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Automatic Design and Monitoring of Mass Concrete Based on Information Technology

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Abstract: Mass concrete construction has the characteristics of large scale, complex technology, high professional requirements, and complex management. In this paper, information technology is introduced into the construction process of mass concrete, aiming to develop a system that integrates the automatic design and visual management of mass concrete construction monitoring schemes to improve its construction efficiency. In this paper, the automatic design of a mass concrete construction monitoring scheme is designed, the information of its data acquisition terminal sensor is extended, and the sensor information model is created based on the IFC framework. Finally, this paper verifies the feasibility and practicability of the automatic design and visual monitoring of the monitoring scheme through the actual case-commercial complex raft foundation. The results show that the method provides a digital and information platform for mass concrete construction, highlighting the advantages of the proposed method and the traditional method.

Keywords: mass concrete; automation design; IFC; sensor information model; information technology

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1. Introduction

Production and transportation of mass concrete are major challenges that the construction industry faces. Effective logistics management is crucial to ensuring concrete quality due to its large volume and strict requirements for quality control [1–3]. In order to effectively manage these risks, mass concrete projects often implement temperature monitoring procedures. This includes embedding temperature sensors in concrete to continuously monitor its core temperature. Through real-time analysis of temperature data, construction teams need to take measures to adjust the temperature of concrete in order to ensure its quality [4,5].

In the Architecture, Engineering, and Construction (AEC) sector, Building Information Modeling (BIM) technology is renowned for facilitating faster project delivery and reducing costs [6–9]. This technology significantly enhances project success rates, thereby boosting industry productivity [10,11]. The digital revolution capitalizes on the accessible and clear presentation of information within three-dimensional models, positively impacting sectors such as architectural design, information exchange, project management, and technical management over time [12,13]. The Internet of Things (IoT) facilitates the integration of endpoint devices and facilities with the Internet, enabling remote monitoring and control from any location [14–18]. Within the context of large-volume concrete construction, IoT initiates a data flow from device endpoints to the platform front end. In data collection, Rio et al. employed Industry Foundation Classes (IFC) in case studies, integrating monitoring data into BIM models to facilitate structural analysis [19]. Recognized and standardized by ISO 16739-1:2024, IFC is defined as an open international standard for BIM data that enables the exchange and sharing across software applications employed in building construction or facility management [20]. Specifically, IFC serves as a data schema translatable into EXPRESS language or Extensible Markup Language (XML), establishing rules and constraints governing object relationships [21,22]. Objects in this schema represent structural elements both geometrically and informationally [23]. Over time, the implementation of IFC has expanded to include information pertinent to infrastructure and structural monitoring. Additionally, Biancardo et al. investigated the application of BIM methodologies to road infrastructure via visual programming software and BIM tools, emphasizing the benefits of programmatic modeling and noting the limited availability of infrastructure components [24].

Concrete engineering is an important component of construction; the good and bad quality of concrete directly affects the overall quality of the building. A rational analysis of important factors affecting concrete quality, such as concrete raw materials, concrete combination ratio, irrigation, construction, transportation, conservation, and so on [25]. In the process of mass concrete construction research, the quality of concrete has been a major factor affecting the overall project. Related research suggests that in addition to the rational control of the concrete matching ratio and the standardization of the use of additional additives, attention should be paid to the production and transportation of cement to provide transportation organization guarantee for concrete transport to avoid excessive time of the transportation and affect the quality or lead to concrete being completely disposed of [26]. It emphasized that uncertainty in concrete transport had a significant impact on concrete quality and that restrictions on mixing time and turnover for pre-mixed concrete for large-scale structures at the present stage remained challenging in controlling the quality of mass concrete [27].

Therefore, this paper focuses on the quality control and monitoring of mass concrete irrigation in the construction process, combining information technology, exploring the automatic design of a concrete monitoring program and the creation of a sensor information model based on IFC, and developing the information management platform for mass concrete construction based on the above two technical studies.

2. Research Work

2.1. Automatic Design of Concrete Monitoring Schemes

2.1.1. The Monitoring Scheme Automatically Designs the Overall Logic

The automated design of monitoring schemes for large-volume concrete strictly follows the specifications for temperature monitoring during construction, as detailed in the "Technical Regulations for Hopper Method Construction of Super-Long Large-Volume Concrete Structures" (DB11/T1200-2015) [28]. This process includes the automated placement of monitoring points and the generation of monitoring plans for large-volume concrete. Typically, in large-volume concrete projects, monitoring points are strategically placed along the semi-axial lines of the concrete's symmetrical axis, with a minimum of four points. In this research, the emphasis is on strategically positioning monitoring points in each compartment during the hopper method construction of super-long large-volume concrete.

Figure 1 illustrates the workflow diagram for the automated design process of a monitoring scheme for large-volume concrete. The core workflow in the automated design of this monitoring scheme encompasses loading model files, automating the placement of monitoring points for large-volume concrete, and generating the monitoring scheme output.

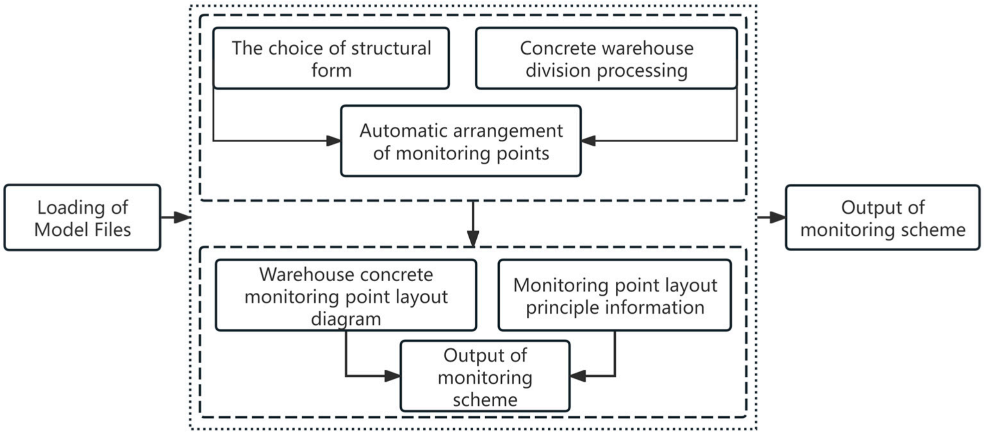


Figure 1. Flow chart of automatic design of mass concrete monitoring scheme.

2.1.2. Automatic Placement of Monitoring Points

1. Loading and reading of model data.

Prior to the placement of monitoring points, the visualization platform necessitates the loading of a model to serve as the basis for point placement. Given that this research utilizes Unity 3D for developing the visualization platform, it restricts model formats to FBX, OBJ, GLTF2, STL, and PLY. Consequently, BIM models must be converted into .fbx files for loading purposes. Within Unity, the process of loading an FBX file requires initially packaging it into a .assetbundle file. Subsequently, the .assetbundle file's path serves as the index path, facilitating the loading and reading of the FBX file.

2. Introduction to automatic layout methods.

The automated deployment of temperature monitoring points in large-volume concrete is primarily based on the concrete's contours, facilitated by algorithms integrated within the system. Placement methods vary across the different components of large-volume concrete, including foundation rafts, subterranean structure slabs, and walls. Furthermore, the algorithms for planar and thickness-direction placements diverge in the automated positioning of monitoring points within large-volume concrete. Figure 2 depicts the specific algorithms associated with various concrete components and their respective directional monitoring point placements.

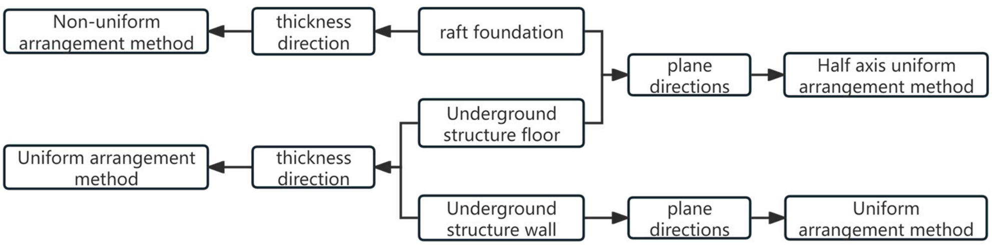


Figure 2. Different components and directions corresponding to the layout algorithm.

- Half-axis uniform arrangement.

As shown in Algorithm 1, the semi-axial uniform deployment method is primarily employed for monitoring point placement within foundation rafts and subterranean structure slabs. This technique utilizes the Vector3. Distance function to determine the length of each edge and identify its midpoint. Subsequently, a perpendicular line is drawn at this midpoint along the edge. The intersection of these perpendicular lines from any two edges establishes the component's center point. The distance from the center point to an edge is calculated using the Vector3.magnitude function. Points are then uniformly distributed along these two perpendicular lines.

Algorithm 1: Distance From Point to Line

Data: Point p, line endpoints $p1$ and $p2$ (all are Vector3 types)
Result: Distance from point p to the line defined by $p1$ and $p2$
begin
  p2pDistance←Euclidean distance between $p2$ and p;
  $p2p1 \leftarrow p2-p1$;
  $p2p \leftarrow p2-p$;
  dotResult← dot product of $p2p1$ and $p2p$;
  $scitaRad \leftarrow \arccos\left(\frac{dot\ Result}{\|p2p1\| \times p2pDistance}\right)$
  distance←*p2pDistance* × sin(*seitaRad*);
  return *distance*;
end

- Uniform layout.

