

<https://doi.org/10.70917/ijcisim-2026-0020>  
Article

# Research on the Whole Process Visualization Management of Engineering Projects Based on Digital Twin Technology

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**Abstract:** Large-scale construction projects with large scale, complex intersection of processes, fragmentation of information, labor shortage and other issues have challenged the traditional project management methods, and the demand for project visualization management is very urgent. This paper constructs a whole-process visualization management model of engineering projects based on digital twin technology, combines the earned value principle of cost dynamic correction with BIM technology, and proposes a method for controlling engineering construction cost. Finally, the method is applied to the construction cost analysis and Monte Carlo simulation experiment of a cross-sea bridge. Through the calculation of earned value parameters and the dynamic cost analysis based on the S-curve, it is found that when the construction of the project proceeds to the end of October 2022, the difference between the actual cost of the completed work and the planned cost of the completed work is 1,626,200 yuan. It shows that the project is characterized by cost overruns, slow progress and low efficiency. It can be concluded that the method of this paper has good applicability in the whole process visualization management of engineering projects.

**Keywords:** digital twin technology; Monte Carlo simulation; BIM technology; project management

## 1. Introduction

With the acceleration of urbanization, there has been a rapid increase in infrastructure, housing, and commercial facility construction. Meanwhile, the structures and shapes of buildings and facilities have become increasingly complex and challenging, leading to higher demands on engineering project management [1-2]. Engineering project management is an essential component for ensuring the orderly progression of engineering projects. In engineering project management, planning management is the primary task. Only by ensuring that engineering projects proceed according to plan can the maximum value of the project be realized [3-4]. Currently, most engineering projects widely utilize software such as PROJECT and P6, along with Building Information Modeling (BIM) tools, to develop project process management plans and conduct comprehensive control activities based on progress management plans. However, since this method primarily relies on charts and text to describe project progress, it struggles to clearly articulate changes in project schedules, leading to insufficient visualization in project progress management [5-8].

Visualization management is a set of purposeful information management methods applied based on the human visual system's ability to quickly perceive surrounding objects [9]. Modern large-scale engineering projects are characterized by high target standards, fast work rhythms, heavy construction tasks, numerous workers, and long construction cycles. The ability of their production systems to operate continuously, healthily, and efficiently primarily depends on the professional competence and execution capabilities of frontline employees [10-13]. Whether frontline employees can effectively execute instructions depends on their level of information perception. Project visualization management can effectively enhance employees' information perception capabilities [14]. Literature [15] employs modern technological tools to design an intelligent project management system with monitoring and visualization functions, which not only improves management efficiency and workflow but also enhances



decision-making capabilities in management. Literature [16] applied three-dimensional visualization technology to engineering project management. By converting drawings and data into graphical and image formats, it enhanced interaction between managers and engineering technicians through simulated virtual visualization, enabling efficient communication and optimization of project planning and other project process management. Literature [17] proposed using geographic information systems (GIS) and virtual reality (VR) technology to construct three-dimensional simulation models for residential construction projects, achieving three-dimensional visualization in construction management. Literature [18] focuses on the digitalization of industrial building management, integrating BIM and lean construction principles to propose a visualization-based construction management method, effectively supporting industrial building production planning and control. Literature [19] combines visualization technology with improved machine learning algorithms to construct a visualization management system for construction projects, which provides project management support through its comprehensive functionalities and efficient operations.

With the continuous development of computer technology, digital twin technology has been widely applied in the field of engineering management. Digital twin technology is a technique that creates a virtual replica of a physical entity to achieve real-time interaction and intelligent management between the physical and virtual worlds. In the engineering field, it can help project teams achieve more efficient and precise management, thereby improving engineering quality and efficiency [20-21]. Literature [22] utilizes drones and image processing software for data management at construction sites (including data collection and updates), enhancing communication efficiency and information sharing among project members. By integrating digital twin technology for project planning and forecasting, risks in project management can be identified, enabling timely implementation of countermeasures. Reference [23] integrates BIM, IoT, and data mining to construct a digital twin architecture. It uses data collected from IoT devices for 4D visualization modeling, simulation execution, and human-machine collaboration. By introducing a multiple autoregressive integrated moving average model, it predicts the completion status of human tasks, thereby achieving construction project management.

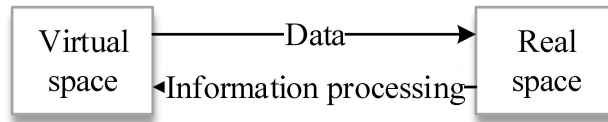
Based on the connotation of digital twin, the article firstly constructs a four-dimensional digital twin maturity evaluation model considering life cycle, model mapping, functionality and data completeness. Secondly, it proposes the method of cost control by BIM5D technology and earned value method, and analyzes the application of construction cost control in building projects. Then based on Monte Carlo simulation method and its specific steps to apply it in the whole process management of engineering projects. Taking a cross-sea bridge in Guangdong Province as an example for empirical research, the method of this paper is applied to the construction cost analysis of a cross-sea bridge. At the same time, four Monte Carlo experiments are designed to simulate and test the actual case.

## **2. Visualization Management of the Whole Process of Engineering Projects Based on Digital Twin Technology**

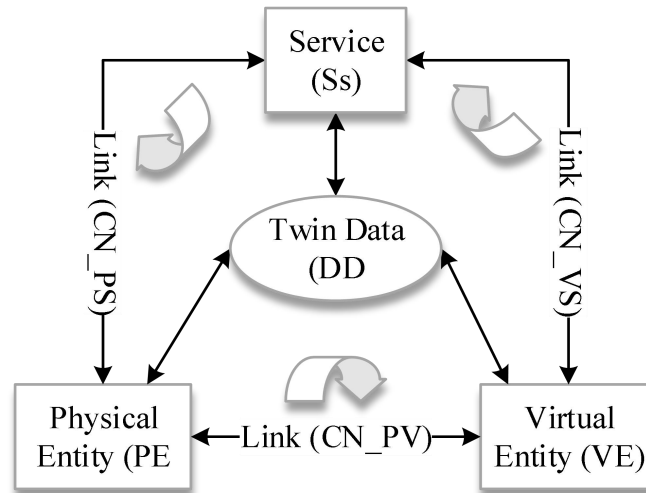
### *2.1. Digital Twin Model for Construction Project Management*

The digital twin is mainly based on the concept of “virtual digital representation equivalent to a physical product” and consists of conceptual models based on: (1) physical products in real space. (2) Virtual products in virtual space. (3) The connection of data and information that links the virtual and real products, as shown in Figure 1 by Michael Grieves. The five-dimensional model of digital twin is shown in Fig. 2: MDT = (PE, VE, Ss, DD, CN), where PE denotes the physical entity, VE denotes the virtual entity, Ss denotes the service, DD denotes the twin data, and CN denotes the connection between the components.

