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Research Article

Investigation of Coal Preparation for Life Cycle by Using Building Information Modeling (BIM): A Case Study

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Increasing the efficiency of coal preparation is the key link of mine production. This study proposed a framework of coal preparation for life cycle based on Building Information Modeling (BIM), in which the data resources can be retransmitted, and the integration of BIM application links has a high level. In this paper, the kappa big data processing architecture is used to realize the integration and unification of stream data and batch data processing process. By using deep learning method and multimodal data fusion method, the multimodal data association fusion is realized, and Bentley software is adopted for verification and integration. Taking a coal preparation plant as an engineering case study, the proposed framework is applied to build a big data subplatform of three-dimensional visual management. The following is suggested: (1) the three-dimensional visual review of the coal preparation online is realized, and the efficiency of the design results is improved; (2) the production and operation management of the coal preparation are carried out through the established platform, which indicated that the proportion of clean coal increased by 1.97%, and the average increase percentage for the total output is about 5.6%. Results from the case study show that the framework proposed in this study can provide efficient reference for coal washing in the coal preparation.

1. Introduction

As one of the strategic energy sources in China, coal assumes an important role in supporting the long-term stable and rapid development of the national economy and society [1–3]. With the development of coal mining from traditional human and mechanical mines to digital and intelligent mines [4–6], major coal processing plants are also bound to accelerate the digital transformation in order to continue to play an important role in the development of the coal industry.

BIM, which means Building Information Modeling, was first proposed by Dr. Chuck Eastman in the United States as a "building description system." With the development of technology, BIM has been attached importance by more and more industries and units at home and abroad [7–9]. At present, BIM technology has been maturely applied in architectural design, and it is also widely used in domestic water conservancy, hydropower, metallurgy, and other infrastructure industries [10–14]. BIM technology can realize three-dimensional visualization and intuitive design, intelligent linkage design [15–18]. BIM model integrates a large amount of information, which has great advantages in information management, cost control, design quality improvement, information communication, etc. It can also be used for project management of complex projects, virtual simulation, engineering digital applications, etc. The application of BIM software in China is mainly concentrated in the two stages of design and construction. The application modes mainly include the following: design-led mode, construction-led mode, and owner-led mode [19–21]. BIM technology and its application in the construction field has been relatively mature [22, 23], and it especially has formed a certain industry BIM standard. From the viewpoint of value-added data utilization, the technical framework based on BIM concept should be a useful exploration practice for the implementation of digital mine and smart mine construction in the coal industry [11, 24–26]. However, domestic BIM software applications generally still exist as independent systems, with simple transfer between systems only through interfaces and lack of overall integration management for data. The information system design by various vendors mainly around the construction industry cannot fully meet the business-specific needs of the coal industry.

In this paper, through BIM, big data, artificial intelligence, and other new generation information technology are effectively integrated into the design, construction, and operation process to solve the traditional single system construction method based on a single coal processing plant that obviously lacks integrated management, cannot realize effective utilization for data resources, and cannot realize the whole life cycle management of coal processing plant from planning and design, construction and construction to production and operation, and equipment from selection, installation to maintenance. The problem of the whole life cycle management of coal processing plant from planning and design, construction to production and operation, and equipment from selection, installation to maintenance, provides some reference for coal washing in coal processing plant.

2. Research Methodology

2.1. Research Objectives. The main objective of this paper is to study the system integration and visualization research of whole life cycle coal washing based on BIM, taking BIM technology as the core and BIM data as the source, acquiring massive, heterogeneous, multidimensional, and dynamic coal processing plant information through different means such as 3D visualization expression, realizing the management of BIM + big data through data standard development, and conducting scientific and orderly coal processing plant information. We can organize, manage, and establish the distributed sharing, collaboration, and utilization mechanism of coal processing plant. It can enable the integrated management of centralized collection, storage and display of production, safety and management data of coal processing plant, and deep excavation of data value and enhance the self-analysis and decision-making ability of coal processing plant with the help of big data, artificial intelligence, and other technologies.

2.2. Research Methodology. To integrate and smoothly interact with data from different software, different data sources, and different stages, a set of standardized data integration standards must be followed. This paper starts from the study of BIM model data integration standards, and through the study of existing commercial and open source CAD, MySQL, Oracle, and BIM software open explicit code standard format based on the use of spatial data processing technology and tool components, to achieve a common and open BIM model information expression technology route for coal processing plant elements, to build a BIM model display and interactive operation framework with protocol adaptation and content resolution technology, and to design the integrated storage and sharing of the model.

Table 1: CPIM format data element table.

Data source type	Parameters
Indicator ID	Indicator coding, Prepared according to the rules set by the specification
English name	English name of the indicator, Corresponding field name in technical metadata, Automatically associated
Chinese name	Indicator Chinese name
Indicator description/caliber	Description of indicators business meaning, statistical caliber
Valid mark	Valid, discarded

2.2.1. BIM Model Multimodal Data Association Fusion Analysis. The basic standard provides the basis for standardizing the content and format of data sources. For the basic data in the data standard system of coal processing plant, it is necessary to develop its classification and code standard, data element standard, and data model standard for the business data of coal processing plant. The public parameters for creating the coal processing plant business data elements are specified as follows (Table 1).

This data standard is a standard developed for the specific scenario application requirements and visualization needs of the intelligent coal processing plant 3D visualization management platform project and is used to standardize the application of comprehensive data such as statistics, analysis, comparison, and evaluation. Standardize the construction and display mode of 3D data visualization of coal preparation plant to meet the needs of visual expression of intelligent coal preparation plant system, which can accurately represent the spatial objects and object characteristics of coal processing plant and meet the needs of simulation rendering, system integration, and visual display.

The visual presentation and instructions are as follows (Table 2). According to the principle of "one number, one source and multiple checking," the data construction of multimode data association and fusion analysis platform of coal preparation plant gathers and integrates the business system data, PLC data, BIM model data, and other data of coal preparation plant, realizing the sharing, integration, storage, update, and service of multimode data of coal preparation plant. The details are shown in Figure 1.