As shown in Algorithm 2, the uniform placement method is principally applied to position monitoring points along the thickness direction of underground structure slabs and on the facades of underground structure walls. The fundamental mechanism entails reading the structural line and utilizing its endpoints as the starting points. The line is subsequently divided equidistantly according to the spacing guidelines for monitoring point placement outlined in the standards.

Algorithm 2: Uniform Arrangement Method

Data: Number of points count, vectors $p1$,$p2$
Result: Array of uniformly arranged points *df Point*
df Point ←new Vector2[*count*];
dfX Length $\leftarrow |p1.x - p2 \cdot x| / (\text{count} + 1)$;
dfY Length $\leftarrow |p1.y - p2 \cdot y| / (\text{count} + 1)$;
for $i \leftarrow 0$ **to** *count*-1 **do**
  if $p1.x \geq p2.x$ **then**
    df Point $[i].x \leftarrow p1.x - ((i+1) \times dfX$ Length);
  else
    df Point $[i].x \leftarrow p1.x - ((i+1) \times dfX$ Length);
  end
  if $p1.y \geq p2.y$ **then**
    df Point $[i].y \leftarrow p1.y - ((i+1) \times dfY$ Length);
  else
    df Point $[i].y \leftarrow p1.y - ((i+1) \times dfY$ Length);
  end
end
return df Point;

- Non-uniform arrangement.

As shown in Algorithm 3, The non-uniform placement method is specifically designed for positioning monitoring points within the thickness direction of foundation rafts in large-volume concrete structures. In the thickness direction of these foundation rafts, variable cross-sections, such as elevator shafts and collection pits, impose specific structural requirements. Consequently, varied placement methods are necessitated for monitoring points at different interfaces within these areas. The non-uniform placement method is predicated on the foundation of planar placement. This method involves projecting the semi-axial line toward the base surface and then calculating the distance between these lines. Monitoring points are strategically added where significant changes in these distance values occur, thereby introducing a new monitoring point within the interval of change.

Algorithm 3: Non-uniform Arrangement Method

```
Data: Positions p0,pl,p2
Result: Various line drawings demonstrating relationships between points
begin
    V1 ← p0-pl;
    V2 ← p2-p1;
    // Draw lines in different colors to demonstrate vectors
    DrawLine(p0,p1, magenta);
    DrawLine(p0,p2,magenta);
    DrawLine(p2,p1,magenta);
    DrawLine(p0,p1,blue);
    DrawLine(pl,p2,gray);
    DrawLine(pl,p0,gray);
    DrawLine(p2,p0,yellow);
    V project ← Project V1 onto V2;
    V Hor ← Vproject-V1;
    DrawLine(p0,p0+V Hor,green);
end
```

3. Layout of monitoring points for large-volume concrete components.

Regarding the arrangement of monitoring points for raft foundations, in the placement of monitoring points for raft foundation construction, the underlying principles remain consistent between monolithic and hopper method pouring. The primary distinction arises from the volume of the large-volume concrete poured. Regardless of the pouring method, planar monitoring points are strategically placed along a semi-axial line of the pour body's symmetrical axis, ensuring a minimum of four points on this line. The placement of monitoring points in the thickness direction is dictated by the positions of the planar monitoring points, aligning directly beneath these in the thickness direction. The arrangement in the thickness direction should follow a three-layer method, comprising top, middle, and bottom layers, with spacing not exceeding 600 mm. Should the spacing exceed 600 mm, additional monitoring points may be introduced. Table 1 depicts the configuration of monitoring points for the raft foundation.

Table 1. Raft foundation monitoring point arrangement.

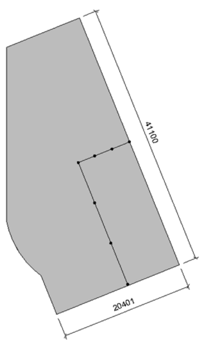
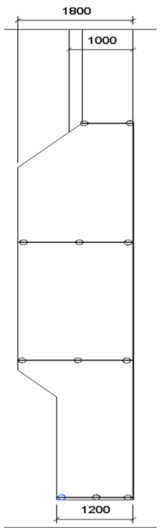
Direction of Monitoring Sites	Graph	Basis of Placement	Layout Algorithms
Horizontal direction		1. Take half of the axis of symmetry of the plane of the concrete body as the test area. 2. Monitoring points on each test axis should not be less than 4 and should be combined with the structural geometry of the uniform layout. 3. Temperature measurement side spacing of 10 m~15 m in the variable section should increase the number of measurement positions.	Half-axis uniform arrangement

Table 1. *Cont.*

Direction of Monitoring Sites	Graph	Basis of Placement	Layout Algorithms
Thickness direction		1. When the thickness of the poured concrete body is uniform, the spacing of the temperature measurement side positions is 10 m~15 m, and the number of measurement positions is increased in the part of the variable cross-section; when the thickness of the poured body is not uniform, the arrangement of the side positions can be carried out in the edge, corner, middle of the concrete, and the parts of the catchment pit, elevator shaft and other parts of the concrete. 2. The arrangement of bottom and surface temperature measurement points should be within 50 mm of the exterior of the casting body and 50 mm on the bottom surface.	Non-uniform placement algorithm

Regarding the arrangement of monitoring points for underground structure floor slabs, the automated placement of monitoring points on underground structure slabs adheres to a principle akin to that employed for raft foundation points, utilizing the semi-axial line of the concrete pour body's planar symmetrical axis as the testing area. Unlike raft foundations, underground structures typically feature regular shapes, facilitating the segmentation of their semi-axial lines. In the thickness direction, underground structure slabs exhibit less complexity than raft foundations, characterized by uniform thickness and fewer variable cross-sections, thereby permitting the use of a uniform placement method for monitoring points. Table 2 depicts the configuration of monitoring points for underground structure slabs.

Table 2. Underground structure floor monitoring point layout.

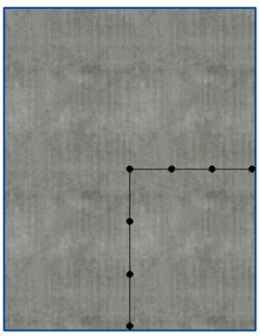
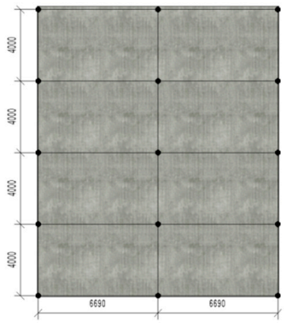
Direction of Monitoring Sites	Graph	Basis of Placement	Layout Algorithms
Horizontal direction		1. Half of the axis of symmetry of the plane of the concrete casting body as the test area. 2. Each test axis should not be less than 4 monitoring points, combined with the structural geometry of the uniform arrangement. 3. The spacing of the temperature measurement side position is 10 m–15 m, and the number of measurement positions should be increased in the variable cross-section part.	Half-axis uniform arrangement

Table 2. *Cont.*

Direction of Monitoring Sites	Graph	Basis of Placement	Layout Algorithms
Thickness direction		1. The thickness of the casting body is generally arranged in the direction of the surface, center, and bottom of the three-layer arrangement, and the measurement point monitoring is not greater than 600 mm; the thickness of the bottom plate is less than 1.5 m for the bottom and the surface of the double-layer arrangement. 2. The arrangement of temperature measurement points on the bottom and surface should be within 50 mm of the exterior of the pouring body and 50 mm on the bottom surface.	Uniform layout

Regarding the arrangement of monitoring points for underground structure walls, when positioning monitoring points on underground structure walls, these walls typically manifest as linear structures, distinct in structural form from rafts and slabs. Consequently, the deployment of monitoring points is restricted to the facades of the walls, with points in the thickness direction aligned along the wall's central line. Table 3 depicts the configuration of monitoring points for underground structure walls.

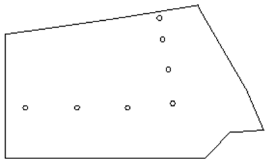
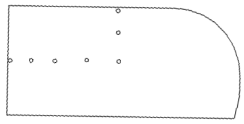
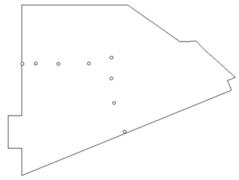
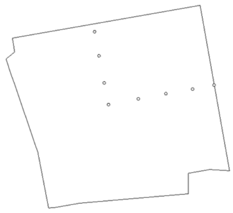
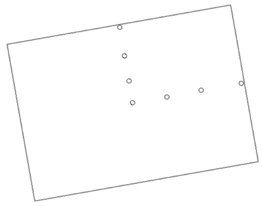
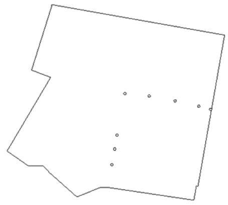
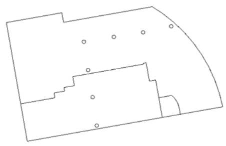
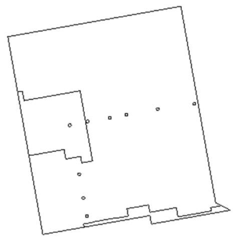
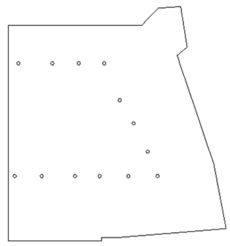
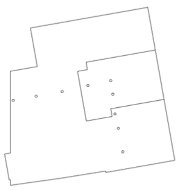
Table 3. Underground structure wall monitoring point arrangement.

