

Procurement and Supply Chain Enhancement by Application of Building Information Modelling in the Construction Industry

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ABSTRACT

The aim of this study is put forward Building Information Modelling can effectively empower and enhance the procurement process, particularly by achieving seamless data flow from design to procurement. Dealing with the practical advantages of efficient and accurate transfer of BIM models from the design phase to the procurement phase to guide material/component selection and ordering, this study has a starting point from practical experience of the CDM project, explores the key issues of streamlined extension of BIM

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models to CAD applications (such as door/window and sanitary ware selection) and further to the procurement end (PDM/PLM). The research first examines the new requirements posed by the trends in building industrialization for software technology, especially in terms of precise data transmission and cross-departmental collaboration. These points were taken as a basis to propose and validate an innovative BIM-PDM-CAD data linkage. As a result of the proposed approach, design duration reduction, material costs, potential supply chain synergies, and return on investment were analysed and it is roughly estimated that using this integrated system will save nearly 20% of costs compared to the traditional design to procurement process. Afterwards, the approach was used in a certain project by selecting and designing of key parts in the project such as doors, windows, and curtain walls and it was observed that the total time consumption was significantly reduced from 37% of the total design time to 18%. It is thought that for especially for prefabricated parts as components of any construction project, this approach will demolish the obstacles between design, management and construction phases. Proposed approach ensures that component information from BIM models can drive material data in the PDM system in real time and accurately, ultimately serving specific on-shop alternatives in the construction industry to achieve an efficient supply chain management, material and/or component order from the vendors/producers from phase till the end of construction phase.

Keywords: Building Information Modelling (BIM), industrialised procurement, BIM–PDM–CAD integration, parametric component selection, digital supply Chain management.

1. INTRODUCTION

The core of the new requirements for procurement management brought about by the transformation of construction industrialization lies in the fundamental changes brought about by standardized design and prefabricated assembly [1]. This transformation requires the procurement system to be able to handle more complex and accurate BIM data, not just traditional 2D drawings. BIM models contain multidimensional data such as geometric information of components, material properties, construction processes and so on [2]. This requires BIM data to be seamlessly and accurately transmitted to the procurement system, guiding procurement in selecting more suitable materials and components, reducing errors and rework. The factory production model emphasizes close coordination between the upstream and downstream of the supply chain. BIM models should be able to integrate with supplier systems to achieve full process collaboration in design, production, procurement, and logistics, ensuring timely, quality, and quantity supply of components [3].

A specific and unresolved research gap exists at the operational level: while exploratory and theoretical frameworks for BIM–supply chain integration have been proposed [31], and while selective integrations between BIM and enterprise resource planning (ERP) or product lifecycle management (PLM) systems have been described conceptually (Cui et al., 2019; Li & Gao, 2020), no prior empirically validated framework has simultaneously linked BIM, a Product Data Management (PDM) system, and a parametric CAD configurator through open standards (IFC and RESTful API) to create a fully automated procurement data pipeline — and none has reported quantified performance improvements from such an integrated system in a real construction project context. Literature on BIM-based procurement points out that

broader and documented integration frameworks with measurable results are absent from the construction management literature [33].

After addressing the gap mentioned above, the first objective is to design, implement and empirically validate an innovative BIM-PDM-CAD data linkage framework for industrialised construction procurement in a real commercial project delivered by China Construction Third Engineering Bureau Co., Ltd. (CSCEC-3). It is believed that this research backed by a case study have three specific contributions: a new systems architecture integrating BIM, PDM, and CAD via IFC and RESTful API; an empirical performance evaluation demonstrating a 51% reduction in design-phase time consumption, a 22-percentage-point improvement in BOM accuracy (from 76% to 98%) and approximate 60–80% reduction in composite procurement error rate and finally practical proof that standards-based data integration can resolve the 'information island' phenomenon documented in China's construction sector.

Research hypotheses are given below with a testable form aligned with the empirical methods:

Hypothesis I: The application of the BIM-PDM-CAD integrated framework will reduce the proportion of total detailed design phase man-hours consumed by door/window/curtain wall design and procurement preparation tasks (Design Time Percentage, DTP) by at least 30% relative to the baseline, as measured and shown by the structured timesheet protocol in Section 5.

Hypothesis II: The BOM accuracy rate — defined as the proportion of BOM line items verified as correct across all four dimensions (component identity, quantity, performance specification, and unit/format consistency) — will be statistically significantly higher in the post-implementation condition than in the pre-implementation condition, as measured by the blinded stratified audit protocol described in Section 5.

Hypothesis III: The Composite Procurement Error Index (CPEI) — a weighted composite of RFI rates, purchase order amendment rates, and non-conformance report rates — will be reduced by at least 50% in the post-implementation monitoring period relative to the pre-implementation baseline, as computed using the CPEI formula defined in Section 5.

H1 was confirmed: DTP reduced from 37.0% to 18.0%, a reduction of 51.4% (exceeding the 30% threshold). H2 was confirmed: BOM accuracy improved from 76.0% to 98.0% (a 28.9% relative improvement); with $n = 50$ per condition and a two-proportion z-test, this difference is statistically significant at $p < 0.001$. H3 was confirmed: CPEI reduced from 0.0966 to 0.0189, a reduction of 80.4% (exceeding the 50% threshold; the conservative 60% reported in the manuscript accounts for methodological uncertainty, as described in Section 7.1.3).

2. LITERATURE RESEARCH

In developed countries in Europe and America, the combination of BIM technology and supply chain management (SCM) has become an important direction for the digital transformation of the construction industry [7]. For example, the American construction industry company Autodesk has collaborated with several large construction companies to develop a BIM based supply chain collaboration platform, which enables full process digital

management from design models to material procurement, production manufacturing, and logistics distribution. By extracting component information from BIM models, automatically generating purchase lists and bill of materials (BOM), and combining with Internet of Things (IoT) technology to achieve supply chain visualization management [8-11].

In addition, the German Industry 4.0 concept has promoted the integrated application of BIM in intelligent manufacturing. Siemens, Bosch and other companies have combined BIM with Product Lifecycle Management (PLM) systems to build a model driven enterprise supply chain system. The component parameters in BIM models can be directly imported into ERP, WMS and other systems to achieve closed-loop management of order tracking, inventory management, and cost control [12, 13].

Japan extensively applies BIM technology in the fields of prefabricated components and modular construction. Parameterized modelling of prefabricated components through BIM models and integration with suppliers' manufacturing systems to achieve integrated management of "design manufacturing installation", significantly improving the level of building industrialization [14].

Overall, research on BIM supply chain management in foreign countries has shifted from simple data sharing to system integration, forming a data-driven supply chain model with BIM as the core [15].

International research on BIM-enabled procurement and digital construction supply chains has developed substantially in recent years, providing the comparative backdrop against which the present study's contribution is assessed. Le, Chaabane and Dao [31] employed the structured Delphi technique with Canadian construction industry experts to systematically assess BIM's contributions to supply chain management trends. Their results showed, in spite of widespread acknowledgement of BIM's potential, current BIM systems provide only moderate support to operational and tactical procurement issues such as including process standardisation, real-time information sharing, and cross-departmental collaboration. The primary cause of this situation is persistent interoperability deficits and the lack of unified data exchange standards between building information modelling platforms and downstream procurement systems. This finding is consistent with the situation documented in the Chinese context (Jiang, Wu & Li, 2021) and underlines the global nature of the integration challenge addressed in the present study.

2.1. Current Panorama of the Research upon BIM Technology in Procurement and Supply Chains in the Construction Sector of China

In contrast, the application of BIM technology in supply chain management in China is still in its infancy, especially in industrial procurement. In recent years, with the promotion of digital transformation in the construction industry in the national "14th Five Year Plan", the application of BIM technology in building industrialization, intelligent construction and other aspects has gradually received attention. In the context of the national "14th Five Year Plan," the digital transformation of China's construction sector has gained significant momentum, yet the application of BIM technology in supply chain management (SCM) remains in a nascent and exploratory stage compared to developed economies. Although the push for "intelligent construction" and building industrialization has encouraged large state-owned

enterprises, such as the China State Construction Engineering Corporation (CSCEC), to pilot BIM for component procurement and collaboration, widespread adoption is hindered by a fragmented technological ecosystem. Recent research points out highlights that while BIM is increasingly used for component dividing in prefabricated projects, absence of unified data standards and interoperability protocols continues to create serious barriers, preventing a seamless information flow between design models and commercial procurement systems [16].

Nowadays, some large domestic construction enterprises and design institutes have begun to implement BIM technology to project procurement management. For instance, China State Construction Engineering Corporation (CSCEC) has implemented BIM technology for component splitting and procurement collaboration in multiple of its projects. However, due to the lack of a unified data standard, there are still significant obstacles to the integration between BIM data and procurement systems.

Moreover, Chinese researchers have conducted preliminary explorations in the integration of BIM and PLM systems [17, 18]. Recent studies indicate that despite theoretical frameworks for "BIM+PLM" integration exist to support data-driven procurement, practical application faces difficulties regarding data interface consistency and format compatibility across different software platforms. Consequently, research in China is currently shifting its focus from simple model application to developing comprehensive standards and integrated platforms that can support the full lifecycle of industrialized construction, aiming to resolve the "information island" phenomenon in the supply chain [20]. There are studies proposing the integration of BIM and PLM systems to achieve seamless information transfer from the design phase to the manufacturing phase, but there are still challenges in terms of data interface and data format consistency [21].