In the equipment entity model table, it can include sieve, coal feeder, fine coal desmearing screen, and electronic belt scale. In the parts entity model table, it can include sieve plate, sieve flange, filter cloth, and bearing. In the process entity model table, it can include raw coal grading, heavy medium tilt wheel sorting, desmearing, and media recovery. In the fault entity model table, it can include abnormal voltage, abnormal noise, tape runout, and motor overload. Personnel entity model table can include staff in the central control room and staff in the production section.

Table 2: Visualization display standards.

Display method	Display effect
Geometric scaling, Width spreading	The width of the system display is the width of the monitor, and the height is scaled according to the width scaling ratio
Geometric scaling, Height spread	The height of the system display is the height of the monitor, and the width is scaled according to the height scaling ratio
Full screen spread	The height of the system display is the height of the monitor, and the width of the display is the width of the monitor
Displayed at a set resolution	The height of the system display is the preset height, and the width is the preset width of the system

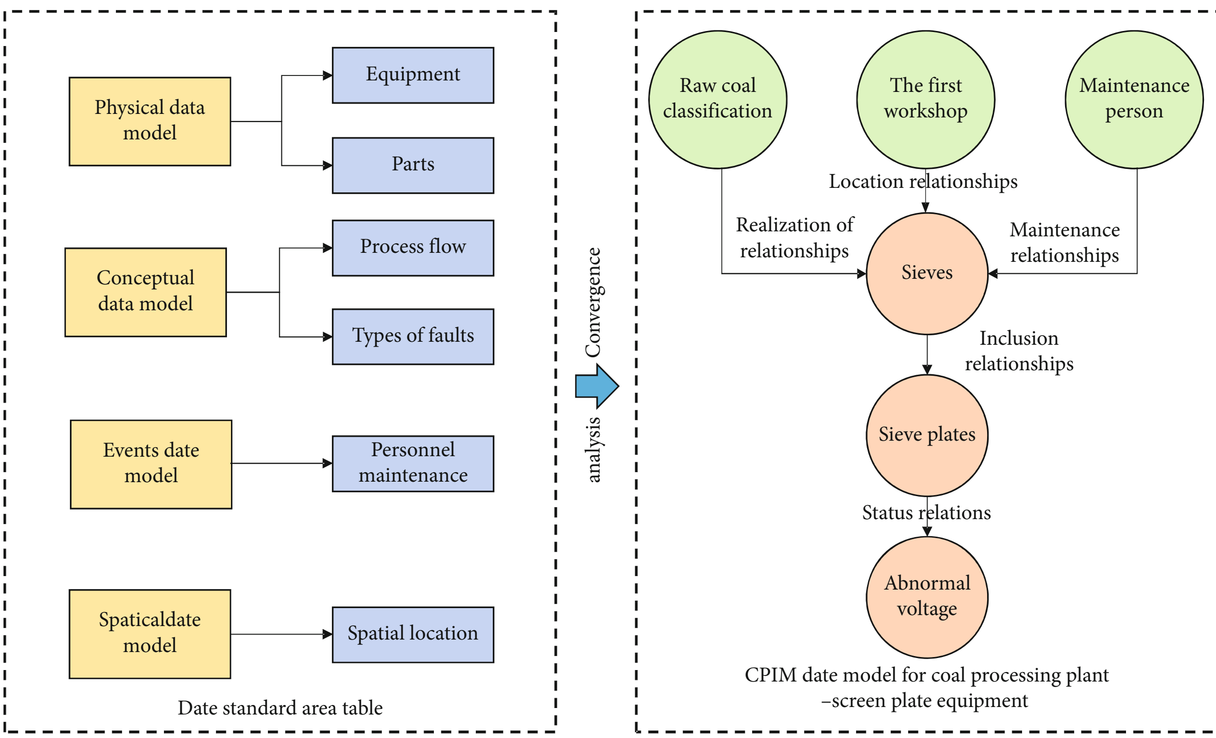

Figure 1: Coal processing plant multimodal data association fusion analysis platform data system construction.

Through the multimodal data correlation and fusion analysis platform of coal processing plant to identify the characteristics and data fusion analysis of the data generated by each business segment of coal processing plant, it can accomplish the coordination and complementation of multiple different modal data information, improving the decision-making process based on uncertain data. At the same time, the platform can be used to solve the problems that cannot be determined by ordinary methods, changing the existing production methods and improving productivity.

2.2.2. BIM Model Application Architecture for Coal Processing Plant

(1) CPIM Whole Life Cycle Application Platform. CPIM whole life cycle application platform carries out the construction of digital design management system, digital construction management system, and digital production operation management system through the unified system portal (as indicated in Figure 2). At the same time, the mobile business APP and WEB terminal of the platform carry out business linkage and data interaction, and the business system is displayed through the management cockpit.

(2) CPIM Big Data Subplatform. The overall design of the platform was carried out according to the requirement analysis design of the platform. The multimodal data analysis platform was divided into three parts: basic environment, processing platform, and platform application. The first two parts are mainly described below:

(1) In basic environment, the platform basic environment is divided into three modules: hardware resources,

