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# An E-Commerce Platform for Industrialized Construction Procurement Based on BIM and Linked Data

**Dandan He [1], Zhongfu Li [1], Chunlin Wu [2] and Xin Ning [3,*]**

[1] Department of Construction Management, Dalian University of Technology, Dalian 116024, China; he__dandan@126.com (D.H.); lizhongfu@dlut.edu.cn (Z.L.)
[2] School of Economics and Management/Beijing Key Laboratory of Emergency Support Simulation Technologies for City Operations, Beihang University, Beijing 100191, China; wuchunlin@buaa.edu.cn
[3] School of Investment and Construction Management, Dongbei University of Finance and Economics, Dalian 116025, China
* Correspondence: ningxin@dufe.edu.cn; Tel.: +86-411-8471-0435

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**Abstract:** Industrialized construction has raised the requirements of procurement methods used in the construction industry. The rapid development of e-commerce offers efficient and effective solutions, however the large number of participants in the construction industry means that the data involved are complex, and problems arise related to volume, heterogeneity, and fragmentation. Thus, the sector lags behind others in the adoption of e-commerce. In particular, data integration has become a barrier preventing further development. Traditional e-commerce platform, which considered data integration for common product data, cannot meet the requirements of construction product data integration. This study aimed to build an information-integrated e-commerce platform for industrialized construction procurement (ICP) to overcome some of the shortcomings existing platforms. We proposed a platform based on Building Information Modelling (BIM) and linked data, taking an innovative approach to data integration. It uses industrialized construction technology to support product standardization, BIM to support procurement process, and linked data to connect different data sources. The platform was validated using a case study. With the development of an e-commerce ontology, industrialized construction component information was extracted from BIM models and converted to Resource Description Framework (RDF) format. Related information from different data sources was also converted to RDF format, and Simple Protocol and Resource Description Framework Query Language (SPARQL) queries were implemented. The platform provides a solution for the development of e-commerce platform in the construction industry.

**Keywords:** e-commerce; industrialized construction procurement; building information modelling; linked data

## 1. Introduction

Industrialized construction is superior to traditional construction, as it reduces construction time and labor requirements [1,2], ensures building quality and work safety [3], and improves environmental sustainability [4]. Accordingly, construction enterprises are inclined to develop industrialized construction methods instead of traditional construction methods. Skeleton infill (SI) and prefabricated construction are the main industrial construction systems used at present. The main steps for industrialized construction are off-site manufacturing, transport, and construction site assembly of building components. Off-site manufacturing and building components are the major parts of building construction. To reduce costs and time taken, and to offer customization, mass customization is employed. The concept of mass customization can be defined either broadly or narrowly [5]. In a broad sense, it is a modernized production and management mode oriented to a multi-directional market; it satisfies personalized customer needs, mass produces customized products, and realizes economies of scope [6]. In a narrow sense, mass customization represents a method and technologies through the whole process of marketing, commodity development, production, and delivery [7]. Mass customization can customize goods or services for individual customers in high volumes at low cost [8–10]. It is a prerequisite for industrialized construction procurement (ICP). ICP activities are very important in the architecture, engineering, and construction sectors, and occur at different phases of an industrialized construction project [11]. However, current implementation of ICP have limitations. The process lacks effective communication—sometimes information is not shared between buyers and suppliers. As different components have many specification parameters, an enterprise cannot manage its component suppliers or compare components with different specification parameters offered by different suppliers. Thus, ICP methods need to be improved through the adoption of an information management and communication platform.

E-commerce is a product information integration platform that can store many product data and help consumers search for and choose satisfactory products. A traditional e-commerce platform considers data integration for common product data, such as a building material procurement platform. The platforms allow for effective communication between buyers and product suppliers, playing an important role in collaborative information management and shared instruments [12,13]. In industrialized construction, the application of e-commerce lags far behind other sectors of the national economy of China and there is still a long way to go in the development of e-commerce. For customers, the development of e-commerce in industrialized construction is urgently needed. For enterprises, ICP method needs to be improved. To increase market competitiveness, construction enterprises need to develop an e-commerce platform. The product characteristics in the construction industry are different from other manufacturing products: there are no uniform standards for industrialized construction components, and ICP products supplied by different suppliers are produced with different technical standards. Thus, it is difficult for customers to find satisfactory products despite a range of options.

In the construction sector, there are many participants and the data types involved are complex. Traditional platforms cannot meet the requirements for building product data integration and it is thus necessary to develop an innovative e-commerce platform that meets the complex data integration requirements of the construction sector. To this end, better applying the latest Information and Communication Technologies (ICT) to e-commerce could bring very large economic benefits to traditional industries (particularly the manufacturing industry), through reduced costs and waste.

This paper proposes an information-integrated e-commerce platform for ICP that uses a Building Information Modelling (BIM) model with linked data in an e-commerce platform to realize an effective framework for e-commerce. BIM, a specific 3D model used in the construction sector, can store and manage all data in the lifecycle of a construction project, and supports architects and engineers by using their models directly for manufacturing and installation. It enables increased quality, speed, and customization. Linked data can connect related data sources on the Internet. The adoption of BIM and linked data in the e-commerce platform can solve problems related to the volume, heterogeneity, and fragmentation of ICP process data. Moreover, the integration of ICP data, such as supplier information, customer information, logistics information, and transaction information, is straightforward to realize.

Established frameworks provide a conceptual approach for overcoming some of the shortcomings of existing e-commerce platform implementation approaches. They relate not only to the improvement and verification of an algorithm. In fact, data comparison testing and evaluation is not the main topic of this paper. Existing research has mainly focused on the conception and design phases [11,14–16]. This paper first reviews e-commerce in the construction industry (Section 2) and proposes a methodology (Section 3). Next, it presents a BIM and linked data-based e-commerce platform (Section 4) for ICP to promote commerce data integration, and uses a case study (Section 5) to validate the model. Finally, conclusions are drawn.

## 2. E-Commerce in the Construction Industry

E-commerce uses modern information technology, flexible production modes, and an agile organizational structure to produce products that meet customer's varying needs and provide corresponding services [17–20]. It also uses computer networks and the Internet to buy and sell products and services, and to transmit information [21]. E-commerce can be divided into different models: Business-to-Business (B2B) is used to manage data exchange between companies [22,23]; Business-to-Consumer (B2C) is used to manage data exchange between companies and consumers [24]; C2C is used to manage data exchange between consumers [25]; Business-to-Manager (B2M) looks for intermediary agents and logistics channels through the network; Business-to-Government (B2G) includes the informal ties between business managers and government officials [26,27]; and Business-to-Employees (B2E) use the network to deliver products or service information to employees [28]. Different from B2B and B2C, B2M is a new e-commerce model. The fundamental difference is that the target audience is different—the first two target audiences which are the final consumer, while B2M target's audience is the enterprise or the seller of the product. By considering current applications of the e-commerce model in the construction industry, this paper summarizes the relevant variables (Figure 1) [22–28]. In the context of mass customization, the key is understanding and responding to the changing needs of each unique customer [29]. Figure 2 shows the e-commerce platform based on mass customization. E-commerce can create a link to the customers [21] and contribute to an environment that enables customers to communicate their needs to suppliers [29]. The e-commerce platform provides the way to integrate customers in the production process through co-designing [30]. Customer involvement in design is a requirement for product customization, so that a customization company and product supplier can fulfil customer demands. The e-commerce platform can be used by customers to analyze customization options for procurement decision support, by customizing company and product suppliers for design, production planning, pricing, and to gather processing information (information required for production) for the products [30].

