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# A Semi-Explicit Practical Coding Method for Prefabricated Building Component Parts in China

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**Abstract:** In the context of building industrialization, the dissemination and transmission of information related to prefabricated building component parts are of paramount importance throughout the building's life cycle and the entire industry chain, necessitating high standards of information integration. At present, the development of information coding for prefabricated building component parts in China is hindered by various challenges, such as the lack of uniform norms and standards across different regions, as well as significant differences in the composition and character length of coded information categories. Through reviewing academic papers and society, group, and local standards related to the coding of prefabricated building component parts, this article identifies the importance of component part coding information categories. Considering the readability of codes, a practical coding system is adopted for the coding design, proposing a semi-implicit practical coding method for prefabricated building component parts. This method has strong flexibility and wide applicability. Additionally, a common coding system for component parts is devised to address the issue of missing information caused by the limited characters of component parts codes. This system enables comprehensive life cycle information management of component parts of prefabricated buildings and promotes the application of prefabricated buildings in China.

**Keywords:** prefabricated building; component parts; coding method; semi-explicit coding; whole life cycle

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**Citation:** Shan, Z.; Fu, D.; Qiu, L.; Liang, Y.; Huang, C. A Semi-Explicit Practical Coding Method for Prefabricated Building Component Parts in China. *Buildings* **2023**, *13*, 1236. https://doi.org/10.3390/buildings13051236

Academic Editor: Jose A. Capitan

Received: 10 April 2023
Revised: 25 April 2023
Accepted: 5 May 2023
Published: 8 May 2023



## 1. Introduction

Prefabricated building is a modern building approach that relies on factory-based production and on-site assembly, and it represents a pivotal component of the contemporary industrialization of the construction sector [1]. In recent years, the Chinese government has been vigorously promoting the implementation of prefabricated buildings by encouraging and supporting enterprises to invest in research and development, as well as production, of prefabricated buildings, thereby facilitating the advancement of the prefabricated building industry. Notably, the component parts are the fundamental units of prefabricated buildings, and they play an indispensable role throughout the entire lifespan of the building, pervading the different stages of design, production, transportation, construction, operation, and maintenance [2]. With the increasing complexity of the component parts involved, their classification and coding have become critical prerequisites for improving retrieval efficiency and matching accuracy and laying the groundwork for an integrated and comprehensive information management system for the component parts in the entire life cycle of prefabricated building. The establishment of a systematic component parts classification and coding framework represents a crucial milestone in realizing the seamless integration of the information flow of the entire industry chain of component parts, and facilitating efficient circulation, transmission, and sharing of component parts information in the entire industry chain [3]. Hence, the research on the method and structure of information encoding within the domain of prefabricated construction has emerged as a crucial and pressing endeavor in contemporary times.

This paper concentrates on the issues and challenges of coding component parts information in Chinese prefabricated buildings, with the aim of proposing a practical coding method for prefabricated building component parts to resolve existing problems and challenges and to facilitate the popularization and application of prefabricated buildings.

This paper takes the classification and coding of component part information as its starting point. In Section 2, the literature review is conducted on typical domestic Chinese and foreign classification and coding systems for building product information, as well as coding methods and structures for prefabricated buildings component parts. Subsequently, in Sections 3 and 4, literature research and questionnaire survey methods were used to identify and screen the important categories of component part coding information, as well as analyze their readability. An innovative semi-explicit coding method was proposed, which consists of both semantic and non-semantic parts in its structure. Then, in Section 5, the coding method is applied to specific engineering projects to verify its rationality and applicability. Additionally, a proposal was made to establish a universal coding system for building component parts that is compatible with the database, and the interface layout of the system was designed. Finally, in Section 6, the application of the coding method is analyzed, and a comparative discussion is conducted with other relevant coding standards and methods.

## 2. Literature Review

In pursuit of the digitization of the construction industry, the International Organization for Standardization (ISO) put forward a comprehensive system for the classification and coding of building information. After more than two decades of collaborative efforts with developed countries in Europe and America, the organization succeeded in developing a series of sophisticated classification and coding systems for building products. Overseas, the classical building component classification and coding frameworks were comprised of four standards: Standard Classification for Building Elements and Related Sitework—Uniformat II [4], CSI MasterFormat: Specifications for Construction [5], the OmniClass Construction Classification System [6], and ISO 12006-2 Building Construction–Organization of information about construction works—Part 2: Framework for classification [7]. Among these, Uniformat II and MasterFormat are traditional classification and coding standards that are suitable for specific disciplines or aspects of the building industry, such as engineering cost, document management, and organizational norms. In contrast, OmniClass and ISO 12006-2 represented cutting-edge classification and coding standards that cover all aspects of the building industry. They are comprehensive classification systems that could satisfy the higher demands of the development of information technology in the construction industry. The research on building information modeling and building product classification and coding in China started relatively late [8,9]. In order to promote the industrialization and standardization of the Chinese construction industry and to move towards internationalization, China conducted extensive research and formulated various classification and coding systems for building products based on internationally advanced standards. China developed three mature frameworks for the classification and coding of building products. The first is the "GB/T 22633-2008 Terms of housing parts" [10], which aimed to promote the standardization and industrialization of China's residential industry and establish a standard system for residential standards. The second is the "JG/T 151-2015 Classifying and coding of construction products" [11], which aimed to strengthen communication and management of building products between civil buildings and general industrial buildings and promote the industrialization and informatization of China's construction industry. The third is the "GB/T 51269-2017 Standard for classification and coding of building information model" [12], which aimed to facilitate the circulation and sharing of building product information throughout the entire life cycle of project construction. In recent years, based on the Chinese building information modeling classification and coding system, various society, group, and local standards for the classification and coding of prefabricated building component parts were established by organizations such as China Civil Engineering Society, China Society for the Promotion of Science and Technology Commercialization, and the housing and construction departments of Fujian, Zhejiang, Hunan, Yunnan provinces and Guangxi Zhuang Autonomous Region [13–19]. Compared with the classical international and domestic Chinese classification and coding methods for building products, the classification and coding standards for prefabricated building component parts combine category codes for component parts with different coding information types to obtain a complete code structure. This was done in order to promote the information management of prefabricated buildings in the design, production, construction, and maintenance stages, meet the application requirements of the entire prefabricated building industry chain, and achieve the transmission and sharing of information throughout the entire life cycle of the building project. Table 1 provides a comparative analysis of the classical international and domestic Chinese classification and coding systems for building products with the society, group, and local standards for the classification and coding of prefabricated building component parts in China and includes examples and names of codes.

