Visual Setting out Method of Complex Curved Arc Building Structure Using BIM and ORS Lofting Robot

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Abstract. Due to the complexity of the geometric shape of curved surface arc structure, it is difficult to carry out accurate setting out. Therefore, a visual setting out method for complex curved surface arc structure using BIM and setting out robot is proposed. Using BIM (Building Information Modeling), the structural model of complex curved surface arc building is constructed according to the three executive steps of structural data conversion processing, steel node data conversion and model analysis; After defining and building a family type with specific parameters and functions by using the Revit family editor in BIM, a lofting point shifting tool is designed, which dynamically links the 3D coordinate value of the lofting point family with the moving value, thus realizing flexible adjustment of the lofting point position. By moving the lofting point to the midpoint of the chord several times and measuring the vertical distance to the arc, gradually adjust it to form an arc shape consistent with the design.. The experimental results show that compared to the comparison method, the design method has the highest accuracy in laying out and the best efficiency in laying out time.

Keywords: BIM; ORS Lofting Robot; Complex curved surface arc building structure; Visual setting out

1 Introduction

In today's construction industry, complex curved building structures are highly favored for their unique aesthetic value and functional design. However, this type of structure faces a series of challenges during the construction process, among which the laying out treatment is particularly crucial. Layout processing is a core step in the construction process, which directly affects the dimensional accuracy, aesthetic appearance, functional integrity, and overall stability of the building structure [1-2]. Due to the complex and variable geometric shapes of curved structures, traditional wire laying methods are often difficult to accurately express and meet high-precision requirements, making the wire laying process a complex and highly technical task. From the perspective of construction accuracy, precise layout is the foundation for ensuring consistency between the building structure and the design drawings. Any small error can have a significant impact on the overall effect, and may even lead to uneven structural stress, affecting

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the safety of the building [3-4]. Therefore, the accuracy and reliability of wire laying technology are crucial.

In existing research, various methods have been proposed to address the layout challenges of complex curved building structures. Wang L et al. proposed a method for generating building layouts based on field-embedded GAN models demonstrating the possibility of an intelligent layout process.[5]. This method can generate high-precision layout data, adapt to changing construction environments, and improve layout efficiency. However, the training of GAN models requires a large amount of data support, and it may be difficult to find sufficient training data for certain special situations. In addition, the complexity of GAN models also poses challenges to their stability and reliability in practical applications. Jiang F et al. proposed a building layout method combining deep learning and graphical algorithms[6]. This method combines the powerful learning ability of deep learning with the accuracy of graphic algorithms, and can generate high-quality layout lines. The flexibility of graphic algorithms enables the layout of the layout to be adjusted according to specific needs, making it easy to implement in actual construction. However, this method is based on preset rules for layout and may not fully adapt to certain special situations. For complex curved structures, achieving optimal layout remains a challenging task.

Although these methods have improved the accuracy and efficiency of wire laying technology to a certain extent, they still have some limitations and shortcomings. To overcome these limitations, a visual layout method for complex curved building structures using BIM (Building Information Modeling) and ORS(Optical Remote Sensing) lofting robot is proposed. BIM technology can provide comprehensive building information, including structural dimensions, material properties, construction processes, etc., providing precise data support for layout. The layout robot has the characteristics of high precision, high efficiency, and high reliability, which can ensure the accuracy and efficiency of the layout process. By combining BIM technology with layout robots, we can achieve visual layout of complex curved building structures, improve construction accuracy and efficiency, and reduce construction costs.

2 Design of a Visualization and Placement Method For Complex Curved Building Structures

2.1 Building Complex Curved Surface arc Building Structure Model with BIM

For the complex curved surface arc building structure, its setting out is much more difficult than the plane result. Therefore, this paper uses BIM (Building Information Modeling) to build the complex curved surface arc building structure model. BIM technology, through its three-dimensional visualization function, enables designers to intuitively understand the form and details of building structures, facilitating precise layout processing. In addition, the collaborative design feature of BIM allows different professional teams to share and modify model data on the same platform, improving work efficiency and reducing errors. The data exchange capability of BIM, such as the use of IFC standards, ensures seamless transfer of model data between different software, further enhancing the universality and practicality of the model [7-8]. The specific implementation process includes three parts: structural data conversion processing, steel node data conversion and model analysis. The operations in each implementation phase are shown in Table 1.

Table 1. Building of complex curved surface arc building structure model using BIM.

Processing process	Processing Objectives	Implementation method
Structural data conversion processing	Create a basic model of curved building structures using BIM software (ArchiCAD)	IFC (Industry Foundation Classes) standard can be used for data exchange , create irregular shapes
Steel node data conversion	Create a 3D model of steel nodes in BIM software and add necessary attributes and information, such as dimensions, materials, connection methods, etc	Convert data from other software to IFC format and import it into BIM software
model analysis	Using the conflict detection function of BIM software to check for spatial conflicts in the model, such as conflicts between pipes and components, conflicts between equipment and walls, etc	Using BIM software analysis tools to perform static analysis, dynamic analysis, nonlinear analysis, etc. on the model

According to the way shown above, BIM software is used to build the structural model of the complex curved surface arc building, providing the execution basis for the subsequent visual setting out processing.

