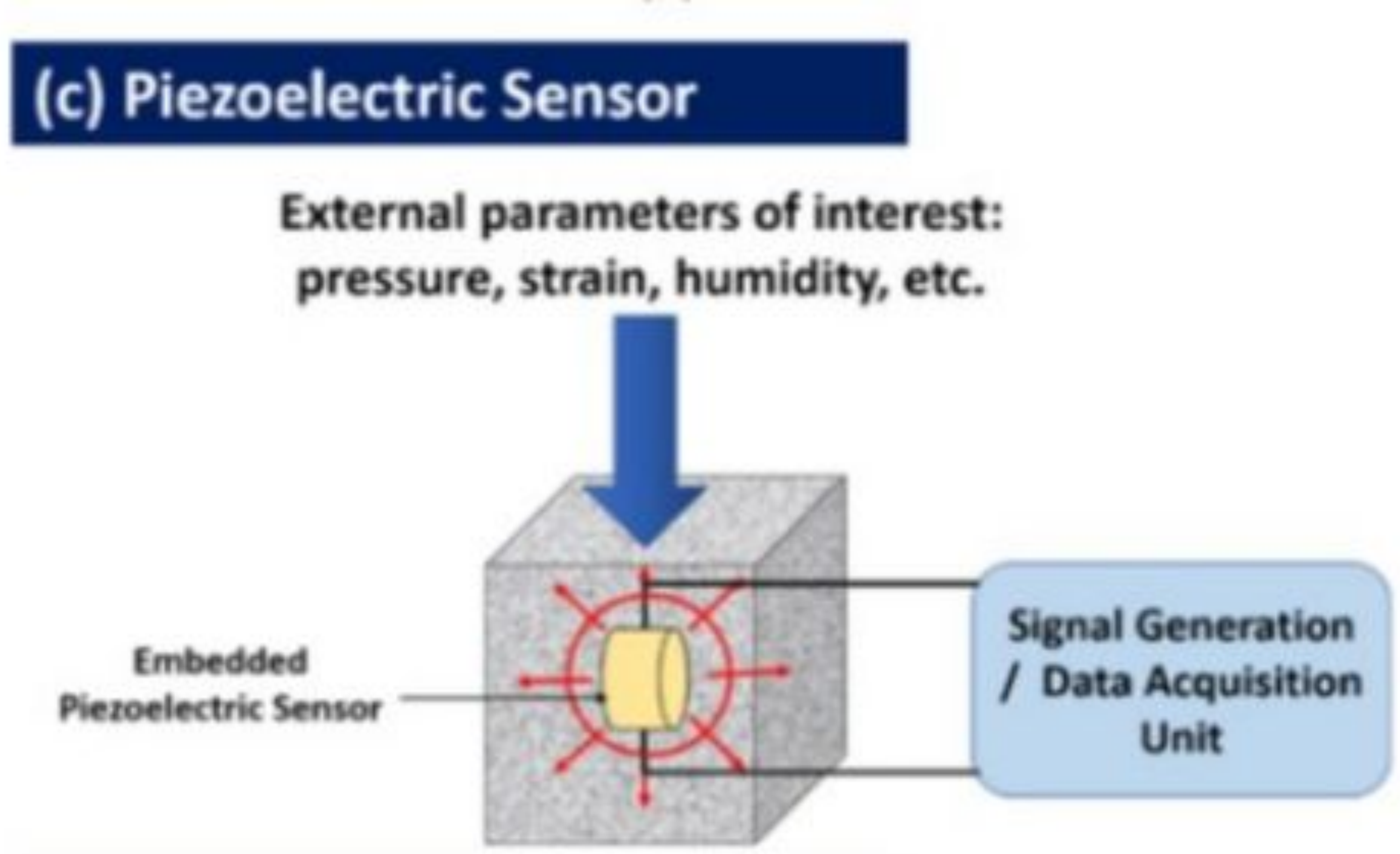
Sensors and Use Cases

In this section, some examples and usage of each sensor, have been listed.

- Strain Sensors:
    - Optical Strain Sensor
    - Electrical Resistance Strain Gauges
    - Vibrating Wire Strain Gauges

- Accelerometers:
    - Microelectromechanical System (MEMS) Accelerometers
    - Piezoelectric accelerometers





Sensors and Use Cases

- Temperature Sensors:
  - Thermocouples
  - Resistance temperature detectors (RTDs)

- Environmental Sensors:
  - Air quality sensors
  - Water quality sensors:
  - Seismic sensors

- Traffic Sensors:
  - Inductive Loop Detectors
  - Radar Sensors

Sensors and Use Cases

3.10 Sensors and Use Cases

Bridge's digital twins often use a range of sensors to monitor the structural health, environmental conditions, and traffic patterns. Following are some examples of sensors used in digital twins of bridges:

1. Strain Sensors: are used to monitor changes in the structural health of the bridge and to measure the amount of deformation in the bridge structure. They are often attached to the beams, cables, and other load-bearing components of the bridge.

Here are some examples of strain sensors:

- Optical Strain Sensors: use changes in light intensity to detect changes in strain. They are remarkably accurate and may be used to monitor changes in strain over long periods of time.