**Table 1.** Comparison of building product classification and coding standards with local standards for classification and coding of component parts of prefabricated buildings in China.

| Classification and Coding Standards | Release Organization | Building Element Coding Method (with Expandable Information) and Related Coding Logical Operators | Sample Codes and Names |
|---|---|---|---|
| ISO 12006-2: 2015 | International Organization for Standardization (ISO) | ISO 12006-2:2015 provides an encompassing framework for the classification of building information, which comprises 17 tables of meticulously recommended classifications. It is imperative to note that the standard does not offer any prescribed coding methods. | / |
| Uniformat II | American Society for Testing and Materials(ASTM) | [Major Group Elements, 2 digits] [Group Elements, 2 digits] [Individual Elements, 2 digits] [Sub-Elements, 2 digits] | C Interiors<br>C10 Interior Construction<br>C1010 Partitions<br>C101001 Fixed Partitions<br>C101002 Demountable Partitions<br>C101003 Retractable Partitions |
| MasterFormat 2016 | Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) | [Major category code Intermediate category code Minor category code, 6 digits]. ([extended code, 2 digits]) | 10 22 19 Demountable Partitions<br>10 22 19.13 Demountable Metal Partitions<br>10 22 19.23 Demountable Wood Partitions<br>10 22 19.33 Demountable Plastic Partitions |
| OmniClass | Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) | [Table Number]-[First Level]-[Second Level]-[Third Level]-[Fourth Level] (-[Fifth Level]-[Sixth Level]-[Seventh Level])<br><br>The symbol "+" denotes the amalgamation of codes extracted from multiple tables. The symbols ">" and "<" serve to indicate the hierarchical order between codes, and the opening direction of the symbol signifies the significance of the concept. Additionally, the symbol "/" designates the definition of a contiguous coded paragraph in a table, wherein the codes preceding and succeeding the symbol represent the start and end of the paragraph, respectively. Primarily, this symbol is utilized for data filtering purposes. | 23-15 00 00 Interior and Finish Products<br>23-15 11 00 Space Division Product<br>23-15 11 11 Fixed Partitions<br>23-15 11 11 11<br>Gypsum Board Fixed Partitions<br>23-15 11 11 11 11<br>Metal Framed Gypsum Board Fixed Partitions<br>23-15 11 11 11 13<br>Wood Framed Gypsum Board Fixed Partitions<br><br>23-15 11 11 11 + 13-23 23 11<br>means building manager office with metal framed gypsum board fixed partitions<br>23-15 11 11 11 > 13-23 23 11<br>means metal framed gypsum board fixed partitions<br>23-15 11 11 11 < 13-23 23 11<br>means building manager office<br>23-15 11/23-15 15 35<br>means filter to find the content between 23-15 11 (Space Division Product) and 23-15 15 35 (Security Wall Protection Products) |