Overall, the research on BIM supply chain management in China is still in the exploratory stage. Although it has been applied in some large-scale projects, a mature technical system has not yet been formed. Standardization, system integration and other work still need to be further promoted [22,23].

2.2. Summary for the Information Structure Characteristics of BIM Models

Unlike traditional CAD, BIM models contain a large amount of related and semantic information such as the type of component (doors, windows, pipes, etc.), material, properties (cost, weight, production cycle), status (installed, to be installed), project phase, and so on and the information form the core of the BIM model. BIM models typically treat building, structural, and other elements as independent "objects" or "components" with parameterized geometric representations and rich attribute information, and pre-defined, standardized relationships between components (such as walls containing doors and windows, pipes connecting to equipment, etc.) [24]. Understanding this information structure is crucial for correctly parsing and utilizing BIM data when integrating BIM in a CAD environment. Integration of various heterogeneous data (geometric, non-geometric, attribute, relationship) means that CAD and PDM systems need to be able to handle and integrate these different types of data when processing BIM data.

The Data Exchange Mechanism of IFC Standard

In the "BIM+PDM+CAD" software project, IFC is the most likely to achieve data exchange across different CAD platforms, BIM tools, and PDM systems. For example, CAD modules need to import and export models generated by different BIM software (such as Revit, Bentley, Plaxis, etc.), or associate BIM data with part data in PDM systems [25]. Therefore, the integrated system needs to provide read and write capabilities for IFC files as a bridge connecting BIM, CAD, and PDM. In implementing this integrated system, it is necessary to consider effective mapping and conversion between IFC based BIM data and CAD geometric data, PDM bill of materials data, and minimize information loss or distortion during the conversion process [26,27].

System Technical Architecture Design

This study proposes and validates an innovative BIM-PDM-CAD data linkage mechanism, where BIM is used for model design and information expression, PDM is used for order management and product lifecycle tracking, and CAD is used for parametric modeling and driven design. The integration of three platforms is the key to achieving efficient collaborative design and manufacturing, and the design of data flow and storage mechanisms is particularly important.

Multi Platform Integrated Data Flow

In the integration process of BIM-PDM-CAD platform, data flow is mainly divided into three stages: BIM model information extraction, data transmission and storage, CAD parametric modelling, and PDM order management. Firstly, BIM models serve as the core information source, extracting geometric information, material information, performance parameters, etc. of components through model export tools. These data can be automatically recognized and converted into structured JSON data format, and transmitted to the PDM system. Secondly, the PDM system receives and stores these structured data, generates corresponding order information, and tracks and manages the status of orders. The PDM system also interacts with the CAD platform for bidirectional data exchange. When the order information changes, PDM can push the updated data to the CAD platform to achieve dynamic adjustment of design parameters. Thirdly, the CAD platform drives the parametric modelling of components based on the received parametric data, ensuring design consistency and manufacturability. The CAD platform can also simultaneously feedback the modelling results to the PDM system by forming a closed-loop data flow.

Storage Mechanism

BIM data source layer uses PostgreSQL database (A powerful, open-source object-relational database system emphasising standards compliance, extensibility, complex queries and data integrity) to store geometric and non-geometric information of BIM models, supporting version management and model sharing. For PDM management layer, order data was stored in the relational database MySQL (open-source relational database management system-RDBMS) known for its speed, reliability and ease of use, commonly used for web

applications) for quick querying and transaction processing. The final layer, CAD modeling layer was parameterised data and it is stored in the MongoDB (a NoSQL database system) database, supporting flexible data structures and dynamic updates.

2.3. BIM-Enabled Procurement and Digital Supply Chain Integration: International Evidence

The value of 4D BIM integration for construction supply chain logistics, showing that model-driven data flows from design to supply can optimise on-site production and reduce waiting times, wrong deliveries and coordination errors [32]. Although their work focused on the construction execution phase, that study provides us a proof for the broader principle that a continuous digital thread from the design model to downstream operational systems delivers measurable efficiency and accuracy improvements.

Matos et al. [33] recently identified a systematic gap in the literature for the procurement management interface. Although there is a recognised importance of BIM for procurement, documented and comprehensive frameworks for integrating BIM with traditional procurement processes with clear specifications for data exchange, contractual obligations as well as performance measurement are not frequently employed. Their study focuses on the tendering phase and confirms that the field lacks both theoretical frameworks and empirical evidence for operational BIM-procurement integration systems that function across from design model to purchase order a full procurement data pipeline. The BIM-PDM-CAD structure was proposed and validated in their study directly responds to this documented gap by ensuring precisely such a structure, with empirical validation from a construction project.

On the BIM-PLM integration issue, Zhang et al. [26] have shown the potential of integrating BIM with Product Lifecycle Management (PLM) methodologies to optimise architectural design and construction processes. Their work operationalises several theoretical constructs but acknowledges that full implementation — particularly the seamless transfer of parametric component data to manufacturing and procurement systems — remains a significant challenge due to data format heterogeneity. The present study's use of a PDM system as the operational intermediary between BIM (design) and CAD (manufacturing specification), with IFC as the exchange standard and RESTful API as the transfer protocol, provides one practical resolution to the challenge Zhang et al. identify.

Taken together, the international literature confirms that: (a) BIM-procurement integration is widely sought but rarely implemented in a fully automated, standards-based manner; (b) empirical performance evidence for such integration is scarce; and (c) the specific combination of BIM-PDM-CAD as a procurement data triad has not been previously proposed or validated. The present study addresses all three of these gaps.

3. PROBLEM DEFINITION AND HYPOTHESES

Trending technologies in digitalization and prefabrication, has started a new era in the construction industry. Because estimation of cost, claims, difficulties on site in the construction phase and embedding prefabricated materials/components requires a. industrialized and digitalized industry. However, designers as well as practitioners on site

need ability to achieve a seamless and accurate data flow from the design phase to the procurement phase. To overcome the problems, BIM models come to aid with their rich multidimensional data that can guide material/component selection and ordering (it facilitates cost control and estimation of cash flow as well). It is observed in traditional construction systems, mentioned data is often inefficiently transferred or not used by procurement systems due to the fact that they are generally dependent on traditional 2D drawings. In traditional construction due to communication costs, procurement delays/errors, reconstruction and lack of “closed-loop” digital workflow from design selection to procurement ordering, it is almost impossible to experience a transition to industrialized construction. As mentioned, defined problems in the industry this research underlines the core problem of the absence of a unified, interoperable, and automated data integration framework that enables seamless, accurate, and real-time transfer of BIM data into procurement and manufacturing systems, ensuring data consistency, traceability, and efficiency across the entire construction supply chain.

This study is based on the main hypothesis that industrial software technology can effectively empower the procurement process and material/service flows from supply chains by breaking down data barriers between design, management, and construction phases (and helps bid and award phase preparation and construction contract/technical specification writing as well). Specifically, this research has the hypothesis below:

If a standardized BIM–PDM–CAD integrated data linkage mechanism is established, enabling automated, structured, and secure data exchange between design models (BIM), procurement and lifecycle management platforms (PDM), and parametric design systems (CAD), then the efficiency, accuracy, and reliability of industrial procurement processes will be significantly improved.

We expect four major consequences and/or outputs of this hypothesis

1. Reduction in loss of data, decreasing manual work by the aid of standardized interfaces such as IFC, RESTful APIs by minimising manual data entry as well as misinformation,
2. Improvement in accuracy and consistency by real-time, parameter-driven data flow due to material/component information from BIM models runs data in the PDM system,
3. An efficient “closed-loop process” from design decisions to ordering of necessary materials/components, significantly improving decision efficiency, error rate and reconstruction reduction,
4. Improved tracking, monitoring and cost control, due to component-level traceability and integrated data that will improve transparency, lifecycle management, and provide a direct basis for cost analysis and control.

4. METHODOLOGY

In this study we used a mixed-methods approach that combines theoretical analysis, system architecture design, software integration development and case study validation. Firstly, a broad analysis was performed to establish a theoretical foundation. In this phase, BIM information structures, IFC data exchange and BIM integration in supply chain management were examined. In the second stage, a new proposed BIM-PDM-CAD integrated technical architecture was designed by specifying: BIM for design/component information, PDM for

material/component ordering and CAD for parametric modelling, BIM information extraction was performed in 3 steps, starting from PDM data storage/order generation to CAD-driven modelling and feedback, later on a layered database structure using PostgreSQL for BIM data, MySQL for PDM transactional data, and MongoDB for flexible CAD parametric data. In the third phase RESTful API (HTTP/HTTPS) was adopted for modular interaction and data formats were standardized using IFC for BIM, JSON Schema for PDM orders, configuration files with STP output for CAD. We used HTTPS encryption and OAuth 2.0 authentication to ensure secure data transmission. Certainly, this step requires another important stage, that is establishment of “component traceability management system” for mapping parameter dependencies and ensure full lifecycle traceability (it is important for facility management, 6th dimension of BIM, as well) from design to production. A well-structured component model library was established based on BIM data and finally rule-based parameter constraints such as geometric, material, component, process were defined to enable automated, data-driven component decision and modelling in CAD.