After the research and application of digital twin, the narrow sense digital twin and the broad sense digital twin are gradually formed to realize the practical promotion of digital twin. Narrow sense digital twin is a set of virtual information that comprehensively describes potential or actual physical production from micro-atomic level to macro-geometric level [24]. The digital twin system contains 3 main components, i.e., the physical space, the digital space and the information processing layer connecting the 2 spaces. For the characteristics of construction project management, based on the digital twin concept and model, a digital twin model for construction project management is proposed. The constructed digital twin framework is divided into 3 parts: physical space, twin space and digital twin application. The physical space and the twin space are linked through intelligent perception and virtual-reality mapping, and the twin space realizes the twin application through data-driven modeling. The digital twin application governs the physical space with supervisory interaction and command and control. The link interaction between the 3 components of digital twin realizes the fine management of digital twin's whole life cycle.



**Figure 1.** Michael Grieves model.



**Figure 2.** Digital Twin five-dimensional model.

## 2.2. Digital Twin Digital Mapping

Connectivity and real-time communication between the physical space of the site, the twin space and the database are critical to enable real-time monitoring and management. Digital twin methods should be developed for existing environments and entities in the field to achieve timely, efficient and accurate model reconstruction. Interaction is the core key for the digital twin to move from stagnation to communication, from static to dynamic, and from isolation to integration. The establishment of dynamic mapping association between physical space and twin space provides a basic guarantee for the accurate correspondence of virtual and real elements, efficient synergy of physical elements, and effective linkage of twin elements. The basis for digital twin to realize interactive services is the linkage interaction of twin data. In the process of digital twin mapping, the quality requirements for twin data are bound to realize accuracy, authenticity, completeness, comprehensiveness, timeliness, immediacy, precision and relevance. Comprehensive digital twin connotation, physical space and twin space mapping characteristics need to satisfy: accuracy of mapping, completeness of mapping, real-time mapping, and bidirectionality of mapping.

## 2.3. Digital Twin Maturity Evaluation

There is no standardized criteria in applying digital twin evaluation process to projects. The process of delivering digital twin models is even more difficult, thus giving rise to digital twin maturity evaluation methods. Maturity evaluation is currently used in traditional project management, industry 4.0 or industrial digitization. In the case of digital twins, many scholars have classified maturity levels based on digital twin characteristics. The digital twin maturity models have all graded the maturity level from the aspect of digital twin realization function. In terms of engineering project management, the impact of the operation and maintenance phase on the infrastructure is equally important, and thus the full life cycle of the digital twin needs to be considered. In addition, the maturity evaluation needs to be comprehensively considered to highlight the characteristics of digital twins; different dimensions have different requirements for digital twins, and high grades of secondary dimensions often lead to errors in the overall maturity evaluation of digital twins. Twin data completeness is mainly categorized into three dimensions: data twin cycle, data twin accuracy and data accessibility. The different needs of different digital twin services often determine the digital twin data quality issues, the quality risk of the structure itself often requires real-time monitoring by IoT devices to ensure that the structure is safe, and the data twin cycle should be at the level of seconds, whereas in terms of progress risk control, data twinning is

only required on a day-by-day basis.

#### *2.4. Re-Engineering Construction Project Management Approach in the Context of Digital Twins*

The digital twin can be applied to other related existing projects, related environments, and partially completed target projects for construction monitoring and management, including construction progress, quality, safety, workers, machinery, and materials. Among them, (1) Construction phase: construction progress monitoring and management, construction quality monitoring and management, construction safety monitoring and management, workers' monitoring and management, machinery monitoring and management, and materials monitoring and management. (2) Operation and maintenance: defect detection, asset monitoring [25]. (3) Analysis and diagnosis: decision-making, automation, retrofitting and demolition, integrated asset management. Using the quantitative results, future requirements are presented, including: data interoperability, IoT, AI, and digital twin platforms during the design and construction phases of building projects.

### **3. BIM5D-Based Whole-Process Management Method for Engineering Projects**

#### *3.1. Construction Cost Control System Based on BIM5D Technology*

##### **3.1.1. Construction Cost Control Based on BIM5D Technology**

In the process of construction cost control, the points of its combination with BIM technology mainly include the formulation of cost plan, actual cost monitoring, cost triple counting comparison and cost correction analysis. Comparing and analyzing these four points, the application of BIM technology in the process of cost control can be obtained as follows: Firstly, the BIM5D model is obtained by relying on the integration of the BIM3D model with the progress and cost information. Second, the data in BIM5D model is realized to be extracted in the process of construction cost prediction. Thirdly, the data in the BIM model is characterized by real-time when the construction cost is controlled. Fourthly, BIM can generate data reports in time when analyzing the cost and correct the deviation in time.

##### **3.1.2. Logic of BIM5D Technology and Earned Value Method for Cost Control**

When the required BIM5D model construction is completed, it is easy to extract data from the database of the model for earned value calculation and analysis, through the analysis of the results of the deviation of the reasons for the occurrence of the deviation at the same time to take appropriate measures to correct the deviation, which is the use of BIM for the principle of the work of the Earned Value Management. The BIM database contains a wide range of data, the Earned Value analysis can be obtained anytime, anywhere, such as progress, resources, costs and other data [26]. Since there is no actual data source at the beginning of the project, the data in the model comes from the construction progress plan and cost plan in the early stage, but at the end of the late construction progress, the actual project progress and cost will deviate from the previous plan, which requires the use of the BIM in the process of construction and timely input of the progress and cost data, so as to get the actual situation of the project. That is to say, in the BIM model contains not only progress, cost and price information such as the planned value, but also contains the actual value of these parameters, for the implementation of timely and effective dynamic control to provide the prerequisite guarantee.