Direction of Monitoring Sites	Graph	Basis of Placement	Layout Algorithms
Wall elevation direction		1. On the façade of the wall, the horizontal spacing of the measurement points is 5 m~10 m, and the vertical spacing is 3 m~5 m. 2. The arrangement of the bottom and surface temperature measurement points should be within 50 mm of the outer surface of the casting body and 50 mm on the bottom surface.	Uniform layout
Wall thickness direction		The direction of the thickness of the wall can be arranged according to the thickness of the wall, and the general center line of the wall on a single layer can be arranged.	Uniform layout

4. Discussions on the automated layout of monitoring programs.

Regarding the output of the automatic layout of the monitoring program, the design of its output method is discussed in the following section, and the results of its monitoring point automatic design are discussed in this section. Due to the shape rules of the underground structural ceilings and the underlying structural walls, the structural error of the output is small, so in this discussion of the results for different shapes of the foundation boards, three different algorithms are used to automatically design monitoring points, which is shown in Table 4 using different layout algorithms.

Table 4. Monitoring point layout obtained using different layout algorithms.

Layout Method	Layout Point Design		
Half-axis uniform arrangement	 (a)	 (b)	 (c)
Uniform layout	 (d)	 (e)	 (f)
Non-uniform arrangement	 (g)	 (h)	 (i)
 (j)	Half-axis uniform arrangement	Uniform layout	Non-uniform arrangement

The above table shows that the design effect is even more ideal in the application scenarios of the same algorithm, as in (a,e,i); its layout effect is also more optimal in applications where the uniform layout is combined with the half-axis uniform arrangement, as shown in (b,d). Their layout is also preferable in applications where non-uniform arrangement and uniform layout are combined, such as in (f,h). There were some errors in the layout of the application scenario associated with the non-uniform arrangement and the half-axis uniform arrangement, as shown in chart (c,g), which resulted in three algorithmic layouts. These three layouts, when combined with the design application scenario, are not very effective, as shown in chart (j); their layout effect is inferior to that of the design of a half-axis uniform arrangement, which only combines the uniform layout and non-uniform arrangement. This can be combined only with the following methods:

1. The result of the automatic design of the monitoring point is ideal in the concrete repository of the shape rules;
2. In the case of irregularly shaped concrete deposits, the following apply:
    a. The result of its own algorithm combination with the design layout is preferable;
    b. There is an error point in the non-self-designed algorithm layout, resulting in the need to optimize the priority of its internal algorithm.

2.1.3. Monitor the Output of the Protocol

1. Design of monitoring program content.

The document detailing the large-volume concrete temperature monitoring scheme is a direct manifestation of the automated design of monitoring points for various compartments. Upon completion of the automated design, the results are presented as plan diagrams. As the results are predominantly displayed as images, to enhance their aesthetic appeal, this research compiles the design outcomes into a comprehensive document of the large-volume concrete temperature monitoring scheme formatted as an Excel file. The document principally encompasses principles for the placement of temperature measurement points and the corresponding plan diagrams for these points across various compartments.

- Principle of temperature measuring point arrangement.

The principles governing the placement of temperature measurement points constitute the primary foundation for arranging these points in large-volume concrete. This encompasses the placement of temperature measurement points within monolithically poured concrete, foundation rafts, underground structure slabs, and walls. These principles form a critical component of the large-volume concrete temperature monitoring scheme.

- Plane layout of temperature measurement points at each warehouse.

The arrangement of temperature measurement points within each compartment constitutes the central focus of this chapter's research. The plan diagrams of temperature measurement points provide the most direct visual representation of this research. Moreover, these plan diagrams act as essential references and bases for construction personnel on-site for the arrangement of temperature measurement points in compartmented concrete.

2. Monitor protocol outputs.

Upon completing the design of the monitoring scheme, the content must be exported in Excel file format to a user-designated folder. This document employs the Unity3D engine as the development platform, with C# serving as the programming language. The export of the large-volume concrete temperature monitoring scheme is executed through C# scripts (.CS files). Several key steps are involved in exporting text files, with critical code snippets presented within this document to elucidate these steps. The specific steps are detailed as follows:

- Create a file.

The initial step in text output involves file creation. Below is the essential code for this process, illustrating the setup of various elements within a C# class dedicated to generating an Excel report. This class initializes different font styles and a document object:

```
public class EXCELReport: IDisposable
{
    BaseFont heiBaseFont; // Basic font
    public Font titleFont; // Style for report title
    public Font firstTitleFont; // Style for main titles
    public Font secondTitleFont; // Style for sub-titles
    public Font contentFont; // Style for content text
    public Document document; // The document object
    string newFontPath; // Path to font file
}
```

- Copy resources to the read–write path.

During this phase, data generated in Section 2.3.2 must be copied to the read/write path to facilitate file access during the planning of monitoring point arrangements. The following code snippet is crucial for facilitating this process:

```
public IEnumerator Initialization (string filePath)
{
    document = new Document(PageSize.A4);
    string dirPath = Path.GetDirectoryName(filePath);
    Directory.CreateDirectory(dirPath);
```

```
        FileStream os = new FileStream(filePath, FileMode.Create);
        PdfWriter.GetInstance(document, os);
        document.Open();
        String oldPath = Application.streamingAssetsPath + "/SourceHanSansSC-Medium.otf";
        newFontPath = Application.persistentDataPath + "/SourceHanSansSC-Medium.otf";
        yield return // Copy resource (oldPath, newFontPath);
        heiBaseFont = BaseFont.CreateFont(newFontPath, BaseFont.IDENTITY_H, BaseFont.NOT_EMBEDDED);
        titleFont = new Font(heiBaseFont, 26, Font.BOLD);
        firstTitleFont = new Font(heiBaseFont, 20, Font.BOLD);
        secondTitleFont = new Font(heiBaseFont, 13, Font.BOLD);
        contentFont = new Font(heiBaseFont, 11, Font.NORMAL);
    }
```

- Add a table and add text and images.

Incorporating tables facilitates the orderly arrangement of layout diagrams for large-volume concrete temperature measurement points. Furthermore, upon integrating tables, the text detailing the design principles for large-volume concrete temperature monitoring points and the plan diagrams for compartment temperature measurement points can be efficiently added. This integration is achieved by utilizing two named paths, <param name="content">content</param> and <param name="imagePath"></param>, to, respectively, insert text and images into the tables.

2.2. Research on the Creation of Sensor Information Models

2.2.1. Study of IFC's Standard Process for Information Extension

Considering the distinct characteristics of information, data collection devices, and data in the large-volume concrete construction process, this study utilizes property set extensions within the native IFC framework to enhance sensor device information. This method is particularly researcher-friendly, given its simplicity and version compatibility. The objective is to facilitate comprehensive and precise monitoring throughout the entire construction process of large-volume concrete.

To monitor the informatization in large-volume concrete construction, extending the information of sensor entities within the native IFC framework is necessary. Utilizing BIM software (Autodesk Revit 2019) for IFC information integration, the extension process initiates the collection of necessary attributes and property sets for the sensor entities. Subsequently, iterating through the necessary properties or property sets within the IFC standards is crucial to ensure compatibility with the IFC framework. Ultimately, the sensor entities require extension and association with corresponding entities. The detailed process is depicted in Figure 3.

2.2.2. Collect Information on Target Sensor Attributes

This article examines commonly utilized sensor types in the construction process of large-volume concrete, including pressure, flow, vibration, and temperature sensors. In the context of traditional project management and intelligent construction management of large-volume concrete, sensor data transmission during construction predominantly comprises information pertaining to the sensors themselves (attributes include sensor model, measurement values, transmission protocols, thresholds, and measurement ranges) and associated information (which primarily covers the location of attached components, component numbers, and their physical properties).

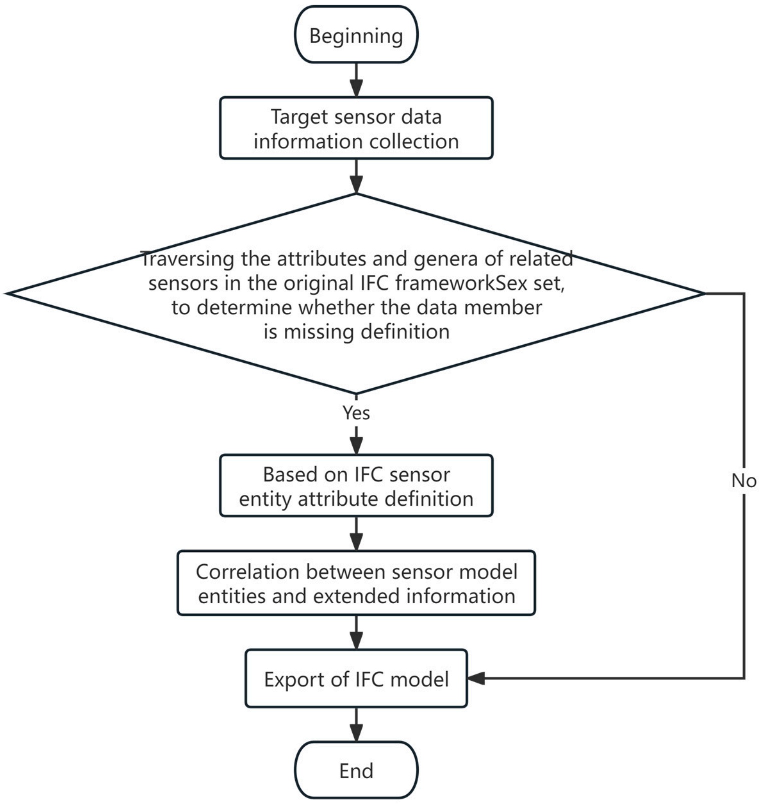


Figure 3. IFC information extension standard process.