2.2 Setting of ORS Lofting Robot Lofting Point Family based on BIM Model

Combined with the release robot constructed in part 1.1, this paper applies the release robot in the specific release processing.

Firstly, the lofting point family of the ORS Lofting Robot is determined in the BIM model. In the specific implementation process, this paper uses the Revit family editor in BIM to define and build a family type with specific parameters and functions when designing the operation focus of this phase. The family is the basic component in Revit, which not only defines the geometric shape of the model, but also carries the parameter information of the complex curved building structure, which is also the basis for building the model with high customizability and data interaction ability. When selecting the family type, this paper selects standard component families to create according to the requirements of lofting points for complex curved building structures. In this way, the parameter types can be customized to provide a basis for subsequent editing, extraction and sharing of data.

During the creation process, the. rfa template file is created outside the project. This file is based on the template family model provided by Revit. At this time, the model only contains geometric features. Then, add the necessary parameters for the loft point family, which can be expressed as

$$f(i) = (Id, w, s) \tag{1}$$

Among them, $f(i)$ denotes the family of release points, Id represents the ID information of the lofting point, w denotes the value of the coordinates of the sample point. s represents the coordinate system that represents the loft point. In this way, the ORS Lofting Robot can establish association and data interaction relationship with the BIM model.

On the basis of the above, when the ORS Lofting Robot associates the BIM complex curved surface arc building structure model, it is mainly realized by setting parameters, and the specific implementation method can be expressed as

$$f(i) = \frac{\sum N\Delta u}{\sum Hh} \tag{2}$$

Among them, N represents the number of data points in the BIM complex curved building structure model, Δu represents the unit scale information of BIM complex curved surface arc building structure model, H and h respectively represent the actual size parameters of the complex curved surface arc building structure and the corresponding size parameters of the complex curved surface arc building structure in the BIM model. In this way, the lofting points are associated with the relevant data in the BIM model, so that the point location information can be viewed and retrieved directly in the model.

2.3 Positioning of Lofting Points of ORS Lofting Robot based on BIM Model

In the traditional CAD processing method, you can adjust the position of the dimensioned coordinates through the move command, but Revit's coordinate dimensioning function does not support moving directly to change its coordinate value after selection. Therefore, this paper designs a lofting point shifting tool, which dynamically links the 3D coordinate values of the lofting point family with the moving values, thus realizing the flexible adjustment of the lofting point position. The specific processing method can be expressed as

$$\begin{bmatrix} x \\ y \end{bmatrix} = (1+m)\begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{bmatrix} x_0 \\ y_0 \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \tag{3}$$

Among them, x and y denote the 3D coordinate values of the family of release points adjusted by the release point shift tool, respectively. m denotes the dynamic coefficient of moving values of the family of release points, α represents the curvature parameter of the surface of a customized complex curved building structure. x_0 and y_0 respectively represent the original lofting point positions in the BIM complex curved building structure model, Δx and Δy denote the 3D coordinate values of the family of release points customizing the scale of movement, respectively.

According to the above method, the chord is formed by connecting the two endpoints of the arc on the surface of the complex curved building structure with the release point shifting tool, and the approximate arc shape is gradually adjusted by moving the release point to the midpoint of the chord several times and measuring the perpendicular distance to the arc. The specific realization is shown in Figure 1.

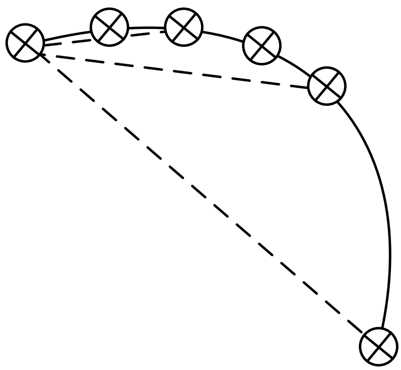

Fig. 1. Positioning of release points for circular arc shapes.

Through the designed positioning method of lofting points, the lofting points of the ORS Lofting Robot are integrated into the BIM complex curved surface arc building structure model in the form of a family, so that the ORS Lofting Robot can easily create the required lofting points on the points, lines, surfaces, arcs and other arbitrary positions of the model, or even on the special-shaped structure to complete the lofting.

3 Testing and Analysis

3.1 Engineering Cases

Dunhuang Research Institute Mogao Grottoes Digital Display Center Project (Phase II), located in Dunhuang Mogao Grottoes Digital Display Center on the east side of the foundation form for the independent foundation, strip foundation + waterproofing subfloor, the structural form for the frame structure, the main body of a large number of applications of arched axillary beams, columns, beams, under the cavity of the hanging plate and other modeling design. As show in table 2.

Table 2. Information on the structural parameters of the project's complex curved building.