The three parameters required for Earned Value Management: Budgeted Cost (BCWS), Actual Cost (ACWP) and Earned Value (BCWP) are actually derived at three different construction stages. The budgeted cost (BCWS) is calculated prior to the start of construction based on the initial schedule and cost schedule entered in the model. Actual Cost (ACWP) is calculated after the project has been underway for a certain period of time by using the actual schedule and cost data of the project obtained in the model. The earned value (BCWP) is calculated based on the actual progress of the work units and the planned prices after the structure is decomposed according to the WBS. After obtaining the three basic parameters mentioned above, the next step is to calculate and analyze the four evaluations, and after the completion of this step, we can obtain the actual status of the project progress and execution, so that we can analyze the cost based on the actual situation for early warning, and make corrections to the deviations that occur.

The following is an analysis of the main functions that can be realized after the combination of BIM5D Earned Value Method:

##### **(1) Cost deviation monitoring**

From the perspective of the principle of earned value analysis, it mainly relies on three basic parameters to monitor the cost deviation in the construction process.

Among them, the schedule deviation index is:

$$SV = BCWP - BCWS \quad (1)$$

The cost deviation is:

$$CV = BCWP - ACWP \quad (2)$$

Cost performance indicators are:

$$CPI = BCWP / ACWP \quad (3)$$

The indicators of achievement for progress are:

$$SPI = BCWP / BCWS \quad (4)$$

1) When:

$$BCWS > BCWP > ACWP (CPI > 1, SPI < 1), SV < 0, CV > 0 \quad (5)$$

When, it represents lagging schedule, cost is not exceeded, efficiency is high, and additional personnel and equipment should be added to speed up the construction schedule.

2) When:

$$ACWP > BCWP > BCWS (CPI < 1, SPI > 1), SV > 0, CV < 0 \quad (6)$$

At the time, the representative was ahead of schedule, cost overruns and inefficiencies. Headcount should be reduced and core members retained.

3) When:

$$BCWP > BCWS > ACWP (CPI > 1, SPI > 1), SV > 0, CV > 0 \quad (7)$$

When this is the case, it indicates that progress is ahead of schedule, costs are not exceeded, and efficiency is on the high side. If the deviation is not significant, the construction status quo may remain unchanged.

4) When:

$$ACWP > BCWS > BCWP (CPI \geq 1, SPI < 1), SV < 0, CV < 0 \quad (8)$$

When, it represents lagging progress, cost exceeding and inefficiency, inefficient personnel should be replaced and efficient personnel should be added.

5) When:

$$BCWS > ACWP > BCWP (CPI < 1, SPI < 1), SV < 0, CV < 0 \quad (9)$$

When this is the case, it represents sluggish progress, cost balances, and inefficiency, and should be introduced to speed up efficiency and improve inefficiency.

(2) Cost warning

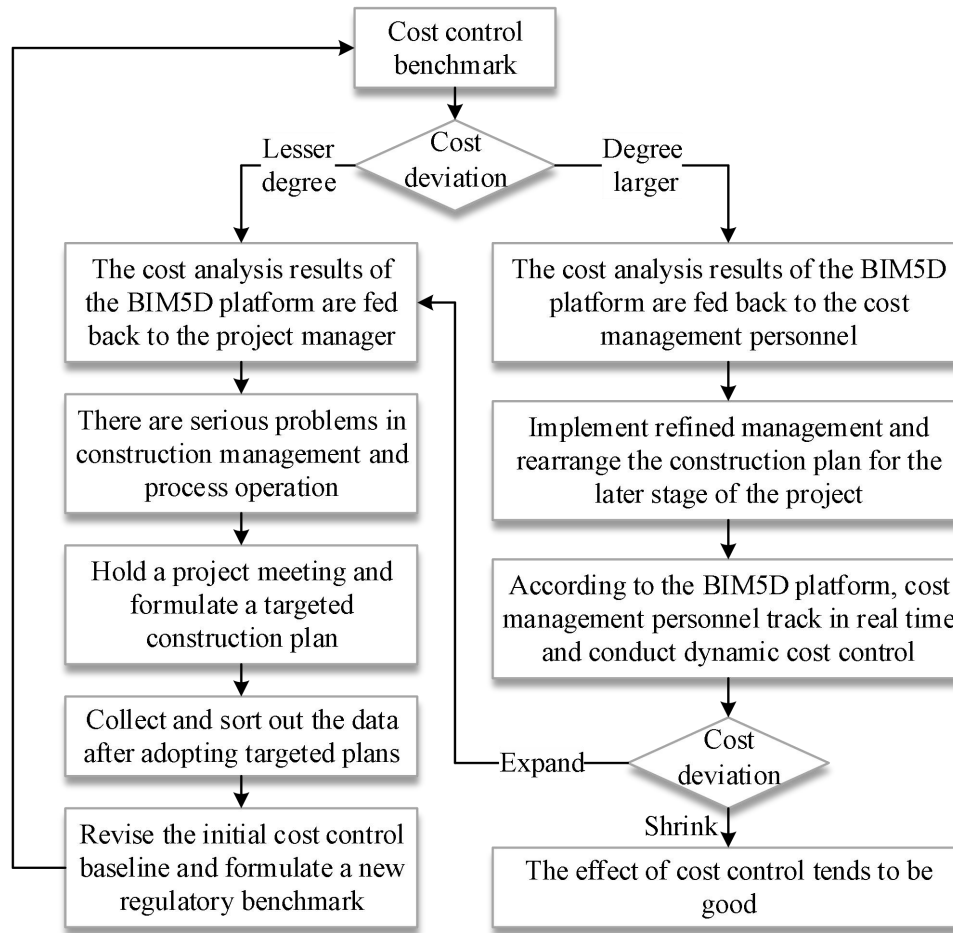
In the calculation of cost deviation, although the deviation can be obtained, there is no actual standard to measure the degree of its deviation, which leads to the inability to target appropriate countermeasures, resulting in missing the best time to correct the deviation. Based on this problem, a lot of relevant information was reviewed, and a hierarchical scale for cost early warning was finally developed in order to realize the hierarchical control of deviation. The CPI center is used to divide the early warning area so that the managers can make corrections accordingly.