2.2.3. Relational Mapping of the BIM Model to IFC Entities

Integration of IFC information through Autodesk Revit 2019 depends primarily on the capabilities of these applications. Currently, many BIM applications, such as Enscape, Revit, and Archicad, possess the capability to export three-dimensional geometric models into IFC files. Compared to other BIM applications, Revit distinguishes itself as a high-quality workflow program, offering more detailed export options for IFC files. Additionally, the latest versions of Revit are compatible with the most current IFC4 standard. Consequently, this study employs Autodesk Revit 2019 as the core modeling software for building sensor models, utilizing its inherent IFC file export capabilities.

In Autodesk Revit, files are primarily categorized into two types: Family files (.rfa) and Project files (.rvt). Hierarchically, Family files serve as components of Project files; however, Family files alone are insufficient to fulfill the requirements for exporting IFC files. Consequently, to export IFC files, it is essential to integrate created Family files into Project files, from which the IFC files are then exported. During the IFC export process, Autodesk Revit 2019 offers a mapping table between Family types and IFC types, enabling users to manage the mapping relationships between target Family files and corresponding entities in the IFC standard. Users can adjust the IFC class names and types of their Family types through the options menu during the export process, followed by direct IFC file exportation.

In the aforementioned mapping table, the mapped entities include Revit family categories and IFC entities. To ensure distinctiveness in the exported IFC files, enabling differentiation between sensors and other components such as large-volume concrete, the family category for sensors is designated as 'Specialty Equipment'. As illustrated in Figure 4, this categorization setting during sensor modeling distinctly defines sensors within the model. During the IFC file export, entity relationship mapping occurs, with the default class name for specialty equipment set as IfcBuildingElementProxy. This class name is then modified to the custom sensor entity IfcSensor, with its IFC type updated to IfcSensor and the PredefinedType attribute set to USERDEFINED. Previously, we noted that

IfcSensor includes 26 predefined sensor types. Adopting a USERDEFINED type facilitates the extension of property sets and attributes specific to sensor entities.

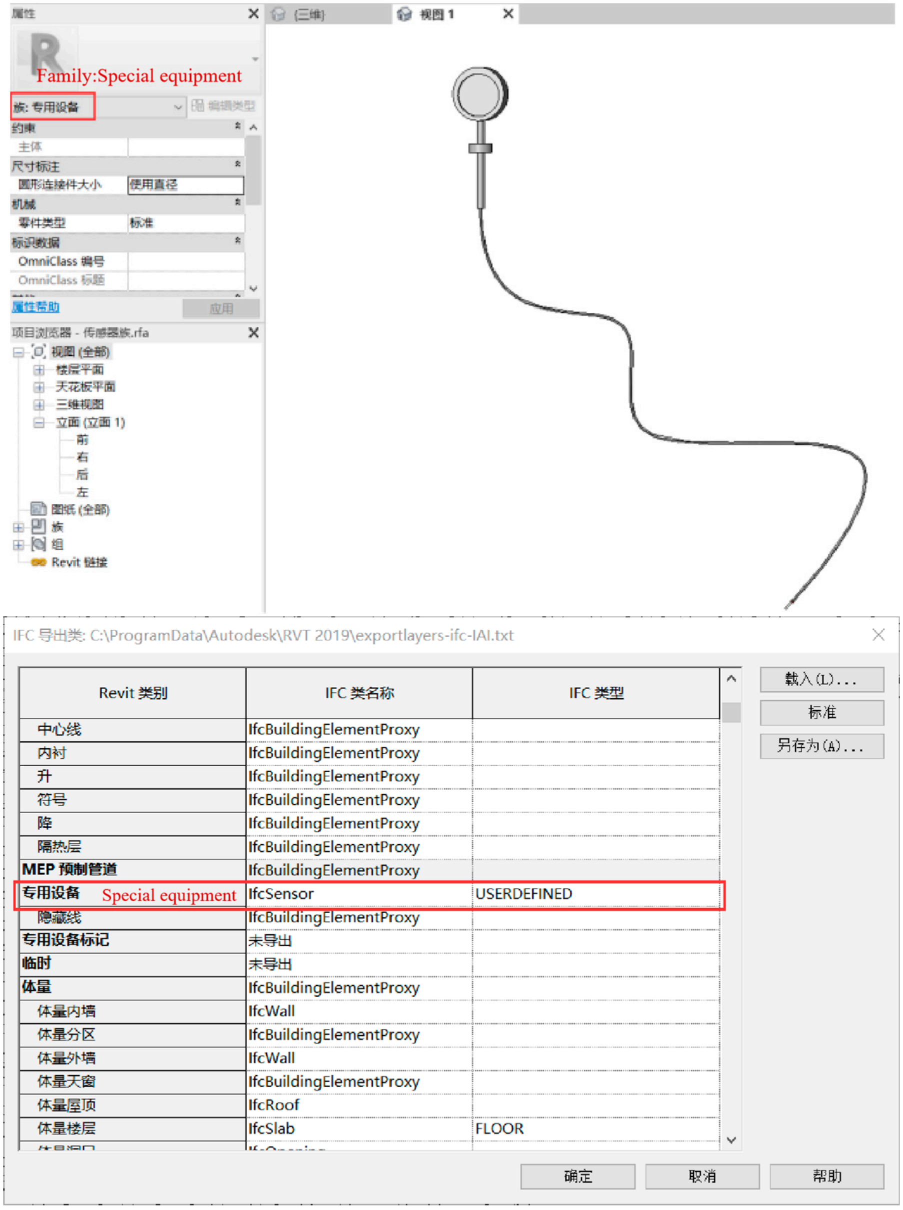


Figure 4. Family type setting and entity mapping relationship setting.

2.2.4. Extended Based on the IFC Sensor Entity Attribute Set

To facilitate user access and improve efficiency in referencing property sets, properties are delineated using a combination of common and characteristic property sets, as depicted in Tables 5–8. Given the gathered target sensor attributes and the demands of large-volume concrete construction management on-site, it is essential to extend the related property sets and attributes of IFC entities. This extension aims to satisfy the requirements of construction management, as detailed in reference [18]. Table 6 organizes the common and characteristic property sets for sensors within the IFC standard.

Table 5. Mapping relationship between Revit family types and IFC entities.

Revit Family Types	IFC Entity Name	Revit Family Types	IFC Entity Name
MEP Prefabricated Pipes	IfcBuildingElementProxy	HVAC Zone	IfcZone
Specialized equipment	IfcBuildingElementProxy	Volume	IfcBuildingElementProxy
Parking Lot	IfcBuildingElementProxy	Bathroom Fixtures	IfcFlowTerminal
Ramps	IfcRamp	Walls	IfcWall
Ceilings	IfcCovering	Roofs	IfcRoof
Rooms	IfcSpace	Structural Columns	IfcColumn
Floor	IfcSlab	Piping	IfcPipeSegment
Care call equipment	IfcSwitchingDeviceType	Stairs	IfcStair
Communication equipment	IfcBuildingElementProxy	Data Equipment	IfcElectricApplianceType

Table 6. IfcSensor common attribute sets and feature attribute sets (part).

	Attribute Sets	Attributes
Common Attribute Sets	Pset_SensorPHistory	Value, Direction, Quality, Status
	Pset_UnitaryControlElementPHistory	Temperature, Mode, SetPoint
Feature Attribute Sets	Pset_SensorTypeFlowSensor	SetPointFlow
	Pset_SensorTypeMovementSensor	MovementSensingType, SetPointMovement
	Pset_SensorTypeRadioactivitySensor	SetPointRadioactivity
	Pset_SensorTypePressureSensor	SetPointPressure, IsSwitch

Table 7. Pset_SensorTypeCommonSets attribute set definition.

Attribute Set	Applicable Entity	Class Value	Description
Pset_SensorTypeCommonSets	IfcSensor/ IfcSensorType	IfcSensor/ IfcSensorType/ UserDefined	Sensor Common Attribute Set

Table 8. Pset_SensorTypeCommonSets property definition.

Attribute Name	Attribute Types	Property Description
SensorNumber	P_SINGLEVALUE/IfcLable	Sensor number
MeasuringPointNumber	P_SINGLEVALUE/IfcLable	Sensor point number
AcquisitionTime	P_SINGLEVALUE/IfcDateTime	Sensor Data Acquisition Time
NumberRange	P_SINGLEVALUE/IfcLable	Sensor monitoring value range
ThresholdRange	P_SINGLEVALUE/IfcLable	Sensor Measurement Threshold Range
AccessoryComponentLocation	P_SINGLEVALUE/IfcLable	Sensor Attachment Location
AccessoryComponentID	P_SINGLEVALUE/IfcIdentifer	Sensor Attachment ID
AccessoryComponentNumber	P_SINGLEVALUE/IfcLable	Sensor Attachment Number
ProtocolName	P_SINGLEVALUE/IfcLable	Sensor transmission protocol
ProtocolVersion	P_SINGLEVALUE/IfcLable	Sensor transport protocol version number

To facilitate the referencing of property sets and attributes within IFC entities and address management needs in large-volume concrete construction, enhancing the physical structure of sensor property sets is crucial. Extensions of property sets and attributes can be directly applied to the target sensors required for the construction process. Extensions are essential for both the common and characteristic property sets of sensor attributes. As analyzed in Figure 5 regarding IFC information extension, iterating through the target sensor property sets and attributes within the IFC standard is necessary before information extension. This paper identifies the IFC entities and property sets corresponding to target sensors as PRESSURESENSOR (Pset_SensorTypePressureSensor), FLOWSENSOR (Pset_SensorTypeFlowSensor), and TEMPERATURESENSOR (Pset_SensorTypeTemperatureSensor). The listed characteristic property sets for these three sensor types include only basic sub-attributes such as measurable values and sensor models. The common property sets comprise attributes such as measurable values, measurement directions, and sensor operational states. These attributes are inadequate to fulfill the management requirements for the transportation, pouring, and maintenance of large-volume concrete. Consequently, extending the information within the common and characteristic property sets of the target sensors is necessary.