**Table 1.** *Cont.*

| Classification and Coding Standards | Release Organization | Building Element Coding Method (with Expandable Information) and Related Coding Logical Operators | Sample Codes and Names |
|---|---|---|---|
| "GB/T 22633-2008 Terms of housing parts" | Standardization Administration of China (SAC) | "GB/T 22633-2008 Terms of housing parts" provides basic, classification, functional, and related terminology for residential parts, but does not provide a coding method. | / |
| "JG/T 151-2015 Classifying and coding of construction products" | China Construction Industry Association (CCIA) | [Major category code, 2 digits]. [Intermediate category code, 2 digits]. [Minor category code, 2 digits]. ([subcategory code, 2 digits]) | 01.10.40 Precast concrete wall board<br>01.10.40.10 Reinforced concrete slab<br>01.10.40.20 Autoclaved aerated concrete slab<br>01.10.40.30 Lightweight aggregate concrete panel |
| "GB/T 51269-2017 Standard for classification and coding of building information model" | Standardization Administration of China (SAC) | [Major category code, 2 digits]. [Intermediate category code, 2 digits]. [Minor category code, 2 digits]. ([subcategory code, 2 digits])<br>Logical operation symbols are encoded using the "+", "/", "<", and ">" symbols, with the same meaning as in the OmniClass classification system. | 14-10.20.00 architectural components<br>14-10.20.03 architectural wall<br>11-10.20.03.03 architectural interior wall<br>11-10.20.03.06 architectural exterior wall<br>11-10.20.03.09 architectural special wall |
| T/CCES 14-2020 Standard for classification and coding of prefabricated building component parts | China Civil Engineering Society | Standard code: [Table code, 2 digits]-[Major category code, 2 digits]. [Intermediate category code, 2 digits]. [Minor category code, 2 digits]. [detailed category code, 2 digits]<br>Property code: [Property type code, unlimited] [Property parameter code, unlimited]<br>There are a total of 2 code segments, 7 or more categories of encoded information, and a character length of 19 or more.<br>The symbols of "+", "/", "<", and ">" have the same meanings as in OmniClass. The parentheses "()" are used to indicate the content of attribute parameter values, which can be used after the standard code or after input type attribute codes. The symbol ":" is used to separate the "standard code" and "property code ". | 30-01.10.10.05:0104 . . . . . .<br>Frame column placed at the standard level (more descriptive information to be provided). |
| T/CSPSTC 49-2020 Classification and coding specification of prefabricated concrete structure BIM | China Society for the Promotion of Science and Technology Commercialization | Standard code: [Project stakeholder code, 2 digits] [Project implementation phase code, 2 digits] [Component sub-category code, 2 digits] [Component detailed category code, 2 digits]<br>Attribute code: [Attribute type code, unlimited] [Attribute parameter code, unlimited]<br>There are a total of 2 code segments, 6 or more categories of encoded information, and a character length of 13 or more. | 01010101:0103 . . . . . .<br>A frame column placed at the standard level (more descriptive information to be provided) by a certain construction party in the stage of construction plan preparation. |
| Fujian Province standard for classification and coding of assembled building component parts | Housing and Urban-Rural Development Department of Fujian Province | [Origin, 4 digits] [Manufacturer, 2 digits] [Reserved fields, 2 digits] [Component category, 2 digits] [Production date, 6 digits] [Production sequence number, 3 digits] [Checksum, 1 digit]<br>There are a total of 7 categories of encoded information, with a character length of 20 digits. | 01010100QT1606130011<br>Wall component produced by manufacturer 01 in Fuzhou, Fujian on June 13, 2016, with a production sequence number of 001 and a checksum of 1. |
| Zhejiang Province Coding Standard for Prefabricated Building Structural Components | Housing and Urban-Rural Development Department of Zhejiang Province | [Category code, 8–11 digits] [Project code, 23 digits] [Building (district) code, 1–3 digits] [Floor (section) code, 1–3 digits] [Component type code, 4–6 digits] [Component name code, 2–10 digits] [Axis location code, 3–11 digits] [Identification code, 1–2 digits]<br>There are a total of 8 categories of encoded information, with a character length of 43–69 digits.<br>The symbol "/" is used to separate codes at different levels; the symbol "-" is used to separate internal information within a code; the symbol "*" is used to separate the position of the vertical and horizontal axis lines. | 01.10.30/2019-330327-70-03-814884/10/20/PC-B/DLB/B-C*2-3/1<br>Prefabricated concrete floor with project code 2019-330327-70-03-814884, located on the 20th floor (section) of Building (area) 10. The component type code is PC-B, the component name code is DLB, the axis location code is B-C*2-3, and the identification code is 1. |
| Hunan province standard for classification and coding of assembled building component parts | Housing and Urban-Rural Development Department of Hunan Province | Basic information code: [Year code, 2 digits] [Project code, 6 digits] [Building number, 3 digits] [Structural system, 2 digits] [Manufacturer code, 3 digits].<br>Standard attribute code: [Component category, 2 digits] [Floor number, 2 digits] [Component number, 4 digits] [Attribute information, 7–9 digits].<br>Supplementary information code: ([Attribute type code, 3 digits] [Attribute parameter, unlimited]).<br>There are a total of 3 code segments, with 8 or more categories of encoded information, and a character length of 31 digits or more. | 18C00001003C2A02-DB200025330215061:012(C8@200)/025(20180519)/040(Changsha City Yuelu District)<br>On May 19, 2018, in the Yuexiu district of Changsha, a composite panel component with a size of 3300*2150*60, made of C30 concrete and HRB400 steel bars, and manufactured by manufacturer code A0 was installed. The component has a straight bar reinforcement of 8 with a spacing of 200. It was installed in building 3 of project code C001, which has 20 floors. The component's number is 0025 and the structural system is an assembled shear wall structure. |