- Electrical Resistance Strain Gauges: use a metal wire or foil that is attached to the bridge structure's surface. Variations in strain create changes in metal resistance, which may be measured to estimate strain.

- Vibrating Wire Strain Gauges: employ a wire that vibrates at a certain frequency when applied to a magnetic field. Changes in strain create changes in the resonant frequency of the wire, which can be used to calculate strain.

2. Accelerometers: detect bridge vibrations produced by traffic or other external factors. They are typically installed on the bridge's surface or on nearby structures.

Here are some examples of accelerometers:

- Microelectromechanical System (MEMS) Accelerometers: small, low-cost sensors that can measure acceleration in three axes. They are frequently used to detect vibrations produced by traffic or other external factors.

- Piezoelectric accelerometers: use a crystal material to generate an electrical charge when subjected to vibration or acceleration. They are commonly used for measuring high-frequency vibrations or impacts.

3. Temperature Sensors: may be used to monitor fluctuations in the temperature of the bridge, which may have an impact on its structural integrity. They are usually installed on the bridge's surface or embedded in the bridge deck.

Here are some examples of Temperature Sensors:

- Thermocouples: sensors that measure temperature based on the voltage created by two distinct metals linked together. They are commonly used due to their high accuracy and ability to measure a wide range of temperatures.

- Resistance temperature detectors (RTDs): sensors that use the resistance of a metal wire or film to determine the temperature. They are exceedingly accurate and stable and are widely used to monitor temperature changes in digital twins of bridges.

Sensors and Use Cases

4. Environmental sensors: may be used to monitor weather conditions such as wind speed, humidity, and precipitation. They may help in predicting the effects of environmental factors on the bridge's structural health.

Here are some examples of Environmental Sensors:

- Air quality sensors: may be used to monitor changes in air pollution levels, including levels of particulate matter, carbon monoxide, and other pollutants. They are commonly used in digital twins of bridges to help assess the effects of air pollution on the bridge structure.

- Water quality sensors: may be used to monitor changes in water quality, including changes in pH, temperature, and the presence of pollutants. They are commonly used in digital twins of bridges to help assess the effects of water on the bridge structure.

- Seismic sensors: may be used to detect seismic activity, including earthquakes and other ground vibrations. They are commonly used in digital twins of bridges to help assess the effects of seismic activity on the bridge structure.

5- Traffic sensors: may be used to monitor the flow of traffic across the bridge. They can provide data on traffic volume, speed, and weight, which can be used to analyze the bridge's structural health and identify potential issues.

Here are some examples of Traffic Sensors:

- Inductive Loop Detectors: use electromagnetic fields to detect changes in the metallic mass of vehicles passing over the bridge. They are commonly used to monitor traffic volume, speed, and density.

- Radar Sensors: use electromagnetic waves to identify the presence of vehicles passing over the bridge. They can be used to measure traffic volume, speed, and direction.

Part 4: Submissions Deliverables and Workflows

4.1.1 Pre-Schematic Design

- Existing Condition Model
- Site Analysis
- Space Program
- Design Authoring-Volumetric Model
- Zone & Orientation

Part 4: Submissions Deliverables and Workflows

- **Existing Condition Model**
  - Virtual representation and current condition of the physical bridge
  - It includes detailed information of bridge’s
    - geometry properties
    - materials properties
    - structural properties
    - environmental factors
  - Usage purposes of the model:
    - Condition assessment
    - Simulation and analysis
    - Monitoring and surveillance

Part 4: Submissions Deliverables and Workflows

- **Existing Condition Model (continued)**
  - Steps of creation:
    - Collecting data using laser scanning techniques including Terrestrial Laser Scanning (LTS).
      - LTS instruments:
        - Leica Geosystems' ScanStation
        - Trimble's TX Series…
    - Then, importing & processing into a 3D model, through softwares such as
      - Revit, Bentley OpenBridge Modeler, and Trimble RealWorks

Part 4: Submissions Deliverables and Workflows

- **Site Analysis**
  - Evaluation of the bridge's location, surroundings, and environmental factors using data sources and analytical tool
  - Purpose is to gain:
    - comprehensive understanding of the site's context
    - any potential risks or challenges that may affect the bridge's performance and lifespan

  - Examples of data sources:
    - Geospatial data: bridge's location, topography, and terrain features
    - Climate and weather data
    - Traffic data
    - Environmental monitoring data: quality of air, water, and soil in the surrounding area
  - Analytical tools:
    - Geographic Information Systems (GIS): to analyze geospatial data and visualize the site's features and context
    - Computational fluid dynamics (CFD): to simulate airflow around it
    - Finite Element Analysis (FEA): to analyze its structural behavior

Part 4: Submissions Deliverables and Workflows

- **Design Authoring-Volumetric Model**
  - Creation of a 3D digital model that includes detailed geometric and structural information
  - Purpose:
    - optimize bridge's performance
    - minimize construction costs
    - reduce risk of design errors or construction issues
  - key steps in creating it:
    - Geometric modeling
    - Structural modeling
    - Analysis and optimization
    - Documentation

Part 4: Submissions Deliverables and Workflows

- **Zoning & Orientation**
  - Process of dividing bridge into different zones and determining its orientation with respect to the surrounding environment
  - Purpose:
    - helps optimize bridge's performance and minimize its environmental impact
  - Criteria for dividing the bridge into different zones:
    - Structural requirement
    - Traffic flow
    - Environmental impact
    - Maintenance needs
    - Construction and material consideration

Part 4: Submissions Deliverables and Workflows

4.1.1.1 Existing Conditions Model

An existing conditions model of a bridge digital twin is a virtual representation of a physical bridge that accurately captures its current state and condition that can be used to improve its safety, performance, and lifespan. The model typically includes detailed information about the bridge's geometry, materials, structural properties, and environmental factors.