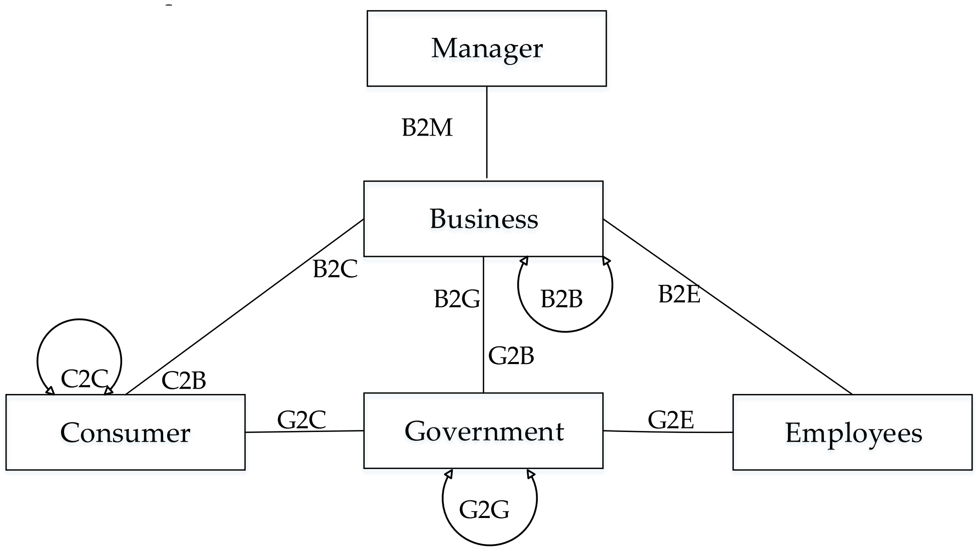


**Figure 1.** Different existing e-commerce models of the construction industry (based on [22–28]). B2B, Business-to-Business; B2C, Business-to-Consumer; C2C, Customer-to-Customer; B2M, Business-to-Manager; B2G, Business-to-Government; B2E, Business-to-Employees.

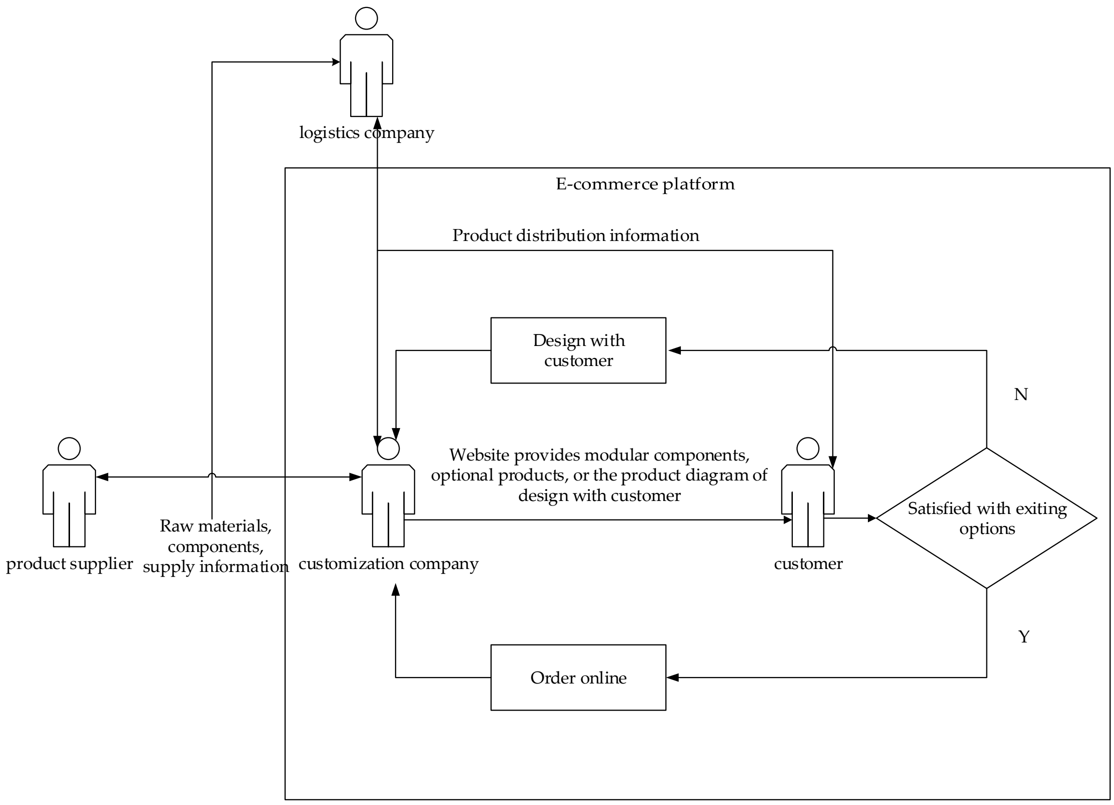


**Figure 2.** An e-commerce platform based on mass customization (based on [29,30]).

Through an e-commerce platform such as described in Figure 2, customization companies, suppliers, customers, and logistics companies can be connected together. With the procurement process offered by an e-commerce platform, construction costs (e.g., from bidding, procurement, service costs, raw materials, production, transactions, management, strategic costs, and labor) can be reduced [14,31,32]. With information technology and business process optimization, repeated demands for key information are reduced [33]. Thus, the overall procurement cycle, the communication period between different participants, and contract completion time are shortened [34]. E-commerce can promote competition between enterprises to improve product quality, by promoting the standardization of products and production efficiency, optimizing the supply chain, and improving efficiency in communication [35]. E-commerce platforms can improve project efficiency and facilitate access to project data through a network-based central database. They can integrate online and offline resources, production, sales and distribution; these include efficient coordination for production integration, network customization, promoting the quality of products, and the design and service level of ascension [36]. E-commerce can improve the transparency of the enterprise workflow, promote time savings, shorten the evaluation time, and improve the enterprise's internal work processes [16]. Construction e-commerce business processes are implemented on the Internet, reducing the need for stakeholder participation and paper document storage, which can shorten the procurement process and the supply chain [12,23]. Construction logistics is an important research area [37,38]; however, this paper mainly studies the data integration in e-commerce platform; logistics is just one of multiple data sources and it is not a main concentration in our research. Others have studied the integration of e-commerce and the supply chain [39], building materials procurement [40], etc. These are also not included in this paper.