(3) Reasons for cost deviation

For the construction manager, the ideal state is that the dispersion between the three parameters BCWS, BCWP and ACWP is very small, and at the same time, the BCWP and ACWP are as close as possible, and the ultimate goal is to make these parameters infinitely close to each other and to make the overall curve show a smooth and effective growth. Based on the data in the BIM5D model, the project manager is able to compare and analyze the above parameters visually and quickly and find out the reasons for the deviations in a timely manner. Over time, common causes of cost deviations are summarized.

(4) Correcting cost deviation costs

Correction of deviation, as the name suggests, is a series of corrective measures taken after the occurrence of deviation, and it should be emphasized here that the corrective measures taken for different degrees of deviation are also different. The cost deviation correction flow chart is shown in Figure 3. Among them, the judgment of the size of the deviation cost is based on the parameters obtained by the earned value method and the actual situation of the construction by the management personnel after the judgment.



**Figure 3.** Flowchart of Cost Deviation Correction.

### 3.2. Monte Carlo Simulation

#### 3.2.1. Fundamentals

The basic principle of the Monte Carlo simulation method can be expressed as follows: there is an item-independent statistical random variable  $x_i (i = 1, 2, 3, \dots, n)$ , its corresponding probability distribution function  $g_i (i = 1, 2, 3, \dots, n)$ , according to the project objectives or regulations to get the project evaluation index function  $y = g(x_1, x_2, x_3, \dots, x_n)$ . According to the probability distribution of the random variable, repeated independent simulations several times will produce N random numbers  $x_1, x_2, x_3, \dots, x_n$  of the sampled values. If there are M random numbers in N random numbers corresponding to the value of the project evaluation index function  $y \leq 0$ , when N tends to infinity, according to the law of large numbers and the normal random variable properties, the probability of failure and the reliability index of  $y$  can be derived which is similar to the actual situation.

#### 3.2.2. Simulation Steps

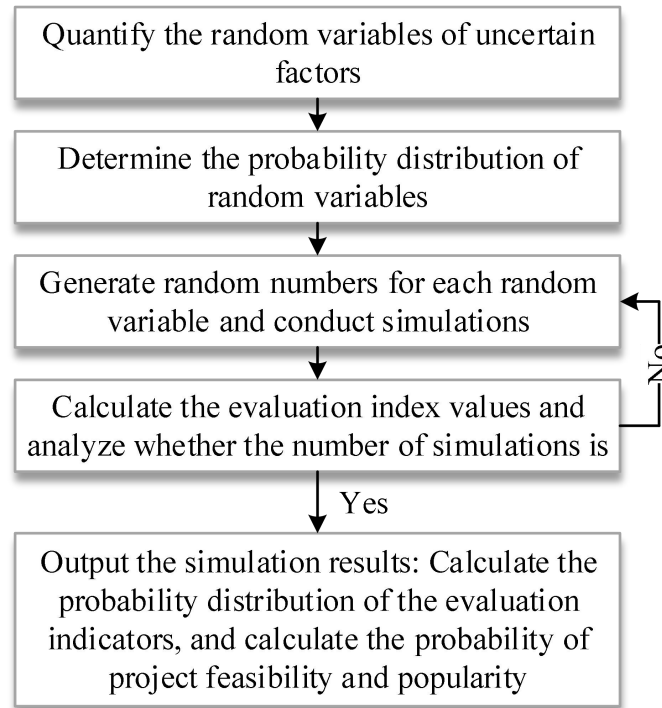
The use of Monte Carlo simulation method for the economic evaluation of the project, is the uncertainty factors affecting the size of the final result of the net present value of the implementation of thousands of simulations on the computer, and ultimately produce the cumulative probability distribution graph of the net present value, for the investment decision of the project to provide a reliable basis for decision-making [27]. Specifically:

- (1) Evaluate the uncertainty factors of the project, and at the same time collect the historical data or simulation data of these uncertainty factors to quantify the uncertainty factors affecting the project.
- (2) Establish the required model according to the actual situation of the project, mainly using these quantified uncertainties as inputs to the model, and quantifying the objects to be evaluated as outputs of

the model. Usually, we take the net present value, internal rate of return and payback period as financial evaluation indexes.

(3) Evaluate the uncertain factors based on historical data or expert knowledge and experience, determine their probability distribution, and finally calculate the simulation results.

(4) By analyzing the results of the probability distribution of each generated index, we use a large amount of experimental data to prove the correctness of the model design, and we are required to improve it continuously in the practical application. The general flow chart of Monte Carlo simulation method is shown in Figure 4.



**Figure 4.** General flowchart of the Monte Carlo Simulation method.

### 3.2.3. Generation of Random Numbers

According to the probability distribution of random variables to generate the corresponding random number is the key to the successful application of Monte Carlo simulation method, is the use of computers in the implementation of the algorithm will generate a random number in a step, and the random number will affect the final results of the entire algorithm. The following analysis of several Monte Carlo simulation method commonly used probability distribution type.

#### (1) Uniform distribution

The uniform distribution, also known as the rectangular distribution, is a symmetric probability distribution in which the probabilities of distributions at intervals of the same length are equally likely. The uniform distribution is defined by two parameters  $a$  and  $b$ , which are the minimum and maximum values on the numerical axis, and is often abbreviated as  $U(a,b)$ . Assuming that a certain random variable  $X$  is uniformly distributed between  $(a,b)$  and that  $X$  has the same probability of taking values between  $(a,b)$ , the random variable  $r$ , which is generated according to the uniform distribution in the interval  $(0,1)$ , can be obtained:

$$X = a + r \cdot (b - a) \quad (10)$$

The probability density function of the uniform distribution is:

$$f(x) = \begin{cases} \frac{1}{b-a}, & a < x < b \\ 0, & else \end{cases} \quad (11)$$

The cumulative distribution function is:

$$F(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & x > b \end{cases} \quad (12)$$

Mean:  $\mu = \frac{1}{2}(a+b)$ , variance:  $\sigma^2 = \frac{1}{12}(b-a)^2$

(2) Normal distribution

Normal distribution according to the central limit theorem, in its influence factors in line with the characteristics of mutual independence, randomness, additivity, a large number of mutually independent random variables of the mean, after appropriate standardization according to its distribution converges to a normal distribution. Its probability density function for the normal distribution of the expected value  $\mu$  determines its position, and its standard deviation  $\sigma$  determines the magnitude of the distribution.