**Table 1.** *Cont.*

| Classification and Coding Standards | Release Organization | Building Element Coding Method (with Expandable Information) and Related Coding Logical Operators | Sample Codes and Names |
|---|---|---|---|
| Guangxi Zhuang Autonomous Region General Coding Standard for Structural Component of Prefabricated Buildings | Housing and Urban-Rural Development Department of Guangxi Zhuang Autonomous Region | Basic code: [Component major type, 2 digits] [Component minor type, 5 digits] [Component number, 6 digits] [Component position, 23 digits] [Component size, 12 digits] [Component strength, 10 digits] [Component weight, 6 digits] [Component volume, 5 digits] [Reinforcement configuration, 23 digits]. Stage code: [Stage code, 11 digits]. General code: [Construction unit information, 18 digits] [Project code, 24 digits] [Project type, 11 digits] [Architectural design unit information, 18 digits] [Component detailed design unit information, 18 digits] [Building area, 11 digits] [Building height, 6 digits] [Building structural safety level, 1 digit] [Seismic fortification category, 1 digit] [Seismic fortification intensity and acceleration, 3 digits] [Production enterprise information, 18 digits] [Hidden acceptance qualified time, 10 digits] [Pouring/making time, 10 digits] [Finished product acceptance qualified time, 10 digits] [Storage time, 10 digits] [Storage location, 10 digits] [Delivery time, 10 digits] [Construction enterprise information, 18 digits] [Supervision enterprise information, 10 digits] [Warehousing time, 10 digits] [Storage location, 10 digits] [Installation completion time, 10 digits] [Acceptance qualified time, 10 digits]. Extension code: [Extension code, 3 digits]. There are a total of 4 code segments, with 34 categories of encoded information, and a character length of 371 digits. | / |
| Yunnan Province General Coding Standard for Structural Component of Prefabricated Buildings | Housing and Urban-Rural Development Department of Yunnan Province | Similar to the coding standard for prefabricated building structural components in Guangxi Zhuang Autonomous Region, the main difference lies in the naming and positioning of the encoded information in the basic code: Basic code: [Component major type, 2 digits] [Component minor type, 5 digits] [Component number, 6 digits] [Component size, 12 digits] [Component strength, 10 digits] [Component weight, 6 digits] [Component volume, 5 digits] [Reinforcement configuration, 23 digits] [Component position, 23 digits]. Other information is the same. | / |

The development of coding for building component parts in the field of prefabricated construction in China is still facing challenges such as the lack of complete regulations and standards in different regions, and significant differences in the composition and character length of coding information. One of the reasons for these challenges is inadequate research on the importance of coding information categories. The traditional method of coding is to classify or code information based on characteristics [20], but a single information attribute cannot provide complete information about building component parts [21]. Therefore, the coding process for building component parts is essentially a process of determining their important attributes [22]. So, which coding information categories should be included in the coding range? How to choose the depth of classification? This requires compatibility with existing international standards as a prerequisite for information coding [23]. Moreover, based on the characteristics of the Chinese construction industry and in line with the features of the coded structure and the identified information subject [21], the code should also establish a mapping relationship with the classification method and level of the coded object to reflect its characteristics and support system integration [24]. Secondly, the degree of readability of the code for human beings has not been fully considered. At present, the domestic Chinese construction process still requires sufficient time to be integrated with the future BIM industry chain, and there is a lack of effective integration of informatization and complexity management in various processes [25]. The various stages of the construction life cycle still involve human–machine interaction [26], and humans play a leading role, with the informatization and digitization capabilities of a large number of practitioners being relatively elementary [27]. Considering the readability of codes by humans, it is because codes are a language with a simplified syntax [28], and the first audience for codes is still humans, not machines [29]. Therefore, in order to make the coding information easy for readers to read, accept, and understand, the coding method and its structure should be intuitive, clear, and concise. Therefore, it is necessary to carry out research on coding methods based on importance and readability.

## 3. Identification of Importance of Coding Information Categories Based on Literature Review and Questionnaire Survey

### 3.1. Literature Search and Selection

Based on the PRISMA guidelines [30], the following keywords were used in this study to search for component part coding information categories: “Prefabricated building component parts,” “Assembled building component parts,” “Modular construction,” “Industrialized building,” “Component part coding,” “BIM coding system,” “Information integration,” and “Life cycle management.” When conducting literature searches, these keywords were combined using either “AND” or “OR” to link them, for example:

(1) (Prefabricated building component parts OR component part coding) AND (information integration OR life cycle management).
(2) Prefabricated building component parts AND component part coding AND information integration AND life cycle management.

This study conducted a literature search on the databases of China National Knowledge Infrastructure, Wanfang Data, Web of Science Core Collection, and Scopus, and recorded the number and relevance of the search results. The literature search and selection process consisted of the following steps:

(1) Conducting keyword searches on the above-mentioned databases using keyword combinations.
(2) Preliminary screening of the literature based on the titles, keywords, and abstracts, resulting in a total of 220 articles.
(3) Reading and evaluating the preliminarily screened articles based on the PRISMA guidelines, such as whether the article is relevant to the research topic and whether it is an original research paper in the field of prefabricated construction. Articles that were irrelevant, low-quality, or duplicates were excluded, resulting in 38 selected articles.
(4) Checking whether the selected articles have a clear coding structure or coding information category, and finally determining the number of selected articles for frequency statistics of the component part coding information category. Thirty-two articles were identified as meeting the requirements.

It should be noted that the PRISMA statement does not specify a minimum or maximum number of articles that should be included in a systematic review, but it is important to include a sufficient number of studies to provide a comprehensive and reliable summary of the available evidence.

### 3.2. Frequency Analysis of Component Part Code Categories

After undergoing a rigorous screening process, this paper ultimately selected a total of 32 literature sources relevant to the coding information category of prefabricated building component parts. Among them, there was 1 academic society standard, 1 group standard, 5 local standards, and 25 academic papers in the field of prefabricated building. These selected documents have been used to extract the relevant component part code categories, resulting in a comprehensive list of 234 information categories. This information has been compiled into an Excel table and subjected to a frequency analysis. As shown in Table 2, examples are provided. This analysis involved examining the coding rules employed in the different documents and standards, breaking down the code composition into various categories, identifying relevant keywords associated with each category, and subsequently tallying the frequency of each category. The results of this meticulous analysis are presented in Table 3, which provides a succinct summary of the frequency of each component part code category.