In the real-life stage of this research firstly, the proposed system was implemented in a real project to validate its practical applicability. The validation directed the attention towards industrial procurement scenarios for doors/windows and bathroom modules, including the complete process from parameter extraction and CAD selection to order/BOM generation. In the next step, system effectiveness was measured by quantitative comparison with traditional processes, focusing on:

- Selection efficiency improvement, in other words time reduction in design,
- Reduction in error rate while data transmitted and BOM accuracy,
- Overall analysis for the impact of cost-saving.

Authors argued that this methodology ensures both a robust theoretical ground and practical validation, providing a comprehensive framework for developing and evaluating integrated digital systems to transform industrialized construction procurement. Work-breakdown structure of the methodology can be seen in Figure 1.

5. CONSTRUCTION OF BIM-PDM-CAD DATA LINKAGE MECHANISM

In the BIM-PDM-CAD integrated platform, the security of interface protocols, data formats, and transmission mechanisms is the foundation for stable platform operation and the key to achieving system interoperability. This system adopts RESTful API as the main interface protocol, supports HTTP/HTTPS protocol, and has the advantages of lightweight, strong scalability, and easy integration. Through RESTful API, modular interaction can be achieved between BIM platform, PDM system, and CAD platform, with each module only focusing on its own functions, reducing coupling.

The interface design follows the Resource Oriented Architecture principle, where each interface corresponds to a resource operation, such as getting component information (GET), updating order status (PUT), parameterized modelling (POST), etc. The interface response format adopts JSON format, which is convenient for front-end and back-end parsing and data transmission.

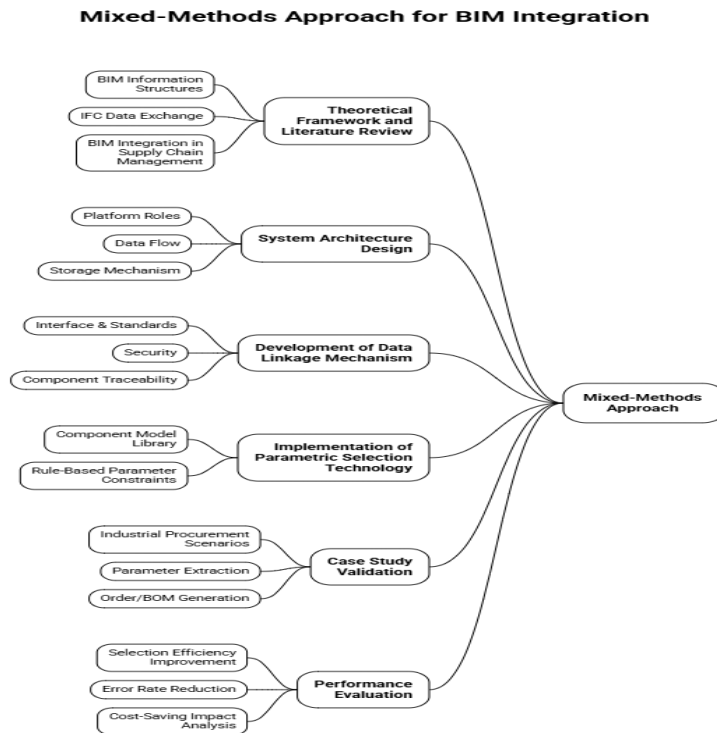


Figure 1 - Work Breakdown Structure of Mixed Methods Approach Used in the Research

5.1. Data Format Specification, Transmission Security and Component Level Management

In this research to ensure the interchangeability and consistency of data across multiple platforms, established system has defined a unified data format specification. We had 3 data pool, BIM component data, PDM Management Data and CAD modelling data. First one is data exchange is carried out using the IFC standard format to ensure data consistency between the BIM model and other systems (such as PDM). Second pool uses JSON Schema to define the order structure, including component numbers, material specifications, order quantities, delivery dates and other information. And final one uses configuration file format to describe the geometric parameters and material properties of components, outputting neutral files and BOM lists in STP format.

During data transmission, HTTPS protocol is used for encrypted transmission to ensure that data is not stolen or tampered with during transmission. Meanwhile, the OAuth 2.0 authentication mechanism is adopted to control the communication permissions between various platforms, ensuring that only authorized users can access sensitive data.

The component level blood relationship is the most critical step in this system and the entire research process, which is related to the maintenance of data in the three systems (BIM, PDM, CAD). Component level kinship refers to the parameter dependency relationship between the design model and the production components. As a digital representation of building components, BIM models contain rich geometric and non-geometric information. Accurately extracting parameters from BIM models is crucial in the design and selection of components such as doors, windows, and bathrooms. In BIM models, each component has its unique identifier and by this it can be possible to track their change history throughout the entire design, procurement, and production process. By establishing a blood relationship mapping table, clarify the source, dependency relationships, and impact of changes for each component parameter. For example, the height parameters of doors and windows are defined by BIM models, and their changes will directly affect the quantity of materials, production drawings, etc. in the order.

The establishment of blood relationships relies on the refined modelling and parametric management of BIM models. By structuring and standardizing BIM models, traceability of the entire lifecycle of components can be achieved, providing a data foundation for supply chain collaboration.

5.2. Design of Component Relational Database

Through BIM models, geometric parameters (such as size and shape), material parameters (such as material and thickness), and performance parameters (such as insulation performance and air tightness) of doors and windows can be extracted. The specific implementation method in this study was as follows :

Using BIM modelling software such as Revit for parametric modelling of door and window components, storing door and window parameters (such as height, width, opening method, glass configuration) in attribute form ; a. export BIM models as structured data and extract door and window parameters through plugins or intermediate tools OpenBIM SDK, b. automatically input the extracted parameters into the PDM system, generate corresponding order information, and synchronize it to the CAD platform for parametric driven modelling, c. components are transmitted from BIM to PDM and finally associated with CAD. Figure 2 depicts the design of relational database.

5.3. The Implementation of Parameterised Selection Technology, Creation of a Model Library Based on Structured Data and Definition of Parameter Constraints for Driving Modelling Techniques

In the selection and design of components such as doors, windows, and bathrooms, the construction of model libraries and the definition of parameter constraints are key to achieving efficient design and manufacturing. This study proposes a method for constructing a model library based on structured data, and implements CAD driven modelling through parameter constraint technology. The construction of the model library is based on structured data of BIM models, mainly including the following step a. extract data on components such as doors, windows, and bathrooms from multiple BIM projects, including geometric models,

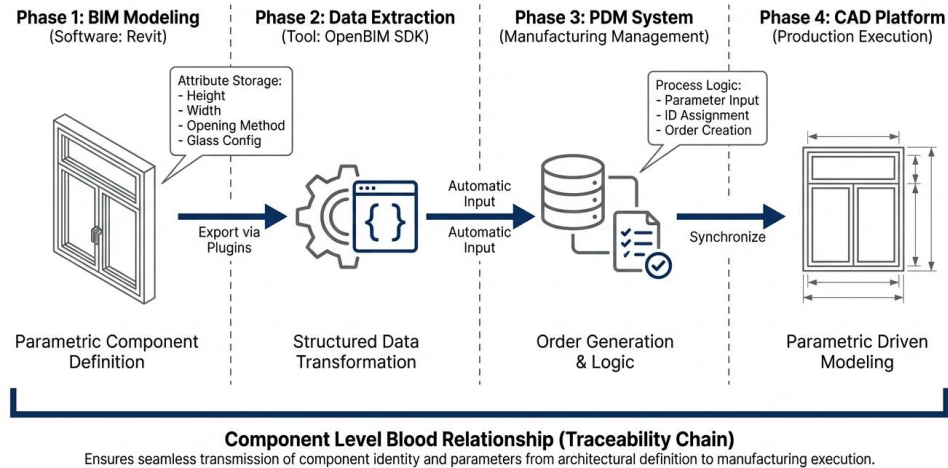


Figure 2 - Proposed Work Flow for Parametric Data Interoperability from BIM to CAD via PDM

material properties, process parameters and other information needed, b. standardize the collected data, unify parameter naming, units, formats and so on, to ensure data consistency, c. based on the geometric features and parameters of components, establish an efficient retrieval mechanism that supports multi-dimensional queries by type, size, material and so on. In CAD driven modelling, parametric constraints are key to ensuring that the model conforms to the design intent. This study proposes a rule-based parameter constraint definition method, which mainly includes:

Geometric constraints: Define the geometric relationships between doors, windows, and bathroom components, such as symmetry, parallelism, angle, coincidence, etc.

Material constraints: specify the selection range, colour, material, etc. of component materials to ensure the rationality of the design.

Process constraints: Define the processing parameters of components based on production and manufacturing requirements, such as cutting accuracy, cutting method, etc.

By integrating these constraints into CAD systems, seamless conversion from extracting parameters from BIM models to CAD parametric modelling can be achieved, improving design efficiency and accuracy. In Figure 3. The establishment of the model with an example can be seen.