The normal distribution when  $\mu = 0, \sigma = 1$  is the standard normal distribution.

The probability density function is:

$$f(x) = \frac{2}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, -\infty < x < \infty \quad (13)$$

Where  $\mu, \sigma (\sigma > 0)$  is a constant, then  $x$  is said to obey a normal distribution with parameters  $\mu, \sigma (\sigma > 0)$ . Denote it as  $X \sim N(\mu, \sigma^2)$ .

The distribution function of  $X$  is:

$$F(x) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^x e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt, -\infty < x < \infty \quad (14)$$

(3) Triangular Distribution

The triangular distribution is a continuous probability distribution with a minimum value of  $a$ , a most likely value of  $c$ , and a maximum value of  $b$ . This is shown in the figure below:

Its probability density function is:

$$f(x) = \begin{cases} \frac{2(x-c)}{(b-a)(c-a)}, & a \leq x \leq c \\ \frac{2(b-c)}{(b-a)(b-c)}, & c \leq x \leq b \end{cases} \quad (15)$$

The distribution function is:

$$F(x) = \begin{cases} \frac{(x-a)^2}{(c-a)(b-a)}, & a \leq x \leq c \\ \frac{c-a}{b-a} + \frac{(x-c)(2b-c-x)}{(b-a)(b-c)}, & c \leq x \leq b \end{cases} \quad (16)$$

Mean:

$$\mu = \frac{a+c+b}{3} \quad (17)$$

Variance:

$$\sigma^2 = \frac{a(a-c) + b(b-a) + c(c-b)}{18} \quad (18)$$

According to the random distribution variable  $r$  in the interval  $(0, 1)$ , the random number of the triangular distribution can be found:

$$x = \begin{cases} a + \sqrt{(c-a)(b-a)r}, & 0 \leq r \leq (c-a)/(b-a) \\ b - \sqrt{(b-c)(b-a)(1-r)}, & (c-a)/(b-a) \leq r \leq 1 \end{cases} \quad (19)$$

## 4. Experiments and Analysis of Results

### 4.1. Example Application Analysis

#### 4.1.1. Background Works

A cross-sea bridge in Guangdong is a key control node in the coastal road and connecting line project, with a total length of 3466.5 m. The main bridge adopts the main span of 160 m continuous girder, with a total length of 322 m, and a span combination of (85+155+75) m. The north approach bridge adopts the standard span of 40 m simply supported and then continuous prestressed precast concrete precast T-beam, with a total length of 936 m, and a span combination of 25 m × 40 m. The south approach bridge adopts the standard span of 50 m simply supported and then continuous prestressed precast concrete precast T-beam, with a total length of 2356.5 m. The span combination of 58 m × 50 m. The south approach bridge adopts standard span 50m simple supported and then continuous prestressed concrete precast T-beam, with total length of 2356.5m and span combination of 58m×50m.

#### 4.1.2. Bridge BIM Model Creation

In this paper, we use REVIT software to create the BIM model of the bridge, the basic unit of REVIT software is a group of tuples-families containing common attribute sets and related graphical representations, such as: basic wall families, structural column families, frame beam families, etc. However, the existing REVIT library is mainly for construction projects, so the BIM model of the bridge needs to use the predefined families provided by REVIT software to complete the creation of bridge component families. However, the existing REVIT family library is mainly for construction projects, therefore, the BIM model of the bridge needs to use the predefined families provided by REVIT software to complete the creation of bridge component families. Combined with the WBS decomposition structure of the cross-sea bridge, this project creates a total of 25 bridge member families, 70 family types, and draws 1,582 family instances.

#### 4.1.3. Volume Statistics

A comparison of the results calculated by the model in this paper with the results of the traditional method is shown in Table 1. Based on the BIM model of the bridge, the volume of the project at any point of time during the construction period can be quickly counted. For example, when the project finished construction, the total concrete square volume calculated using BIM5D was 12901.16 m<sup>3</sup>, while the concrete square volume of the traditional design method was 13040.79 m<sup>3</sup>. The difference between the two was very small.

**Table 1.** The results of this model are compared with the traditional method(m<sup>3</sup>).

Tribe	The Quantity Of The Method In This Article	Traditional Method Engineering Quantity	Error
Box Girder	12901.16	13040.79	-139.63
Cap Beam	3512.2	3521.41	-9.21
Abutment	3101.37	3095.81	5.56
Socket	3088.21	3089.21	-1
Foundation	30200.33	28466.15	1734.18
Top Girder	538.47	559.83	-21.36
Pier	2416.69	2441.96	-25.27
Precast T Beam	18250.59	18149.69	100.9
T Beam Is Now Watered	3198.59	3178.91	19.68

#### 4.1.4. Resource Input Plan

The contract duration of this project is 36 months. Due to space limitation, only the concrete resource input plan for some of the sub-projects is shown. The concrete resource input plan curves for some of the sub-projects are shown in Figure 5.

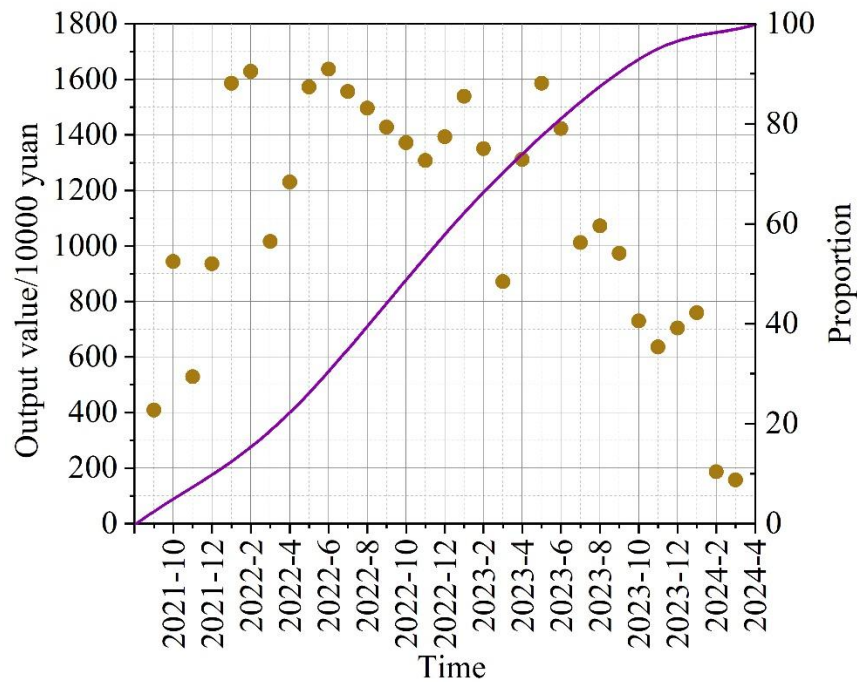


Figure 5. Resource input planning curve for the concrete of some subdivisional work.

