Research Article

Analysis of BIM in the Whole-Process Cost Management of Construction Projects

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In order to improve the quality of project cost management, this paper uses BIM technology to analyze the whole-process project cost to improve its management effect, uses the method of digital processing nuclear pulse signal to conduct simulation analysis, and conducts preliminary simulation. Moreover, this paper discusses the characteristics of cost management data, analyzes the process of BIM in the whole-process cost management of construction projects, and analyzes the possibility of using pulse digital method to improve stability. In addition, this paper constructs the whole-process cost management of engineering projects based on BIM. Through the experimental research, it is verified that the whole-process cost management system based on BIM constructed in this paper has a good effect and can effectively improve the quality of cost management of construction projects.

1. Introduction

The construction of engineering material price informatization will involve a series of contents such as material price information collection, data analysis and processing, and material price prediction theory and model research. When researching these contents, it is necessary to collect a large amount of data and conduct qualitative and quantitative analysis based on certain theoretical knowledge and with the help of scientific research methods. Therefore, it is necessary to conduct a research review from the two aspects of literature research and application research and collect and study the current information on project cost and material price and application. At the same time, it is necessary to learn from advanced engineering cost informatization construction experience and scientific research methods related to information collection, data processing, information prediction, etc., so as to achieve the purpose of improving the accuracy of material price information [1].

Some scholars have discussed the content and function of the cost database at the theoretical level. The research believes that the cost database is to decompose the collected cost data according to the index dimension, so as to provide decision support for the early stage and development of the project [2]. According to the research, the project cost database is composed of cost index database, material price database, bid evaluation committee, and credit archive database [3]. The cost database is a management system, which can be divided into multiple modules, and describes the design and establishment steps of each module in detail, including price database, project database, cost index database, enterprise quota database, and query module [4]. Some scholars also want to describe the composition and implementation method of cost database. However, due to the insufficient collection of data samples of completed projects, their research depth was hindered [5]— according to the project cost index and construction standard, plan the function scheme of the cost database [6]; Compared with the enterprise cost, according to the data status and the actual needs of the enterprise, the project cost database management system is constructed by using the structured method to help the construction enterprise predict the bidding project cost, give full play to the value of the project cost, and complete the project cost data [7]. The whole-process management of engineering cost should be based on the centralized management and collaborative management of information at each stage. The sharing and circulation of cost

information in the whole process can be realized by integrating the cost index analysis system, enterprise database, construction of bill of quantities, and other subsystems [8]. Based on the theoretical basis of dynamic cost management, this paper expounds the application of cost database in decision-making and bidding links [9]; on the basis of the technical parameters and cost indicators of the existing cost database, the management method of the installation project cost database is mainly analyzed, and an example analysis was carried out [10].

In practice, rules are frequently changed and new constraints are added to the original rules, and the actual classification effect is also unsatisfactory. The rule base that costs a lot of manpower and time can only be applied to some classification projects with a large sample size; there are a large number of unclassifiable cases in practical applications, which all reflect the limitations of traditional methods [11]. Reference [12] learned that a relatively advanced classification rule base system in the industry will generate about 20% to 30% of unclassified lists in the process of classifying lists in a project cost document. Reference [13] assumes that the system can The results of the classified list are all correct; that is, the accuracy rate is up to 80%, which is used to measure the effectiveness of several methods. After analyzing the idea of the rule matching method, we still focus on the main list attributes of concern to the traditional rule matching method, but the main list attributes are extracted as a whole rather than a combination of several attributes, and the text classification method based on machine learning is used. System intelligent finds the degree of correlation between text features and each category label, gives the predicted classification label of the list in the form of realiability, and can use the entire training sample set as a reference for classification, avoiding the limitations caused by manual labor. It has more reference value and saves a lot of manpower and time costs, and the accuracy rate is also improved. It is a better standardized classification method than the traditional rule matching method [14].

The massive heterogeneous data owned by the cost data management and analysis system contains a lot of information, which is the basis for cost management and decision-making. Integrating cost engineering data resources, building a cost data warehouse, and developing reports and risk warning systems on this basis are the keys to improving cost data management and analysis efficiency. However, it is also possible that a large amount of dirty data exists in the data warehouse system. The main reasons for dirty data are misuse of abbreviations and idioms, different units of measurement, missing values of words, data entry errors, spelling changes, duplicate records, outdated encoding, etc. [15]. Even if the design and planning of the data warehouse system are complete, if there is a lot of dirty data in the system, then the data warehouse system is still meaningless; because the data of this system is garbage data, the result is the output of garbage data that cannot be effectively dealt with; that is, the system is a "garbage in, garbage out" system. Therefore, in order to effectively remove dirty data, the data must be cleaned reasonably in the data warehouse system [16].

The data cleaning process of the cost data management and analysis system must meet the following conditions: First, whether it is a single data source or multiple data sources, all obviously inconsistent data information or errors in the data source are required to be detected. Second, try to reduce the amount of manual operations and procedures, and the data source is required to be easy to expand and add. Third, data cleaning should be combined with data transformation. Fourth, there should be corresponding rules for data conversion and data cleaning [17].

The underlying reason for the trend of big data is that more and more things exist in the form of data. In the field of engineering construction, whether it is a quota, an estimated index, or a bill of quantities throughout each stage of the project construction, the cost information related to the project is all in the form of data. The form can be transformed and expressed and can be analyzed using tools such as computers. Project cost information refers to the integration of all project-related cost characteristics, states, and information about their changes. Its content includes various quota data, specifications, national policies, and decrees. Estimated indicators, estimated budget quotas, and other technical and economic indicators and parameters, as well as the basis for studying the trend of project cost changes, are the basis for compiling and reviewing project proposals and feasibility study reports, comparing and selecting design schemes, compiling design estimates, and bidding quotations from contractors. The management of power grid project cost information refers to the process of collecting, processing, storing, analyzing, publishing, and feeding back cost information [18].