Developing an e-commerce platform is highly dependent on the sharing and interaction of commercial information [41]. However, in the construction industry, the information is large, fragmented, diverse, and semantically heterogeneous, which increases the difficulty of developing e-commerce. The main difficulties regarding these barriers are shown as follows:

- Large volumes of information: With increases in enterprise production capacity and the expansion of sale reach, there are more and more companies involved in e-commerce, offering many kinds of products and services. The amount of commercial information has thus increased sharply [42].
- Fragmented information: Information in different e-commerce platforms hosted independently, so when users search for relevant information on the network, it is displayed online in different formats. It is difficult to apply a query across all relevant information [43], mainly due to the separation of information between different websites.
- Diversified information: In the construction industry, the structure of commercial information is diverse, with different e-commerce platforms having different information types and search methods. Each e-commerce platform has its own product search engine and presentation model, including structured information, semi-structured information, and unstructured information. Examples of each type are traditional relational database, multimedia information, and document and HTML information, respectively.
- Semantically heterogeneous information: There is heterogeneity in managing similar types of information for different suppliers [42]. When two suppliers sell the same or similar products, different properties may be used to describe the stored information. However, for contractors, it is difficult to find similarities between two suppliers' products—this leads to semantic heterogeneity. In addition, there is a difference in the meaning of terms applied to different systems [43]. This leads to semantic heterogeneity.

Established e-commerce platforms offer saving on costs and time, improving product quality, enhancing the competitiveness of enterprises and simplifying the business process. These advantages form a basis for the development of e-commerce platforms in the construction industry. To solve the difficulties described above, we built an e-commerce platform specifically for ICP.

## 3. Methodology

The research goal of this paper is to build an information-integrated e-commerce platform for ICP to overcome some of the shortcomings of traditional e-commerce platforms. To achieve the aim, we followed the research framework proposed by Lee et al. [44] and Aguiar Costa et al. [15]. Lee et al. proposed a platform for sharing construction defect information using BIM and an ontology. Aguiar Costa et al. proposed an innovative approach to construction e-procurement based on BIM. We propose an e-commerce platform for industrialized construction procurement based on BIM and linked data. We focused on three major phases: (1) a literature review of e-commerce in the construction industry; (2) an exploratory study and implementation of an e-commerce platform for ICP, including the function of BIM and linked data in the platform; and (3) simulation and testing of the platform developed, using an ICP case study to assess the platform's validity and sustainability (Figure 3).

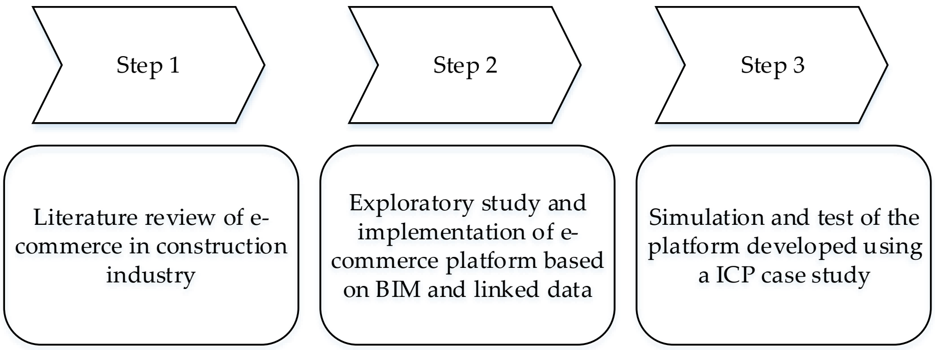


**Figure 3.** Research method roadmap.

In Section 2, e-commerce in construction industry is summarized with the aim of identifying the main barriers to e-commerce development. In the following sections, the most important outcomes achieved during the other two major phases of the study are presented.

## 4. The Framework and Implementation of an E-Commerce Platform for ICP Based on BIM and Linked Data

An e-commerce set-up is an integrated electronic environment using ICT to manage information and achieve effective regulation of contracts [45]. In a fully-integrated, paperless environment, to reduce management workload and achieve automation of the operational process, all the relevant information in the e-commerce process must be digitized. Based on the advantages of e-commerce, some countries encourage the use of e-commerce in the public sector. Gradually, the private sector also noticed the advantages of e-commerce, and the construction industry has also begun to implement e-commerce. BIM technology plays an important role in e-commerce in the construction industry. In the description of information, BIM is used for storage and to describe products or services. It achieves the integration of all commercial information in the construction lifecycle and describes construction products. In addition, e-commerce information includes supplier information, customer information, etc. These data sources can use linked data to correlate with BIM models to achieve total information environment integration. In this section, a novel e-commerce platform for ICP is proposed. BIM and linked data are applied to the platform to meet the demands of an e-commerce platform for ICP.

### *4.1. The Framework of the Proposed E-Commerce Platform*

The development of BIM technology allows the industrialized construction to develop increased informatization. It can be used as an integrated product model for the industrialized construction, to achieve collaborative work between the participating units of a construction project, and allow information sharing. Linked data were proposed under the semantic web concept, which connects the entire network with Uniform Resource Locators (URI), RDF, and the Hyper Text Transfer Protocol (HTTP). In theory, linked data can integrate different data sources on the Internet into a network; it is an effective means of information integration. The framework of the e-commerce platform developed in this study is shown in Figure 4.

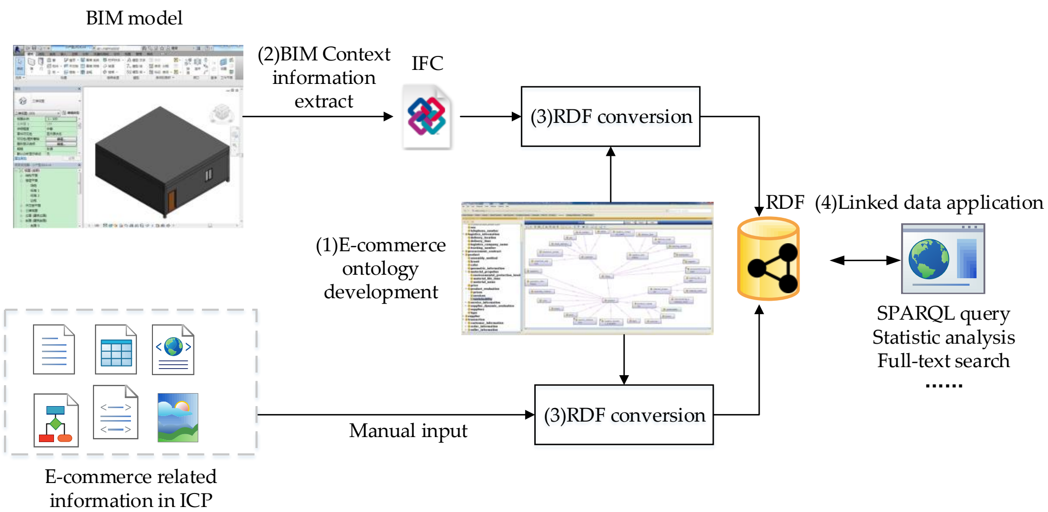


**Figure 4.** An outline of the proposed e-commerce platform for ICP.

The core part of this platform forms a converged data environment, using BIM as the product data model. It uses linked data to bring together supplier, customer, logistics, and transaction information to the BIM model. To realize a linked data framework, an e-commerce ontology needs to be developed for