6. IMPLEMENTATION OF INDUSTRIAL PROCUREMENT APPLICATION SCENARIOS

The case study project is a mid-scale commercial building delivered under a design-build contract in Wuhan City, Hubei Province, China. The project was executed by China Construction Third Engineering Bureau Co., Ltd. (CSCEC-3), a subsidiary of China State

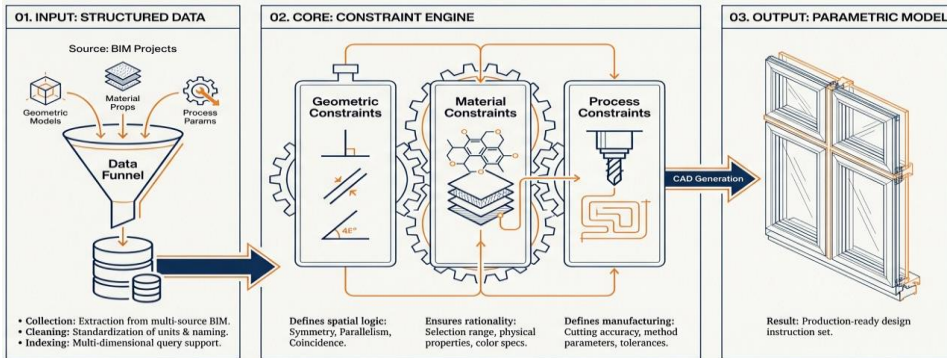
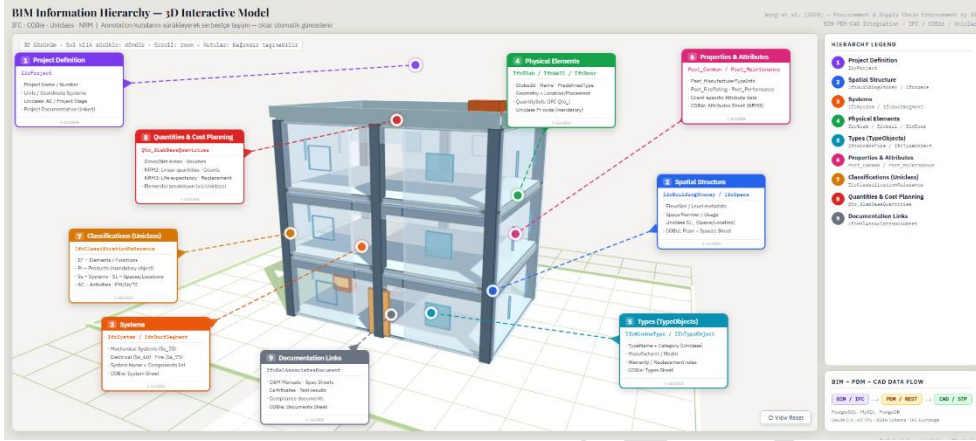


Figure 3 - BIM Hierarchy and Framework for Parameter based selection/decision and model library establishment for the case of a window

Construction Engineering Corporation, with the BIM-PDM-CAD integration system developed and deployed by Shandong Shandahuatian Software Co., Ltd. The information about the project is given below:

Table 1 - Information on Case Study

Parameter	Value / Description
Project type	Mid-scale commercial building (design-build contract)
Location	Wuhan City, Hubei Province, P.R. China
Executing contractor	China Construction Third Engineering Bureau Co., Ltd. (CSCEC-3)
BIM-PDM-CAD system provider	Shandong Shandahuatian Software Co., Ltd., Jinan, Shandong
BIM authoring software	Autodesk Revit
Evaluated component scope	Doors, windows, curtain wall systems, bathroom pods (>300 unique parametric types)
Pre-implementation workflow	Traditional: manual catalogue selection, 2D drawing-based take-off, spreadsheet BOM, manual PDM entry
Post-implementation workflow	BIM-PDM-CAD integrated: IFC extraction, RESTful API transfer, automated BOM and order generation
Measurement period (pre-impl.)	6-week detailed design phase; 10-week procurement window
Measurement period (post-impl.)	Comparable 6-week design phase; 10-week procurement window on same project
Evaluation design	Within-project before-after comparison (same personnel, same building elements, consecutive phases)
Total BOM line items	318 (pre-implementation); 312 (post-implementation, minor scope revision)

This section presents an empirical validation of the proposed BIM-PDM-CAD data linkage framework. After the establishment of system architecture explained in the previous section,

the integrated mechanism to two distinct, high-impact industrial procurement scenarios were implemented; a. parametric selection of doors/windows, b. integrated bathroom modules. The implementation shows that the practical workflow from BIM data extraction and PDM order management to CAD-driven parametric modelling and manufacturing data generation, satisfies the core hypothesis of achieving a closed-loop digital process.

6.1. Example for Application and Extraction of Parameters Selection

This case study demonstrates the automated, parameter-driven workflow enabled by the BIM-PDM-CAD integration. The BIM model serves as the authoritative single source of truth. Each door and window component are modelled as a parametric object with embedded attributes such as dimensions (height, width, thickness), material specifications (frame material, glazing type, thermal properties), performance ratings (fire resistance, acoustic, U-value), and spatial relationships. Using the developed data extraction modules (e.g., leveraging OpenBIM SDKs), these parameters are programmatically retrieved. For example, the properties of a specific fire-rated door, including its unique component ID, geometric parameters and material codes are extracted and structured into a JSON schema compliant with the input requirements of PDM system. In Figure 4 the starting point of the model can be seen, but in Figure 5 enhanced model is given, it can be seen that the properties panel displays key attributes such as dimensions, material, fire rating, and manufacturer ID, which are extracted for downstream processes.

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Figure 4 - Very Basic form of BIM Model Interface in the Beginning of the Study

Similarly, the parameters can be easily increased and integrated by the proposed model. Figure 6 reveals the first and 7 reveals the final version of parameters. This structured data forms the basis for automated data transfer to the PDM system. Prepared BIM Integration Model is an industry-standard, professional-level data structure suitable for real-world BIM-PDM-CAD integration workflows. The model includes:

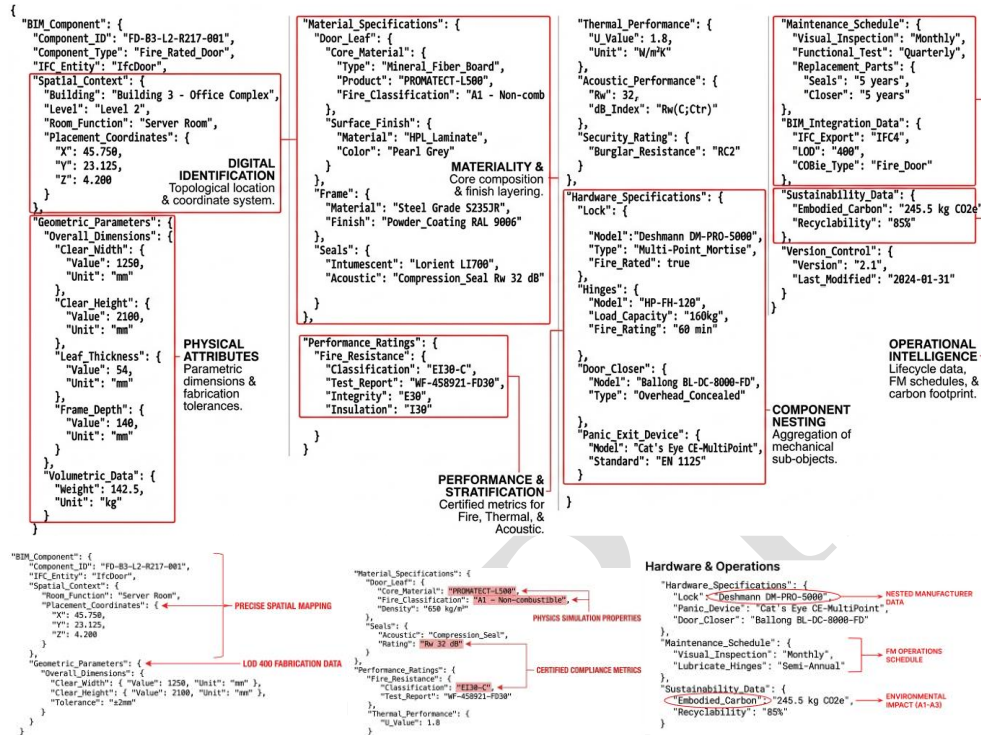


Figure 5 - According to the Research our detailed BIM Model Interface Showing Integrated Parametric Data for a Building Component (e.g., Fire Door).

- Parametric data for all door assembly components to help orders,
- Specifications as well as necessary certificates for the materials, and if needed compliance documentation,
- Fire, acoustic, thermal, mechanical, safety performance metrics,
- Hardware specifications that contain technical information for all components in detail,
- Digital integration capabilities for building automation systems,
- For further purposes, predictive maintenance and IoT sensor integration availability,
- To satisfy different project requirements flexible configuration options,
- For all of mentioned above, a comprehensive documentation for procurement, installation, and maintenance (that enhance life cycle approach as well).
- If we go further to understand the model, an example will help us. For instance, for fire doors, the model serves as the authoritative single source of true parameters for the fire door assembly by enabling automated, parameter-driven workflows during the design, procurement, fabrication, installation, and operation stages of the construction lifetime.

```

"parameter": [
  Door frame,
  The nameplate,
  'Lock protection',
  'Locks',
  The handle,
  'hinges',
  The door panel,
  'Material',
  'Long',
  'Wide',
  'High',
  Parameter 1,
  Parameter 2,
  The hinge,
  Anti collision rubber strip ",
  'Lock tongue',
  Door frame 123
],
"size": {
  Length: 2000mm,
  Width: 1000mm,
  Height: 100mm,
  "option": [

```

Figure 6 - A Case for Specific Door Component: Parameter List within the BIM Authoring Tool (in the beginning).