**Table 2.** Examples of component coding information category statistics.

| Category No. | Name of Encoding Information Category | Word Frequency | The Included Indicators and Corresponding Frequencies |
|---|---|---|---|
| 1 | Component Part Major Category | 26 | Type (3), component type (7), component category (5), part type (1), part product type (1), precast component category code (1), component classification code (1), component part category (2), major component type (2), structural component part (1), product type (1), component code (1) |
| 2 | Project Code | 16 | Project number (4), project code (9), residential project number (1), (project) prefabricated unit (2) |
| 3 | Floor Code | 14 | Height (1), story height/elevation (5), story (2), story code (4), level (section) number code (1), level number (1) |
| 4 | Building Code | 12 | Building number (8), building code or name (1), monolithic area code (1), building/area number code (1), prefabricated building (1) |
| 5 | Serial Number | 12 | Special component processing code (1), serial number (3), sequence code (4), component sequence number (2), quantity code (1), component part number (1) |
| 6 | Location Code | 11 | Component location (4), location number (4), positioning code (1), location code (1), location attribute (1) |
| 7 | Component Part Subcategory | 10 | Component sub-category (1), part name (1), standard code (1), part code (1), component name code (1), component sub-type (2), component name (1), BIM7AA corresponding standard code (1), Uniformat/Masterformat standard code (1) |
| 8 | Component Part Extension Code | 9 | Expansion code (4), attribute type/parameter code (3), reserved field (1), extended area (1) |
| 9 | Project Phase | 9 | Project phase (6), project implementation phase code (1), phase code (2) |
| 10 | Geometric Information | 8 | Geometric dimension (1), component dimension (3), component specification (1), cross-sectional form (1), shape (1), size (1) |
| 11 | Grid Information Code | 8 | Horizontal grid-vertical grid (3), grid (1), component location (2), positioning code (1), grid location code (1) |
| …… | | | |

**Table 3.** Frequency analysis of component part code categories.

| No. | Keywords | Word Frequency | No. | Keywords | Word Frequency |
|---|---|---|---|---|---|
| 1 | Component Part Major Category | 26 | 28 | Building Structural Safety Level | 2 |
| 2 | Project Code | 16 | 29 | Earthquake Resistance Category | 2 |
| 3 | Floor Code | 14 | 30 | Concealed Acceptance Time | 2 |
| 4 | Building Code | 12 | 31 | Pouring/Manufacturing Time | 2 |
| 5 | Serial Number | 12 | 32 | Finished Product Acceptance Time | 2 |
| 6 | Location Code | 11 | 33 | Storage Time | 2 |
| 7 | Component Part Subcategory | 10 | 34 | Warehouse Location | 2 |
| 8 | Component Part Extension Code | 9 | 35 | Delivery Time | 2 |
| 9 | Project Phase | 9 | 36 | Warehouse Entry Time | 2 |
| 10 | Geometric Information | 8 | 37 | Storage Location | 2 |
| 11 | Grid Information Code | 8 | 38 | Construction Acceptance Time | 2 |
| 12 | Material Type | 5 | 39 | Component Part System | 1 |
| 13 | Manufacturer | 5 | 40 | Bearing Capacity | 1 |
| 14 | Structural System | 4 | 41 | Use Scenario | 1 |
| 15 | Project-Related Information | 4 | 42 | Style | 1 |
| 16 | Material Specification | 3 | 43 | Place of Origin | 1 |
| 17 | Production Time | 3 | 44 | Specific Project Work | 1 |
| 18 | Installation Time | 3 | 45 | Drawing Version Number | 1 |
| 19 | Project Phase Task | 3 | 46 | Engineering Category | 1 |
| 20 | Project Address | 3 | 47 | Construction Type | 1 |
| 21 | Component Part Identification Code | 3 | A | Attribute Type | 5 |
| 22 | Functional Attributes | 2 | B | Attribute Parameters | 3 |
| 23 | Weight Information | 2 | C | Sub-Category Code | 3 |
| 24 | Reinforcement Information | 2 | D | Detailed Sub-Category Code | 3 |
| 25 | Project Type | 2 | E | Basic Code | 2 |
| 26 | Floor Area | 2 | F | Table Code—Major Category Code | 2 |
| 27 | Building Height | 2 | G | Mid-Category Code | 2 |

### *3.3. Results of Selection of Component Parts Coding Information Categories*

As shown in Table 3, the top 10 frequency-sorted coding information categories are component part major category, project code, floor code, building code, serial number, location code, component part subcategory, component part extension code, project phases, geometric information, and grid information code.

Upon preliminary sorting, it is evident that the number of coding information categories is significantly large. Additionally, the national, industrial, and provincial coding standards employ terminologies such as "attribute type," "attribute parameters," "sub-category code," and "detailed sub-category code" (No. A–G). Although these categories serve as basic codes for relevant information, they do not offer any insight into the importance of this information. They can be likened to a reference dictionary that lacks indications of commonly used or crucial words. Thus, it is unsuitable for direct questionnaire design.

In response to the two existing issues related to the Chinese prefabricated building component parts coding mentioned in the literature review, this paper explores the importance and readability of coding methods. The expected outcome is a coding structure consisting of 6–8 combinations of coding information categories and their corresponding coding methods, which balance the presentation of important component parts information and the readability of the code for humans. To optimize the coding information categories, this study conducted a frequency-based ranking and selection of the identified coding information categories. A total of 20 coding information categories were chosen to highlight the importance of component parts coding information categories for questionnaire design. The setting of 20 coding information categories has the following advantages: (1) it can cover most of the information categories, effectively reflecting the opinions and views of the questionnaire respondents; (2) it is conducive to data analysis and interpretation, as choosing too many coding information categories requires consideration of more variables and factors, which may make data analysis and interpretation difficult; (3) it reduces the burden on questionnaire respondents, as choosing too many coding information categories may increase the burden on them, thus affecting the effectiveness of survey results.