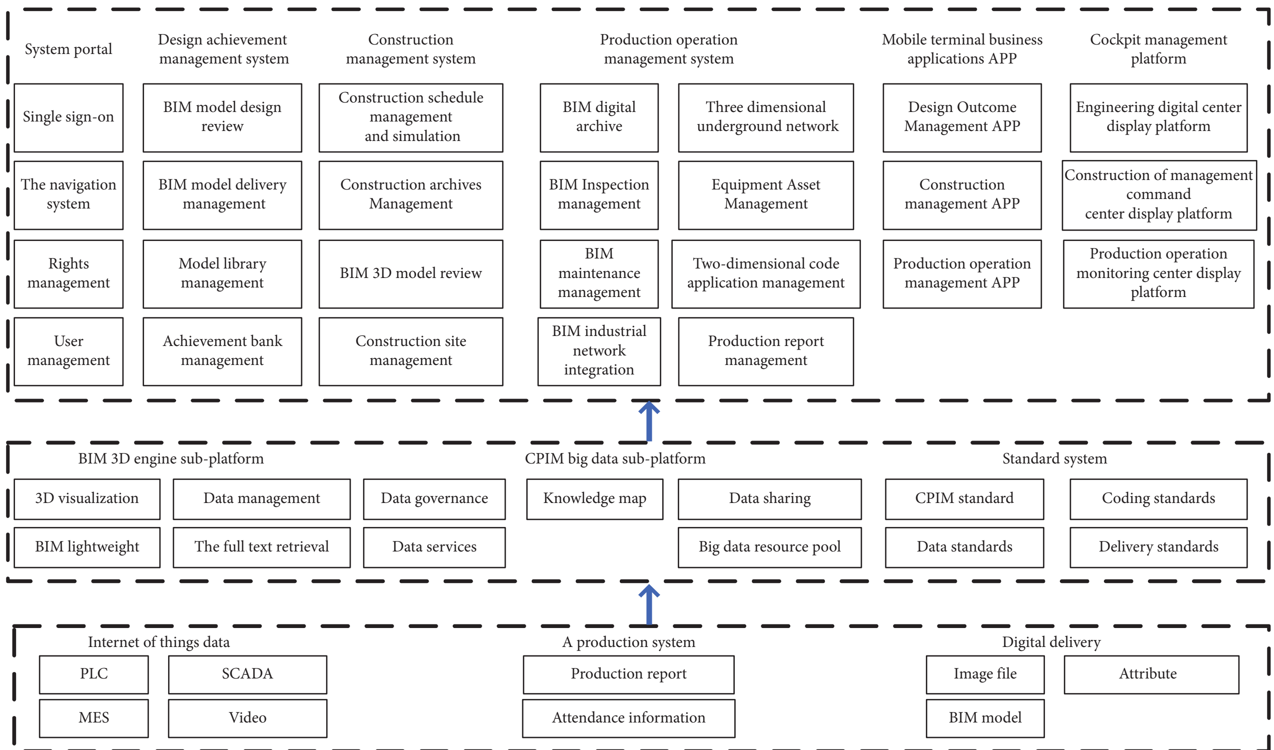

Figure 2: Application architecture diagram.

physical clusters, and cluster management. The hardware resources include not only the common switches, high-performance servers, and storage devices of big data platforms but also GPUs. This is because the multimodal data analysis platform adopts deep learning technology in order to analyze image data effectively, and the deep learning models run much more efficiently on hardware GPUs than CPUs. This part of the physical cluster is mainly to be able to support the various modules of the processing platform. The physical cluster is mainly designed based on CPU + GPU heterogeneous computing, which can make full use of the respective advantages of CPU and GPU to analyze and process the multimodal data of coal processing plant. The final part of the platform infrastructure environment is the management of the cluster, which is designed to efficiently and easily manage and extend the platform. This part mainly includes deployment management, resource monitoring, resource scheduling, and security management.

(2) Processing platform part. In order to meet the multimodal data collection, storage, analysis, and visualization of multimodal data analysis platform, the module decomposition and design of the processing platform part is carried out from the perspective of software engineering design according to the functional characteristics. Each module is realized by using big data technology and deep learning technology to finally meet the requirements of the functions of this part of the processing platform.

In order to meet the storage of different modal data, the data storage module mainly includes the distributed file system HDFS, nonrelational database HBase, and relational database MySQL. Distributed file system is mainly used to store the raw data of text and images. Nonrelational database HBase has good random read and write performance; then, the results of data analysis will be stored in HBase, which facilitates the process of reading results for visualization system display. The relational database MySQL mainly stores the metadata of users in the visualization system.

The most core module of the multimodal data analysis platform is able to handle multimodal data because the data analysis module is built based on the distributed computing framework Spark and the deep learning framework TensorFlow. The data analysis module is mainly divided into text data analysis, image data analysis, video data analysis, and multimodal data fusion analysis. The data analysis module combines Spark's ability to process massive data and TensorFlow's ability to process images and videos as a deep learning framework, so that the multimodal data analysis platform simultaneously satisfies the ability to process text, images, and videos. To enhance the platform's capabilities in processing images and videos, the data analytics module also combines Spark with the traditional image processing software OpenCV. On this basis, the data analysis module designs a multimodal data analysis algorithm library, which is divided into text analysis algorithm library, image analysis

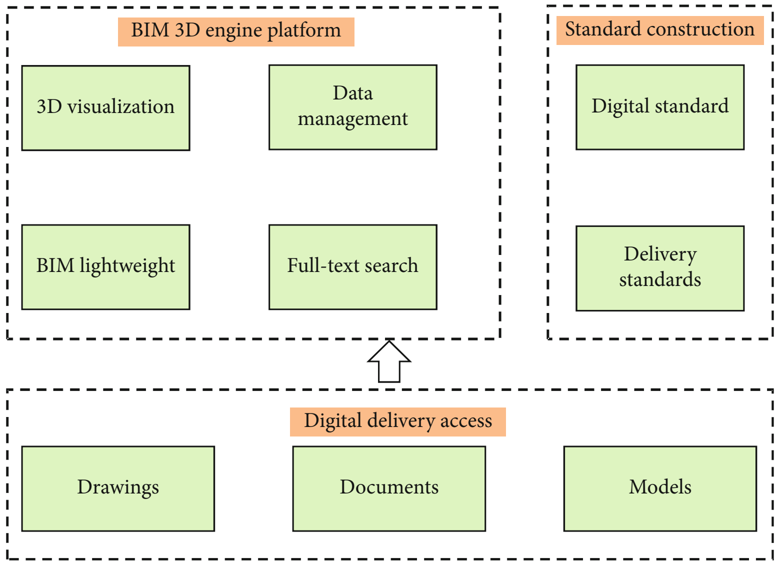

FIGURE 3: Application architecture.

algorithm library, video analysis algorithm library, and multimodal fusion algorithm library, containing algorithms commonly used for text analysis, image analysis, video analysis, and multimodal fusion.

(3) BIM 3D Engine Subplatform. The 3D foundation platform is based on BIM graphics engine to build a visualization platform, which consists of data access layer, BIM 3D engine platform, and standard construction, as shown in Figure 3.