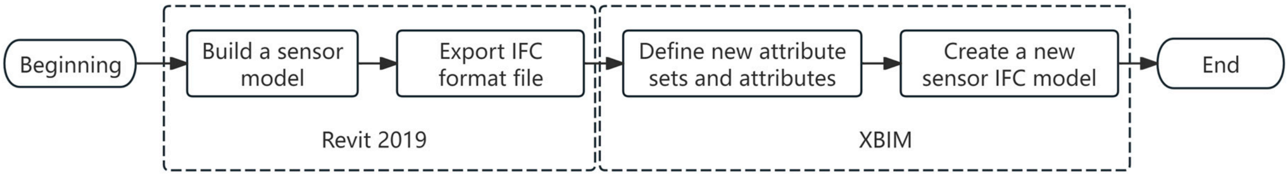


Figure 5. IFC extended information flow chart and related application software.

1. Sensor entities share a common set of attributes and property definitions.

Within the IFC framework, the extension of common property sets and attributes for sensors necessitates the definition of new property sets. Table 7 presents the new definition of the common property set Pset_SensorTypeCommonSets, while Table 8 specifies the attributes of this property set. To address practical needs, this property set includes attributes such as sensor ID, sensor measurement point ID, data collection time, monitoring value range, measurement threshold range, location of attached components, attached object ID, transmission protocol, and protocol version, among others.

2. Sensor entity feature attribute sets and attribute definitions

To facilitate more comprehensive and precise monitoring of large-volume concrete construction processes, it is crucial to extend the characteristic property sets and attributes for each sensor type, aligned with construction site management needs, following the initial definition of common property sets and attributes. This extension primarily encompasses sensor-related technical parameters. The definition process adheres to the established sensor property set extension method, utilizing the predefined USERDEFINED attribute from the enumeration type P_ENUMERATEDVALUE for each sensor type.

- Pressure sensors

As indicated in Table 8, the characteristic property set for pressure sensors is delineated by Pset_SensorTypePressureSensor. To prevent naming conflicts with existing property sets in the IFC standard, the newly defined properties are designated as Uset_SensorTypePressureSensor. Within Pset_SensorTypePressureSensor, the existing attributes comprise SetPointPressure (pressure set point) and IsSwitch (device switch status). The newly defined attributes encompass the sensor device's name, data monitoring time, type of pressure, and the device's switch status, among others. Table 9 presents the property set definition for Uset_SensorTypePressureSensor, while Table 10 specifies the properties of Uset_SensorTypePressureSensor.

Table 9. Uset SensorTypePressureSensor attribute set definition.

Attribute Set	Applicable Entity	Class Value	Definition Description
Uset_SensorTypePressureSensor	IfcSensor/IfcSensorType	IfcSensor/IfcSensorType/UserDefined	Pressure Sensor Property Set

Table 10. Uset_SensorTypePressureSensor attribute definition.

Attribute Name	Attribute Types	Property Description
EquipmentName	P_ENUMERATEDVALUE/ IfcLabel/	Sensor device name
TimeConstant	P_SINGLEVALUE / IfcTimeMeasure	Data monitoring time
PressureType	P_ENUMERATEDVALUE/ IfcLabel/ UEnum_ PressureType	Pressure type
SetPointPressure	P_SINGLEVALUE / IfcReal	Pressure Setpoint
IsSwitch	P_SINGLEVALUE / IfcReal	Device switching status

- Flow sensors

Similar to the approach taken with pressure sensors, the characteristic property set for flow sensors is designated as Uset_SensorTypeFlowSensor. Within Pset_SensorTypeFlowSensor, an existing attribute is SetPointFlow (flow set point). The newly defined attributes encompass the sensor device's name, data monitoring time, and type of flow value Tables 11 and 12).

Table 11. Uset_SensorTypeFlowSensor attribute set definition.

Attribute Set	Applicable Entity	Class Value	Definition Description
Uset_SensorTypeFlowSensor	IfcSensor/IfcSensorType	IfcSensor/ IfcSensorType/ UserDefined	Flow Sensor Property Set

Table 12. Uset_SensorTypeFlowSensor attribute definition.

Attribute Name	Attribute Types	Property Description
EquipmentName	P_ENUMERATEDVALUE/ IfcLabel/	Sensor device name
TimeConstant	P_SINGLEVALUE / IfcTimeMeasure	Data monitoring time
FlowType	P_ENUMERATEDVALUE/ IfcLabel/ UEnum_ FlowType	Type of flow value
SetPointFlow	P_SINGLEVALUE / IfcReal	Flow value

- Temperature sensor

The characteristic property set for temperature sensors is designated as Uset_SensorTypeTemperatureSensor. Within Pset_SensorTypeTemperatureSensor, the existing attributes are TemperatureSensorType (temperature sensor model) and SetPointTemperature (temperature set point). Newly defined attributes for this property set include the sensor device's name, data monitoring time, and temperature value type (Tables 13 and 14).

Table 13. Uset_SensorTypeTemperatureSensorattribute set definition.

Attribute Set	Applicable Entity	Class Value	Definition Description
Uset_SensorTypeTemperatureSensor	IfcSensor/IfcSensorType	IfcSensor/ IfcSensorType/ UserDefined	Temperature Sensor Property Set

Table 14. Uset_SensorTypeTemperatureSensor attribute definition.

Attribute Name	Attribute Types	Property Description
EquipmentName	P_ENUMERATEDVALUE/ IfcLabel/	Sensor device name
TimeConstant	P_SINGLEVALUE / IfcTimeMeasure	Data monitoring time
TemperatureType	P_ENUMERATEDVALUE/ IfcLabel/ UEnum_ PressureType	Temperature value type
SetPointTemperature	P_SINGLEVALUE / IfcReal	Temperature Setpoint
TemperatureSensorTyp	P_SINGLEVALUE / IfcReal	Temperature Sensor Model

2.2.5. IFC-Based BIM Model Entities Are Integrated with Extended Information

In the above text., we explored methods for extending IFC information via core BIM modeling software's (Autodesk Revit 2019) capabilities for managing IFC files, which facilitate the association of extended information with entities. However, a fundamental prerequisite for such associations is the capability of existing entities within the IFC standard to be linked accordingly. Despite these capabilities, the previous section, which disols becomes necessary to enable the association of extended information with entities.cussed the expansion of property sets and attributes for sensor entities, indicated that some extended information did not satisfy this prerequisite. Consequently, the use of IFC extension tools becomes necessary to enable the associa-tion of extended information with entities.

Currently, various open-source platforms offer toolkits for extending IFC, notably Xbim. Xbim, utilizing C# as its core programming language, facilitates the reading, creation, and viewing of Building Information Modeling (BIM) models in IFC format. This functionality significantly mitigates the challenges associated with linking extended information and entities, as discussed in this chapter. In this section, we employed Xbim Essentials and Xbim Xplorer, core libraries of Xbim.

To aid in comprehending the process of associating extended IFC information, Figure 5 illustrates an overall flowchart that delineates the IFC extension information association process.

Utilizing Xbim to extend information about sensor entities necessitates the use of a development platform. This paper employs Visual Studio 2022, based on the .NET Framework 4.7, and utilizes C# for development. The version of the Xbim parsing toolkit used is 5.2.324. A crucial aspect of the information extension process involves referencing the IFC file and bridging using the ID value from the BIM model and the Tag value in the IFC file. Within Visual Studio 2022, operations include reading and writing IFC files, as well as defining new property sets and attributes. As shown in Figure 6, the ID values in the BIM model and the Tag values in the IFC file coincide, serving as unique identifiers for Visual Studio to recognize and utilize, culminating in the defined IFC file.

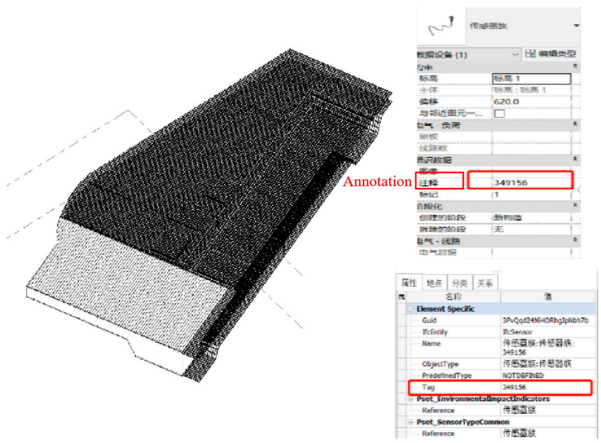


Figure 6. Correlation between Revit ID value and Tag value of IFC file.

2.3. Visualization Platform Development

2.3.1. The Overall Framework of the Visualization Platform

This study is based on the Unity 3D engine for the development of the visualization platform, which is now the dominant visualizing platform, with the advantages of cross-platform support, ease of use, powerful asset store, rich features, and real-time editing capabilities. At the same time, it uses the C# programming language, which is suitable for developing all kinds of games and applications and is friendly to beginner developers. In addition, Unity has a huge community and rich resources that make it easy for developers to access help.