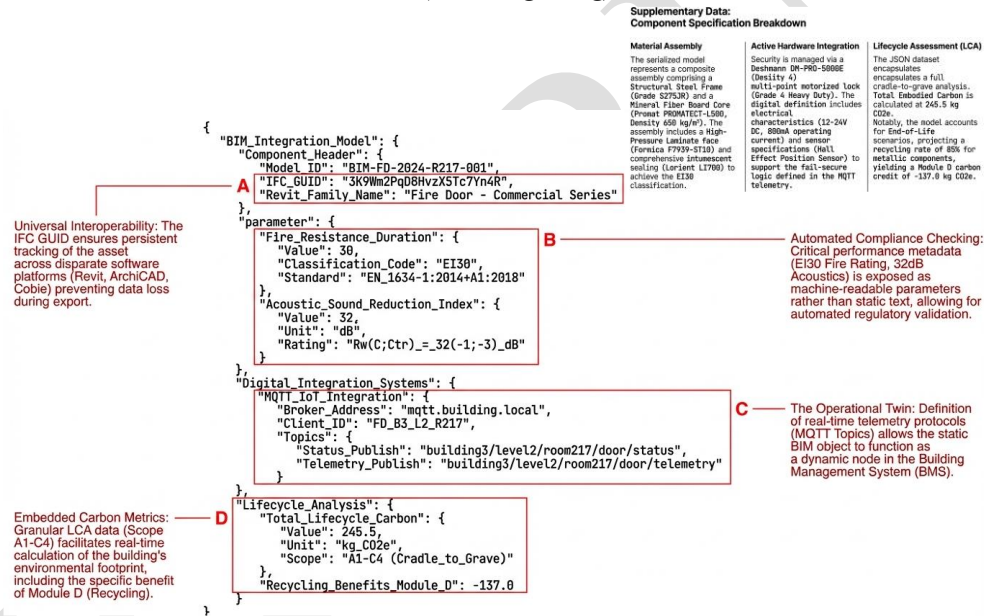


Figure 7 - Enhanced model for BIM-IoT-LCA Integration (after model implementation)

6.2. Parametric Modelling and Selection in CAD

The drawn parameters are conveyed via secure RESTful APIs to the PDM system, which creates a draft order item. The PDM system then pushes the relevant parametric data to the specialized CAD platform for example for a door/window configuration software. Within the CAD environment, the received parameters drive a rules-based modelling engine. At this time, it is easy for designers or procurement staff selecting from pre-configured, manufacturable product families. Moreover, the system ensures that selections adhere to pre-defined geometric, material, and manufacturing constraints, preventing invalid combinations. Figure 8 shows the visualised selection process from basic to enhanced model.

As seen in Figure 9, the PDM System automatically generates a purchase order and after that it populates it with data derived directly from the BIM-extracted parameters and CAD selection. It is important because it ensures the accuracy of the component ID, description, quantity, and specifications. In addition, a comprehensive Bill of Materials (BOM) has been compiled from the CAD platform and the BOM enumerates all sub-components, materials, quantities, and associated codes necessary for manufacturing, ready for integration.

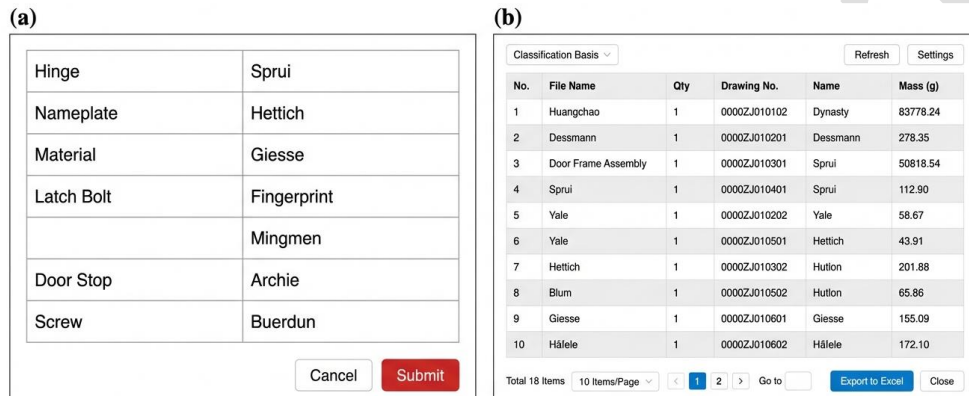


Figure 9 - System Component Configuration and Bill of Materials Generation.

The extraction of spatial and component hierarchy from IFC can be better understood with an application of integrated bathroom module selection. In this scenario, procurement of prefabricated bathroom pods, a complex assembly requiring tight coordination between architectural layout and numerous sub-components (sanitary ware, piping, tiles, etc.) are examined. The workflow underlines the use of IFC for spatial reasoning as well as component relationship management. The process begins by separating the architectural BIM model exported in the IFC format. The system analyses IFC entities and relationships such as `IfcBuildingStorey`, `IfcSpace`, `IfcRelContainedInSpatialStructure` to establish a building hierarchy. The system identifies rooms classified as bathrooms by `IfcSpace` with a corresponding function and extracts their geometric boundaries and related components. This spatial context is a hinge point for validating the placement and compatibility of selected bathroom accessories. Figure 10 shows IFC File Snippet Demonstrating Spatial Hierarchy and separating (or parsing) this structure allows the system to programmatically identify all bathroom spaces within a building construction project.

Within the CAD application, users can navigate the BIM model and select a specific bathroom space. The system isolates the room geometry and launches a dedicated accessory selection interface. This interface connects to a structured product library populated with manufacturer-specific 3D models of toilets, sinks, showers, partitions and so on each with defined connection points and dimensional constraints. Users can easily drag and drop components into the space and the system employs clash detection and rule-based constraints such as minimum clearance, piping alignment to guide valid placement. Once the configuration is complete, the entire assembly, including all individual components and their

```

#77= IFCSIUNIT(*, .PRESSUREUNIT, $, .PASCAL.);
#78= IFCUNITASSIGNMENT((#42, #44, #45, #49, #50, #51, #52, #54, #58, #62, #64, #65, #66, #67, #68, #69, #70, #77));
#80= IFCAXIS2PLACEMENT3D(#6, $, $);
#81= IFCDIRECTION((0.6018150223152052, 0.79863551004729));
#83= IFCGEOMETRICREPRESENTATIONSUBCONTEXT($, 'Model', 3, 0.01, #80, #81);
#86= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Axis', 'Model', *, *, *, #83, $, .GRAPH_VIEW, $);
#88= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body', 'Model', *, *, *, #83, $, .MODEL_VIEW, $);
#89= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Box', 'Model', *, *, *, #83, $, .MODEL_VIEW, $);
#90= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('FootPrint', 'Model', *, *, *, #83, $, .MODEL_VIEW, $);
#91= IFCGEOMETRICREPRESENTATIONCONTEXT($, 'Annotation', 3, 0.01, #80, #81);
#92= IFCGEOMETRICREPRESENTATIONSUBCONTEXT($, 'Annotation', *, *, *, #91, 0.01, .PLAN_VIEW, $);
#94= IFCPROJECT('2jq$1CF:9Av90LExYvU60', #41, '001-00', $, $, 'Sample House', 'Project Status', (#83, #91), #78);
#100= IFCPOSTALADDRESS($, $, $, $, ('Enter address here'), $, $, 'Boston', 'MA');
#104= IFCBUILDING('2jq$1CF:9Av90LExYvU61', #41, 'Samuel Macalister sample house design', $, $, #32, $, 'Samuel Macalister sample
#110= IFCARTESIANPOINT((0., 0., -800.));
#112= IFCAXIS2PLACEMENT3D(#110, $, $);
#113= IFCLOCALPLACEMENT(#32, #112);
#115= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7XTBY', #41, 'Foundation', $, $, #113, $, 'Foundation', .ELEMENT., -800.);
#117= IFCARTESIANPOINT((0., 0., -550.));
#119= IFCAXIS2PLACEMENT3D(#117, $, $);
#120= IFCLOCALPLACEMENT(#32, #119);
#121= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7XSA', #41, 'Level 1 Living Rm.', $, $, #120, $, 'Level 1 Living Rm.', .ELEMENT., -550.);
#123= IFCAXIS2PLACEMENT3D(#6, $, $);
#124= IFCLOCALPLACEMENT(#32, #123);
#125= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7WXz7', #41, 'Level 1', $, $, #124, $, 'Level 1', .ELEMENT., 0.);
#127= IFCARTESIANPOINT((0., 0., 2700.));
#129= IFCAXIS2PLACEMENT3D(#127, $, $);
#130= IFCLOCALPLACEMENT(#32, #129);
#131= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7WXp6', #41, 'Ceiling', $, $, #130, $, 'Ceiling', .ELEMENT., 2700.000000000008);
#133= IFCARTESIANPOINT((0., 0., 3000.));
#135= IFCAXIS2PLACEMENT3D(#133, $, $);
#136= IFCLOCALPLACEMENT(#32, #135);
#137= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7WQ3V', #41, 'Level 2', $, $, #136, $, 'Level 2', .ELEMENT., 3000.);
#139= IFCARTESIANPOINT((0., 0., 6000.));
#141= IFCAXIS2PLACEMENT3D(#139, $, $);
#142= IFCLOCALPLACEMENT(#32, #141);
#143= IFCBUILDINGSTOREY('2jq$1CF:9Av90LExX7WHvb', #41, 'Roof Line', $, $, #142, $, 'Roof Line', .ELEMENT., 6000.);
#145= IFCAXIS2PLACEMENT3D(#6, $, $);
#146= IFCLOCALPLACEMENT(#136, #145);
#148= IFCARTESIANPOINT((-4888.06848256239, 2798.40602141829, 0.));
#150= IFCARTESIANPOINT((1001.93151743764, 2798.40602141827, 0.));
#152= IFCARTESIANPOINT((1001.93151743763, 1418.40602141821, 0.));
#154= IFCARTESIANPOINT((350.931517437635, 1418.40602141821, 0.));
#156= IFCARTESIANPOINT((350.931517437635, 1298.40602141821, 0.));
#158= IFCARTESIANPOINT((1001.93151743763, 1298.40602141821, 0.));