#### 4.1.5. Calculation of Earned Value Parameters

Use BIM-5D data model to extract the planned cost, actual cost data of the project. According to the “Construction Ledger of a Cross-Sea Bridge in Guangdong”, the specific time of the construction of each bridge component such as T-girder prefabrication, T-girder erection, cover girder, tie girder, bearing platform, etc. can be attacked, and the actual progress of some sub-projects in 2024 is shown in Table 2.

Table 2. Actual progress of some subdivisional work in 2024.

Pier number and location	Time of binding	Template installation time	Concrete casting time
Right width7#girder	0123~0127	0125	0126
Left width8#girder	0211~0212	0212	0213
Right width8#girder	0210~0212	0211	0211
Left width9#girder	0225	0225	0225
Right width9#girder	0302	0302	0303
Left width10#girder	0408	0411	0412
Right width10#girder	0405	0405	0407

According to a cross-sea bridge in Guangdong BIM model export “component details” can be obtained for each bridge component of the amount of work extracted to the concrete of the pier columns, for example, the amount of work of the pier columns concrete engineering construction. The actual cost of the completed work of some pier column concrete is shown in Table 3.

Table 3. Actual cost of work completed of some part of the pile concrete.

Time	Actual project schedule	C50 concrete quantity/m <sup>3</sup>	Actual unit price/yuan	Actual cost/ 10000 yuan
2024-01	1#-Left width-two	12.65	610	0.75
	1#-Right width-two	15.6	610	0.9
	7#-Right width-two	21.39	610	1.08

Using the same method the ACWP can be calculated for the concrete work of pile foundations, cover beams, tie beams, T-beams, box girders, etc. The budgeted cost of the completed concrete work for some of the sub-projects is shown in Table 4. The budgeted cost of concrete planned work for some

sub-projects is shown in Table 5.

**Table 4.** Part of the project concrete has been completed budget cost.

Time	Concrete type	Budget unit price/yuan	Quantity of engineering/m <sup>3</sup>	Budget cost / 10,000 yuan	total/ 10,000 yuan
2024-01	C40	420	3114.24	147.33	185.14
	C45	550	187.98	9.92	
	C50	580	504.78	27.89	

**Table 5.** Budgeted cost for work scheduled for the concrete of some subdivisional work.

Time	Concrete type	Budget unit price/yuan	Quantity of engineering/m <sup>3</sup>	Budget cost / 10,000 yuan	total/ 10,000 yuan
2024-01	C40	420	4849.89	230.37	269.95
	C45	550	229.11	8.24	
	C50	580	538.42	31.34	

#### 4.1.6. S-Curve Plotting and Parameter Analysis

The budgeted cost of concrete and the actual cost of concrete completed work for the completed work of the bridge from October 2021 to October 2022, combined with the budgeted cost data for the planned work of the project, were plotted as a project S-curve, and the S-curve analysis is shown in Figure 6.

Earned value analysis method is used to calculate the calculation results of cost deviation and duration deviation and other parameters as of October 2022, and the calculation results are compared and analyzed with the actual situation of the project.

The above calculation results combined with the analysis of the actual situation on the construction site show that.

(1) According to the data analysis of a sea-crossing bridge in Guangdong, it can be seen that the cost execution index  $CPI < 1$ , and the cost deviation  $CV < 0$ , and the cost deviation index is 5.7%, which indicates that the project is poorly executed in accordance with the requirements of the project plan, i.e., the project is overspent. The progress execution index  $SPI < 1$  and progress deviation  $SV < 0$  indicates that the project progress is slow and will delay the schedule. Combined with  $BCWP < ACWP < BCWS$ ,  $SV < 0$  and  $CV < 0$ , it indicates that the input of various resources in the actual construction of the project is late, the construction of the project is inefficient, and at the same time, the actual progress of the project is slow compared to the planned progress.

(2) When the construction of the project proceeds to the end of October 2022, the actual cost of the completed work is 27,516,200 yuan, and the completed planned cost is 25,890,000 yuan, and the difference between the two is 1,626,200 yuan. After analyzing the actual situation at the site, it is found that due to insufficient scientific management, inadequate preparation for material procurement, insufficiently accurate market expectations, failure to make purchases at a reasonable time, and a high rework rate due to the impact of price fluctuations and lack of rigorous construction management, the corresponding cost is increased.

(3) The earned value curve shows that the earned value of the project as of the end of October 2022 is 2756.29 million Yuan, which is delayed compared with the schedule. By analyzing the records of the construction process, it was found that the project encountered greater resistance in communicating and coordinating the land acquisition work with the local government in the early stage of the project, which led to a delay in the entry of machinery and equipment into the site. In March 2022, there was a change in the operation team, which led to a delay in the construction schedule. In April 2022, due to the slow hole formation of the main pier pile foundation due to the high strength of the rock strata, additional portions of the pile foundation were not utilized in conjunction with rotary drilling. The approach bridge increased the late entry of the drilling rig, long preparation time for drilling, and insufficient personnel in the steel team. The drilling platform and individual work surfaces of the support trestle were not provided in time, and the steel trestle work team was understaffed and under-equipped, which led to delays in the work schedule. In May 2022, some of the drilling rigs suffered mechanical failures that took an inordinate amount of time to repair, causing delays in the schedule. In June 2022, due to the long time of T-beam formwork modification, the late entry of raw steel and bearing steel plates, and discontinuous steel processing operations, the schedule was delayed. In July 2022, the prefabricated girder yard steel shed collapsed and the girder transportation channel was opened late, which affected the prefabrication and erection of T-beams and led to the schedule delay. Adverse weather conditions, such as typhoon days,

were also a major cause of the project's schedule delays.