Furthermore, some coding information categories have been complemented with their respective meanings, and the categories have been sorted based on their frequency of use in descending order. The resulting comprehensive list of building component coding information categories, along with their corresponding meanings, is presented in Table 4.

**Table 4.** Selected categories and meanings of component part codes.

| Category No. | Name of Encoding Information Category | Meaning of Encoding Information Category |
|---|---|---|
| 1 | Component Part Major Category | Further classifying the component part structure system by hierarchy. For instance, for a prefabricated frame structure system, the component part major category would be prefabricated concrete beams, columns, slabs, etc. |
| 2 | Project Code | Indicating the identification number of the project where the component part is located. |
| 3 | Floor Code | Specifying the floor number where the component part is located. |
| 4 | Building Code | Specifying the building number where the component part is located. |
| 5 | Serial Number | Indicating the sequential order in which the component part is produced on the production line, such as PCB001, PCB002, and so on. |
| 6 | Location Code | Specifying the location number of the component part based on the axis grid. |
| 7 | Component Part Subcategory | Further classifying the component part by hierarchy within a component part major category. For example, for a prefabricated concrete beam, the component part subcategory would be frame beams, foundation beams, cantilever beams, etc. |
| 8 | Component Part Extension Code | A reserved field for additional information related to the component part code. |
| 9 | Project Phase | Indicating the specific phase of the component part within its entire lifecycle. |
| 10 | Geometric Information | Providing information on the shape, cross-sectional form, size, and other geometric aspects of the component part. |

**Table 4.** *Cont.*

| Category No. | Name of Encoding Information Category | Meaning of Encoding Information Category |
|---|---|---|
| 11 | Grid Information Code | Indicating the plane axis grid where the component part is located, such as cross-axis grid and longitudinal-axis grid, A-1. |
| 12 | Material Type | Specifying the category of material used to produce the component part. |
| 13 | Manufacturer | / |
| 14 | Structural System | / |
| 15 | Project-Related Information | Providing information on the construction, design, construction supervision, and other related parties involved in the project where the component part is located. |
| 16 | Material Specification | Indicating the strength level, size, and other specifications of the component part material. |
| 17 | Production Time | Indicating the time of production for the component part. |
| 18 | Installation Time | Indicating the (planned) installation time for the component part. |
| 19 | Project Address | Providing information on the address where the project is located. |
| 20 | Component Part Identification Code | A code used to identify the component part. |

### *3.4. Questionnaire Survey and Data Collection*

Based on the literature review, 20 categories of component part coding information were selected, and their importance was identified through a survey using the Likert Scale with five levels. This survey was conducted among professionals in the field of prefabricated building and distributed anonymously via an online questionnaire system. A total of 154 questionnaires were distributed, with 132 valid responses collected, resulting in a response rate of 85.7%. The 132 valid respondents were mainly distributed across owner units (10), design enterprises (23), production enterprises (15), construction enterprises (43), consulting enterprises (7), and schools/research institutions (25), totaling 123, accounting for approximately 93.2% of the valid sample. The distribution of the respondents' work units reflects the basic characteristics of the survey sample. The questionnaire collection period ended on 22 February 2023.

### *3.5. Data Descriptive Analysis and Reliability and Validity Analysis*

#### 3.5.1. Descriptive Analysis of Data

The statistical analysis of data was conducted using SPSS 26.0 software. After the questionnaire survey, descriptive statistics were first performed on the observed data to test whether the data satisfied normal distribution. The normal distribution of data is a basic prerequisite for subsequent statistical analysis. The descriptive statistics of observed data for the encoding information categories are shown in Table 5.

**Table 5.** Descriptive statistics of the observed data for the encoding information categories.

| Category No. | Sample Size | Mean | Standard Deviation | Skewness | Kurtosis | Category No. | Sample Size | Mean | Standard Deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 132 | 4.30 | 0.814 | −1.097 | 0.806 | 11 | 132 | 3.94 | 0.944 | −0.525 | −0.397 |
| 2 | 132 | 4.25 | 0.792 | −1.028 | 0.907 | 12 | 132 | 4.08 | 0.893 | −0.723 | 0.087 |
| 3 | 132 | 4.16 | 0.860 | −0.811 | −0.001 | 13 | 132 | 3.64 | 1.031 | −0.366 | −0.669 |
| 4 | 132 | 4.21 | 0.844 | −1.178 | 1.911 | 14 | 132 | 3.80 | 0.917 | −0.305 | −0.736 |
| 5 | 132 | 4.04 | 0.949 | −0.667 | −0.532 | 15 | 132 | 3.64 | 1.001 | −0.468 | −0.104 |
| 6 | 132 | 4.25 | 0.801 | −0.833 | 0.087 | 16 | 132 | 4.11 | 0.850 | −0.737 | 0.324 |
| 7 | 132 | 4.14 | 0.872 | −0.762 | −0.166 | 17 | 132 | 3.72 | 0.940 | −0.289 | −0.536 |
| 8 | 132 | 4.03 | 0.912 | −0.657 | −0.101 | 18 | 132 | 3.77 | 0.966 | −0.439 | −0.288 |
| 9 | 132 | 3.77 | 0.958 | −0.569 | −0.098 | 19 | 132 | 3.42 | 1.023 | −0.198 | −0.343 |
| 10 | 132 | 3.78 | 1.010 | −0.565 | −0.178 | 20 | 132 | 3.98 | 0.904 | −0.583 | −0.148 |

According to Table 5, the top 10 ranking mean values of the importance degree of coding information categories are as follows: component part major category, project code, location code, building code, floor code, component part subcategory, material specification, material type, serial number, and component expansion code. Additionally, the absolute values of skewness and kurtosis of the observed data for coding information categories are all less than 3 and 10, respectively, indicating that all observed data are normally distributed and can be subjected to further statistical analysis [31].