2.2.3. BIM Model Data Architecture. In terms of data sources, BIM model data architecture mainly includes BIM model data, business system data, and implementation design document data, which are the source of the whole data flow (as presented in Figure 4). In terms of data collection, BIM model data architecture is mainly through the parsing interface (database, offline files, sensors, form entry, etc.) to parse and store the contents of unstructured data and structured data for coal processing plants. In the aspect of correlation and fusion, BIM model data architecture is mainly based on the structured data stored in the original data area after collection, guaranteeing data availability through rules and auditing of data quality, using the processing process of data extraction, conversion, cleaning, and loading to build the data resource pool of coal processing plant, so as to realize the fusion and analysis of multiple BIM data models with IOT data, construction design data, and business system data to produce CPIM format data to form a data model.

3. BIM-Based 3D Visualization Platform Development

3.1. Coal Processing Information Model (CPIM) Standard Study. Coal Processing Plant Information Model (CPIM for short) Standard Study includes Coal Processing Plant 3D Design Specification, Coal Processing Plant 3D Design Modeling Specification, and Coal Processing Plant 3D Design Model Interaction Specification.

3.1.1. Coal Processing Plant 3D Design Specification. The specification of three-dimensional design of coal processing plant stipulates the requirements of BIM three-dimensional design scope, depth, and collaborative design in the engineering design stage of coal processing plant, which is applicable to the three-dimensional design of preliminary design, construction drawing design, and as-built drawing design.

3.1.2. Coal Processing Plant 3D Design Modeling Specification. The three-dimensional modeling of coal processing plant stipulates the requirements of geometric information and attribute information for BIM construction of coal processing plant in engineering design stage and specifies the detailed requirements of coal processing plant modeling scope and depth.

3.1.3. Coal Processing Plant 3D Design Model Interaction Specification. The interaction specification of 3D model of coal processing plant specifies the architecture, storage structure, and other data interaction requirements of 3D model files in the design stage of coal processing engineering. It has the characteristics of completeness, correlation, consistency, uniqueness, and extensibility, which can meet the requirements of visualization, analysis, editing, and drawing for the whole life cycle of the project.

3.2. CPIM Big Data Subplatform Research. Based on CPIM data standards, the CPIM big data subplatform is developed to support three-dimensional visual management of the whole life cycle of coal preparation plant design, construction, and operation.

3.2.1. Study of Flow Batch Fusion Processing Technology in Coal Processing Plant. For the complex scenario that batch

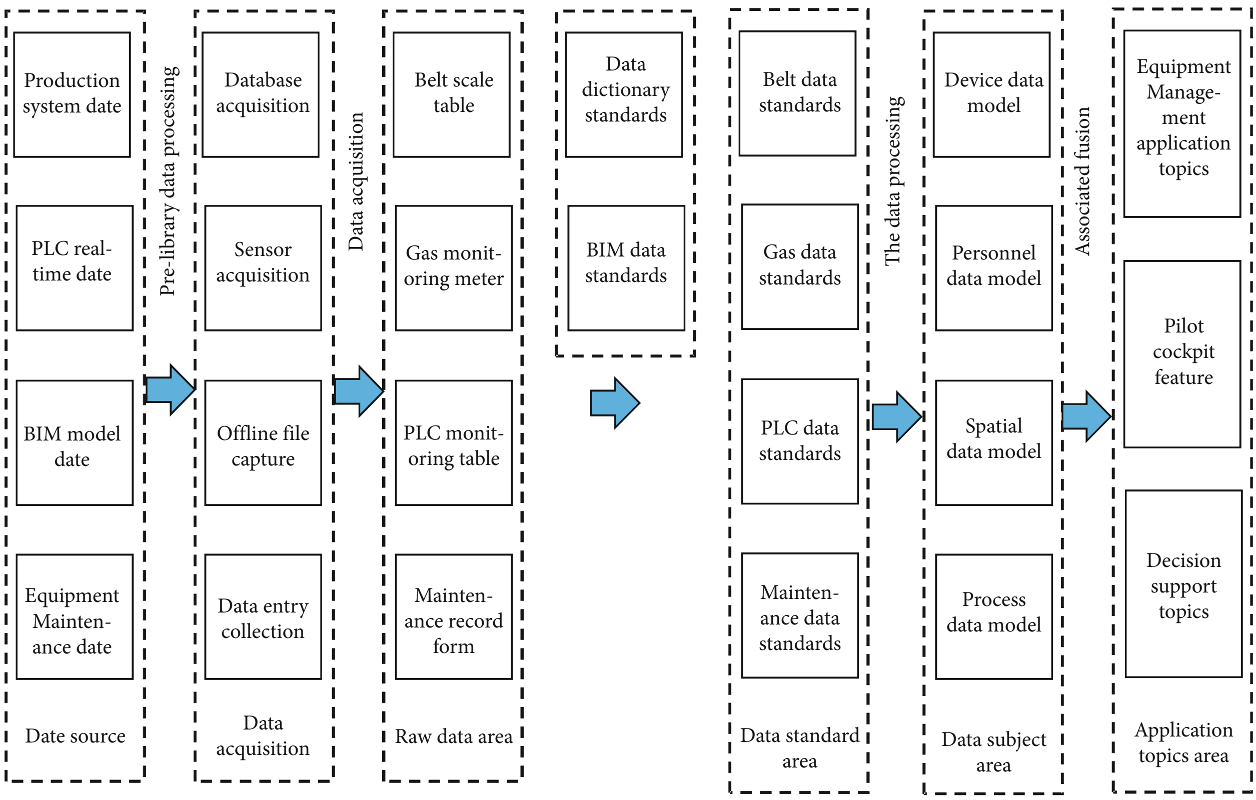

Figure 4: Data architecture diagram.

data and stream data coexist and intermingle in the CPIM data model of coal processing plant, the three-layer big data framework including infrastructure layer, platform layer, and data processing layer is studied, and the big data architecture capability based on stream-batch fusion processing of coal processing plant is proposed. The big data framework based on Kappa big data processing architecture is studied to realize the fusion and unification of stream data and batch data processing process.

Existing big data processing systems can be divided into two categories: batch processing big data systems and stream processing big data systems. The batch processing big data system represented by Hadoop needs to aggregate data into batches first and load them into analytical data warehouse after batch preprocessing for high-performance real-time query. Although such systems can achieve efficient on-the-fly query for complete big data sets, they cannot query the latest real-time data and have problems such as data lag. Compared with batch big data systems, stream processing big data systems represented by Spark Streaming, Storm, and Flink load real-time data into high-performance in-memory databases for querying through stream processing one by one. Such systems can achieve efficient querying of the latest real-time data with predefined analysis and processing models and low data latency. However, the system which is limited by the memory capacity needs to discard the original historical data and cannot support ad-hoc query analysis processing on the complete large data set. Therefore, it is urgent to develop real-time streaming big data processing technology and platform with fast, efficient, intelligent, and controllable characteristics.