RDF data transformation. BIM models can be extracted in industry foundation class (IFC) format and converted into RDF [46]. E-commerce-related information for ICP can be exported in RDF manually. In association with these RDF data using the e-commerce ontology, an integrated RDF dataset can be formed. Retrieval and other applications can be performed the RDF data.

### *4.2. The Function of BIM in the E-Commerce Platform*

With the rapid development of ICT, the construction industry has improved tremendously. These improvements include increased production performance, reduced resource waste, and changing production methods. BIM has brought improvements to construction projects, mainly for information sharing and visualization [47]. BIM can be regarded as the only information warehouse for participants in a typical construction project [48]. The information produced by these participants can be stored in the BIM model using a unified information structure, realizing the sharing and interoperation of information. BIM can solve issues related to information management and exchange between different stakeholders, phases, and applications. The information must be timely, accurate, and adequate, and the ultimate goal of BIM is to get the right information at the right time for the right person.

In the development of e-commerce in the construction industry, application of BIM includes product databases and price databases. A major challenge emerges when these composite models are developed by collaborating teams using different software tools, and who are often geographically dispersed. They require, however, that components, reference models, and software applications be interoperable [11].

The business process supported by e-commerce platforms extends the consumption behavior to the network so that consumers' choice of products can be greatly expanded [49]. However, the application of e-commerce is limited and ineffective for ICP. In construction projects, the main reason is that different systems are non-interoperable, which creates problems for the different stakeholders [49]. BIM can improve the efficiency of the business process, enhance the role of product information, and create an information-based environment. BIM can integrate all information produced in the life cycle of the construction projects. However, many of the purchase activities' information relate to the ICP of different supplies, such as supplier information, customer information, logistics information, and transaction information. All of this information needs to be integrated together, which is discussed in the next section.

### *4.3. The Function of Linked Data in the E-Commerce Platform*

The term linked data provides a basic recipe for publishing and connecting structured data on the web [44], and linked data is simply about using semantic web technology to create links between different data sources [50]. Linked data encourages users to format their data and publish it on the web in machine-readable formats, so that other data sources can be linked to this published data [51]. The key features of linked data are links between data from different data sources, which ensures that data are not isolated data islands and supports data integration [52].

Linked data can use semantic web technologies to publish structured data on the web, and create links between data from one data source to data within other data sources. The development of linked data is based on four basic principles [44,50]: (1) use URIs as names for things; (2) use HTTP URIs so that people can look up those names; (3) when someone looks up a URI, provide useful information using standards (RDF, SPARQL); and (4) include links to other URIs, so that users can discover more things.

Our e-commerce platform uses a linked data technology stack (includes URIs, HTTP, and RDF) to form an integrated data environment. Data can be described by RDF data models, identified by URIs, and retrieved over the HTTP protocol, which allows for discovery, identification, and integration of construction e-commerce information resources. The two main advantages of the application of linked data are summarized as follows:

- The integration or sharing of commercial information sources: The commercial information characteristics in the construction industry are determined by the characteristics of the construction project itself. Procurement activities are very important in the construction industry and occur throughout the total building lifecycle. In addition, there are many participants in the building lifecycle. As a result, commercial information is stored on different systems, including e-commerce platforms. Using linked data ensures the connection between different data sources. In the linked data network for commercial information, there are links between different associated data sources. Through the linked data search engine, users can access the URIs of different entities according to their own needs. From the currently-accessed URIs, users can access the other URIs, along with links to other data sources, until relevant data are found.
- The semantic relevance of commercial information: The RDF data model is the main data description format in the semantic web. It describes the semantic relationship between entities and enhances the description of the form data. Through the semantic relationship descriptions between different pieces of commercial information, we can find such information that users themselves may need, but do not confidential commercial information, achieving the goal of knowledge discovery.

### *4.4. The Implementation of an E-Commerce Platform for ICP*

According to the framework described in Figure 4, the implementation of an e-commerce platform for ICP can be realized as follows:

Step 1. Apply BIM for industrialized construction components integration

Based on the research about BIM and linked data in ICP, and the generic SOA4BIM framework presented by Jardim-Goncalves and Grilo [53], a basic e-commerce platform (see Figure 4) for ICP was used. Presenting BIM for industrialized construction components, Figure 5 shows an integrated framework based on BIM and electronic procurement. The framework was constructed using a model-driven architecture (MDA) and a service-oriented architecture (SOA).

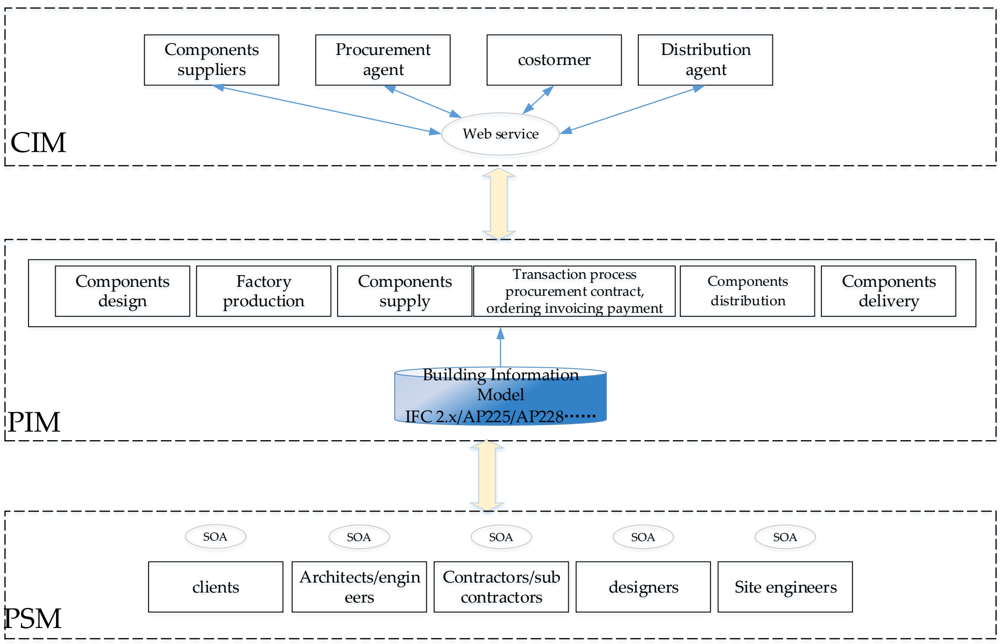


**Figure 5.** Applying BIM for product data integration.

MDA is a software implementation architecture and contains three parts: a computation independent model (CIM), a platform-independent model (PIM), and a platform-specific model