The cost index information of various projects contains unique cost information and general cost laws, which can provide a basis for the cost estimation of proposed projects or projects under construction. By processing the collected historical cost data of completed projects according to the project construction stage, the project cost indicators of subcomponent projects, unit projects, and even single projects can be obtained. The project cost of the construction project is calculated, and the individual or comprehensive project cost index is calculated. Whether it is a data sharing platform or a cost prediction system, it is based on a large amount of data provided by all parties involved in the project. Based on the massive and complete data reserve, the database of the completed project is used to predict the cost index, and the cost information is analyzed. Systematic analysis can realize the effective management and interactive use of "big data" and achieve the benefit sharing of all parties involved in the project [19].

This paper uses BIM technology to analyze the whole-process project cost to improve its management effect and promote its refined management.

2. Digital Processing Simulation and Cost Data Signal Simulation

2.1. Digital Simulation of Signals. Due to the existence of various interference factors in the actual measurement system, noise signals will be superimposed on the actual measurement signal. We use random functions to simulate noise and construct a single digital nuclear engineering cost data signal in the form of (1). The simulation effect is shown

in Figure 1. The noise in (1) adopts a fixed noise level, and the method of proportional noise can also be used as shown in (3).

$$I = \begin{cases} 0 \, (i = 1 \sim 200), \\ 2000 \times e^{((200-i)/100)} + 200 \times (0.5 - \mathrm{Rnd}\,(i))\,(i = 201 \sim 2048). \end{cases} \tag{1}$$

The generation of random signals can also be generated by the design method of the mixed congruence method, and the actual simulation effect is also very ideal. The basic algorithm is shown in (2), and the output $X\,(i)$ is a random number between 0 and 1.

$$X\,(i) = (K \times X\,(i-1) + C)\bmod M,$$
$$X\,(i) = \frac{X\,(i)}{M}. \tag{2}$$

Among them, $K = 2045$, $C = 1$, $M = 32768$, and $X\,(0)$ can be set arbitrarily.

Using the pseudorandom number $R\,(i)$, we design $y\,(i) = 200 \times R\,(i) + 1000$ $(i = 1 \sim 4096)$ and get the amplitude distribution as shown in Figure 2 and the amplitude spectrum as shown in Figure 3.

The continuous digital nuclear engineering cost data signal is generated by (3), the engineering cost data signal is digitally shaped, then the pulse amplitude is analyzed, and the pulse amplitude spectrum as shown in Figure 4 is obtained. In the experiment, S–K digital forming and triangle digital forming are mainly adopted. The results show that the distribution of pulse amplitude basically conforms to the normal distribution and the resolution reaches 6.64%.

$$I = \begin{cases} 0 \, (i = 1 \sim 49), \\ 2000 \times e^{((50-i)/100)} + 600 \times (0.5 - \mathrm{Rnd}\,(i))\,(i = 50 \sim 128), \end{cases} \tag{3}$$

2.1.1. S–K Forming Digital Simulation Method. By modifying the calculation model of the single nuclear engineering cost data signal (as shown in (4)), the change ratio of the noise and the signal is made consistent. In the analog system, S–K shaping 1S can improve the S/N of the signal, which may change the amplitude distribution of the pulse, so the S–K distribution signal as shown in Figure 5 can be obtained by digital S–K shaping of the original pulse. The formula of digital S–K forming is shown in (5), and the circuit model of digital S–K forming is shown in Figure 6. By analyzing the pulse amplitude of the digital pulse after digital S–K shaping, the Gaussian pulse amplitude spectrum whose distribution conforms to the normal distribution as shown in Figure 7 is obtained. The resolution of the amplitude spectrum is 3.73%. Since the noise in the original signal is much reduced, there are no interfering peaks in the calculated spectrum.
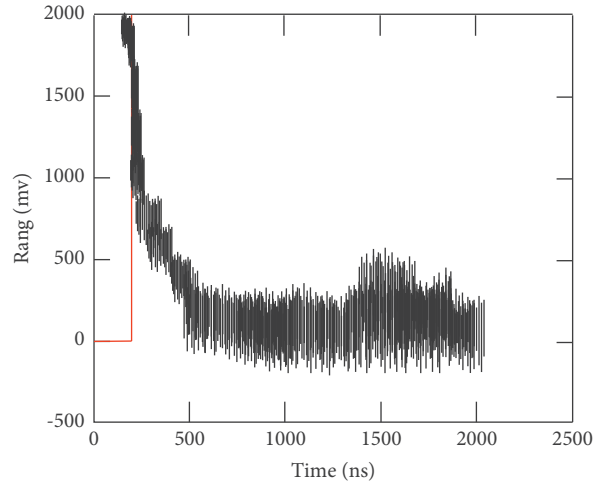

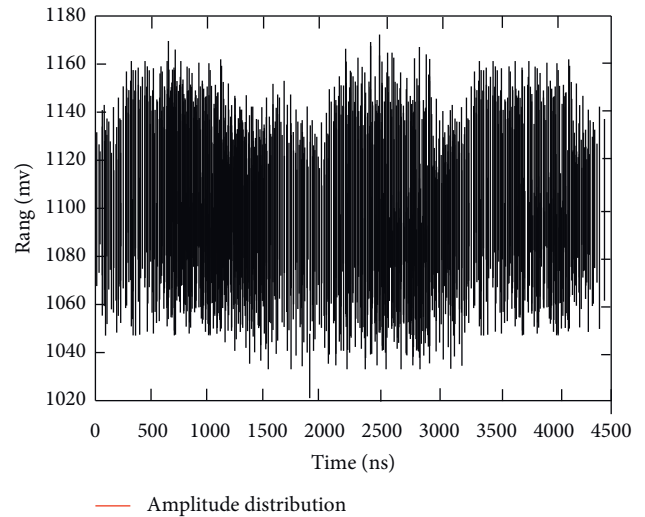Figure 1: Simulation of a single nuclear signal.

Amplitude distribution

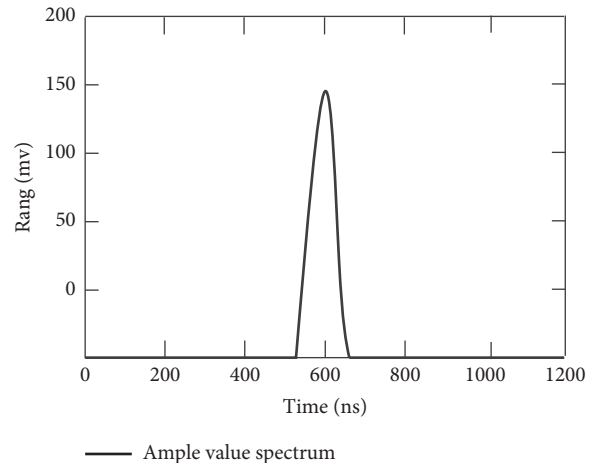Figure 2: Amplitude distribution diagram.