Batch processing: In batch processing, data is stored first and then analyzed. MapReduce is a very important batch processing model. The core idea of MapReduce is that the data is first divided into small chunks of data, which are then processed in parallel to produce intermediate results in a distributed manner, and finally, these intermediate results are combined to produce the final result.

In stream processing, it is assumed that the underlying value of the data is fresh and needs to be processed as quickly as possible to get results. In this approach, data arrives as a stream. During the continuous arrival of the data, only a small portion of the stream data is kept in limited memory as the stream carries a large amount of data. The stream processing approach is used for online applications and usually works at the second or millisecond level.

Stream processing systems perform calculations on data that comes into the system at any time. This is a very different type of processing compared to the batch mode. Instead of performing operations on the entire data set, the stream processing method performs operations on each data item that is transferred through the system.

In order to realize a system-level scheme that integrates batch and stream processing systems and is transparent to application, this paper carries out incremental calculation of complex indexes, parallel computing based on distributed memory, and multiscale time window drift dynamic data processing. The high availability and high expandable memory computing mode provides technical support for the 3D visual management platform of the whole life cycle of coal preparation plant design, construction, and operation.

3.2.2. Research on CPIM Data Model Management Engine Technology for Coal Processing Plant. The data integrated by CPIM big data platform includes two parts: static data and dynamic data of coal processing plant. Among them, the static data of coal processing plant mainly includes geometric and attribute information of equipment and its process flow. Ideally, these data can be delivered by design and construction BIM. However, due to the existence of data barriers, data sharing often encounters obstacles. For the delivered BIM information models, the O&M BIM data is often incomplete due to the lack of uniform BIM delivery standards. Therefore, it is crucial to form a set of BIM delivery standards by specifying the delivery granularity, iconic deliverables, and file naming. The dynamic data of the coal processing plant is mainly collected by the PLC system, and there are also some data that need to be uploaded and supplemented by the operation and maintenance staff of the coal processing plant, such as the operation and maintenance log files. For the data collected by PLC, the data standards of sensing systems from different vendors are not uniform and the data formats vary, and the data formats of log files also differ significantly from those of IoT systems. Therefore, how to realize the interaction of dynamic data of coal processing plant with BIM from multiple heterogeneous sources is the research focus of the industry.

We need to manage the full lifecycle of the BIM data model of the coal processing plant, using data pooling and data governance tool technologies to preprocess and integrate the data to ensure high data quality. In turn, the data is diagnosed and integrated in full dimensions based on machine learning technology to eliminate data inconsistency. Based on the distributed architecture of hot-pluggable microservices, an elastic and scalable data space efficient management architecture is established. Within the infrastructure framework of CPIM data model management system of coal processing plant, the basic elements of the whole process business are refined and the description method of unified data model oriented to the domain is established. By establishing the storage and management method of information resources based on the unified resource catalog, accurate data matching for different business scenarios is realized. The multidimensional and multigranular representation of coal processing plant data at different levels is carried out by using granular computing. A machine learning algorithm is used to establish an entity relationship evolution model to capture the effect of time on the evolution of entity attribute values and interentity association relationships. A multisource heterogeneous data fusion method based on deep learning and information fusion technology is used to realize the fusion of product whole life cycle data at different abstraction levels. Based on the intelligent algorithm of BIM data model and data query demand of intelligent service of coal preparation plant, the heterogeneous data acquisition mechanism is researched and designed to realize data service component. Data integration, data evolution, data governance, and data service components are integrated with microservice mechanism architecture. A semantem-based CPIM data model management engine for coal preparation plant is designed to realize data space management based on natural language processing and knowledge graph.

3.2.3. Research on Multimodal Data Association and Fusion Analysis Technology for Coal Processing Plant. In response to the real problem of massive multimodal data in coal processing plant business, however, the multimodal data of coal processing plant and the multimodal data generated by business systems have the characteristics of low quality of modality, low real-time processing, and uneven modality, which poses serious challenges for data association fusion. In view of the above characteristics of multimodal data, this paper carries out the research of multimodal data association and fusion analysis methods for four aspects: low quality modal analysis fusion, incremental modal clustering fusion, heterogeneous modal migration fusion, and low dimensional modal sharing fusion.

The main research components are shown in Figure 5.

(1) It is a low-quality multimodal data fusion method on the basis of deep semantic matching. Based on the high-level semantic abstraction characteristics of deep learning network, a unified deep model of coupled mode private deep network and low-quality mode shared feature learning is designed to realize the deep correlation fusion of low-quality multimode data and reduce the semantic deviation of mode shared feature. Based on the geometric characteristics of modal space, a local invariant graph regularization factor was designed to combine the multimodal shared features and the original modal features in the subspace to further improve the accuracy of fusion results. Effective correlation matching of low-quality multimodal data through deep semantic abstraction ensures the accuracy of the fusion results.

(2) Parameter-free multimodal data incremental coclustering class fusion method. A new multimodal data similarity measure is adopted and a new incremental clustering strategy is designed to perform parameter-free incremental clustering fusion of multimodal data, which improves the efficiency of the method while ensuring the robustness of the fusion results. An adaptive modal weight update mechanism is designed to dynamically adjust the modal weights during the coclustering fusion process to meet the dynamic change demand of modal influence on the fusion results and enhance the scalability of the method. It effectively improves the efficiency of dynamic data processing while maintaining the accuracy of the new multimodal data clustering fusion.