The development framework of the Unity 3D visualization platform system is depicted in Figure 7.

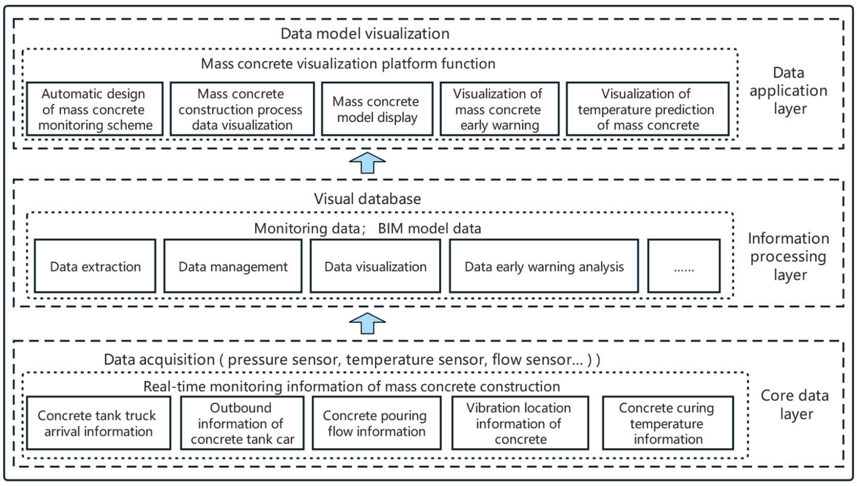


Figure 7. Visualization platform system framework.

The platform framework is segmented into two primary modules: the Data Integration Module and the Data Application Module. The Data Integration Module is dedicated to aggregating and integrating monitoring data from the large-volume concrete construction process, employing database technology for data management and integration, with detailed elaboration provided in the subsequent section. The Data Application Module leverages the Unity 3D engine to reference monitoring and BIM model data, enabling data visualization and predictive analysis.

The platform is structured into three distinct layers: the Core Data Layer, the Information Processing Layer, and the Data Application Layer. The Core Data Layer acts as the foundation of the platform, supplying monitoring data from the large-volume concrete construction process along with BIM model data. Monitoring data encompasses entries and exits of concrete tank trucks, flow data from large-volume concrete pouring, and temperature data for concrete curing. BIM model data includes sensor three-dimensional geometric models extended with IFC information, comprehensive project three-dimensional geometric models, and model data information.

This layer manages data from the Core Data Layer and provides support to the platform's Data Application Layer. Initially, database technology is utilized to integrate monitoring information. Within the database, data are organized, managed, and exported to enable data extraction by the visualization platform.

The Data Application Layer is critical for enabling the diverse functionalities of the visualization platform. This layer includes functionalities such as visualization of large-volume concrete construction process data, BIM model visualization, temperature prediction visualization, and alert visualization for large-volume concrete. This feature visualizes both the ingress and egress of large-volume concrete in the early stages and the temperature data during curing. It enables real-time viewing of data to monitor concrete weigh-ins and exits, thereby facilitating the tracking of concrete usage. Utilizing predictive models, this function analyzes concrete curing temperature data and visually displays the results, thus enhancing decision-making regarding concrete quality and curing processes. This functionality provides a real-time display of BIM models within the visualization platform, aiding construction management personnel in accurately assessing potential issues at specific locations.

Through the deployment of sensors at mass concrete construction sites, the platform captures critical data, such as temperature, humidity, and other data, during the construction process in real time. These data are extended and integrated through the IFC standard and transmitted into the BIM model, allowing managers to view and analyze data in real time on the visualization platform and make corresponding construction adjustments.

The platform mainly involves sensor information model expansion based on the IFC framework and a visualization monitoring platform based on Unity 3D. The development environment for the platform includes Visual Studio 2022 and Unity 3D, and the Xbim toolkit is used to read and write IFC files and extend properties. The choice of applications is aimed at improving transparency and management efficiency in large-scale concrete construction and to help construction managers better understand and control the construction process through visualization.

2.3.2. Platform Implementation

1. Development environment setup: In this study, the programming environment is configured with Visual Studio 2022, utilizing .NET 4.7.2 for compilation.
2. Scene building and page layout: Additionally, the .NET Core SDK, a C# plugin, is installed within Unity 3D. Based on a functional analysis, the page layout was designed on the visualization platform. As the platform primarily focuses on visualizing large-volume concrete projects, a single-page component approach is employed.
3. Visualization of component building: This research adopts the XCharts plugin. Using UGUI to reference the XCharts API, features are accessed and designed on the platform based on XCharts source file data.
4. Monitoring the access to databases: Data are converted into a DataTable and subsequently transformed into JSON. This JSON is then converted into the required data type. Finally, access to the data is facilitated through the SqliteAPI.dll.
5. Data visualization: Data visualization is primarily achieved through the ClickMonitorButton and OperaSensorDevice classes, which are used to visualize data for current and sensor devices, respectively.

Figure 8 presents a detailed development flowchart.

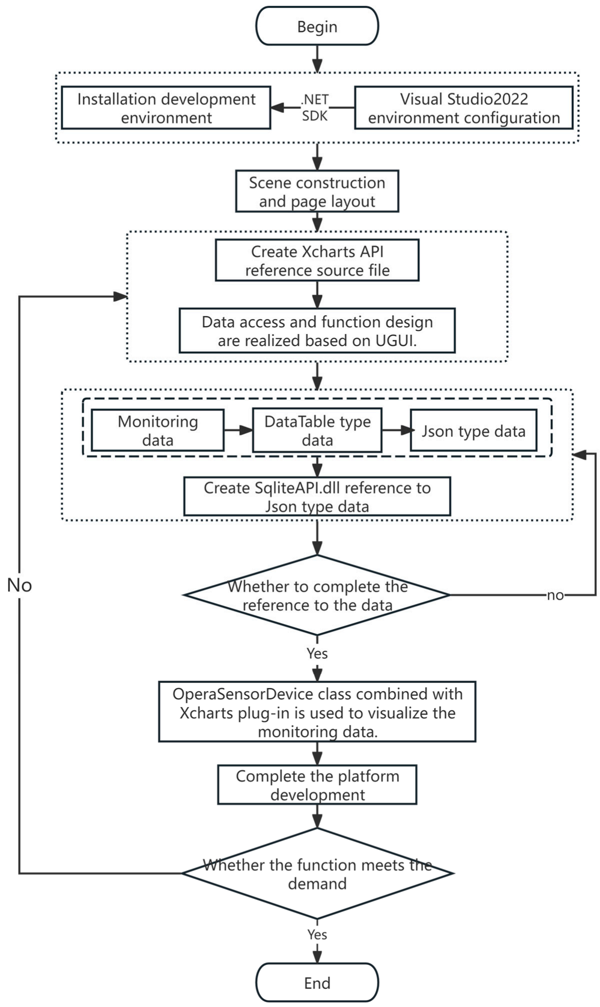


Figure 8. Visualization platform development flow chart.

1. Login interface for the visualization platform

This login interface is mainly used to enable user system login. Users must ensure that they use the correct login account and password to log in to the visualization platform, and if the account or password is wrong, the system will report errors and urge them to re-login. The user login interface is shown in Figure 9.

Figure 9. visualization platform user login interface.

2. Mass concrete temperature monitoring program design module

The mass concrete temperature monitoring program design module is mainly for the automatic layout of mass concrete temperature measurement points. Its specific realization process is first the loading of the external model file of the visualization platform through the system-built algorithm for the automation of the design of the concrete heat monitoring point in the warehouse, and finally, the output of the large volume of concrete temperature monitoring program design. As shown in Figure 10.

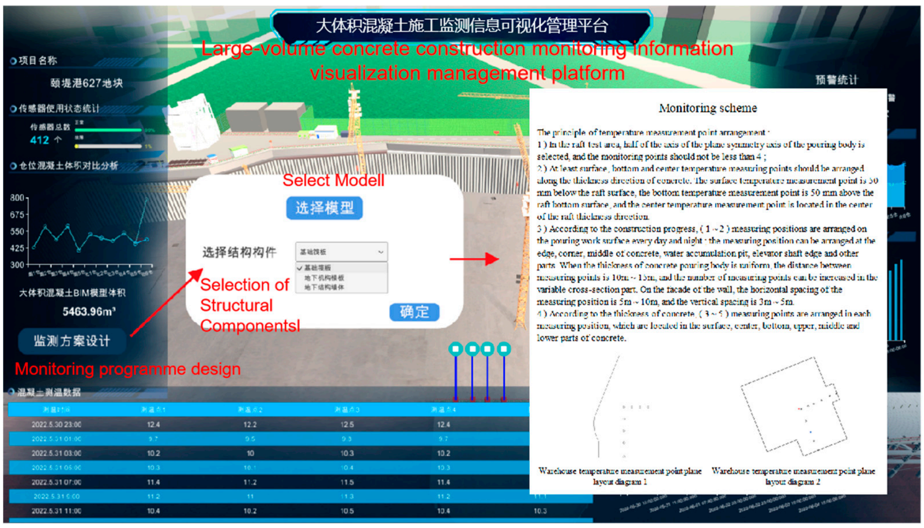


Figure 10. Mass concrete temperature monitoring scheme design diagram.