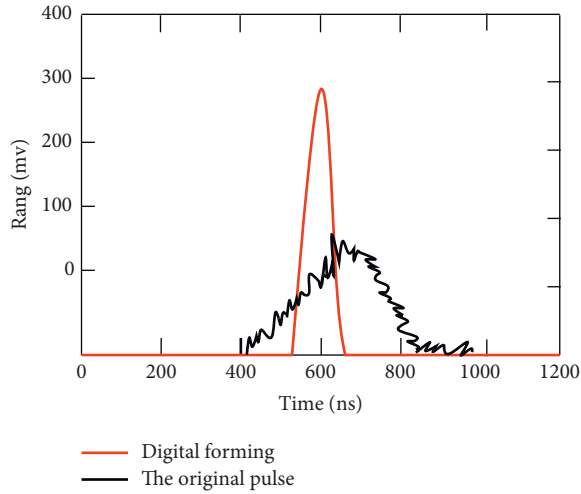Ample value spectrum

Figure 3: Amplitude spectrogram.

FIGURE 4: Amplitude spectrum distribution of analog and digital engineering cost data signal (1024 channels).
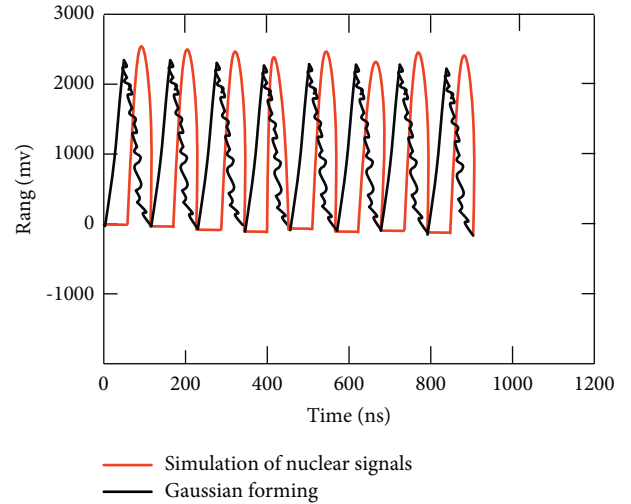

FIGURE 6: Signal simulation and digital $S–K$ forming results of continuous nuclear engineering cost data.
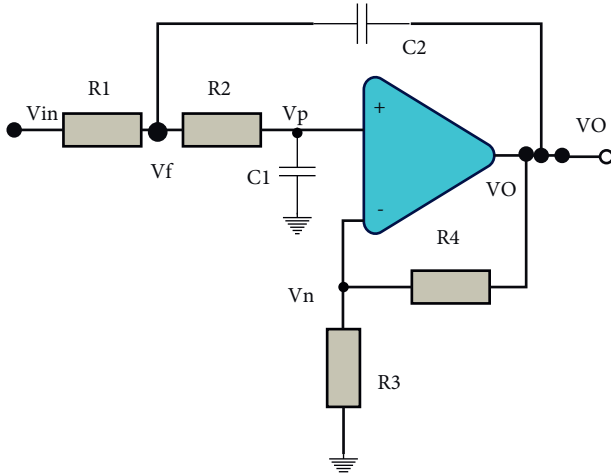

FIGURE 5: Circuit model diagram of digital $S–K$ forming.

FIGURE 7: Amplitude spectrum distribution of analog and digital engineering cost data signal (original signal + digital $S–K$ shaping).

experimental data show that the noise level is an important factor affecting the signal amplitude resolution of the nuclear engineering cost data. The size of the noise depends on the detector itself and subsequent circuits. Therefore, in the simulation process, the amplitude distribution of the output digital engineering cost data signal can be determined by adjusting the noise level, so as to realize the signal simulation of different types of detectors with different resolutions.

$$y_1 = 1000 \times e^{((50-i)/20)}. \tag{6}$$

$$y_1 = 600 \times e^{((50-i)/20)} \, (i = 50 \sim 128),$$

$$y_2 = \begin{cases} 0 \, (i = 0 \sim 49), \\ 2000 \times e^{((50-i)/20)} + y_1 \times (0.5 - \mathrm{Rnd}\,(i)) \, (i = 50 \sim 128) \end{cases} \tag{4}$$

$$y_n = \frac{\left(k + 2k^2\right) \times y_{n-1} - k^2 \times y_{n-2} + 2x_n}{1 + k + k^2}, n > 0,$$

$$y_n = 0, n \le 0. \tag{5}$$

The noise level in the signal is increased, as shown in (6), the signal still adopts (3), and the above steps are repeated to obtain the Gaussian pulse amplitude spectrum distribution shown in Figure 7. The pulse amplitude spectrum also conforms to the normal distribution, the resolution of the amplitude spectrum is reduced to 6.22%, and there is no interference peak. The
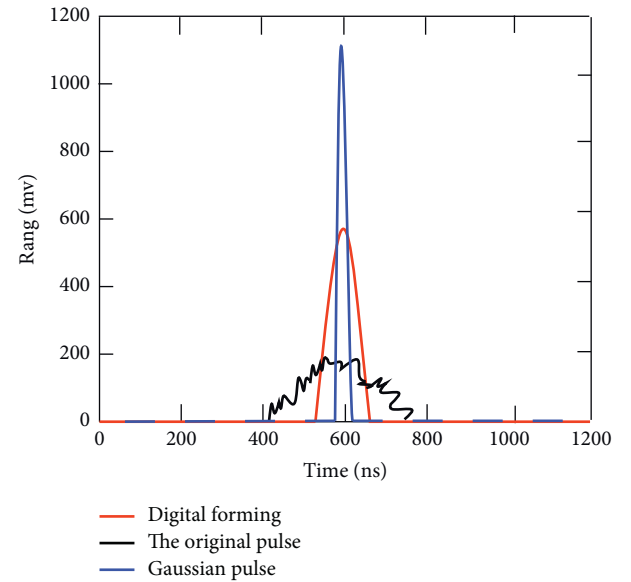
2.1.2. Digital Simulation Method of Triangle Forming. Triangular digital shaping can also improve the S/N of the nuclear signal, potentially changing the amplitude