(3) It is a heterogeneous modal data migration fusion method based on multilayer semantic matching. A unified deep network architecture based on multilevel semantic matching is designed by coupling

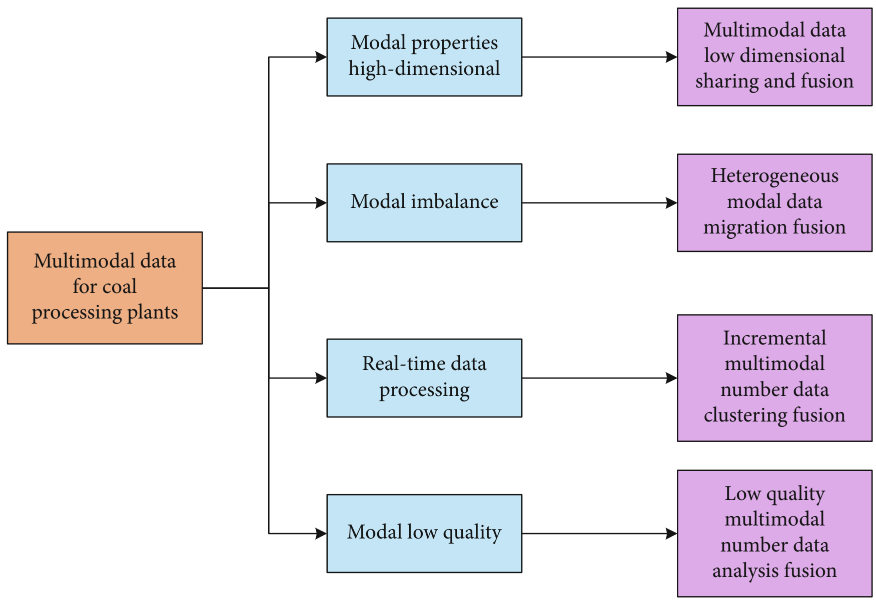

Figure 5: Main research elements of multimodal data association fusion analysis.

modal deep network and modal semantic correlation model. The overall optimization of the modal network is adjusted using the maximum correlation of the top layer output features to further improve the semantic relevance of the modal depth. A new objective function is defined to jointly optimize the heterogeneous modal depth matching network to obtain a cross-modal high-level semantic fusion subspace, in which the transfer learning from source modal knowledge to target modal task is completed. The semantic bias between heterogeneous modal data is effectively compensated by multilayer correlation matching, and more reliable migration fusion results are obtained.

(4) The unsupervised multimodal data nonnegative correlation feature sharing fusion method designs modal private (uncorrelated or negatively correlated) features and cross-modal shared (correlated) features colearning models to improve the accuracy of low-dimensional shared feature representation through the separation of modal private features. The coupling of shared features is used to establish the joint optimization objective function of each modality, and the modal invariant map regularization and projection matrix sparsification are used to assist the model optimization process and further enhance the accuracy of the fusion results. Robust cross-modal shared fusion features in low-dimensional potential subspaces are obtained by iterative cotraining and updating of correlated and uncorrelated features. The shared features of multimodal data are effectively achieved by separating modal private features to complete the low-dimensional fusion of high-dimensional modal data.

3.3. CPIM Whole Life Cycle Application Technology Research. In this paper, the research of CPIM model interface of coal processing plant is carried out through data sharing with CPIM standard based on Bentley software and other formats. Based on CPIM model, CPIM model data is applied throughout the whole cycle of CPIM design application, CPIM construction management application, and CPIM production operation, including WEB terminal application and mobile terminal application. Research on CPIM design application (BIM model delivery management), CPIM construction management application (BIM 3D model review, digital construction file management), and CPIM production operation application (underground pipe network application, 2D code application management, etc.) for CPIM whole life cycle application technology are introduced.

3.4. BIM 3D Engine Platform Research

3.4.1. BIM Lightweight Engine Study. Research on BIM 3D engine platform, including front-end display platform, mobile platform (such as cell phone webpage), back-end database support, and corresponding data processing tools are conducted. The platform loads basic GIS data and BIM 3D models and supports 3D browsing, roaming, querying, measuring, and other common 3D operations.

3.4.2. Research on Equipment Identification Coding Standards. In order to standardize the coal processing production equipment identification coding standard system, establish and improve the data standard basis for data governance and sharing mechanism, in order to unify and standardize the coal processing production equipment identification, so as to be able to realize the application of the whole life cycle equipment coding of the assets of the coal processing plant production equipment.

By establishing the digital delivery standard of coal processing plant, we realize the delivery and subsequent application of coal processing plant equipment data, which is in line

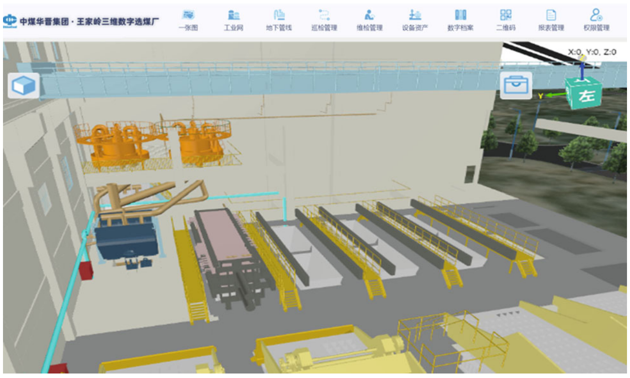

FIGURE 6: BIM-based 3D visualization platform of Wangjialing Coal Preparation Plant.

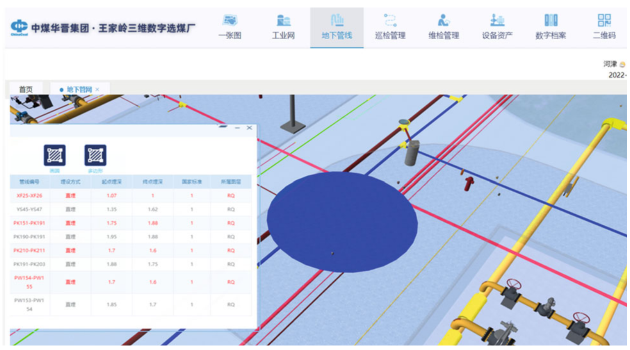

FIGURE 7: Spatial analysis of underground pipe network of Wangjialing Coal Preparation Plant.

with the application standard of the whole process of coal processing plant design, construction, and production.

3.4.3. Digital Delivery Study of Coal Processing Plant. Implement digital delivery in the pilot coal processing plant. The digital delivery content and process shall meet the corresponding coding standard system and digital delivery standards. The digital delivery content and process should meet the corresponding coding standard system and digital delivery standards.