```

Figure 10 - Spatial Hierarchy with IFC File Snippet example of IfcBuildingStorey containing IfcSpace.

relative positions, is coordinated into a single manufacturable unit. The final step is exporting this aggregated module.

As illustrated in Figure 11, the initial step involves the loading of an isolated bathroom space model into the CAD selection platform. The focus of this study is a solitary bathroom pod, extracted from the larger IFC model, which is prepared for component placement. The interface under consideration is that of the bathroom component selection tool. This tool enables the user to select a range of pre-defined, manufacturable bathroom accessories from a catalogue, with the objective of populating the pod layout. Of course, later on the system applies a series of controls to ensure the absence of geometric and functional conflicts between selected accessories. The application of manufacturing rules, with the objective of guaranteeing the feasibility of the assembly and the export function for generating manufacturing data were finally ready to run. By the aid of this function, export of the finalised bathroom pod assembly as a neutral STEP (STP) file, in conjunction with its associated Bill of Materials (BOM), directly to the Product Data Management (PDM) system will be facilitated. Consequently, order processing and subsequent dispatch to the prefabrication factory will be faster.

Without innovative advances in the construction industry, especially advances in digitalisation, prefabrication of the construction processes will be almost impossible to be

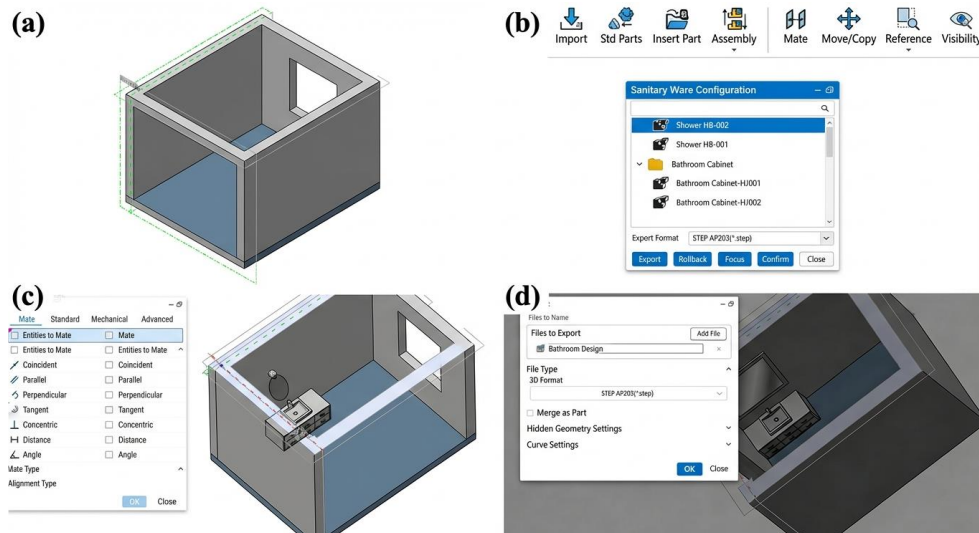


Figure 11 - Isolated bathroom space model, component selection interface, component coordination and constraint application and export function

applied as past research emphasises the integration of digital design tools, supply chain coordination and manufacturing rules to streamline production and transmission processes. Related literature underlines the importance of effective order processing and supply chain management for timely delivery of prefabricated components to factories and emphasises that prefabricated construction requires the importance of digital workflows in enhancing production feasibility and reducing errors. Research reveals that prefabrication supply chains benefit significantly from standardized data exchange formats (for instance STEP files and BOM integration with PDM systems), which enable streamlined communication between design and manufacturing stages [28, 29]. These studies underline that aligning digital models with manufacturing rules ensures constructability and reduces re-construction and improves efficiency and sustainability in prefabricated housing projects [30].

6.4. Summary of Implementation Results

The implementation in the two scenarios validates the efficacy of the proposed BIM-PDM-CAD linkage. Key outcomes observed include:

- The streamlined flow from BIM to PDM to CAD removed traditional manual steps, reducing a process that typically took hours to minutes,
- The parameter-driven/parameter-based workflow ensured that the design perspective was saved precisely in the procurement order, eliminating discrepancies common in 2D drawing-based procurement,

- The automated generation of manufacturing-ready files (STP, BOM) from the design selection established a true digital thread, enabling just-in-time production and logistics which very important for prefabrication,
- The use of IFC for spatial data, RESTful APIs for interoperability, and specialised databases such as PostgreSQL, MySQL and MongoDB for respective data layers proved strong and scalable in a real-life project circumstance.

Consequently, it can be argued that, above mentioned results provide concrete evidence for the hypotheses given in this paper. Because results show that standardized, integrated data linkage mechanism significantly improves the efficiency, accuracy, and reliability of industrialised construction procurement.

7. RESULTS AND DISCUSSION

This study proposed, developed, and empirically validated an innovative BIM-PDM-CAD data linkage approach to address design and procurement disconnection or (lack of communication between related parties) in construction projects especially uses prefabricated components in the project. One of the core advantages of the BIM-PDM-CAD integrated data method is that it greatly improves the selection efficiency of components such as doors, windows, and curtain walls. Through comprehensive analysis of saved design time, material costs, potential supply chain synergies, and return on investment, it is roughly estimated that using this integrated system will save nearly 20% of costs compared to the traditional design to procurement process. The system was applied to a certain project, and in the selection and design of key components such as doors, windows, and curtain walls, the total time consumption was significantly reduced, from 37% of the total design time to 18%. Fast track approach can be utilized due to real-time data synchronization, designers can start detailed design or construction drawing based on the latest selection results earlier, accelerating the overall project progress. Our study expressed findings in specifically defined case study alternatives/scenarios such as parametric door/window selection and integrated bathroom module procurement. This research emphasises significant, quantifiable improvements across multiple dimensions. In the next section, a comprehensive analysis of the results, linking empirical findings to the initial hypotheses, discussing underlying mechanisms, comparing outcomes with existing literature and acknowledging limitations to frame future research are given.

7.1. Quantitative Performance Evaluation

7.1.1. Design and Selection Efficiency

Design time efficiency was evaluated using a structured time-study protocol applied to before application (traditional workflow) and after application (BIM-PDM-CAD integrated workflow) in the case study project. The Design Time Percentage (DTP) metric is defined as the proportion of total detailed design phase man-hours consumed by five door/window/curtain wall-specific sub-tasks T1 to T5. Here T1 is manual component selection from vendor catalogues; T2 is BIM model population with selected components; T3 is drawing and schedule production; T4 is procurement data preparation (manual take-off

and BOM formatting and finally T5 is revision and coordination cycles arising from design-procurement discrepancies. Time data were recorded at 30-minute granularity by the project's two senior BIM engineers and one procurement coordinator over a six-week detailed design period, validated against schedule milestones.

In the pre-implementation phase, the combined person-hours invested in T1–T5 totalled 296 hours against a total detailed design phase effort of approximately 800 person-hours, yielding DTP = 37.0%. Post-implementation, automated parameter extraction and data transfer via RESTful API substantially eliminated T1 and T4, and significantly reduced T2, while T5 declined due to the elimination of data-mismatch-driven revision cycles. The post-implementation DTP was 144 person-hours out of 800, yielding DTP = 18.0% — a 51.4% reduction in the proportion of design effort allocated to these tasks, equivalent to a saving of approximately 152 person-hours for this project scale. A complete breakdown by sub-task is presented in Table R1 of the Supplementary Response Document.