(PSM). CIM describes the business model for the ICP system, usually created by the analyst. PIM is an abstract model, independent of any implemented technology, which can describe the essential characteristics of the system. It uses UML or another appropriate mark-up description that has nothing to do with the specific implementation details. PIM can only be used to describe the function and behavior of the business, including static systems and dynamic semantics. It can maintain its value over a long time, needing to be changed only when the business requirements change. PSM contains all of the features represented in PIM and adds design ideas for the platform implementation, including technical implementation details.

SOA transforms various business activities into services with uniform interface standards, and aggregates corresponding services through a specified business process to meet changes in enterprise organization and business functions. SOA, through the static description of the service, provides information standardization and ensures the function of the service, using a standard service port to connect to the outside, including to services or the entire business process. Dynamic application of the services comes through combining the service data exchange between the service port and a port, or between a port and process to enable information exchange.

Under our framework, BIM is the main tool for data sharing and storage. The data involved in the e-commerce process need to be connected with the BIM model to ensure the effective interaction and integration of data from different participating units in different phases. However, there are many kinds of data involved in the process of e-commerce for ICP. Some of them are not convenient to store in the BIM platform, such as contract information, transaction information, supplier information, customer information, and so on. The main obstacle to creating an e-commerce platform for ICT is connecting the information with the BIM model. This study uses linked data for the integration of the BIM model and other commerce-related data, creating an effective e-commerce platform for ICP.

Step 2. Using the linked data integration framework to integrate other information

In accordance with the basic principles of linked data, all information resources need to be converted into RDF format. RDF is a data model optimized for information sharing and exchange [54]. RDF has the characteristics of a simple structure and a global namespace provided by the use of URIs. It formats data in terms of the subject, predicate, and object triples [55]. The subject is the description object, and the predicate describes the relationship between the subject and the object. The subject and object are both URIs. Each URI identifies a resource, or a URI and a literal.

In the linked data integration framework, we must convert supplier, customer, logistics, and transaction information into RDF format, creating typed links between these RDF datasets.

A triple is an effective tool for information integration. Triples are collections of URIs and literals, and each URI and literal has a global name. They can be integrated without name translations by using the global names. RDF data can be transmitted and integrated without any transformation, which is a great advantage in the process of data integration.

Step 3. Integrate BIM with the linked data framework

Finally, the two frameworks are combined to an integrated e-commerce platform for ICP. Our proposed platform is based on the MDA and SOA integration model and introduces the linked data method, which integrates other information into the process of e-commerce with the BIM model. The new platform integration framework improves the information exchange processes.

The following section is a case study to prove the validity of the proposed platform supported by BIM and linked data.

## 5. Case Study

### *5.1. The E-Commerce Process in ICP*

The standard electronic procurement process described by the European standards association is described in Figure 6 [56]. Analysis of the electronic procurement process combined with the characteristics of ICP and the relationship between the e-commercial information entity for ICP is summarized in Figure 7, using linked data to integrate information on a data level.

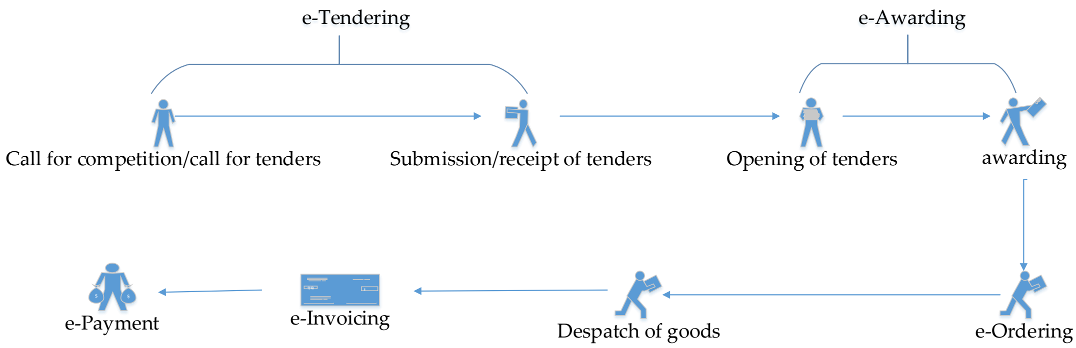


**Figure 6.** Reference e-procurement process.

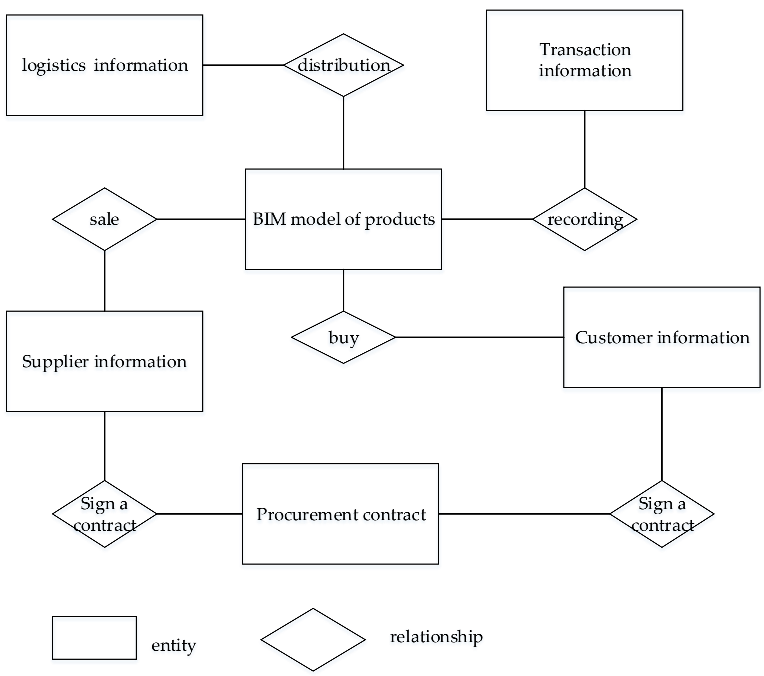


**Figure 7.** The relationship between the e-commerce information entity for ICP.

This information entity relationship diagram is based on BIM and linked data. It uses the parametric design and visual design of BIM for the 3D storage of construction product information. Compared with 2D information, such as pictures or video on traditional e-commerce platforms, the product description is more detailed and specific, and provides a more intuitive product display for customers. The interaction between the product BIM model and the BIM model in the project construction lifecycle can reduce the workloads of the designer, construction, buyer, cost estimator, and accountant. The information can be applied directly to design and cost estimation to achieve the goal of simplifying the workflow, saving time and costs.