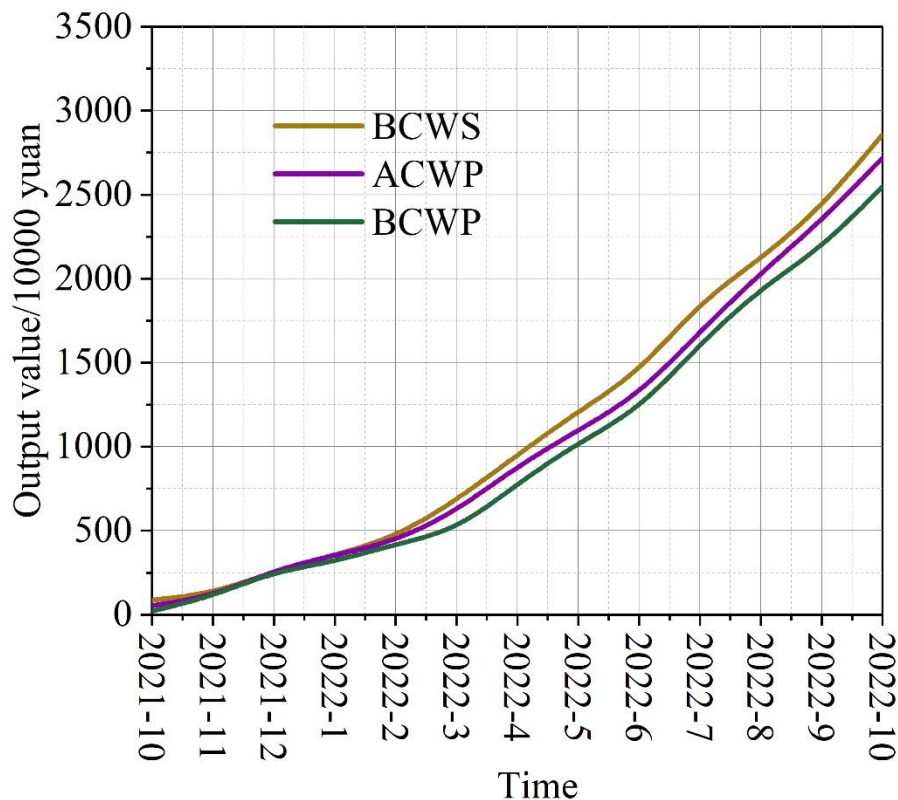


Figure 6. Analysis of S curve.

#### 4.2. Comparative Analysis of Simulation Results

The number of simulation experiments in this section is set to 1000. This number of simulation times is set with reference to other critical chain project management research literature, and it is considered that 1000 times of Monte Carlo simulation experiments can be carried out to meet the accuracy requirements of engineering progress simulation.

Combined with the engineering project management method of BIM5D technology, the simulation experiment simulates a total of four scenarios, which are set as follows.

Scenario 1: Adopting the original duration size of the project process, without deducting the safety time, without considering the impact of resource conflicts, and because the actual construction process has a certain possibility to exceed its planned process time.

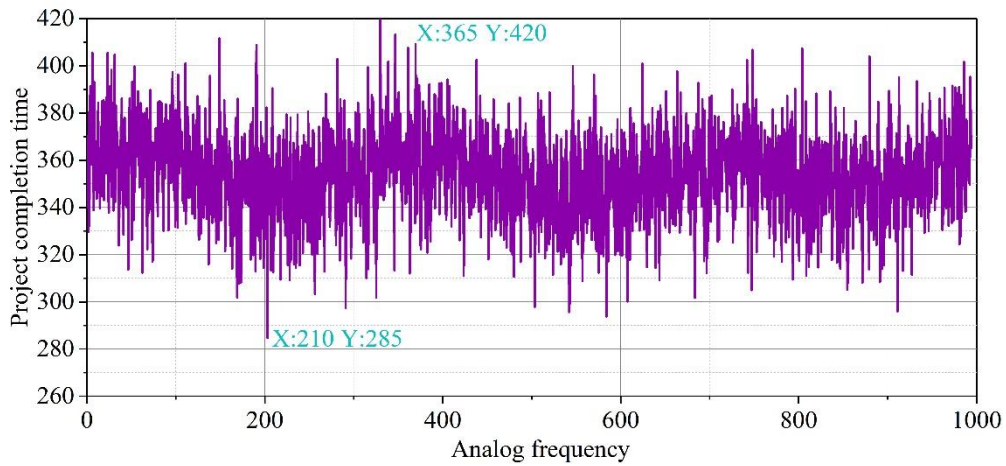
Option 2: Adopting the duration of the project process after deducting the safety time, without considering the influence of resource conflict.

Option 3: Adopt the duration size of the project process after deducting the safety time, and consider the impact of resource conflicts, but do not insert a buffer to protect the project.

Scenario 4: Adopt the duration size of the project process after deducting the safety time, and consider the impact of resource conflicts, while inserting a buffer to absorb the project uncertainty to ensure the normal progress of the project schedule.

##### (1) Simulation experiment results of Scheme I

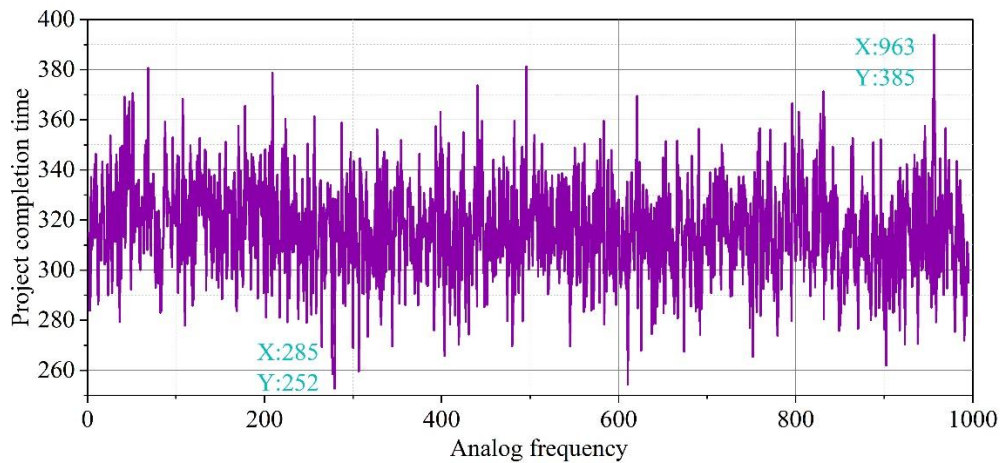
In the case of the duration of the simulation based on the method of this paper, the project completion time calculated using the critical path method is 230 days, using the method of this paper to simulate the size of the duration of the process, the average completion time of 356.33 days, the shortest completion time of 285 days, the longest completion time of 420 days, and its on-time completion rate of 1.2%. The simulation of the completion time of Option 1 project is shown in Fig. 7.