distribution of the pulses. Therefore, the original pulse simulated by the (4) is calculated by the triangular digital shaping (7)–(9), and the triangular-shaped pulse as shown in Figure 8 can be obtained. As with S–K digital shaping, the digital pulse after triangular digital shaping is subjected to pulse amplitude analysis to obtain the triangular pulse amplitude spectrum (triangular pulse) as shown in Figure 9. The results show that the pulse amplitude spectrum also conforms to a normal distribution and that the resolution of the amplitude spectrum is 1.18%, which almost has the same effect as the digital S–K shaping. Further, the level of noise is modified to (6), resulting in a triangular-shaped pulse amplitude spectrum (triangle 1) with a reduced resolution of 5.95% in Figure 9. At this point, no interfering peaks appear, and the output signal of most detectors can be simulated very well.

$$d^{k,1}(j) = v(j) - v(j-k) - v(j-1) + v(j-k-1), \quad (7)$$

$$p'(n) = p'(n-1) + d^{k,1}(n), \, n \geq 0, \quad (8)$$

$$s(n) = s(n-1) + p'(n) + d^{k,1}(n)M, \, n \geq 0. \quad (9)$$

In a word, through digital simulation, whether it is a single project cost data signal or a continuous project cost data signal, using digital S–K filter to process the continuous nuclear engineering cost data signal with random noise can convert the analog nuclear signal that does not conform to the normal distribution into the nuclear engineering cost data signal that conforms to the normal distribution. Moreover, the signal simulation of different types of detectors with different resolutions is realized by adjusting the level of noise, and the signal simulation effects for detectors with different resolutions are basically the same.

2.2. Application Research of Digital S–K Filter in Nuclear Signal Processing. The low-pass S–K filter is numerically analyzed; four nodes (nodes 1~4) are marked in Figure 5; and the corresponding voltages V_f, V_p, V_n, and V_o are, respectively, identified. According to the KCL (Kirchhoff Current Law) and so on, four transfer formulas such as (10)–(13) can be established:

$$\frac{(V_{in} - V_f)}{R_1} = \frac{(V_f - V_p)}{R_2} + C_2 \times \frac{d(V_f - V_o)}{dt}, \quad (10)$$

$$\frac{(V_f - V_p)}{R_2} = C_1 \times \frac{dV_p}{dt}, \quad (11)$$

$$V_n = V_o \times \frac{R_3}{R_3 + R_4}, \quad (12)$$

$$V_n = V_p. \quad (13)$$

In the above formulas, we take $R_1 = R_2 = R$, $C_1 = C_2 = C$, and $(R_4 + R_3)/R_3 = a$.

After combining (10)–(13), we first write the input signal and output signal as a digital sequence $x(n)$, and then write it
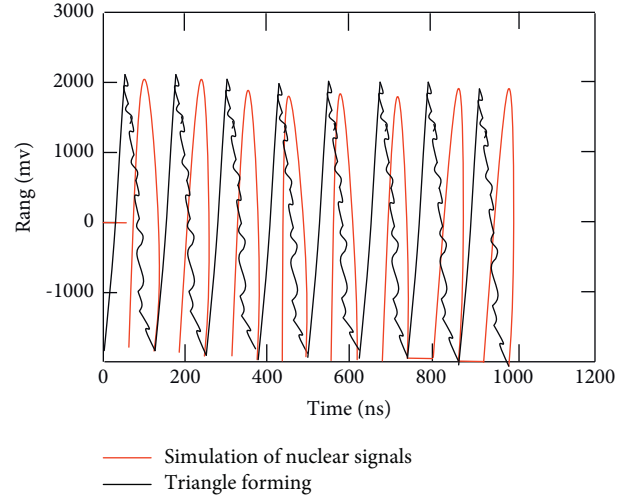

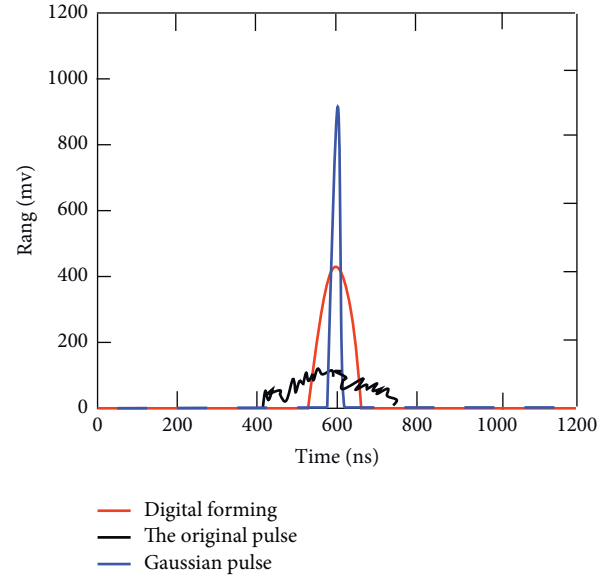FIGURE 8: Signal simulation and digital triangulation results of continuous nuclear engineering cost data.

FIGURE 9: Amplitude spectrum distribution of analog and digital engineering cost data signal (original pulse + triangular shaping).

in the form of digital differential: select $dt–At$, and set $(R \times C/\Delta t = k)$. By derivation, the form of digital recursion of (14) and (15) can be obtained.

$$y_n = \frac{(k \times (3-a) + 2k^2) \times y_{n-1} - k^2 \times y_{n-2} + sx_n}{1 + k + k^2}, \, n > 0, \quad (14)$$

$$y_n = 0, \, n \leq 0. \quad (15)$$

To sum up, the digital S–K shaped output signal of nuclear engineering cost data signal can be realized by recursive calling of (14) and (15). Among them, k and a represent the adjustment parameters of the S–K shaping output signal, and adjusting k and a can, respectively, adjust the pulse width and pulse amplitude of the output Gaussian

waveform. Therefore, k is defined as the frequency filter factor, and a is defined as the amplitude filter factor.