The existing conditions model of a bridge digital twin may be created by collecting data from various sources, such as laser scanning softwares like Trimble RealWorks, photogrammetry, or manual measurements. This data may then be processed and integrated into a 3D model, through softwares such as Autodesk Tandem, Bentley's iTwin, and Ansys Twin Builder, that identically exhibit the bridge's current condition.

The existing conditions model can be used for a variety of purposes, such as:

- Condition assessment: The model can be used to assess the current condition of the bridge and identify any signs of damage, wear, or deterioration. This information can be used to plan maintenance and repair activities to ensure the bridge's continued safe operation.
- Simulation and analysis: The model can be used to simulate and analyze the bridge's behavior and performance under different conditions, such as traffic loads, wind speeds, or earthquake events. This can help engineers and operators to optimize the bridge's design and operation and improve its safety and efficiency.
- Monitoring and surveillance: The model can be used to monitor the bridge's condition and performance in real-time by integrating data from sensors and other monitoring systems. This can help detect potential problems early on and prevent accidents or failures.

Part 4: Submissions Deliverables and Workflows

4.1.1.2 Site Analysis

Site analysis is an important part of creating a digital twin of a bridge as it provides critical information about the site's context and potential risks or challenges that can affect the bridge's performance and lifespan. A site analysis of a bridge digital twin involves the evaluation of the bridge's location, surroundings, and environmental factors using various data sources and analytical tools. The purpose of site analysis is to gain a comprehensive understanding of the site's context, as well as any potential risks or challenges that may affect the bridge's performance and lifespan.

Here are some examples of data sources and analytical tools that can be used for site analysis of a bridge digital twin:

- Geospatial data: This includes data on the bridge's location, topography, and terrain features. This data can be collected using satellite imagery, aerial photography, or other remote sensing techniques.
- Climate and weather data: This includes data on precipitation, temperature, wind speed and direction, and other climate variables. This data can be collected from weather stations or other sources and can be used to analyze the bridge's response to different weather conditions.
- Traffic data: This includes data on the volume, speed, and weight of vehicles that use the bridge. This data can be collected using traffic sensors or other monitoring tools and can be used to analyze the bridge's structural response to traffic loads.
- Environmental monitoring data: This includes data on the quality of air, water, and soil in the surrounding area. This data can be collected using sensors or other monitoring tools and can be used to analyze the potential impact of environmental factors on the bridge's condition and performance.

Analytical tools that can be used for site analysis of a bridge digital twin include:

- Geographic Information Systems (GIS): GIS tools can be used to analyze geospatial data and visualize the site's features and context.
- Computational fluid dynamics (CFD): CFD tools can be used to simulate airflow around the bridge and analyze the impact of wind on the bridge's structural response.
- Finite Element Analysis (FEA): FEA tools can be used to simulate the bridge's response to different loading conditions and analyze its structural behavior.

4.1.1.3 Space Program

A space program of a bridge digital twin involves the development of a comprehensive plan that defines the bridge's operational and maintenance requirements, including inspection schedules, repair and maintenance procedures, and potential upgrades. The purpose of a space program is to ensure that the bridge remains safe, reliable, and in good condition throughout its lifespan. The program should be regularly updated to reflect changes in the bridge's condition, operational requirements, or environmental factors that may impact its performance.

Here are some of the key elements of a space program for a bridge digital twin:

- Maintenance schedule: The space program should define a regular maintenance schedule that includes routine inspections, cleaning, and minor repairs. The maintenance schedule should be based on the bridge's design, operational requirements, and environmental factors that may impact its condition.
- Repair and maintenance procedures: The space program should include detailed procedures for repairing and maintaining the bridge's various components such as the deck, superstructure, substructure, and foundation. The procedures should be based on industry best practices and manufacturer recommendations.
- Upgrades and modifications: The space program should also consider potential upgrades or modifications to the bridge to improve its safety, performance, or capacity. This can include upgrades to the bridge's lighting or electrical systems, installation of new safety features, or modifications to the bridge's structural components.
- Risk assessment and mitigation: The space program should also include a risk assessment that identifies potential hazards or risks to the bridge's condition and performance. The risk assessment should consider factors such as environmental conditions, traffic volume and patterns, and the bridge's age and condition. The program should also define strategies for mitigating these risks and preventing potential failures.