**Figure 7.** Project completion time simulation.

(2) Results of simulation experiments of Scheme II

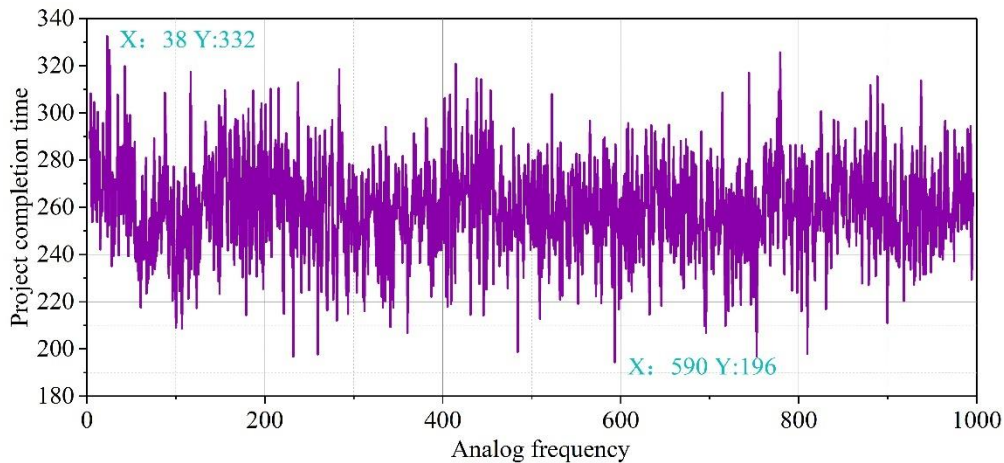
Without the simulation of the duration based on the method of this paper, the project completion time calculated using the critical path method is 178 days, and after the simulation of the size of the process duration using the beta right-skewed distribution, the average completion time is 315.41 days, the shortest completion time is 252 days, and the longest completion time is 385 days, and its on-time completion rate is 0%. The simulation of the project completion time for Option 2 is shown in Figure 8.



**Figure 8.** Project completion time simulation.

(3) Results of simulation experiments of Scheme III

Without simulation of the duration based on the method of this paper, i.e., according to the size of the process duration after removing the safety time, the calculated project completion time is 236 days, while after simulation of the size of the process duration using the method of this paper, the average completion time of the project is 272.55 days, the shortest completion time is 196 days, and the longest completion time is 332 days, with an on-time completion rate of 2.3%. The simulation of project completion time for option 3 is shown in Fig. 9.



**Figure 9.** The completion time simulation of the plan.

(4) Results of simulation experiments for Scenario IV

The simulation process of Scenario 4 is the same as that of Scenario 3, except that a buffer is added to improve the completion rate of the project. After adding the buffer, the project completion period is 310 days, the on-time completion rate is 99%, and the consumption of each buffer is shown in Table 6.

The reason for the very small on-time project completion rates for both Scenario 1 and Scenario 2, where it is almost impossible to complete the project on time, is obviously because resource conflicts are not taken into account in the scheduling of the project, which makes it difficult to complete the project on time. However, the average completion time of the project of Program 2 is 315.41 days, compared with Program 1, the average completion time of the project is shortened by 40.92 days, which is mainly due to the reduction of the safety time of the process of Program 2, to a certain extent, reduce the psychological factors and adverse behavioral factors on the duration of the process caused by the impact of the project completion time is reduced. And from the scheme four itself to analyze, from the table can be seen, according to the method of this paper to calculate the project buffer consumption is more appropriate, the buffer overflow ratio is also within the appropriate range, the buffer can actually achieve the role of the project's protection, so that the project on time completion rate of 99%. Therefore, the project schedule after adding the buffer is practically feasible in reality.

On the whole, the on-time completion rate of Program 1, Program 2 and Program 3 is extremely low, but only the on-time completion rate of Program 4 reaches 99%, which indicates that a reasonable progress planning, the reduction of process safety time, the deployment of resources between processes and the critical chain buffer should be considered, in order to get a realistic, practical guidance for the construction of the progress plan.

**Table 6.** Buffer consumption.

Buffer type	PB	PB <sub>1</sub>	PB <sub>2</sub>	PB <sub>3</sub>	PB <sub>4</sub>
Average buffer rate	49%	41.8%	27.8%	37%	27.2%
Buffer overflow rate	3.6%	14.4%	13.1%	26.7%	29.7%

## 5. Conclusion

Construction project visualization management is a professional service that provides project owners with effective management of project schedule, cost, quality, safety, scope and functionality. Based on the basic principles of digital twin technology, this article studies the digitalization method of construction project management based on digital twin, and explores the advantages and applicability of this article's method through case studies. The conclusions drawn by the article are as follows:

(1) Through the experiments of quantity statistics, it is found that the total concrete square volume calculated based on BIM5D and the earned value method is 12901.16m<sup>3</sup>, while the concrete square volume of the traditional design method is 13040.79m<sup>3</sup>, which is a very small difference between the two. This shows the applicability of the method of this paper.

(2) In Monte Carlo simulation experiments, through the simulation of the four programs, it is found that the on-time completion rate of the projects in Program 1, Program 2 and Program 3 is extremely low, and the on-time completion rate of the projects in Program 4 reaches 99%, which shows that a reasonable schedule planning, cutting the safety time of the process, allocating the resources between the processes and the buffer of the critical chain are indispensable.

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