A random noise signal (amplitude is 0~500, which is implemented by the random number generator function in Matlab) is superimposed on the original sinusoidal signal (amplitude is $-1000\sim +1000$, and 360 points are one cycle) as input signal. After adjusting the filter parameters, the output signal is obtained (the more suitable filter parameters are $k = 25$, $a = 1.15$), and the output signal has a phase shift, as shown in Figure 10.

A random noise signal is superimposed on the ideal negative index input signal, so that the simulation effect is closer to the real nuclear engineering cost data signal. It is easier to analyze the improvement effect of the digital $S–K$ filter on the S/N of the digitally shaped signal with noise, thereby improving the simulation effect in the literature. As shown in Figure 11, the input signal with negative index has $r = 50$, the maximum value is 2000, the noise is a random number between -100 and $+100$, and the SN of the input signal is 10 db. After being shaped by digital $S–K$ filter ($k = 40$, $a = 2$), the SN of the output signal reaches more than 30 db. This is consistent with the performance of the analog low-pass $S–K$ filter, which shows that the digital low-pass $S–K$ filter can improve the signal quality with small SN.

Because the nuclear spectrum measurement has certain statistical fluctuation characteristics, the original spectrum data obtained by the instrument is not very smooth, and there will be some burrs. The pulse amplitude spectrum obtained by inputting a nuclear pulse with very good smoothness also has this characteristic. Therefore, smoothing must be performed on the spectral data. In the smoothing method of nuclear spectrum data, multipoint (such as 5-point) smoothing is generally used in the early days. In recent years, new methods such as FFT transform filtering, Kalman smoothing filtering, and wavelet smoothing filtering have been adopted. Figure 12 is the processing effect of the digital $S–K$ filter on the Cs-137 spectral measurement data. The k value and the a value are continuously adjusted by analog calculation, and finally a satisfactory value is obtained. The calculated raw spectral data is the raw spectral data of Cs-137 measured by a high-precision lithologic density logging digital energy spectrum measurement system (without data processing). The instrument uses a NaI (Tl) scintillation detector with MCA of 256 channels.

To specifically analyze the effect of smoothing, we mainly analyze the smoothness of spectral data and changes in the resolution of spectral data.

Because Kalman smoothing filtering and wavelet smoothing filtering are more complicated to calculate, they are generally analyzed by a software tool (such as Matlab, OriginLab). Therefore, digital $S–K$ filtering, FFT filtering, and multipoint smoothing filtering are generally used in practical applications.

For the change of spectral line smoothness, the smoothness of the peak tail part is analyzed by intercepting the spectral data of 250–750 channels, and the effect of fitting the curve using a quartic polynomial is shown in Figures 13(a)–13(c).
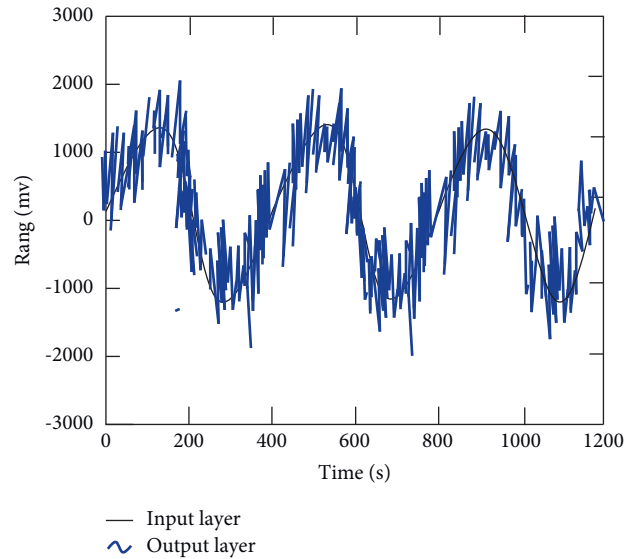

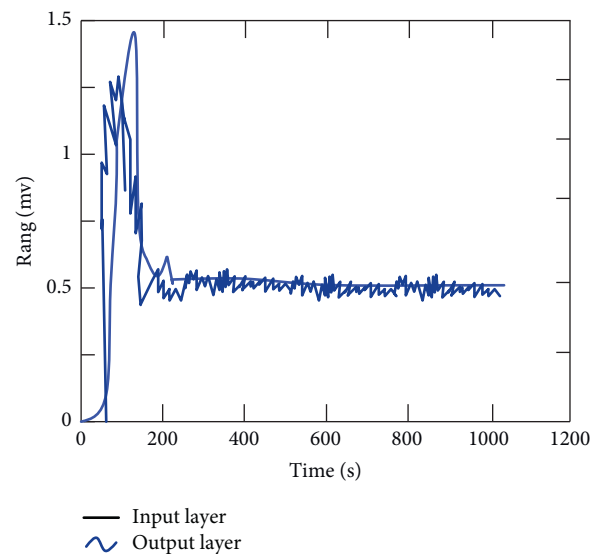FIGURE 10: The effect diagram of $S–K$ filter processing data.

FIGURE 11: Digital shaping simulation of nuclear engineering cost data signal.

In addition, the algorithm of the digital $S–K$ filter uses data processing from left to right. Because of the problem of the iterative algorithm itself, the subsequent output results are all shifted backwards, as shown in Figure 13. By improving the algorithm, all the filtered output data can be shifted to the left by the number of offset channels, and the previous corresponding offset data can be discarded. The post-offset data is set to zero to overcome the spectral peak shift problem of the $S–K$ digital filter for spectral line smoothing.