### 3.5.2. Reliability Analysis of Data

Conducting a reliability analysis on the observed data of coding information categories aims to test whether the selected scale in the study truly reflects the measured variable. The results are shown in Table 6.

**Table 6.** Reliability statistics of observed data of coding information categories.

| Category No. | Corrected Item–Total Correlations | Cronbach's $\alpha$ after Item Deletion | Category No. | Corrected Item–Total Correlations | Cronbach's $\alpha$ after Item Deletion | Overall Cronbach's $\alpha$ |
|---|---|---|---|---|---|---|
| 1 | 0.654 | 0.917 | 11 | 0.804 | 0.913 | 0.921 |
| 2 | 0.588 | 0.918 | 12 | 0.631 | 0.917 | |
| 3 | 0.769 | 0.914 | 13 | 0.639 | 0.917 | |
| 4 | 0.588 | 0.918 | 14 | 0.634 | 0.917 | |
| 5 | 0.786 | 0.913 | 15 | 0.606 | 0.918 | |
| 6 | 0.653 | 0.917 | 16 | 0.764 | 0.914 | |
| 7 | 0.676 | 0.916 | 17 | 0.641 | 0.917 | |
| 8 | 0.775 | 0.914 | 18 | 0.750 | 0.914 | |
| 9 | 0.741 | 0.917 | 19 | 0.577 | 0.919 | |
| 10 | 0.667 | 0.916 | 20 | 0.769 | 0.914 | |

Based on Table 6, the overall Cronbach's alpha coefficient of the coding information category observation data is 0.921 (greater than 0.7), indicating good internal consistency reliability. The corrected item–total correlations for each measurement item are all greater than 0.5. Moreover, the Cronbach's alpha coefficient after deleting each item is smaller than the overall Cronbach's alpha coefficient, suggesting that the coding information category observation data has good reliability [32].

### 3.5.3. Validity Analysis of Data

Validity analysis was conducted on the observed data of the encoding information category to examine the extent to which the selected scale reflects the accuracy of the measured data. The results are presented in Table 7.

**Table 7.** KMO and Bartlett's test of sphericity for observation data of code information categories.

| KMO Measure of Sampling Adequacy | | 0.840 |
|---|---|---|
| Bartlett's Sphericity Test | Chi-Square Value | 1640.299 |
| | Degrees of Freedom | 190 |
| | Significance | 0.000 |

Based on Table 7, the KMO measure of sampling adequacy for the coding information category observational data was 0.840, indicating that the selection of 20 coding information categories had a significant relationship (greater than 0.7). Additionally, the Bartlett's test of sphericity had a significance value of 0.000 (less than 0.001), indicating that the observed variables were related to each other [33].

The collected data passed the tests of reliability and validity, indicating that the coding information categories used in the questionnaire were reasonable and that the results of the related investigations could be used in subsequent research.

### 3.6. Analysis of the Importance of Component Part Coding Information Categories

Based on the literature review and questionnaire survey, the importance of component part coding information categories was analyzed. The frequency ranking of coding information categories in the literature and the scores of the importance level given by practitioners in the prefabricated building industry were obtained. Eight coding information categories were identified in the top 10 frequency and mean scores, including component part major category, project code, floor code, building code, serial number, location code, component part subcategory, and component part extension code. This indicates a high degree of attention and consistency among coding standard makers, scholars, and practitioners in the prefabricated building industry towards these coding information categories in the code structure.

Further analysis showed that these information categories can be divided into three types: category information, project information, and other information. Category information refers to information on the category and naming of component parts, including component part major category and component part subcategory; project information refers to information on the project and location of component parts, including project code, building code, floor code, and location code; and other information has no obvious meaning but serves as identification or reserved fields in the code structure, including serial number and component extension code.

Therefore, using these eight coding information categories for component part code structure design can fully describe the basic information of component parts and meet their needs in different application scenarios.

## 4. Semi-Explicit Coding Method Based on Human Code Readability

The readability of code primarily concerns the degree of difficulty that individuals face in reading, comprehending, and utilizing information that has been encoded. This notion serves as a fundamental consideration when designing coding methods for the various component parts. To achieve optimal readability, it is necessary to synthesize multiple aspects of information encoding, including the comprehensibility of the coded language, the readability of symbols and patterns, the clarity of typography, the technical difficulty, and the cultural background. The overarching goal of this design process is to maximize the extent to which the meaning or features conveyed by the code are accepted and to minimize the cognitive burden required for semantic processing [34,35].