## *5.2. Ontology Development*

An ontology was established to align a BIM product model with an ICP process. Using the analysis in Section 5.1, we summarized the entity attributes (see Table 1). We analyzed the relationship between different entities and established relationships using the linked data principle. Our e-commerce ontology for ICP is based on the analysis in Section 5.1 and used Protégé software. The ontology is shown in Figure 8.

**Table 1.** Detailed descriptions of the information entities.

| Entity Name | Entity Description | Sub-Entity Description |
|---|---|---|
| 1. Supplier information | 1.1. Supplier name<br>1.2. Credit rating<br>1.3. Registration code<br>1.4. Setup time<br>1.5. Address<br>1.6. Products<br>1.7. Legal representative<br>1.8. Financial information | |
| | 1.9. Assessment information | 1.9.1. Product description match<br>1.9.2. Seller' service attitude<br>1.9.3. Logistics service attitude |
| | 1.10. Service situation | 1.10.1. Transaction rate<br>1.10.2. Refund rate |
| 2. Customer information | 2.1. ID number<br>2.2. Name<br>2.3. Sex<br>2.4. Age<br>2.5. Residential address<br>2.6. Telephone number<br>2.7. Email address | |
| 3. Transaction information | 3.1. Seller information | 3.1.1. Seller Name<br>3.1.2. Seller Address<br>3.1.3. Seller Phone<br>3.1.4. Seller Emil address |
| | 3.2. Customer information | 3.2.1. Customer Name<br>3.2.2. Customer Address<br>3.2.3. Customer phone |
| | 3.3. Order information | 3.3.1. Transaction record<br>3.3.2. Transaction amount<br>3.3.3. Transaction frequency |
| 4. logistics information | 4.1. Logistics company name<br>4.2. Tracking number<br>4.3. Delivery time<br>4.4. Delivery location | |
| 5. Procurement contract | 5.1. Contract number<br>5.2. Time<br>5.3. Object<br>5.4. Content | |
| 6. Product information | Part 1. Stored on e-commerce platform<br>6.1. Price<br>6.2. Color<br>6.3. Brand<br>6.4. Suppliers<br>6.5. Assembly method | |

**Table 1.** *Cont.*

| Entity Name | Entity Description | Sub-Entity Description |
| --- | --- | --- |
| | 6.6. Product evaluation | 6.6.1. Sustainability<br>6.6.2. Price<br>6.6.3. Service |
| | 6.7. Supplier dynamic evaluation | 6.7.1. Consistent description<br>6.7.2. Delivery speed<br>6.7.3. Service attitude |
| | 6.8. Service information | 6.8.1. Claims<br>6.8.2. Return rate<br>6.8.3. Return time<br>6.8.4. Number of punishments |
| | Part 2. Stored in BIM model<br>6.9. Geometric information | |
| | 6.10. Material properties | 6.9.1. Material name<br>6.9.2. Material life time<br>6.9.2. Environmental protection level |
| | 6.11. type | |

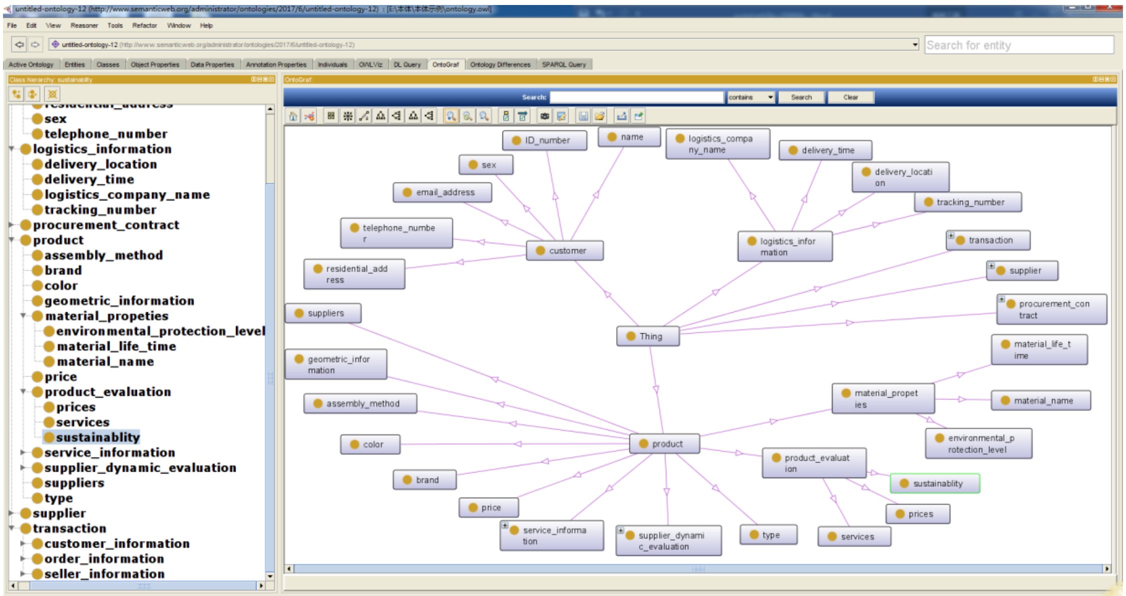


**Figure 8.** Construction of the e-commerce ontology.

## 5.3. Extraction of Product Information from the BIM Model

Product or component information is stored in the BIM model. The purpose of extracting information from the model is to form structured data. In this paper, the BIM model was created using Autodesk Revit software, and the data in IFC format was exported (Figure 9).

## 5.4. RDF Conversion

To establish linked data for information sharing and Internet searches, all the information was converted to an RDF file. An open source library D2RQ was used to handle the conversion process. D2RQ accesses data in a relational database in a virtual RDF manner and helps to handle RDF and SPARQL. We defined mapping documents, converted relational databases to RDF databases, and used SPARQL for queries. The tool could then handle relationship generation among different data items, according to the ontology mentioned in the previous section, through a mapping document. A file in

RDF format is the output. All the information was defined using the classes of the ontology. As the ontology schema is published online, SPARQL queries made on the web can trace the relationship between different stakeholders. For other types of information, data properties used codes instead of files for storage in relational databases, which could then be explicitly expressed in the RDF file.