Part 4: Submissions Deliverables and Workflows

4.1.1.4 Design Authoring-Volumetric Model

A Design Authoring-Volumetric Model of a bridge digital twin involves the creation of a 3D digital model of the bridge that includes detailed geometric and structural information. This model allows engineers and designers to optimize the bridge's performance, minimize construction costs, and reduce the risk of design errors or construction issues.

Here are some of the key steps involved in creating a Design Authoring-Volumetric Model of a bridge digital twin:

- Geometric modeling: The first step is to create a 3D digital model of the bridge's various geometrical components, including the deck, superstructure, substructure, and foundation.
- Structural modeling: Once the geometric model is complete, engineers can add structural details to the model, such as material properties, cross-section dimensions, and member connections. This creates a detailed volumetric model of the bridge that accurately represents its structural behavior and response to different loading conditions.
- Analysis and optimization: The volumetric model can then be used for structural analysis and optimization, allowing engineers to simulate different loading scenarios and test design changes. This can help identify potential issues, such as structural weaknesses or excessive stresses, and optimize the bridge's design for improved performance and durability.
- Documentation: Once the volumetric model is complete, designers can use the model to generate detailed construction drawings, material specifications, and other documentation necessary for the construction of the physical bridge.

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4.1.1.5 Zoning & Orientation

Zoning and orientation of a bridge digital twin refer to the process of dividing the bridge into different zones or segments and determining its orientation with respect to the surrounding environment. This is an important step in the design process as it helps optimize the bridge's performance and minimize its environmental impact.

The factors for dividing a bridge into different zones in a digital twin may vary depending on the specific bridge and its intended use. However, here are some common criteria that may be considered:

- Structural requirements: The bridge may be divided into zones based on its structural requirements, such as the strength and stiffness needed to support different types of loads.
- Traffic flow: The bridge may be divided into zones based on traffic flow, with different areas designated for different types of vehicles or modes of transportation.
- Environmental impact: The bridge may be divided into zones based on its impact on the surrounding environment, such as areas designated for noise reduction or to protect wildlife habitats.
- Maintenance needs: The bridge may be divided into zones based on maintenance needs, with different areas requiring different levels of maintenance and inspection.
- Construction and material considerations: The bridge may be divided into zones based on construction and material considerations, such as areas where different types of materials are used or where specialized construction techniques are required.

Part 4: Submissions Deliverables and Workflows

The factors for the orientation of a bridge digital twin may vary depending on the specific bridge and its intended use. However, here are some common criteria that may be considered:

- Environmental factors: The orientation of the bridge should be optimized to minimize its impact on the surrounding environment. This may include considerations such as wind direction, water currents, and seismic activity.
- Traffic flow: The orientation of the bridge should be optimized to accommodate traffic flow, with considerations such as the location of entry and exit points, the direction of traffic, and the need for turning or merging lanes.
- Structural considerations: The orientation of the bridge should be optimized to meet structural requirements, such as the need to support specific types of loads or to resist certain types of forces.
- Aesthetics: The orientation of the bridge should be optimized for aesthetic considerations, such as the need to provide a visually appealing structure or to blend in with the surrounding landscape.

Part 4: Submissions Deliverables and Workflows

4.1.2 Schematic Design

- Design Authoring-Preliminary Model
- Programming
- Phase Planning
- Preliminary Cost Estimate (Square Footage)
- Design Review
- Preliminary Clash Detection

4.1.2.1 Design Authoring-Preliminary Model

Design Authoring-Preliminary Model of a bridge digital twin refers to the initial design stage where designers create a preliminary 3D model of the bridge based on the requirements and specifications identified in the earlier stages of the design process.

Here are some key considerations for Design Authoring-Preliminary Model of a bridge digital twin:

- Bridge specifications: The designers may need to consider the specifications of the bridge, such as its span, load capacity, and intended use. These specifications will guide the design process and determine the overall shape and size of the bridge.

- Structural requirements: The designers may need to consider the structural requirements of the bridge, such as the need for reinforcement or additional support. This will ensure that the bridge is safe and stable.
- Materials and construction techniques: The designers may need to consider the materials and construction techniques that will be used to build the bridge. This will determine the overall appearance and durability of the bridge.
- Environmental impact: The designers may need to consider the environmental impact of the bridge, such as its potential impact on wildlife habitats or waterways. This will guide the orientation and design of the bridge.
- Aesthetics: The designers may need to consider the aesthetic aspects of the bridge, such as its overall appearance and how it will blend into the surrounding environment.

Part 4: Submissions Deliverables and Workflows

4.1.2.4 Phase Planning

Phase planning of a bridge digital twin involves breaking down the project into manageable phases, each with its own set of objectives, tasks, and timelines. This helps to ensure that the project is completed on time, within budget, and meets the desired quality standards.