In a word, the digital $S–K$ filter can be applied to the real-time processing of nuclear engineering cost data signals by improving the digital $S–K$ filter by using the differential method. Moreover, it can also be applied to the smoothing of spectral data of nuclear spectrum measurement, and it shows its certain superiority in real-time data processing of nuclear
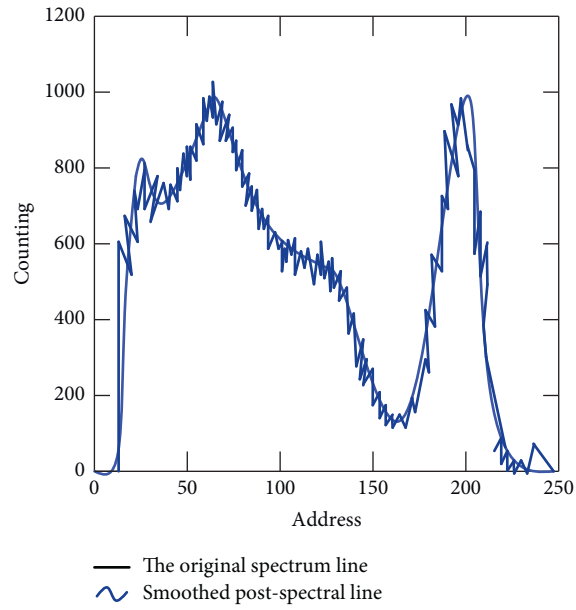
Figure 12: Cs-137 spectrum processed by S–K digital filter.
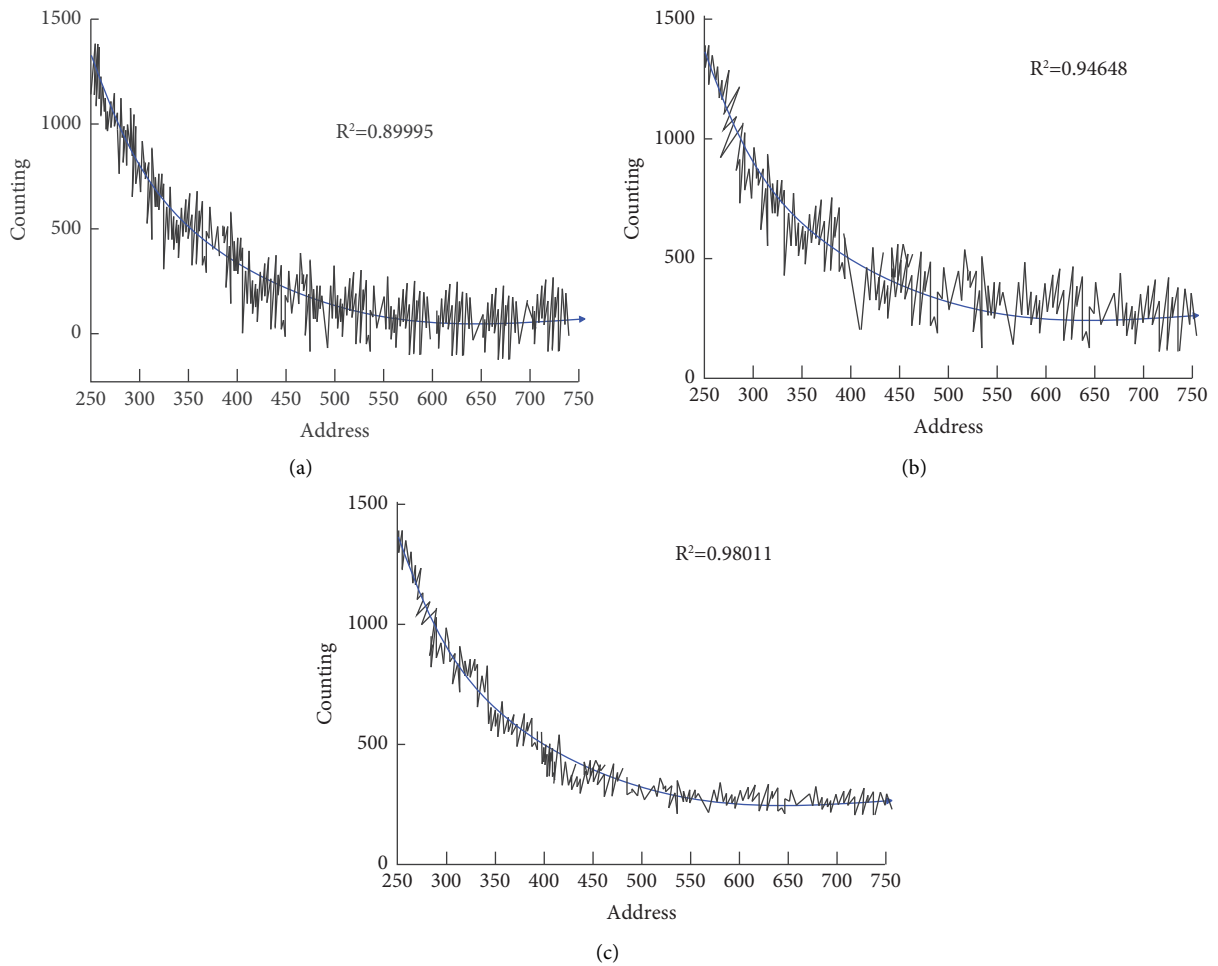

(a)

(b)

(c)

Figure 13: Filtering effect: (a) no smoothing filter effect; (b) 5-point smoothing filter effect; (c) S–K filtering effect.
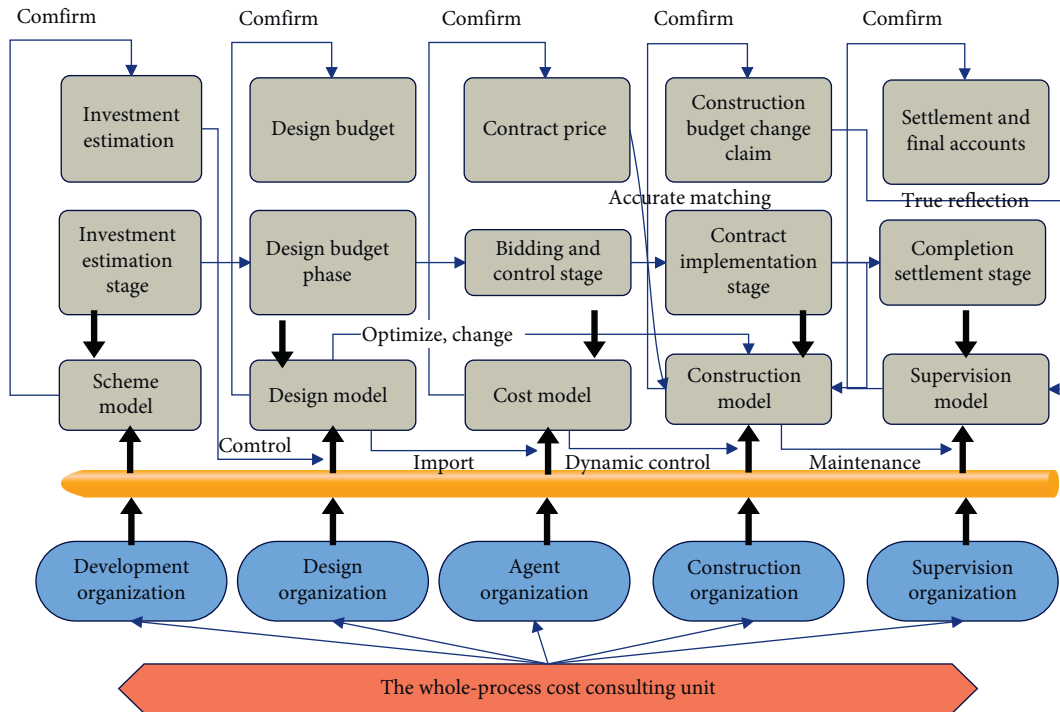
FIGURE 14: The whole-process cost consulting information management environment based on BIM technology.