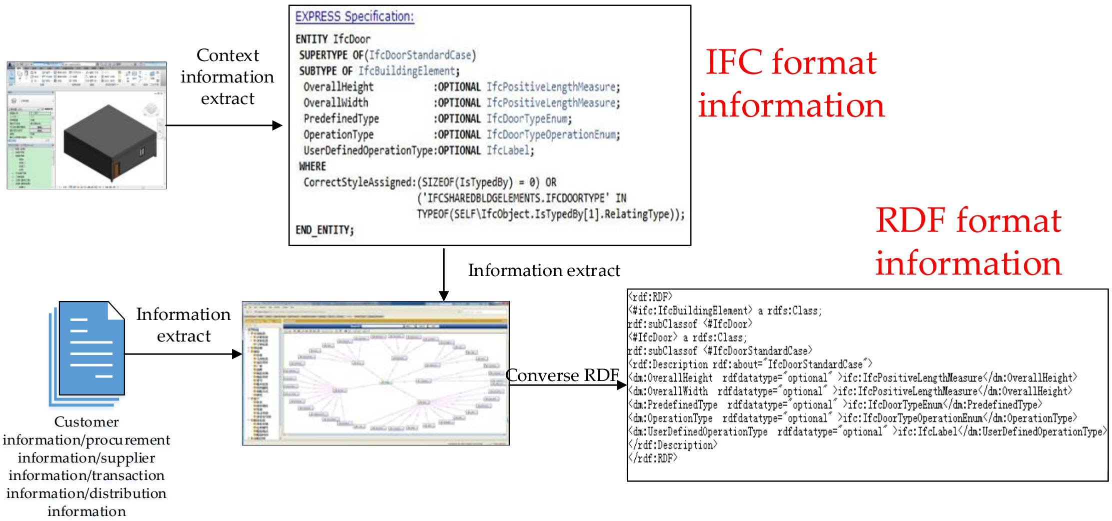


**Figure 9.** Sample application process for the information fusion framework.

### *5.5. Information Retrieval Using SPARQL Queries*

This section presents some query examples for specific purposes. SPARQL is a W3C-recommended RDF query language, and we used SPARQL endpoints to test the query statements. The results show the ability and flexibility to retrieve information from RDF-formatted information. An example is shown in Figure 10. The query was for the wood doors priced between 1000 and 2000, showing the product name, price, and color.

```
SPARQL Query 1
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX vocab: <http://localhost:2020/resource/vocab/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX map: <http://localhost:2020/resource/#>
PREFIX db: <http://localhost:2020/resource/>
SELECT ?name ? price ?color
WHERE{?x name ?name
?x vocab:product_material 'wood_door'
  ?x price ?price
}
PREFERING ?price BETWEEN[1000,2000]
```

The output from query 1:

| name | price | color |
|---|---|---|
| Tata wood door | 1020 | white |
| 3D wood door | 1500 | white |
| Muyu wood door | 2000 | white |

**Figure 10.** SPARQL Query 1 and the result.

The second SPARQL query example is shown in Figure 11. This query was to find all people who have purchased wooden doors with price greater than 1000, displaying their name, sex, and age.