Here are the key steps involved in phase planning for a bridge digital twin:

- Define project deliverables: The first step in phase planning is to define the project deliverables. This includes identifying the key milestones, such as design completion, construction start, and project completion.
- Break down the project into phases: Next, the project is broken down into phases, each with its own set of objectives, tasks, and timelines. The number and scope of the phases will depend on the size and complexity of the project.
- Define the scope of each phase: For each phase, the scope is defined in detail, including the specific deliverables, tasks, and timelines. This helps to ensure that each phase is well-defined and focused on achieving its objectives.
- Develop a project schedule: Based on the scope of each phase, a project schedule is developed. This includes identifying the start and end dates for each phase, as well as any dependencies between phases.
- Identify project resources: The next step is to identify the resources needed for each phase, such as personnel, equipment, and materials. This helps to ensure that the necessary resources are available when needed.
- Develop a budget: Based on the project schedule and resource requirements, a budget is developed for each phase. This includes estimating the costs associated with each phase, such as personnel, equipment, and materials.
- Monitor and control the project: Throughout the project, progress is monitored and controlled to ensure that each phase is completed on time, within budget, and meets the desired quality standards. This may involve making adjustments to the project schedule, resource allocation, or scope as needed.

Part 4: Submissions Deliverables and Workflows

4.1.2.3 Programming

Programming of a bridge digital twin involves defining the project requirements, goals, and objectives, and developing a clear understanding of the purpose and scope of the project. The programming phase lays the foundation for the entire design process and helps ensure that the bridge digital twin meets the needs of its users and stakeholders.

Here are the key steps involved in programming a bridge digital twin:

- Identify project goals and objectives: The first step in programming is to identify the project goals and objectives. This includes understanding the purpose of the bridge, its intended users, and the desired outcomes of the project.
- Determine user needs and requirements: Next, it is important to determine the needs and requirements of the bridge users. This may involve conducting user surveys or focus groups to gather feedback on the desired functionality, aesthetics, and accessibility of the bridge.
- Define project constraints: In addition to identifying the project goals and user requirements, it is also important to define any constraints that may impact the design process. This may include budget constraints, regulatory requirements, or environmental considerations.
- Develop a project scope: Based on the information gathered in the previous steps, a project scope is developed. This document outlines the overall project goals, user requirements, constraints, and any other relevant information that will guide the design process.
- Establish design criteria: The next step is to establish design criteria for the bridge digital twin. This includes identifying the performance requirements for the structure, such as its load-bearing capacity and durability, as well as the desired aesthetic and functional characteristics.
- Create design alternatives: Finally, the programming phase may involve the creation of multiple design alternatives for the bridge digital twin. These alternatives are evaluated against the project goals, user requirements, and design criteria to determine the most effective and feasible design solution.

Part 4: Submissions Deliverables and Workflows

4.1.2.5 Preliminary Cost Estimate (Square Footage)

The preliminary cost estimate of a bridge digital twin can be calculated using a square footage method, which involves estimating the total cost of the project based on the total square footage of the digital twin.

It's important to note that this method provides a rough estimate and the actual cost may vary based on factors such as the level of detail required, the complexity of the model, the use of specialized software, and the level of customization needed for the project. Therefore, it's recommended to consult with a qualified professional or team to obtain a more accurate cost estimate for a bridge digital twin.

Here are the general steps to estimate the cost of a bridge digital twin using the square footage method:

- Determine the total area of the bridge that will be modeled in the digital twin. This can be calculated by measuring the length and width of the bridge deck and any other significant components that will be included in the model.
- Estimate the cost per square foot for developing the digital twin. This can vary based on the level of detail, complexity, and customization required for the project.
- Multiply the total area of the bridge by the estimated cost per square foot to obtain the preliminary cost estimate for the digital twin.

4.1.2.7 Preliminary Clash Detection

Preliminary clash detection is an important step in the development of a bridge digital twin, which involves identifying and resolving any conflicts or collisions between different elements of the design. This can help to minimize errors, reduce costs, and ensure that the final digital twin meets the project requirements and expectations.

Here are the key steps involved in performing preliminary clash detection for a bridge digital twin:

- Identify the elements to be analyzed: The first step is to identify the elements of the digital twin that will be analyzed for potential clashes. This may include structural components, utilities, mechanical systems, and other elements that may interact with each other.
- Generate the 3D model: This model should include all of the elements that will be analyzed for potential clashes.
- Run the clash detection analysis: Once the 3D model has been generated, the clash detection analysis can be run using specialized software such as Navisworks or Revit. This software will identify any potential clashes between different elements of the digital twin, based on their positions and properties.
- Review the clash report: Once the clash detection analysis is complete, a clash report will be generated, which identifies the location and severity of any potential clashes. This report should be reviewed carefully to identify any clashes that require further investigation or resolution.
- Resolve any clashes: Once the potential clashes have been identified, they can be resolved by making adjustments to the 3D model or design. This may involve changing the location or orientation of certain elements, modifying their size or shape, or adjusting their properties to eliminate any potential conflicts.

Part 4: Submissions Deliverables and Workflows

4.1.3.1 Design Authoring-Models

In the design authoring phase of a bridge digital twin, various models are created that represent different aspects of the bridge's design. These models are used to create the 3D model of the bridge that will be used in the design development phase of the digital twin.