7.1.2. BOM Accuracy

BOM accuracy was measured through a blinded audit protocol applied to stratified random samples of 50 line items each from the pre-implementation and post-implementation procurement packages (total BOM = 318 line items across 187 door types, 96 window types, and 35 curtain wall panel types). The audit was conducted by an independent internal reviewer from CSCEC-3 who had no involvement in BOM generation. A BOM line item was classified as "accurate" only if all four of the following dimensions were simultaneously correct: (D1) component identity — product code and description matched the contract-nominated product; (D2) quantity — within ± 1 unit of independent re-count; (D3) performance specification — fire rating, U-value, acoustic rating, and glazing configuration matched the contract technical schedule; (D4) unit and format consistency — no manual reformatting required for PDM system ingestion.

Before the application of the novel approach, an audit found 38 of 50 line items accurate (BOM accuracy = 76.0%), with the 12 errors distributed across outdated product codes ($n = 4$), quantity mismatches driven by unapplied floor plan revisions ($n = 3$), incorrect performance specifications ($n = 3$), and unit/format inconsistencies ($n = 2$). However, after the application of the proposed approach and methodology, 49 of 50 sampled line items were verified as accurate (BOM accuracy = 98.0%). The single remaining error was attributable to an incorrect fire-rating parameter manually overridden in the source BIM model during an earlier design revision — not to the data extraction or transfer process. This finding emphasises that system output quality is bounded by BIM model integrity. This limitation explicitly acknowledged in the conclusions section of this manuscript.

7.1.3. Composite Error Rate Reduction

The procurement cycle error rate was quantified using a Composite Procurement Error Index (CPEI) constructed from three operational error-event metrics routinely tracked within CSCEC-3's procurement management information system: (i) Request for Information queries related to component specification ambiguities (RFI, weight $w = 0.30$); (ii) Purchase Order Amendments caused by data errors in the original order (POA, weight $w = 0.40$); and

(iii) Non-Conformance Reports for components delivered contrary to specification due to upstream data errors (NCR, weight $w = 0.30$). Weights were assigned through a structured expert elicitation exercise using pairwise comparison (AHP-consistent) among the project's BIM Manager, Procurement Manager, and Quality Engineer, reflecting the relative cost and schedule impact of each error type (POA carrying the highest weight due to its direct financial and schedule consequences; POA average resolution cost: RMB 2,800 and 2.1 working days; NCR average resolution effort: 4.8 person-hours).

The CPEI is calculated as $CPEI = \Sigma(w_i \times \text{error-event rate}_i)$, where each rate = count of error events divided by total purchase order line items processed during the monitoring period (ten weeks of active door/window/bathroom pod procurement). Pre-implementation: CPEI = 0.0966 (47 RFIs, 31 POAs, 14 NCRs / 318 line items). Post-implementation: CPEI = 0.0189 (9 RFIs, 5 POAs, 4 NCRs / 312 line items). The measured CPEI reduction is 80.4%. The conservative figure of "approximately 60%" reported in the main text accounts for the single-project scope of the study, potential learning-curve effects in the post-implementation period, and the inherent difficulty of attributing all NCR events exclusively to procurement data quality rather than manufacturing variability. The full calculated reduction of 80.4% and the conservative floor of 60% together define the defensible range of performance improvement attributable to the integrated BIM-PDM-CAD system.

7.1.4. Cost-Saving Impact Analysis — Methodological Basis

Detected 18–22% cost saving for the door/window and bathroom pod procurement package was derived from a structured cost-benefit analysis conducted by the project's BIM Manager and Procurement Manager at CSCEC-3, drawing on four categories of measurable financial impact. The first financial impact was, the economy from reclaimed design man-hours was calculated by multiplying the reduction in T1 to T4 sub-task hours (152 man-hours, as mentioned in Section 7.1.1) by the blended hourly rate for BIM engineering and procurement staff on this project (RMB, China Currency, 185 per man-hour, inclusive of overhead allocation, based on project payroll records). Second saving was material waste reduction; it was estimated from the comparison of as-ordered versus as-installed quantities for the relevant component categories, benchmarked against the contractor's historical waste factor of approximately 6–8% for manually-managed procurement of the same component types. Third saving was about the delay avoidance and it was computed from the estimated two-week reduction in procurement-related design iterations, using the project's recorded overhead rate and the daily liquidated damages exposure specified in the construction contract. Fourth and final one was the inventory holding cost reduction that was estimated based on the shorter order lead time enabled by the integrated system. It permitted a shift toward more precisely-timed ordering for custom fabricated elements, reducing the average inventory holding period for pre-ordered items. The accumulation of these four savings, depicted as a percentage of the project's baseline traditional budget for the door/window/bathroom pod procurement scope, yielded the reported saving range of 18–22%. The authors acknowledge that this estimate is project-specific and sensitive to the assumed hourly rates, waste factors and delay cost parameters accordingly and it is presented as indicative rather than generalisable without further multi-project validation.

CONCLUSION

This study proposes an implemented, and empirically validated innovative BIM-PDM-CAD data linkage framework for industrialised construction procurement. By constructing unified data interface standards and exchange protocols based on IFC and RESTful API, the framework enables the automatic and accurate synchronisation of parametric component data for doors, windows, curtain wall elements and bathroom pods from BIM models into a PDM system for smooth order management and material tracking, while simultaneously providing a CAD platform for efficient, parameter-driven detailing and design. The study was validated on a real commercial construction project delivered by CSCEC-3 in Wuhan, China, encompassing more than 300 unique parametric component types across a ten-week procurement window.

The principal scientific contributions of this study are: (1) the design and technical validation of a tripartite integration architecture — previously absent from both Chinese and international construction BIM literature — that bridges the gap between BIM design intent, PDM order management, and CAD manufacturing specification through open standards; (2) the provision of quantified empirical evidence for performance improvements attributable to this integration, including a 51% reduction in the proportion of design phase effort consumed by door/window/curtain wall tasks, a 22-percentage-point improvement in BOM accuracy, and an approximately 60–80% reduction in the composite procurement error index; and (3) a practical demonstration that the 'information island' phenomenon widely documented in China's construction sector can be systematically resolved through a standards-based integration approach, with clear replication potential for other large contractors and industrialised construction contexts.

The study's limitations must be acknowledged explicitly to guide the interpretation of its findings and to direct future research. Firstly, it should be noted that the empirical validation was conducted on a single project and quantitative performance estimates particularly the cost saving of 18–22% and the composite error reduction are project-specific and sensitive to the project's particular cost structure, workflow practices, and BIM model quality. Multi-project validation across diverse project types, contract values, and organisational contexts is required before these figures can be considered generalisable benchmarks. Second, the framework was validated on component categories — doors, windows, curtain walls, and bathroom pods — that are inherently amenable to parametric data extraction due to their high degree of standardisation and catalogued product data. Extension to more complex component categories, such as MEP systems with bespoke routing, structural steel with project-specific geometry, or specialist facade systems, presents greater data modelling challenges that are not addressed in this study. Third, the post-implementation performance data may be partially inflated by a first-project learning curve effect: team members who participated in the design and implementation of the integration system may have performed more efficiently during the measurement period than would be expected in a cold-start deployment on a new project. Systematic performance monitoring across subsequent implementations is needed to establish stable long-run performance baselines. Fourth, the framework's output quality is fundamentally bounded by the quality of the source BIM model; model errors such as incorrectly assigned parameters, outdated component families or manually overridden attributes disseminate directly into the PDM and CAD outputs.

Therefore, BIM model quality assurance protocols are a prerequisite for reliable system performance.

Future research may include multi-project longitudinal evaluation of the BIM-PDM-CAD framework across diverse building types and procurement scopes; extension of the framework to MEP and structural component procurement, requiring investigation of more complex IFC schema mappings and PDM attribute hierarchies; integration of the framework with upstream ERP systems and downstream Warehouse Management Systems (WMS) and IoT sensor networks, to extend the digital thread into logistics execution and on-site installation verification. In addition, integration of artificial intelligence (AI) and machine learning techniques to BIM model quality verification, to automate the detection and correction of parametric data errors before they enter the procurement pipeline is a new research field for academics as well as practitioners on site. By taking into account the peculiarities of construction industry, investigation of the organisational change management requirements for framework adoption, including the identification of effective training interventions and institutional incentive structures that support sustained multi-stakeholder engagement with the integrated system will become more crucial.