spectrum measurement, which forms a relatively complete digital S–K filter.

3. The Whole-Process Cost Management of Construction Project Based on BIM Technology

The whole-process cost consulting information management environment based on BIM technology is shown in Figure 14.

In the investment estimation stage of the whole-process cost consultation process based on BIM technology, firstly, the whole-process consultation unit no longer communicates with some or a certain participant alone, but communicates and coordinates information with the participants based on the collaborative management platform. The parties are no longer only involved in a certain stage of the construction project. For example, the design unit no longer only participates in the design of the project but, based on the collaborative management platform, comprehensively sees the feedback information of all parties involved. Moreover, it adjusts and revises the design model in a timely manner, continuously optimizes the model, and reduces changes in subsequent stages, which plays an important role in reducing the cost of rework changes. Secondly, in the cost consulting management environment, based on investment estimates, contract prices, construction budget changes, claims, settlement decisions, sub-construction plan models, design models, cost models, construction models, and as-built models are designed. Based on the model, the cost management and control of different stages can be clearly compared with the technical and economic indicators of each stage, which plays a good role in

cost control. Thirdly, according to the investment estimate determined by the scheme model, the design model can be controlled when the model is built, and then the design budget can be reasonably determined. The design model is imported into the cost model, then the construction is simulated, and the construction model can be reasonably determined. The optimization and change of the design model can be reflected in the construction model in time, which greatly reduces the double accounting of costs. The cost model can reasonably control the contract price, and the construction model can accurately match the contract price. Finally, the construction model meets the needs of the builder and plays a good guiding role in the later operation and maintenance. Due to the comprehensive information of claims and other information in the construction stage, the as-built model truly reflects the final accounts of the project. The whole-process cost realizes the smooth communication and application of information.

BIM can provide great help for each stage of the whole-process cost consulting business of construction projects, improve the effectiveness of business processes at each stage, predict unreasonable projects, and greatly reduce project physical and virtual costs. An example of project cost management using BIM technology is shown in Figure 15. Therefore, it is of far-reaching significance to apply BIM to the information environment required for the development of project business processes. The information sharing platform built by BIM can keep dynamic contact at all stages of the whole-process cost consulting business of the construction project, which is beneficial to control the total cost of the entire construction project and improve the investment efficiency of the entire project.
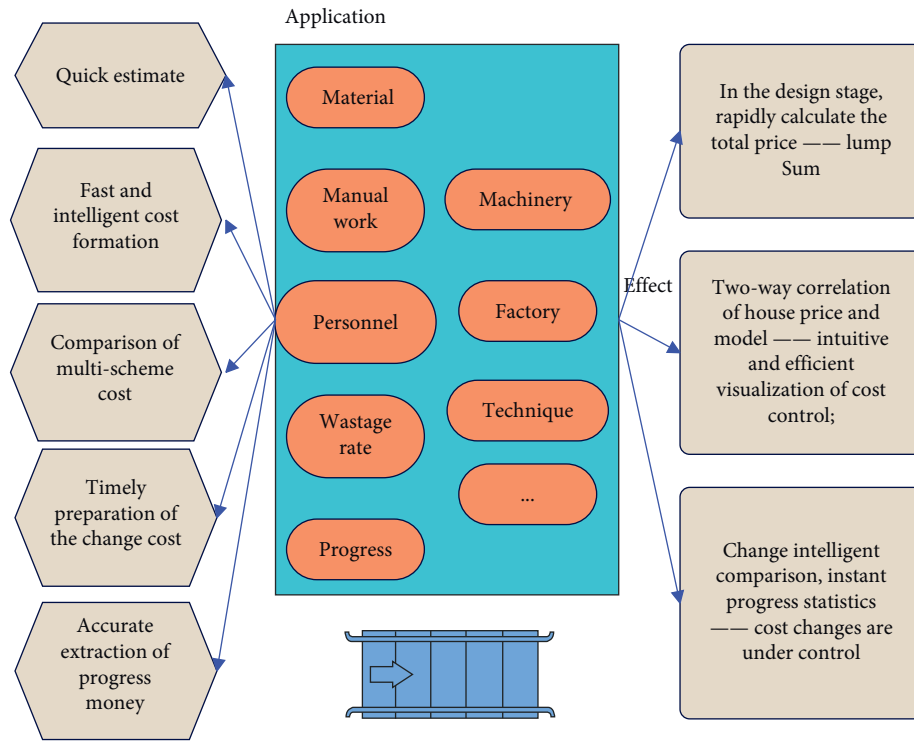
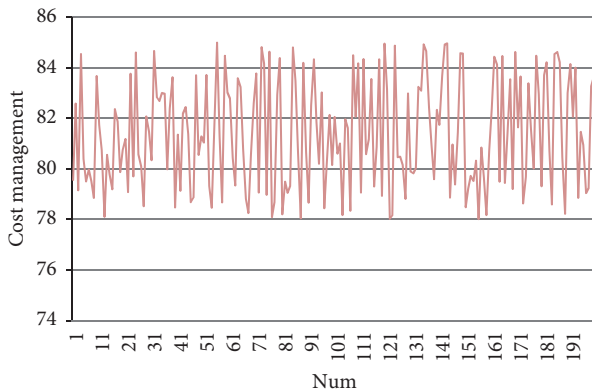FIGURE 15: Example of project cost management using BIM technology.