Number	Parameter category	Detailed information
1	Building area	The total construction area is 8205m2
2	Number of building floors	First floor above ground (partial second floor)
3	Building height	13.65 m
4	Roof morphology	Complex Dissurface with Variable Elevations
5	Maximum length of surface	180m
6	Maximum width of the surface	Approximately 150m
7	Facade design	Curved walls, door and window openings, niches, etc
8	Surface net height variation	Changes with external morphological fluctuations
9	Color craftsmanship	Special research on yellow washed stone technology
10	Basic form	Independent foundation, strip foundation+waterproof bottom plate
11	Structural form	frame construction
12	Special structural elements	Arched haunched beams, cylinders, hollow hanging plates under beams, etc

Based on the curved surface structure in the above test project, the setting out method designed in this paper is adopted respectively. Literature [5] proposed the building setting out generation method based on the on-site embedded GAN model, and literature [6] proposed the building setting out layout method based on in-depth learning and graphic algorithm for test analysis.

3.2 Test results and Analysis

When analyzing the setting out effect of different methods, this paper takes the roof as the basis, cuts 8 arc sections according to the spacing standard of 20.0cm, and analyzes the setting out effect based on the deviation degree between the position information of the random points of the arc line at the upper end of the section and the design requirements. The corresponding test results are shown in Table 3.

Table 3. Comparison table of test results of different methods.

Point number	Design location information	Reference [5] Method	Reference [6] Method	Design method of this article
FYD-01	(12.66, 1.44, 4.20)	(12.56, 1.44, 4.20)	(12.60, 1.14, 4.20)	(12.66, 1.44, 4.20)
FYD-02	(12.71, 1.54, 4.20)	(12.31, 1.54, 4.20)	(12.68, 1.50, 4.20)	(12.71, 1.54, 4.20)
FYD-03	(12.88, 1.64, 4.20)	(12.68, 1.24, 4.20)	(12.88, 1.66, 4.20)	(12.88, 1.64, 4.20)

FYD-04	(13.06, 1.94, 4.20)	(13.00, 1.74, 4.20)	(13.06, 1.96, 4.20)	(13.06, 1.94, 4.20)
FYD-05	(13.62, 2.40, 4.20)	(13.62, 2.40, 4.20)	(13.66, 2.40, 4.20)	(13.62, 2.40, 4.20)
FYD-06	(13.93, 2.42, 4.20)	(13.73, 2.42, 4.20)	(13.99, 2.42, 4.23)	(13.93, 2.42, 4.20)
FYD-07	(14.14, 2.39, 4.20)	(14.04, 2.39, 4.20)	(14.14, 2.30, 4.21)	(14.14, 2.39, 4.20)
FYD-08	(15.33, 2.56, 4.20)	(15.36, 2.50, 4.20)	(15.30, 2.54, 4.22)	(15.33, 2.56, 4.20)

Combined with the test results shown in Table 3, it can be seen that under the three different release methods, the corresponding errors show more obvious differences. Among them, the method designed in this paper has the highest accuracy.

In order to further verify the superiority of the visual layout method for complex curved building structures combining BIM and layout robots proposed in this article, a new experimental indicator is introduced: Time Efficiency (TE) for layout. This indicator measures the total time required from the start of laying out to the completion of laying out, in minutes. The radiation time efficiency of different methods was tested, and the test results are shown in Table 4.

Table 4. Comparison results of time efficiency for different methods of wire laying.

Point number	Design location information	Reference [5] Method (TE)	Reference [6] Method (TE)	Design method of this article (TE)
FYD-01	(12.66,1.44,4.20)	25 min	20 min	15 min
FYD-02	(12.71,1.54,4.20)	28 min	22 min	16 min
FYD-03	(12.88,1.64,4.20)	30 min	24 min	17 min
FYD-04	(13.06,1.94,4.20)	32 min	26 min	18 min
FYD-05	(13.62,2.40,4.20)	35 min	28 min	19 min
FYD-06	(13.93,2.42,4.20)	38 min	30 min	20 min
FYD-07	(14.14,2.39,4.20)	40 min	32 min	21 min
FYD-08	(15.33,2.56,4.20)	45 min	35 min	22 min

From Table 4, it can be seen that the proposed method has better payback time efficiency than the methods in references [5] and [6] at all test points. On average, the method proposed in this article is about 40% faster than the method in reference [5] and about 25% faster than the method in reference [6].

4 Conclusion

This article studies the visualization and layout method of complex curved building structures using BIM and layout robots, successfully achieving accurate measurement and layout of building structures, significantly improving construction accuracy and efficiency. The visualization function of the BIM model ensures the accuracy of the layout points and overcomes the error problem in traditional methods. Although this study has achieved significant results, it still faces some limitations, such as challenges in technology integration and complexity in data processing. Future research can further explore the intelligent upgrading of BIM and layout robots, introducing artificial intelligence and machine learning technologies to promote innovation and development in construction practice.

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