Some of the models that may be created during the design authoring phase of a bridge digital twin include:

- Conceptual Model: The conceptual model is created during the early stages of the design process and represents the general design intent of the bridge. This model is used to explore different design options and to communicate the design intent to stakeholders.
- Geometric Model: The geometric model represents the physical shape and dimensions of the bridge, including its length, width, and height. This model is used to ensure that the bridge meets the required design standards and regulations.
- Structural Model: The structural model represents the detailed structural design of the bridge, including its beams, columns, and other components. This model is used to ensure that the bridge can withstand the loads it will be subjected to and to optimize the design for maximum strength and durability.
- Materials Model: The materials model represents the different materials used in the bridge's construction, such as concrete, steel, or timber. This model is used to optimize the design for the best combination of strength, durability, and cost.
- Environmental Model: The environmental model represents the environmental conditions that the bridge will be exposed to, such as wind, temperature, and humidity. This model is used to ensure that the bridge is designed to withstand the environmental conditions in which it will be located.

4.1.3.2 Sustainability (LEED) Analysis

A sustainability analysis of a bridge digital twin can be performed during the design development phase to assess its environmental impact and to identify opportunities for making the bridge more sustainable. One commonly used standard for sustainability analysis is the Leadership in Energy and Environmental Design (LEED) rating system, which provides a framework for evaluating the sustainability of buildings and infrastructure projects.

The LEED rating system assesses various aspects of a project's sustainability, including energy efficiency, water efficiency, materials and resources, indoor environmental quality, and innovation.

The following are some of the key steps involved in performing a LEED analysis of a bridge digital twin during the design development phase:

- Gather data: The first step is to gather data on the bridge's design and specifications, including information on its materials, energy use, water use, and other relevant parameters.
- Determine the LEED rating system: Next, determine which LEED rating system is most appropriate for the project based on its location, size, and other factors. For example, a bridge project in a densely populated urban area may be evaluated using the LEED for Neighborhood Development rating system, while a bridge project in a rural area may be evaluated using the LEED for New Construction rating system.
- Conduct an initial assessment: Using the appropriate LEED rating system, conduct an initial assessment of the project's sustainability performance based on the data gathered in step 1. This may involve evaluating the project's energy efficiency, water efficiency, materials and resources, and other factors.
- Identify opportunities for improvement: Based on the initial assessment, identify opportunities for improving the project's sustainability performance. This may involve making changes to the project's design or specifications, such as using more sustainable materials or incorporating energy-efficient technologies.
- Refine the design: Using the results of the sustainability analysis, refine the design of the bridge digital twin to incorporate sustainable features and to optimize its sustainability performance.

Part 4: Submissions Deliverables and Workflows

4.1.3.3 Cost Estimation

Cost estimation of a bridge digital twin involves evaluating the various costs associated with the creation and maintenance of the digital twin throughout its lifecycle. By accurately estimating the cost of the digital twin, bridge owners and operators can make informed decisions about its value and prioritize its development accordingly.

The following are some of the key factors that should be considered when estimating the cost of a bridge digital twin:

- Software and hardware costs: The cost of software and hardware required to create and maintain the digital twin, including computer hardware, digital twining software and platforms, simulation software, and data storage systems.
- Data acquisition costs: The cost of collecting and processing data on the physical bridge, including sensor data, design drawings, and other relevant documents.
- Personnel costs: The cost of personnel required to create and maintain the digital twin, including engineers, designers, data analysts, and other specialists.
- Maintenance costs: The cost of maintaining and updating the digital twin over its lifecycle, including software upgrades, data storage, and ongoing data analysis.
- Training costs: The cost of training personnel on how to use and maintain the digital twin, including training on software and hardware systems, data analysis, and other related topics.
- Opportunity costs: The cost of missed opportunities or lost revenue resulting from delays in bridge maintenance or repairs due to a lack of access to accurate and up-to-date information provided by the digital twin.
- Benefits: The potential benefits of the digital twin, such as increased efficiency, reduced maintenance costs, and improved safety, should also be considered when estimating the cost of the bridge digital twin.

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4.1.3.4 Clash Detection

Clash detection is an important process during the development of a bridge digital twin. It involves identifying and resolving any clashes or conflicts that may exist between various elements of the bridge, such as the structural elements, utilities, or other infrastructure. It helps ensure that potential clashes or conflicts are identified and resolved early in the design and construction process, which can help avoid costly delays and rework later on.

The following are some key considerations for clash detection in a bridge digital twin:

- Identify potential clashes: The first step in clash detection is to identify potential clashes or conflicts between different elements of the bridge. This can be done by reviewing the design and construction plans, as well as any other relevant documentation.
- Use appropriate software: Clash detection can be facilitated through the use of specialized software, which can then be used to identify clashes between different elements.
- Collaborate with stakeholders: Clash detection is a collaborative process that involves multiple stakeholders, such as engineers, designers, and contractors. Effective communication and collaboration between stakeholders is essential for identifying and resolving clashes.
- Resolve clashes: Once clashes have been identified, they must be resolved. This may involve making adjustments to the design or construction plans, or modifying the location or placement of certain elements.
- Update the digital twin: Once clashes have been resolved, the digital twin should be updated to reflect the changes. This ensures that the digital twin accurately reflects the as-built condition of the bridge.