The main advantages of the proposed framework are summarized as follows. (1) It has the advantages of self-control, safety, and reliability. (2) The whole process management mode covering the design, construction, production and operation, and maintenance of coal washing industry has been created. (3) It solves the performance problems caused by the large amount of data and complex structure of BIM model. While the main disadvantage may be that there is still room for improvement in efficiency.

4. Application of CPIM in Wangjialing Coal Preparation Plant

Wangjialing Coal Preparation Plant is located in Xiangning county, Shanxi Province, which is constructed to provide the service for Wangjialing coal mine project. The design production capacity of phase I of Wangjialing coal preparation plant is 6.0 mt/a. At present, the coal preparation plant mainly feeds No. 2 coal mined by beneficiation. No. 2 coal is a high-quality lean coal with low and medium ash, ultralow sulfur, low phosphorus, low volatile, high calorific value, and high ash melting point. It is a rare and scarce resource in China's lean coal resources. The sulfur content of the incoming raw coal from the coal preparation plant is less than 0.6%, and the ash content is about 30%.The product structure of the coal preparation plant is clean coal, washed mixed coal and slime. Among them, the ash content of cleaned coal products is ≤10.0%. The coal preparation methods are +50 mm large moving screen jigging gangue discharge, 50-0 mm raw coal pre-desliming, 50-1 mm raw coal two product dense medium cyclone main reconcentration, 1-0.25 mm coarse slime TBS separation, and 0.25-0 mm fine slime direct flotation.

FIGURE 8: QR code management for equipment of Wangjialing Coal Preparation Plant.

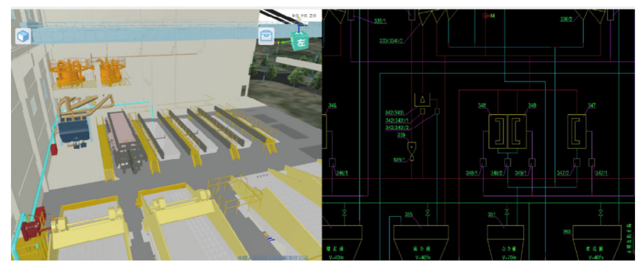

FIGURE 9: Linkage between PID diagram and CAD model of Wangjialing Coal Preparation Plant.

The CPIM 3D visualization whole life cycle management platform of coal washing project is based on BIM model fusion through the whole process data information of coal processing plant design, construction, and production operation stages to realize the whole life cycle management of coal washing project in design stage, construction, and production operation stage. Figure 6 shows the CPIM 3D visualization whole life cycle management platform of Wangjialing Coal Preparation Plant. Relying on the platform, coal engineering design and construction stage management are completed. In the engineering design stage, the platform is relied on to establish the management process of BIM-based coal processing plant design collection, professional collaboration, model review, and result delivery, which assists business personnel to control the progress and quality of BIM model design of coal processing plant.

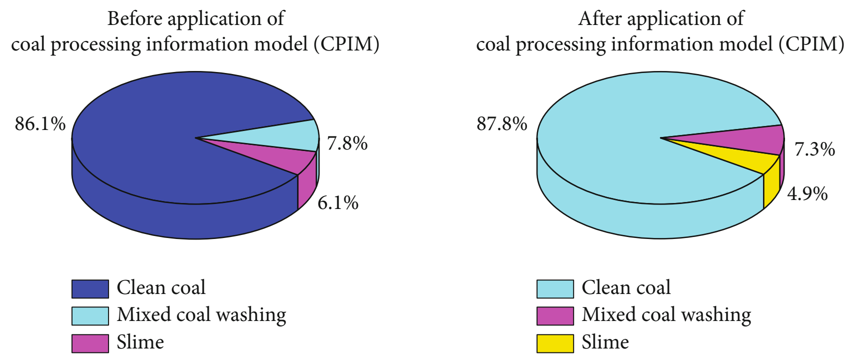

Figure 10: Comparison of coal preparation products between before and after application of Coal Processing Information Model (CPIM).

Meanwhile, as the management platform of engineering data center, it unifies the management of digital design results of engineering data center. In the engineering construction stage, based on BIM technology, it realizes construction progress management, 3D model review management, safety management, and construction digital file construction of coal processing plant and builds a convergence center for various kinds of information of coal processing engineering construction management (as shown in Figure 7).

At the same time, the digital delivery standard and coding specification of coal processing plant engineering were established, including flowchart, model and attributes, drawing documents, and data association requirements, based on which the digital delivery work of pilot coal processing plant was completed. The pilot coal processing plant equipment data is divided into 1078 sets of production equipment (as presented in Figure 8) and 422 sets of auxiliary equipment, forming a complete equipment digital ledger; and the coal processing plant drawing documents have been completed, 7721 drawing documents for phase I, 2931 drawing documents for phase II, 493 pipe network and construction photos, all documents total 11050; 39 model monomer structures (as presented in Figure 9) and digital plant 3D model data volume: 2.85G have formed a complete digital plant model corresponding to the actual plant 1 : 1 and have been associated with the design, construction, and production data and documents to realize the 2-3D linkage.

After the upgrading and transformation of phase II project, the total production capacity of the main washing system of the coal preparation plant has reached 10.0 mt/a, and the total production capacity of the raw coal preparation system is 8.0 mt/a. Figure 10 presents the comparison of coal preparation products between before and after application of Coal Processing Information Model (CPIM). It is shown that the proportion of clean coal changed from 86.1% to 87.8% and increased by 1.97%, which has a significant impact on the improvement of clean coal production capacity.

Figure 11 shows the comparison of the output per month between before and after application of Coal Processing Information Model (CPIM). It is suggested that the output of clean coal per month changed from 268606 t (1 t = 103 kg) to 289479 t and increased by 7.8%. It also can be seen that the total output (clean coal + mixed coal washing + slime) per month changed from 311970 t to 329779 t and increased by 5.7%, which indicated that application of Coal Processing Information Model (CPIM) in Wangjialing Coal Preparation Plant has increased total production capacity significantly.