SPARQL Query 2

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX vocab: <http://localhost:2020/resource/vocab/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX map: <http://localhost:2020/resource/#>
PREFIX db: <http://localhost:2020/resource/>
SELECT ?name ? sex ?age
WHERE{?x name ?name
?x vocab:product_material 'wood_door'
FILTER(?price > 1000)
}
```

The output from query 2:

| name | sex | age |
|---|---|---|
| Ling Li | male | 30 |
| Lulu Zhang | female | 22 |
| Peng Qing | male | 41 |

**Figure 11.** SPARQL Query 2 and result.

### *5.6. Validation of Results on the E-Commerce Platform for ICP*

We also conducted validation of the results by comparing with other e-commerce platforms. This process comprised three steps: (1) obtain the test dataset from the web—5200 data records of doors were download from the Taobao webset (https://www.taobao.com); (2) use the keywords "aluminium alloy door", "aluminium alloy door", and "1000 < price < 2000" to search relevant records both on the proposed platform and the Taobao webset; and (3) compare the search results (Table 2). Table 2 reveals that the Taobao search method returned more records than the proposed platform, the proposed platform better retrieved the first ten most relevant records (see Table 2), and the results obtained using the proposed platform are better than the Taobao search method based on the precision indicator (see Table 2). This was because the proposed approach could capture the hierarchical structure through the e-commerce ontology with more precise results. Thus, more relevant results can be provided by the proposed platform compared with other e-commerce platforms.

**Table 2.** Comparison of the search results.

| Key Words | Proposed Platform | | | Taobao.com | | |
|---|---|---|---|---|---|---|
| | Total Records | Relevant/The First Ten Records | Precision | Total Records | Relevant/The First Ten Records | Precision |
| "aluminium alloy door" | 1061 | 10/10 | 0.85 | 5200 | 10/10 | 0.45 |
| "aluminium alloy door" and "1000 < price < 2000" | 19 | 10/10 | 0.74 | 28 | 7/10 | 0.45 |

To further explain the contribution of the proposed platform, we interviewed four experts (Table 3) and asked them to evaluate the application performance of the platform. Each evaluation criterion was given a number between 1 and 5 (totally unimportant, fairly unimportant, neither unimportant nor important, fairly important, and very important, respectively). Table 4 shows the evaluation criteria and performance indicators of the e-commerce platform [16,57].

Evaluation criteria were calculated by the sum of the choice of each performance indicator. The evaluation criteria of the two platforms were calculated separately and the results are shown in Table 5. To compare the cost performance for the two platforms, the specific function, i.e., the cost performance ratio, was used. The cost performance ratio is:

$$\text{cost performance ratio} = \text{quality}/\text{cost} \tag{1}$$

The cost performance ratio of the proposed platform (value = 41/37 = 1.11) was higher than the taobao.com (value = 31/30 = 1.03). The proposed platform's service value was 92, and the service value for taobao.com was 55. The proposed platform's information sharing value was 39, and 9 for taobao.com. Thus, our platform also outperformed taobao.com in terms of service and information sharing.

**Table 3.** Profiles of the four experts asked to compare the e-commerce platforms.

| Experts | Type | Working Experience (Years) | Time Using of E-Commerce Platforms (Years) |
|---|---|---|---|
| 1 | Project manager | 5 | 10 |
| 2 | Site superintendent | 7 | 11 |
| 3 | Formwork manager | 3 | 10 |
| 4 | Chief estimator | 7 | 13 |

**Table 4.** Expert opinion on the evaluation criteria and performance indicators of the e-commerce platforms.

| Evaluation Criteria | Performance Indicator | Choice of Proposed Platform (1 to 5) | | | | Choice of taobao.com (1 to 5) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E1 | E2 | E3 | E4 |
| Cost [57] | Total cost | 3 | 3 | 3 | 2 | 4 | 3 | 2 | 2 |
| | Price stability | 5 | 2 | 3 | 4 | 1 | 3 | 2 | 1 |
| | Discount rate | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Quality [57] | Return rate | 4 | 1 | 2 | 5 | 4 | 4 | 2 | 1 |
| | Failure prevention | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 1 |
| | Appearance and function | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| Service [16] | User interface | 5 | 5 | 5 | 5 | 3 | 4 | 2 | 5 |
| | Service standard | 5 | 4 | 5 | 3 | 1 | 2 | 1 | 1 |
| | Technical assistance and support | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 5 |
| | Response time | 4 | 5 | 3 | 3 | 3 | 5 | 3 | 1 |
| | Links service | 5 | 5 | 5 | 5 | 1 | 3 | 2 | 2 |
| Information sharing [16] | Use of electronic data interchange | 4 | 5 | 5 | 5 | 1 | 1 | 1 | 1 |
| | Willing to share sensitive information | 5 | 5 | 5 | 5 | 2 | 1 | 1 | 1 |
| Search performance | Precision | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Recall | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Overall ability | Technical ability [16] | 5 | 5 | 5 | 4 | 3 | 3 | 3 | 4 |
| | Conform to BIM standard [16] | 5 | 5 | 5 | 5 | 1 | 1 | 1 | 1 |
| | Data scale and content | 5 | 4 | 5 | 3 | 5 | 3 | 3 | 3 |

**Table 5.** Totals of experts' choices regarding performance of taobao.com and our e-commerce platform.

| Evaluation Criteria | Performance Indicator | Choice of Proposed Platform | Choice of taobao.com |
|---|---|---|---|
| Cost | Total cost | 11 | 11 |
| | Price stability | 14 | 7 |
| | Discount rate | 12 | 12 |
| | | 37 | 30 |
| Quality | Return rate | 12 | 11 |
| | Failure prevention | 12 | 8 |
| | Appearance and function | 17 | 12 |
| | | 41 | 31 |
| service | User interface | 20 | 14 |
| | Service standard | 17 | 5 |
| | Technical assistance and support | 20 | 16 |
| | Responsive time | 15 | 12 |
| | Links service | 20 | 8 |
| | | 92 | 55 |
| Information sharing | Use of electronic data interchange | 19 | 4 |
| | Willing to share sensitive information | 20 | 5 |
| | | 39 | 9 |
| Search performance | precision | 20 | 20 |
| | recall | 20 | 20 |
| | | 40 | 40 |
| Overall ability | Technical ability | 19 | 13 |
| | Conform to BIM standard | 20 | 4 |
| | Data scale and content | 17 | 14 |
| | | 56 | 31 |

## 6. Discussion

Our research is set against the background of industrialized construction, which uses electronic procurement processes described by European standards associations. Industrialized construction design consists of many components, which include standardized design, factory manufacturing, and on-site assembly [58]. Industrialized construction is less fragmented—the design and manufacturing of components are usually performed by the same enterprise [59]. Industrialized construction components data are mostly structured, permitting easy integration to e-commerce platforms, while with traditional on-site construction, procurement is characterized by high levels of unstructured data, which makes the use of e-commerce platforms more difficult [11]. Traditional construction e-commerce platforms are based on those used by the manufacturing industry, and do not fully consider the characteristics of the construction industry. This paper analyzes the e-commerce process for the construction industry in the context of industrialized construction, and puts forward an effective framework for an e-commerce platform.

The research on the application of BIM for e-procurement begun in 2010, with Grilo and Jardim-Goncalves proposing BIM-based e-procurement [11]. However, the required effort to edit the different document and linkages to the BIM models came with great cost. This editing requires specialized ICT support to combine data from different sources into the BIM-based procurement process. Our proposed e-commerce platform uses linked data to connect various pieces of information to the BIM model and provides an effective solution for data integration. The traditional e-commerce platforms use relational databases to store data, where the data structure in different platforms is different, and information interoperability cannot be realized. There are many problems in the traditional e-commerce platforms, such as large amounts of information, fragmented information, diversity information, semantically heterogeneous information. However, our platform extends existing capabilities to include design components, factory manufacturing, distribution strategies, and contract management.

BIM can be used as an integrated product model for industrialized construction, to achieve collaborative work between participating units, and information sharing. It improves the efficiency of the business process, enhances the role of product information, and creates an information-based environment. It does this by integrating all information produced in the life cycle of the construction projects. Linked data was proposed as part of the semantic web concept and can integrate different data sources on the internet into a network. It is an effective means of information integration. E-commerce platforms use a linked data technology stack (including URIs, HTTP, and RDF) to form an integrated data environment. An e-commerce ontology for ICP was established to align a BIM product model with the ICP process. BIM, linked data and our ontology can solve problems of previous e-commerce platforms. Data can be described by RDF data models, identified by URIs, and retrieved over the HTTP protocol. This process is able to realize the discovery, identification, and integration of construction e-commerce information resources.

## 7. Conclusions

First, we analyzed existing e-commerce platforms in the construction industry, where there are barriers to information integration. Next, an e-commerce platform based on BIM and linked data for ICP was proposed to support the integration of procurement information. BIM itself has certain information integration functions, but construction commercial information also includes other relevant information. Linked data is an effective means to integrate information in a network environment.

Our proposed BIM and linked data-based e-commerce platform for ICP is a novel integrated information platform, providing a solution for the integration of e-commerce information in the construction industry. All of the component (product) data are stored in the BIM model, which makes it easy to show the product to customers and access related data. The proposed platform used linked data to connect data from different sources, overcoming the integration problems. This study provides a solution for further development of an e-commerce platform in the construction industry.

However, there are still some limitations with our implementation, including IFC to RDF automatic transformation difficulties. The IFC data exported by BIM may be missing and, when a BIM model is transformed into IFC, the model will lose some information. There are no specific IFC classes for procurement-related information [15], which can hinder data integration. Another issue is that the procurement process is simplified, and the analysis process included only the most important aspects, which theoretically completes the integration of information. Further, the query in the model is a simple SPARQL query statement. However, in the real world, many aspects need to be considered. This paper mainly uses linked data to realize the integration of e-commerce data on the web, although the publication of linked data is not the focus of this article. In addition, the platform needs to be more intelligent so that IFC can be converted to RDF automatically; ontology development for industrialized construction components need to be complemented with more data sources and participation subjects; and queries should be more complex and intelligent.

Our research covered an e-commerce platform for ICP, illustrating the conceptual framework from the perspective of data integration. Previous literature [60,61] provides important references for our future research on how to identify sustainability indicators to develop a sustainable e-commerce platform, how to effectively integrate the e-commerce platform with urban logistics, how to effectively integrate the e-commerce platform with the supply chain, and how to use dashboards to support user decisions.

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