FIGURE 16: Effect verification of the whole-process cost management system of construction projects based on BIM.

After constructing the whole-process cost management system of construction project based on BIM, the effect of the system is verified. In this paper, multiple sets of construction data are combined to perform system verification, and the test results shown in Figure 16 are obtained.

Through the above research, it is verified that the whole-process cost management system based on BIM constructed in this paper has good effects and can effectively improve the quality of cost management of construction projects.

4. Conclusion

At present, the standardized classification of engineering cost list mainly relies on a rule-based matching method. In this method, the cost list is regarded as the sum of several

attributes, and the commonality of the attributes of similar lists in the historical project cost list is manually summarized into rules by engineering cost experts. In the future project cost list data, the new list data is classified by matching the rules in the rule base. However, this method is inevitably affected by the professional level of cost experts, personal experience, and other human supervisory factors. Humans can only summarize explicit knowledge but cannot find hidden associations among data, and there may be a problem of one-sidedness in manually concluded rules. This paper uses BIM technology to analyze the whole-process project cost to improve its management effect. Through the experimental research, it is verified that the whole-process cost management system based on BIM constructed in this paper has a good effect and can effectively improve the quality of cost management of construction projects.

Data Availability

The labeled dataset used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

References

[1] I. Othman, Y. Y. Al-Ashmori, Y. Rahmawati, Y. Mugahed Amran, and M. A. M. Al-Bared, "The level of building information modelling (BIM) implementation in Malaysia," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 455–463, 2021.

[2] R. R. Dong, "The application of BIM technology in building construction quality management and talent training," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 13, no. 7, pp. 4311–4317, 2017.

[3] X. Qin, Y. Shi, K. Lyu, and Y. Mo, "Using a TAM-TOE model to explore factors of Building Information Modelling (BIM) adoption in the construction industry," *Journal of Civil Engineering and Management*, vol. 26, no. 3, pp. 259–277, 2020.

[4] Y. C. Kim, W. H. Hong, J. W. Park, and G. W. Cha, "An estimation framework for building information modeling (BIM)-based demolition waste by type," *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 35, no. 12, pp. 1285–1295, 2017.

[5] M. N. Kocakaya, E. Namli, and U. Isikdag, "Building information management (BIM), a new approach to project management," *Journal of sustainable construction materials and technologies*, vol. 4, no. 1, pp. 323–332, 2019.

[6] A. Okakpu, A. GhaffarianHoseini, J. Tookey, J. Haar, A. Ghaffarianhoseini, and A. Rehman, "A proposed framework to investigate effective BIM adoption for refurbishment of building projects," *Architectural Science Review*, vol. 61, no. 6, pp. 467–479, 2018.

[7] L. Ustinovičius, A. Puzinas, J. Starynina, M. Vaišnoras, O. Černiavskaja, and R. Kontrimovičius, "Challenges of BIM technology application in project planning," *Engineering Management in Production and Services*, vol. 10, no. 2, pp. 15–28, 2018.

[8] E. Papadonikolaki, C. van Oel, and M. Kagioglou, "Organising and managing boundaries: a structurational view of collaboration with building information modelling (BIM)," *International Journal of Project Management*, vol. 37, no. 3, pp. 378–394, 2019.

[9] Y. Y. Al-Ashmori, I. Othman, Y. Rahmawati et al., "BIM benefits and its influence on the BIM implementation in Malaysia," *Ain Shams Engineering Journal*, vol. 11, no. 4, pp. 1013–1019, 2020.

[10] A. Koutamanis, J. Heuer, and K. D. Könings, "A visual information tool for user participation during the lifecycle of school building design: BIM," *European Journal of Education*, vol. 52, no. 3, pp. 295–305, 2017.

[11] S. M. Luo, J. Xu, and B. K. Li, "Practice and exploration on teaching reform of engineering project management course in universities based on BIM simulation technology," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 14, no. 5, pp. 1827–1835, 2018.

[12] C. J. Chen, S. Y. Chen, S. H. Li, and H. T. Chiu, "Green BIM-based building energy performance analysis," *Computer-Aided Design and Applications*, vol. 14, no. 5, pp. 650–660, 2017.

[13] H. R. Abed, W. A. Hatem, and N. A. Jasim, "Adopting BIM technology in fall prevention plans," *Civil Engineering Journal*, vol. 5, no. 10, pp. 2270–2281, 2019.

[14] L. Joblot, T. Paviot, D. Deneux, and S. Lamouri, "Literature review of Building Information Modeling (BIM) intended for the purpose of renovation projects," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 10518–10525, 2017.

[15] P. Wu, R. Jin, Y. Xu, F. Lin, Y. Dong, and Z. Pan, "The analysis of barriers to bim implementation for industrialized building construction: a China study," *Journal of Civil Engineering and Management*, vol. 27, no. 1, pp. 1–13, 2021.

[16] I. Kim, J. Choi, E. A. L. Teo, and H. Sun, "Development of K-BIM e-Submission prototypical system for the openBIM-based building permit framework," *Journal of Civil Engineering and Management*, vol. 26, no. 8, pp. 744–756, 2020.

[17] A. Dainty, R. Leiringer, S. Fernie, and C. Harty, "BIM and the small construction firm: a critical perspective," *Building Research & Information*, vol. 45, no. 6, pp. 696–709, 2017.

[18] A. Ahankoob, K. Manley, C. Hon, and R. Drogemuller, "The impact of building information modelling (BIM) maturity and experience on contractor absorptive capacity," *Architectural Engineering and Design Management*, vol. 14, no. 5, pp. 363–380, 2018.

[19] M. Deng, C. C. Menassa, and V. R. Kamat, "From BIM to digital twins: a systematic review of the evolution of intelligent building representations in the AEC-FM industry," *Journal of Information Technology in Construction*, vol. 26, no. 5, pp. 58–83, 2021.