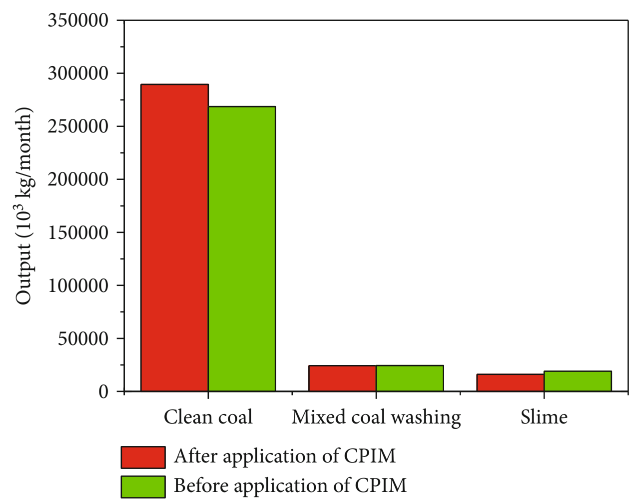

Figure 11: Comparison of the output per month between and after application of Coal Processing Information Model (CPIM).

Figure 12 depicts the variation of sales composition for clean coal due to application of Coal Processing Information Model (CPIM). As can be seen, the sales structure has been improved at a certain extent. Due to the application of CPIM, the proportion of train outbound sales varies from 53.7% to 55.3% and increased by 2.98%, which suggested that the income of the Coal Preparation Plant will be increased. Figure 13 presents the variation of the total output with time for different months. It is shown that the total output has been increased for the time interval (2020.07-2020.12) after the application of CPIM. Comparing to the total output for the time interval (2018.07-2018.12), the maximum of the increase percentage occurred in September and the value is about 6.5%, while the minimum of the increase percentage occurred in November and the value is about 4.7%. It can be also indicated that the total output has a significant improvement and the average increase

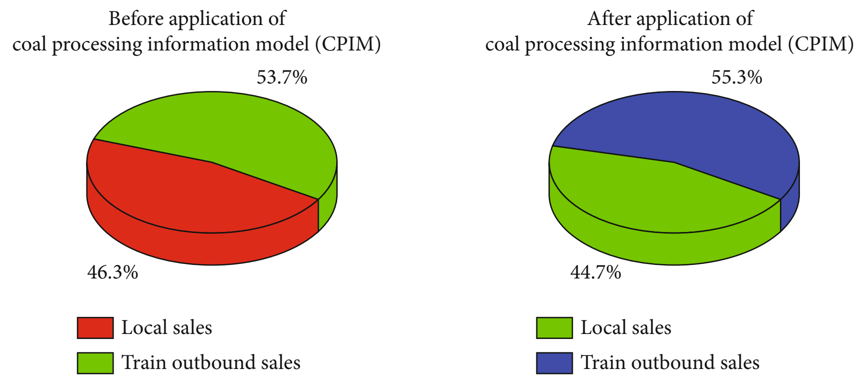

FIGURE 12: Variation of sales comparison for clean coal due to application of Coal Processing Information Model (CPIM).

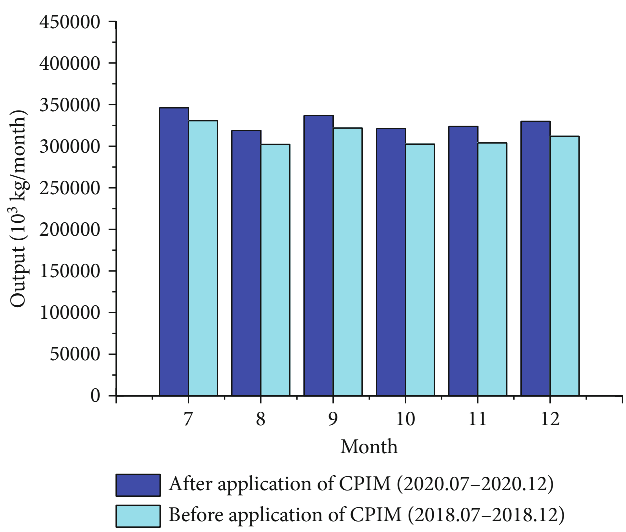

FIGURE 13: Variation of the total output with time for different months.

percentage is about 5.6%. The increase in the total output may be due to that there is a great improvement of the Coal Preparation efficiency after the application of the proposed framework.

5. Conclusion

In this paper, by introducing Building Information Modeling (BIM) technology, a framework of coal preparation for life cycle is provided. The proposed framework is applied to a case study successfully, and the following concluding remarks are mainly obtained:

(1) For the current situation of imperfect BIM information, the information generation technology of coal processing plant is investigated. Based on the logical chain ontology and spatial connection relationship, the upstream and downstream relationships of production equipment are generated. The generated logical relationships can provide the necessary positioning data for intelligent operation and maintenance, expand the coal processing plant information stored in BIM, and reduce the manual data entry workload efficiently.

(2) This study proposes a data multidimensional model, which is an extensible multidimensional data matrix and can effectively organize real-time dynamic data in different data formats and dimensions to realize efficient management of dynamic data of coal processing plant. Facing the massive static and dynamic data of coal processing plant stored in BIM, this study proposes a hybrid data governance method of fusion analysis, dimensional analysis, and data standards. The original data quality can be improved by preprocessing under data standards. The dimensional analysis is adopted to analyze the potential entity laws of CPIM data model and guide the data model construction. Fusion analysis is conducted to discover the entity association in CPIM data model and open the fusion of BIM dynamic data and static data, so as to form a complete solution based on the association of CPIM data model.

(3) The "digital design result system," "construction management system," and "production operation management system" were built by applying BIM technology, combining with mobile application and management cockpit. These systems can transparently manage the whole life cycle digital files of coal processing plant in a three-dimensional visualization way, forming a safe, efficient, and stable system for the whole life cycle management of equipment.

(4) The proposed Coal Processing Information Model (CPIM) was applied in Wangjialing Coal Preparation Plant, which has a significant improvement of the production capacity. It is indicated that the proportion of clean coal increased by 1.97%, and the average increase percentage for the total output is about 5.6%. It is indicated that the proportion of train outbound sales varies from 53.7% to 55.3% and increased by 2.98%.

Data Availability

The data used to support the findings of this research work are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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