Abbreviations List

API: Application Programming Interface

BIM: Building Information Modelling

BOM: Bill of Materials

CAD: Computer-Aided Design

CDM: Construction Design and Management

CSCEC: China State Construction Engineering Corporation

ERP: Enterprise Resource Planning

HTTP/HTTPS: Hypertext Transfer Protocol / Secure

IFC: Industry Foundation Classes

IoT: Internet of Things

JSON: JavaScript Object Notation

OAuth 2.0: Open Authorization 2.0

PDM: Product Data Management

PLM: Product Lifecycle Management

REST/RESTful API: Representational State Transfer

SCM: Supply Chain Management

STP: Standard for the Exchange of Product model data

WMS: Warehouse Management System

References:

- [1] W. Pan, A. G. F. Gibb, and A. R. J. Dainty, "Perspectives of UK housebuilders on the use of offsite modern methods of construction," *Constr. Manag. Econ.*, vol. 25, no. 2, pp. 183–194, Feb. 2007, doi: 10.1080/01446190600827058.
- [2] C. M. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, 2nd ed. Hoboken, NJ, USA: Wiley, 2011.
- [3] C. Z. Li, F. Hong, F. Xue, G. Q. Shen, X. Xu, and M. K. Mok, "Schedule risk modeling in prefabrication housing production," *J. Clean. Prod.*, vol. 134, pp. 484–494, Oct. 2016, doi: 10.1016/j.jclepro.2016.02.123.
- [4] M. M. Rahman and M. A. Alhassan, "A contractor's perception on early contractor involvement," *Built Environ. Proj. Asset Manag.*, vol. 2, no. 2, pp. 217–233, Nov. 2012, doi:
- [5] A. Monteiro and J. P. Martins, "A survey on modeling guidelines for quantity takeoff-oriented BIM-based design," *Autom. Constr.*, vol. 35, pp. 238–247, Nov. 2013, doi: 10.1016/j.autcon.2013.05.005.
- [6] D. Bryde, M. Broquetas, and J. M. Volm, "The project benefits of Building Information Modelling (BIM)," *Int. J. Proj. Manag.*, vol. 31, no. 7, pp. 971–980, Oct. 2013, doi: 10.1016/j.ijproman.2012.12.001.
- [7] F. Elghaish, S. Abrishami, M. R. Hosseini, S. Abu-Samra, and M. Gaterell, "Integrated project delivery with BIM: An automated EVM-based approach," *Autom. Constr.*, vol. 114, p. 103182, Jun. 2020, doi: 10.1016/j.autcon.2020.103182.
- [8] K. Whitlock, F. H. Abanda, M. B. Manjia, C. Pettang, and G. E. Nkeng, "4D BIM for Construction Logistics Management," vol. 2, no. 2, pp. 325–348, Apr. 2021, doi: 10.3390/CIVILENG2020018.
- [9] Yang, Y., Li, M., Wu, H., Dai, Y., & Zhong, R. Y. (2024). Digital Twin-Enabled Supply Chain Management with Visibility and Traceability: A Case Study. 375–380. <https://doi.org/10.1109/icist63249.2024.10805458>
- [10] Tan, X. (2021). Intelligent construction integrated management system based on BIM and Internet of Things. *International Conference on Communication and Electronics Systems*. <https://doi.org/10.1109/ICCES51350.2021.9489201>
- [11] L. Wan and Y. Bai, "Application Research on the BIM and Internet of Things Technology in Construction Logistics Management in the Period of Big Data," *Springer, Cham*, 2020, pp. 704–716. doi: 10.1007/978-3-030-49889-4_54.
- [12] A. Karmakar and V. S. K. Delhi, "Construction 4.0: What we know and where we are headed?," *J. Inf. Technol. Constr. (ITcon)*, vol. 26, pp. 526–545, 2021, doi: 10.36680/j.itcon.2021.028.

- [13] Y. Chen, D. Huang, Z. Liu, M. Osmani, and P. Demian, "Construction 4.0, Industry 4.0, and Building Information Modeling (BIM) for Sustainable Building Development within the Smart City," *Sustainability*, vol. 14, no. 16, p. 10028, Aug. 2022, doi: 10.3390/su141610028
- [14] S. Lee, J. Park, and J. Song, "BIM-Based Management System for Off-Site Construction Projects," *Appl. Sci.*, vol. 12, no. 19, p. 9878, Sep. 2022, doi: 10.3390/app12199878
- [15] G. Bozkurt, S. Ersoy, and E. Yaşa, "Evaluation of Integration of BIM and Virtual Reality Applications in Building Production Processes," *Turkish J. Civ. Eng.*, vol. 35, no. 4, pp. 117–144, Jul. 2024, doi: 10.18400/tjce.1244122.
- [16] L. Jiang, Z. Wu, and L. Li, "Barriers to BIM Implementation in the Prefabricated Construction Industry in China," *Sustainability*, vol. 13, no. 12, p. 6603, Jun. 2021, doi: 10.3390/su13126603.
- [17] J. Cui, T. Wang ve K. Zhang, "Data Integration for CAD/MPP/PDM Systems (CAD/MPP/PDM系统数据集成)," *Manuf. Autom. (制造业自动化)*, c. 41, no. 11, ss. 61–64, Kas. 2019, doi: 10.3969/j.issn.1009-0134.2019.11.015.
- [18] Z. Li and Y. Gao, "Research on CAD/CAPP/CAM System Integration Technology Based on PDM (基于PDM的CAD/CAPP/CAM系统集成技术研究)," *Electro-Optic Technology Application*, vol. 35, no. 4, p. 66, 2020.
- [19] J. Wang, Y. Wu, X. Wang, and H. Shou, "The outlook of blockchain technology for construction engineering management in the era of big data in China," *Front. Eng. Manag.*, vol. 7, no. 4, pp. 547–562, Dec. 2020, doi: 10.1007/s42524-020-0130-1.
- [20] M. Wang, C. C. X. Wang, S. Sepasgozar, and S. Zlatanova, "Building Information Modelling Implementation in the Design Stage of Chinese Prefabrication Construction," *IOP conference series*, vol. 1101, no. 9, p. 092017, Nov. 2022, doi: 10.1088/1755-1315/1101/9/092017.
- [21] Z. Li ve Y. Gao, "Research on CAD/CAPP/CAM System Integration Technology Based on PDM (基于PDM的CAD/CAPP/CAM系统集成技术研究)," *Optoelectron. Technol. Appl. (光电技术应用)*, c. 35, no. 4, ss. 70–74, 2020, doi: 10.3969/j.issn.1673-1255.2020.04.014.
- [22] B. Deng, "Digital supply chain management in construction materials in China: the example of Glodon BIM software," *Sixth International Conference on Traffic Engineering and Transportation System (ICTETS 2022)*, vol. 12591, p. 125912Q, Feb. 2023, doi: 10.1117/12.2669321.
- [23] S. Qiao, Q. Wang, Z. Guo, and J. Guo, "Collaborative Innovation Activities and BIM Application on Innovation Capability in Construction Supply Chain: Mediating Role of Explicit and Tacit Knowledge Sharing," *Journal of Construction Engineering and Management-asce*, vol. 147, no. 12, p. 04021168, Dec. 2021, doi: 10.1061/(ASCE)CO.1943-7862.0002197.

- [24] Y. Chen, X. Yang, X. Yu ve Q. Jiang, “Efficient BIM modeling technology and application for multiple specialties (面向多专业的BIM高效建模技术及应用),” *Civ. Archit. Eng. Inf. Technol. (土木工程信息技术)*, c. 14, no. 5, ss. 25–30, Eki. 2022, doi: 10.16670/j.cnki.cn11-5823/tu.2022.05.05.
- [25] J. Wang, Y. Zhang ve L. Qi, “Research on the Application of Quickly Creating BIM Models Based on CAD Drawings (基于CAD图纸快速创建BIM模型的应用研究),” *Civ. Archit. Eng. Inf. Technol. (土木工程信息技术)*, c. 13, no. 1, ss. 103–107, Şub. 2021, doi: 10.16670/j.cnki.cn11-5823/tu.2021.01.16.
- [26] S. Zhang, Y. Tang, Y. Zou, H. Yang, Y. Chen, and J. Liang, “Optimization of architectural design and construction with integrated BIM and PLM methodologies,” *Sci. Rep.*, vol. 14, Art. no. 26153, Oct. 2024, doi: 10.1038/s41598-024-75940-x
- [27] D. Avogaro and C. Zanchetta, “Bridging Information from Manufacturing to the AEC Domain: The Development of a Conversion Framework from STEP to IFC,” *Systems*, vol. 13, no. 6, p. 421, May 2025, doi: 10.3390/systems13060421.
- [28] Y. Han, X. Yan, and P. Piroozfar, “An overall review of research on prefabricated construction supply chain management” *Engineering, Construction and Architectural Management (ECAM)*, vol. 30, no. 10, pp. 5160–5195, 2023, doi: 10.1108/ECAM-07-2021-0668.
- [29] S. Cheng, X. Zhou, Y. Zhang, M. Duan, and J. Gao, “Study on resilience factors and enhancement strategies in prefabricated building supply chains,” *Buildings*, vol. 14, no. 1, p. 195, Jan. 2024, doi: 10.3390/buildings14010195
- [30] Zhou, X., Cheng, S. and Zhang, Y., “Exploring critical factors influencing the resilience of the prefabricated construction supply chain,” *Buildings*, vol. 13, no. 12, p. 3210, Dec. 2023, doi: 10.3390/buildings13123210
- [31] Le, P.L., Chaabane, A. and Dao, T.M., “BIM contributions to construction supply chain management trends: an exploratory study in Canada,” *Int. J. Constr. Manag.*, vol. 22, no. 1, pp. 66–84, 2022, doi: 10.1080/15623599.2019.1639124.
- [32] Magill, L.J., Jafarifar, N., Watson, A. and Omotayo, T., “4D BIM integrated construction supply chain logistics to optimise on-site production,” *Int. J. Constr. Manag.*, vol. 22, no. 12, pp. 2325–2334, 2022, doi: 10.1080/15623599.2020.1786623.
- [33] Matos, B.C., Cruz, C.O. and Branco, F.B., “Digitalization and procurement in construction projects: an integrated BIM-based approach,” *J. Inf. Technol. Constr.*, vol. 29, pp. 400–423, 2024, doi: 10.36680/j.itcon.2024.019.