3. Mass concrete construction information visualization function module

The mass concrete construction information visualization function module is mainly used to display concrete monitoring information data at all stages of the concrete construction process, including sensor usage, concrete irrigation contrast analysis, temperature conservation statistics for concrete, irrigation statistics, and concrete input and output statistics. This module provides a real-time view of concrete engineering monitoring data to assist construction managers in viewing and analyzing the data as shown in Figure 11.

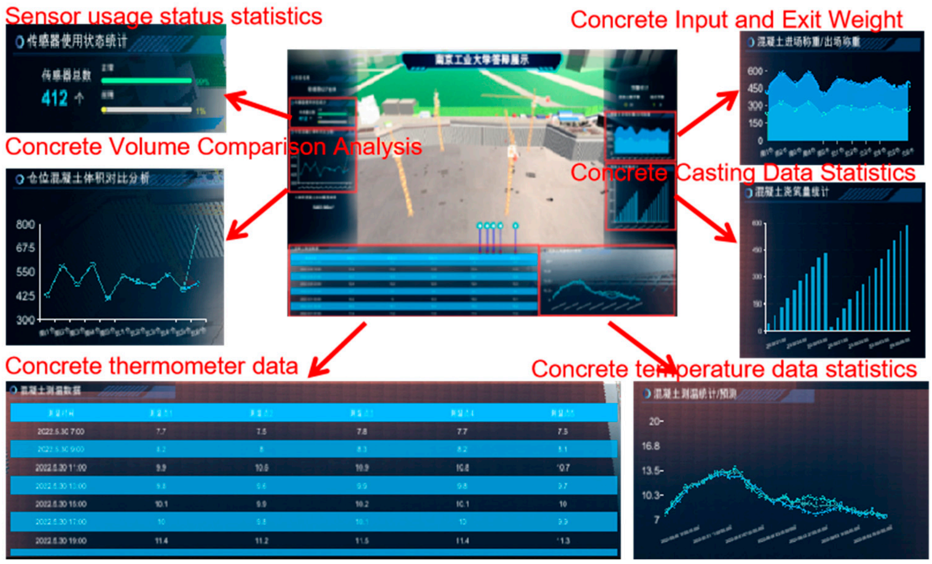


Figure 11. Large volume coagulation visualization function module diagram.

4. Sensor Monitoring Information Module

In the visualization platform, the expression of information monitoring for concrete construction process sensors is mainly assisted by construction managers to monitor and view the information of each monitoring point in real time. In the visual platform, sensors can display information about sensor monitoring points, including the sensor model, monitor point number, and measurement point location as shown in Figure 12.

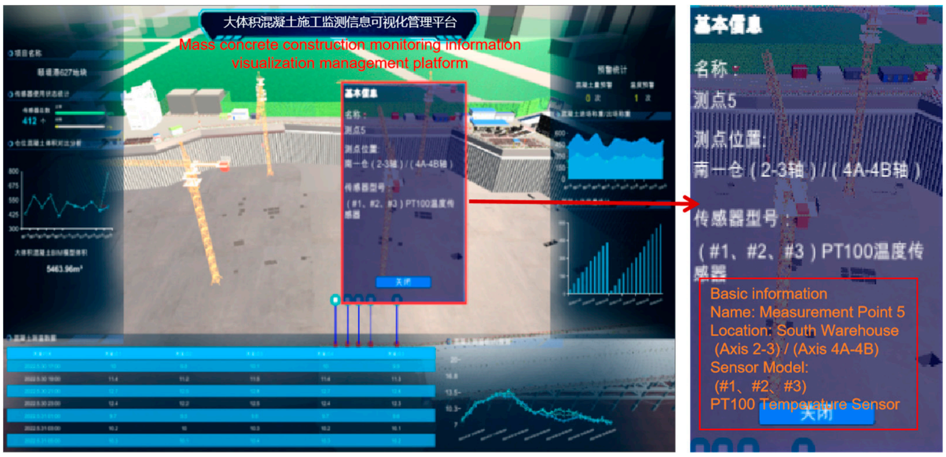


Figure 12. Sensor monitoring information display diagram.

5. Concrete temperature monitoring data forecasting module

In the process of mass concrete conservation, its temperature data changes are influenced by a number of factors; in the actual construction process, its site construction personnel need to keep an eye on the changes in their conservation temperature to ensure that the temperature of the concrete and the corresponding temperature difference is within the standard range, the monitoring point temperature data abnormality requires the manager to take immediate reduction measures on it, but there will be a certain time gap; that is, when the temperature data appear abnormally, its unusual temperature difference data have had a certain effect on the conservation of mass concrete.

In response to the above issues, concrete temperature data forecast in the visualization platform helps the field manager to understand the rules of conservation temperature changes in concrete in advance so that the temperature of the conservation of concrete can be predicted and effective thermal reduction measures can be taken to ensure the preservation quality of mass concrete as shown in Figure 13.

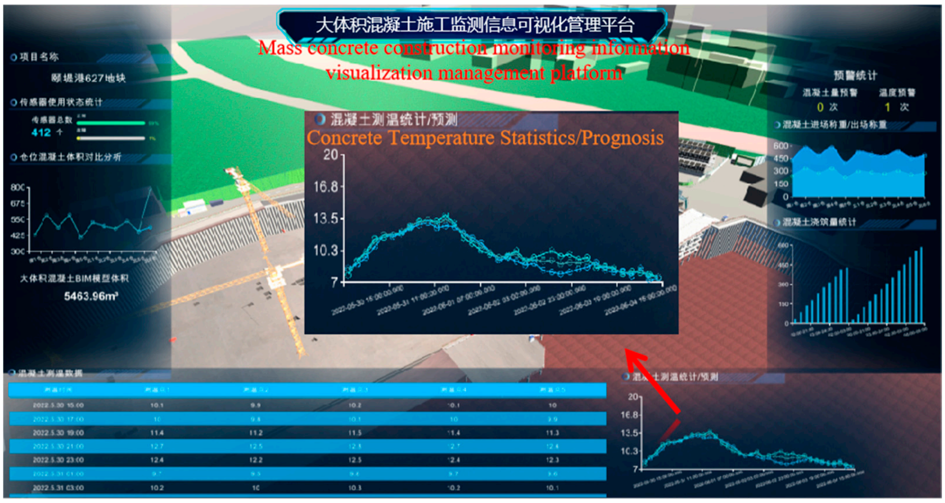


Figure 13. Concrete temperature monitoring data statistics and prediction.

6. Monitoring early warning module.

In the large volume concrete conservation phase, because of the large volume of concrete, the internal hydration heat of the concrete is severe; once the internal and external temperature difference exceeds a certain temperature value, it will lead to concrete cracks; therefore, the temperature data of the stage of the conservation need to be monitored. At the same time, this platform, in combination with concrete entry data for the management of the quantity of cement and the input, irrigation, and output data for monitoring, will ensure the concrete utilization rate. Therefore, in this platform, the monitoring early warning module is divided into two parts: concrete maintenance temperature monitoring and concrete utilization monitoring.

- Temperature monitoring.

When the temperature difference between the interior and exterior of large volumes of concrete exceeds 25 °C and the temperature between the surface, and the atmosphere exceeds 20 °C, it can seriously affect the quality of masse concrete, thus affecting the normal operation of the whole project. The early warning function of this platform is, first of all, to store the data collected by the sensor through the communication of the database to the database; the platform obtains data from the database in real time by setting the threshold of the temperature of the difference, to the early warnings function of the concrete temperature, as shown in Figure 14.

- Concrete volume monitoring.

The principle of monitoring concrete volume is to calculate the difference value of the concrete input and output data and then compare it with concrete output. In theory, the difference in concrete inputs and outputs should be the same as the value for concrete irrigation, but taking into account the real concrete watering quality and accuracy of the system data collection, this paper, by consulting the related project concrete utilization rate, is set to 1 ± 3; when its utilization rates exceed this range, the system will statistically report on it.

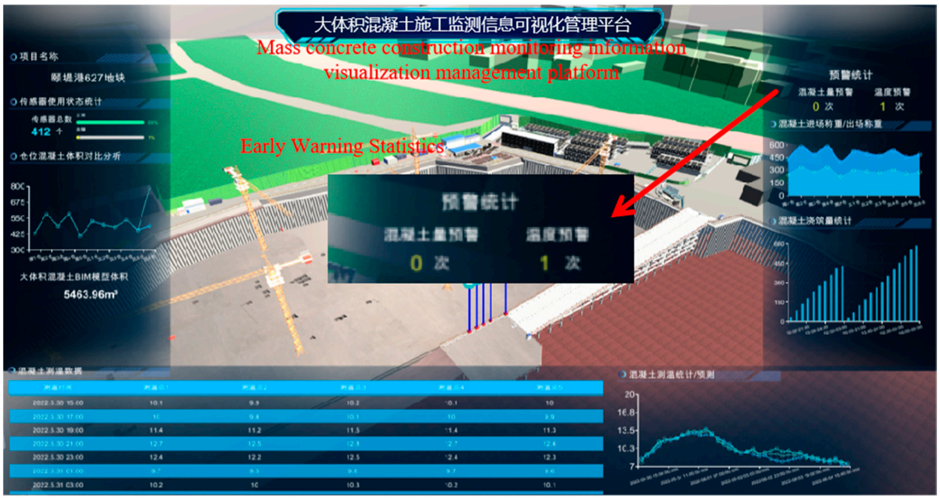


Figure 14. Visualization platform early warning statistical chart.

3. Case Study

This section describes the application of the above technologies and platforms in the actual construction project. The case project is the foundation of the brass plate in the commercial complex; its thickest floor plate is 2.2 m thick, the average floor plate thickness is about 1.8 m, and concrete has a total accumulation of approximately 55,000 m^3. The objective of this case study is to validate the automated design of the detection program, the development of a sensor information model, and the feasibility and authenticity of its application within the information management platform.