4.1.3.5 Program Validation

Program validation is an important process during the development of a bridge digital twin, as it helps ensure that the digital twin meets the desired objectives and performance requirements.

The following are some key considerations for program validation in a bridge digital twin:

- Define the objectives: The first step in program validation is to clearly define the objectives of the digital twin. This includes identifying the desired functionality, performance metrics, and other key requirements.
- Develop validation criteria: Validation criteria should be developed based on the defined objectives. This includes developing performance metrics, acceptance criteria, and other measures that can be used to evaluate the digital twin's performance.
- Test the digital twin: The digital twin should be tested against the validation criteria to ensure that it meets the desired objectives. This may involve simulating various scenarios or conditions to test the digital twin's performance.
- Compare results: The results of the digital twin tests should be compared against the validation criteria to determine whether the digital twin meets the desired objectives. Any discrepancies or areas for improvement should be identified and addressed.
- Document the results: The results of the program validation process should be documented in a report that outlines the testing methodology, results, and any recommendations or action items for improvement.
- Continuous improvement: The program validation process should be an ongoing effort, with regular assessments and updates to the digital twin as necessary. This helps ensure that the digital twin remains up-to-date and relevant to the bridge's ongoing operations and maintenance.

4.1.4 Construction Documents

- Design Authoring-Final Model
- 3D Coordination Validation
- Cost Estimation
- Sustainability (LEED) Reporting

Construction documents are written, graphic and pictorial documents prepared or assembled for describing and communicating the design, location, and physical characteristics of the elements of a project necessary for obtaining a building permit and administering the contract for its construction

4.1.4 Construction Documents

4.1.4.1 Design Authoring-Final Model

It is very necessary to build a model based on the design authoring analysis in Digital Twin technology. Compared with BIM, Digital Twin can allow the project management team to have a more efficient communication with stakeholders. It also has an important function to connect the design plans, related data, and real model together, which helps to review the whole process and find where to refine. Similarly, this model could be considered as an original reference for the future quality control. The project manager can develop a couple of initial pieces of information on it, so that they can go back to compare the real situation with the elementary thoughts in the first place.

4.1.4.2 3D Coordination Validation

Since BIM coordination based on 2D drawings by AutoCAD has already made a great contribution to the development of the construction industry, Digital Twin technology will continue to lead this innovative trend by creating a new coordination based on 3D real-world objects. It can achieve multiple coordinations within different disciplines in a particular 3D project.

Part 4: Submissions Deliverables and Workflows

4.1.4.3 Cost Estimation

Since digital twins have a couple of advantages such as information all-sharing, efficient communication, and design authoring models, it will cost much more than common construction technology. However, digital twin technology also has an optimization for costs on some aspects such as transportation and materials. For example, the engineering team will use digital twin technology to simulate oil metals, pipelines, and process plants. In this case, the team will get a more accurate and economical cost estimation based on the detailed cost report.

4.1.4.4 Sustainability (LEED) Reporting

The ultimate goal of LEED is to reflect the environmental and human effects to the health around buildings' environment. Since the construction site requires a huge amount of materials such as rebars, fences, and concrete, it always creates a lot of waste to the surrounding environment. This LEED report is very necessary to check how the construction site affects the environment nearby, which can eliminate the chemical harms immediately.

Part 4: Submissions Deliverables and Workflows

4.1.5 Bid, Award and Registration

- LOD 400
- Informational Purposes

4.1.6 Construction Services

- LOD 500
- Achieve the desired Digital Twin Use

4.1.5 Bid, Award and Registration

When bids are received, all deliverables such as technical specifications, floor plan drawings, and other related documents must be signed and approved. At the same time, the model should be shown for an informational purpose during the bidding process. Service for the bid process should refer to LOD 400, which is the fourth Level of Development.

4.1.6 Services during Construction

The general contractor is supposed to use the initial design plans to build the model during the construction process. In this case, it can check the difference between the model and building itself. This service refers to LOD 500, which is the fifth Level of Development.

Part 4: Submissions Deliverables and Workflows

4.1.6.2 Phase Planning

Digital Twin requires the engineering team to use Microsoft Project to build the timeline structure so that it can coordinate the phase planning for the construction process. Meanwhile, they also need to deal with different relationships between each task. Otherwise, the start date and finish date for each task may be mixed, and it will cause a huge mistake on the schedule management.

4.1.6.3 Scheduling

Digital Twin will provide a detailed schedule management by categorizing all tasks by Microsoft Project. Each task will also show the specific contents, which allows engineers to check the progress.

- Structural System—structural framing components including foundations, grade beams, columns, loading bearing walls, floor and roof deckings.
- Exterior building envelope—stud wall, exterior panels and assemblies, curtain walls, openings, and glazing.
- Interior partitions—main interior walls, plumbing walls, and wall assemblies.
- Mechanical systems— main ductwork and equipment, separated by floors.
- Roof systems—roof assemblies, major equipment, and openings
- Site work—excavation work, footings, foundations, and slabs on grade.
- Plumbing systems—main connection lines from site and main plumbing lines.