Visual control of large-scale concrete construction monitoring data based on the BIM model as the model base and the real-time monitoring of the sensor as the database. The monitoring system mainly has the following functions:

1. Visualization of the construction model

Using the Unity 3D plugin, Unity Reflect, the BIM model is loaded into Unity 3D. This method of integration preserves the inherent attributes of the BIM model while maintaining the material properties of the model itself. For example, Figure 15 showcases a BIM model integrated into Unity 3D.

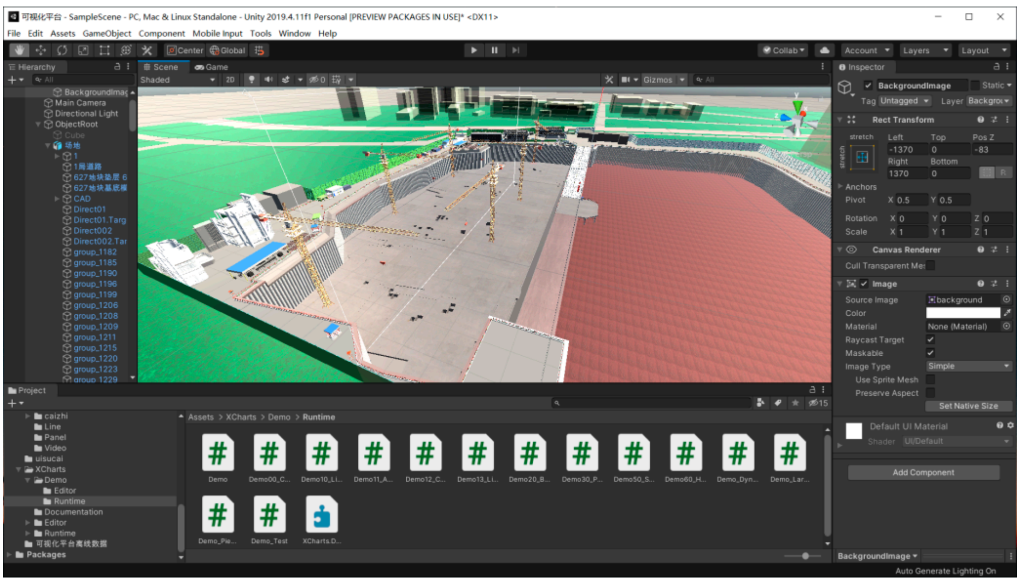


Figure 15. Unity 3D loading BIM model.

2. Design of a temperature monitoring scheme for bulk concrete

Based on the design of the large-volume concrete temperature monitoring scheme within the visualization platform, Figure 16 displays the final output of this monitoring program.

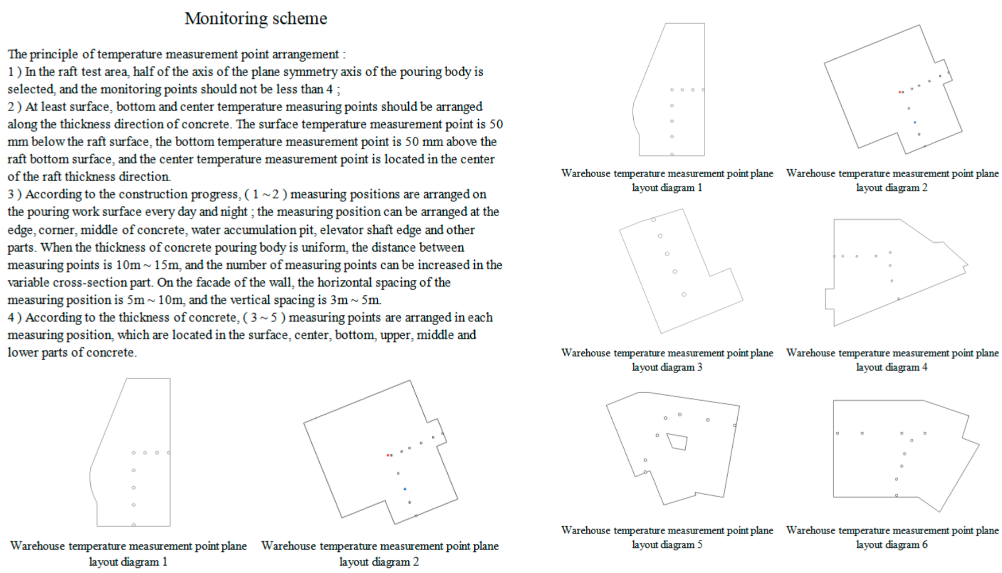


Figure 16. Mass concrete temperature monitoring scheme design (part).

3. Visualization of large-volume concrete construction monitoring data

In the visualization platform, monitoring data are categorized into several key areas: sensor usage statistics, comparative analysis of concrete volume in bins, concrete temperature measurement data, concrete temperature and weighing statistics, early warning statistics, and concrete pouring volume statistics. Several modules comprehensively cover both the mass concrete construction data and the visualization of temperature and volume warnings throughout the construction process. In the early warning data, statistics are integrated with the construction specifications. During concrete curing, a center-to-surface temperature difference exceeding 25 °C or a surface-to-atmosphere temperature difference exceeding 20 °C triggers alarms on the platform while simultaneously displaying early warning statistics. Discrepancies exceeding 2% between the recorded and actual poured concrete volumes trigger alarms on the platform, prompting personnel to verify the concrete volumes. Figures 11–14 depict the visualization control platform for mass concrete.

4. Discussion

This paper discusses the numerous advantages of applying information technology to mass concrete construction. Management of the concrete construction process is optimized via the automated design of the monitoring scheme and the utilization of the open IFC file format. This format enables the use of any compatible software, thereby obviating the need for specific software to create sensor information models. Such flexibility proves advantageous when addressing the diverse software requirements of various disciplines and specific structural or sensor-related needs.

In our case study, we demonstrate the use of Autodesk Revit 2019 to construct and optimize the mass concrete and sensor models. These models are exported to the IFC file format to enhance the attributes within Xbim, and the accuracy of this extended information is verified through the visualization platform. Additionally, it details the acquisition and management of real-time monitoring data during the project's construction process. Subsequently, the model and data are loaded into the visualization platform, enabling the visual display of monitoring data and predictive warnings for mass concrete construction. Through the application of the control method and practical construction processes, the study confirms not only the theoretical validity but also the practicality of the method in actual construction scenarios. This validates the substantial benefits of information technology in managing large-volume concrete construction.

We compared this study with traditional information technology, in which the automation design of monitoring programs could reduce the work-hour inputs by about 91.7% and improve the efficiency of work by about 80%; the establishment of sensor information models solved the problem of model and data linkage; saved the process of data processing and data interface development; and, finally, the development of visualization platforms, through digitalization, improved the transparency of the construction process and management efficiency.

5. Conclusions

The focus of this study is on the application of information technology in mass concrete construction, and the focus is on innovation in automation design and monitoring. The study included the following key conclusions:

1. Automated design of monitoring schemes: The study proposed an automated design approach for mass concrete monitoring points using uniform distribution, non-uniform distribution, and semi-axis uniform distribution methods. The automated design and output of the mass concrete monitoring scheme improve monitoring efficiency and accuracy, enabling real-time acquisition and processing of construction data, thereby effectively supporting quality control and progress management during the construction process.
2. Creation of a sensor information model: In the process of monitoring mass concrete, a sensor information model was created based on the IFC framework. The model extends the public and characteristic attributes of sensors to meet the monitoring needs during mass concrete construction, achieving the linkage between data and the sensor information model in the monitoring process. This model enhances data standardization and interoperability, improves the accuracy of information, and system maintainability, laying the foundation for future intelligent construction.
3. Development of a visualization monitoring platform: Using the Unity 3D engine, a visualization monitoring platform for mass concrete was developed. The platform integrates the automated design of monitoring schemes and the driving of sensor information model data and models, thereby validating the effectiveness of the automated monitoring scheme design and the reliability of the linkage between sensor information model data and models. This platform combines automated design and monitoring functions, improving the transparency and management efficiency of the construction process through digital means.

This research has several limitations. First, the sensor standard model based on the IFC information extension proposed in this paper has low standardization and interoperability of sensor data, being limited to use in Revit. Second, due to the complexity of on-site construction, the algorithm for the automated design of monitoring schemes cannot fully cover all shapes of concrete structures. Lastly, in the development of the visualization monitoring platform, the overall architecture of the platform and the hierarchical relationships between application modules are somewhat disorganized. To address these issues, the following improvements are suggested:

1. Standardization of sensor data: It is recommended that sensor data formats be standardized and more versatile data interface protocols be developed to meet the requirements of most 3D modeling software on the market.
2. Optimization of automated monitoring scheme design: Optimizing the automated placement algorithm for monitoring points using the LangChain framework and developing workflows for the automated placement of monitoring points based on the LangChain framework are suggested, making the designed monitoring schemes more complete.
3. Improvement of monitoring scheme reliability: It is recommended that a knowledge database be established and machine learning methods be applied to achieve the

automated design and output of monitoring schemes, enhancing the reliability and completeness of monitoring scheme documents.

4. Enhancing platform flexibility and scalability: Future research should focus on improving the flexibility and scalability of the information platform so that it can adapt to construction projects of different scales and complexities. Consideration should be given to adopting modular design principles, enabling the platform to expand and adjust its functions based on different needs.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could not have appeared to influence the work reported in this paper.

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