4.1.6.4 3D Coordination

3D coordination is an advanced process compared with 2D drawing by AutoCAD. It will collect the data from 3D real-world objects, then process them according to related standards. 3D coordination is also very important to build the design authoring model.

4.1.6.5 Digital Fabrication

A couple of intended objects will be included in the construction process. They will also be modeled based on the characteristics and features from the construction specifications.

4.1.6.6 Record Modeling

Digital twin will be updated for any progress and changes during the construction process, which is very necessary to track the construction work.

4.1.6 Submission and Deliverable

Discipline Code

Discipline Name	Designator Code
Architectural	A
Civil	C
Electrical	E
Fire Protection	FP
Landscape	L
Mechanical	M
Plumbing	P
Structural	S

Part 4: Submissions Deliverables and Workflows

Electronic Deliverables

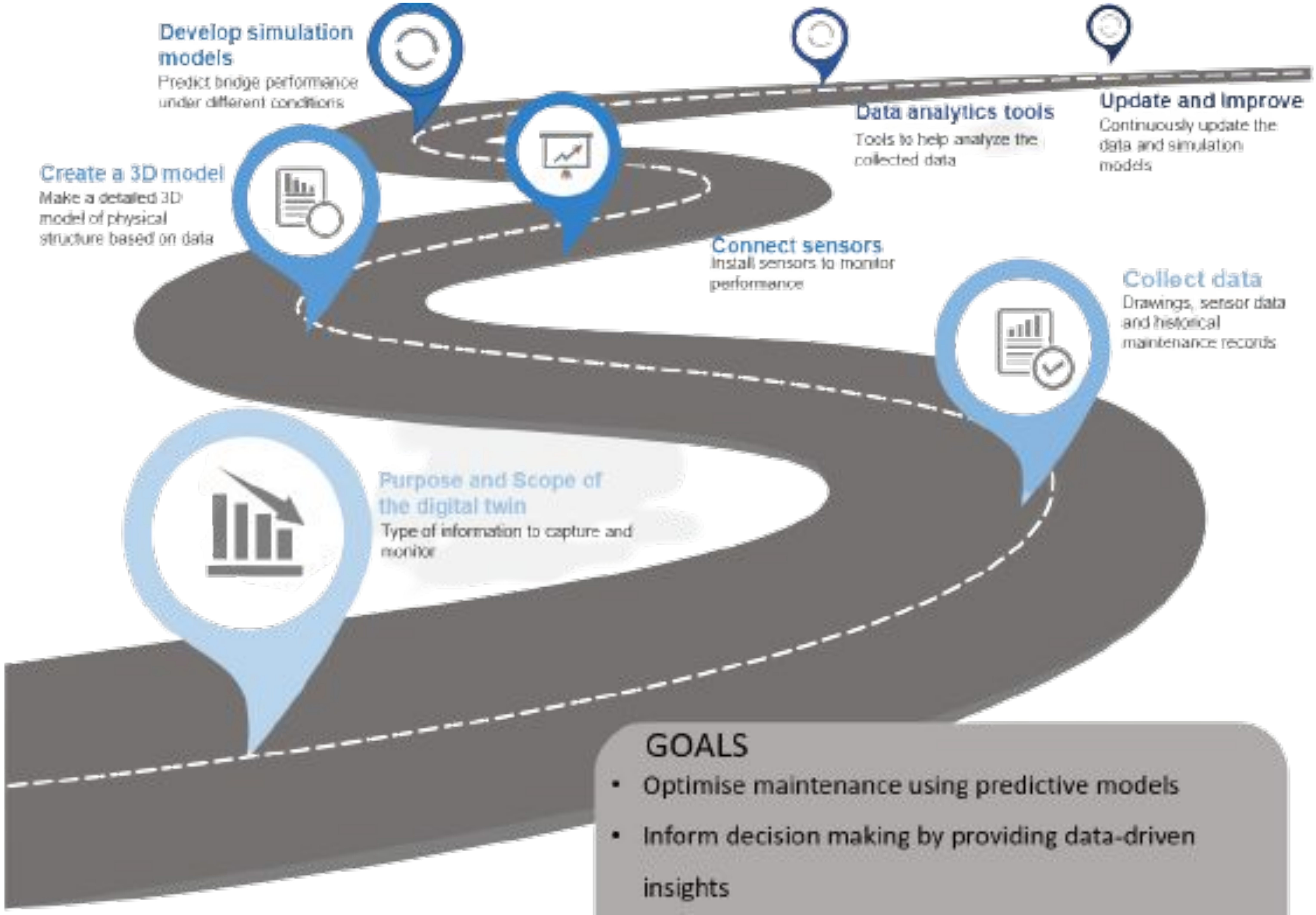
3D MODEL FILES REQUIRED:

* NWD: Autodesk Navisworks Master Files (containing all Model geometry)
* 3D DWF Autodesk 3D Design WEB Format files

2D MODEL FILES REQUIRED:

* 2D DWF: Autodesk 2D Design WEB Format files
* PDF: Adobe Acrobat files

Roadmap



GOALS

- Optimise maintenance using predictive models
- Inform decision making by providing data-driven insights
- Increase efficiency by using real time data
- Boost resilience by studying the bridge's behavior