### 4.1. Characteristics of Code

#### 4.1.1. Classification of Code

Code can be classified into two categories: meaningful code and meaningless code, based on their expressions and functions [36]. Meaningful code conveys meaning directly (e.g., abbreviation codes) or indirectly (e.g., hierarchical codes, matrix codes, juxtaposition codes, etc.), while meaningless code lacks this expressive ability. Generally speaking, meaningful code has a certain semantic structure and norms, which provide a foundation for additional information and are easier and more reliable for human use. On the other hand, meaningless code is preferable for identification and referencing purposes. The code classification structure is illustrated in Figure 1.

Meaningless codes are commonly used as material identification codes in warehouses for ERP systems. These codes are encoded in the form of serial numbers, making them the simplest and most convenient method for material coding. However, since serial numbers lack any particular meaning, they are difficult to read. Therefore, companies require sound technical and management standards and consistent data sharing among different departments to ensure readability and consistency. The main difference between meaningful codes and meaningless codes is that meaningful codes are primarily intended for human viewers. Companies usually develop a specific set of code standards with particular meanings based on the properties and features of materials. Practical codes are a combination of meaningless and meaningful codes, which combine the advantages of both approaches. Based on the actual needs of the enterprise, practical codes ingeniously incorporate material classification information and enable employees to read the necessary information from the code description.

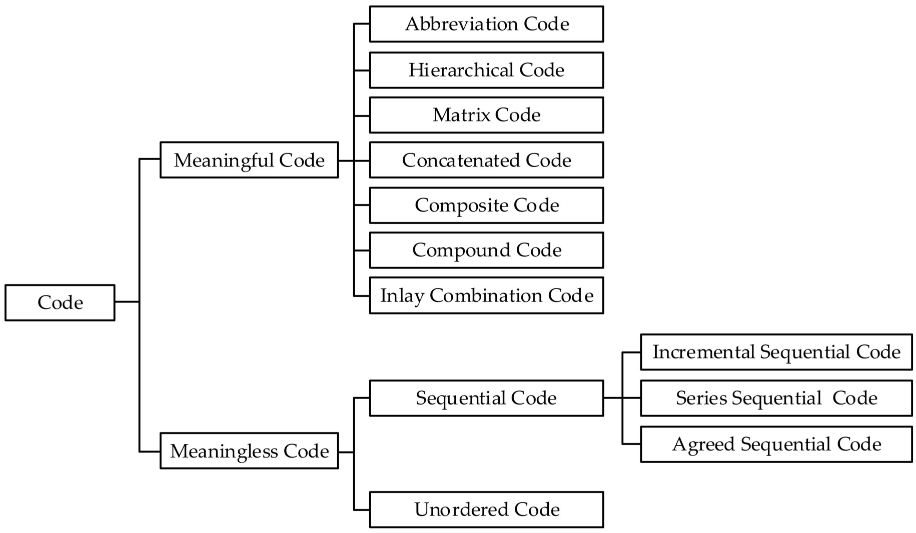


**Figure 1.** Code classification structure.

Therefore, when designing component part codes, it is worth considering the adoption of practical code forms.

#### 4.1.2. Forms of Code Representation

Code can take various forms, such as numerical formats, alphabetical formats, mixed formats, and special characters. Among them, the mixed-format code is a type of code that combines numbers and letters, possessing the advantages of both numerical and alphabetical codes. It is characterized by a tightly structured format, good intuitiveness, and ease of use.

To ensure the reliability and stability of mixed-format codes, controlled mixed-format code values always use alphabetical or numerical formats in predetermined positions, rather than randomly arranged letters and numbers. This can prevent or minimize confusion and errors and facilitate code verification and validation. When designing mixed-format codes, it is recommended to avoid using characters that are easily confused with others, such as the letters "I" and "O". Therefore, to enhance the readability and expressiveness of the code, it is suggested to use the 24 alphabetical characters without "I" and "O" and the 10 numerical digits, which provide sufficient coding space while avoiding confusion and errors.

#### 4.1.3. Length of Code

The length of code is used to represent the number of characters in a particular code, which can be set as fixed or variable. Although variable-length codes offer flexibility and adaptability, they also present some drawbacks and issues, among which the most significant are alignment and error detection problems. An alignment problem refers to a situation where an increase in the number of characters in the code value beyond the original capacity of the data field used to store the code leads to alignment issues, making storage and transmission of data complex and inefficient, while also increasing the difficulty and error rate of decoding. Another issue is error detection, which is caused by the presence of character redundancy or addition in variable-length codes, making it difficult to detect errors manually or automatically, thereby increasing the error rate and uncertainty of data and posing potential threats to the stability and security of the system. In addition, variable length codes may result in wasted storage space, reduced conversion efficiency, and limited compatibility. In contrast, fixed-length codes are more standardized and reliable in use because their length is fixed and will not lead to errors due to formatting or layout issues.

Therefore, it is recommended to use fixed-length codes, composed of the minimum number of characters necessary, to save space and reduce data communication time. However, code optimization design should also consider factors such as code users' reading ability and cognitive load in manual decoding.

### 4.2. Design of Component Part Codes

Based on the preceding analysis, eight categories of code information, namely the component part major category, project code, floor code, building code, serial number, location code, component part subcategory, and component part extension code, are encoded using a mixed-format code. To enhance the applicability of the component part code, the mixed classification system of OmniClass is adopted, which combines the benefits of both linear and planar classification methods [6,37].

#### 4.2.1. Design of Category Information Codes

Category information is divided into component part major categories and subcategories, which represent the component category information to different degrees.

(1) Component Part Major Category Code

Through literature research and field investigations of prefabricated factories, the types of component parts in prefabricated buildings can be categorized into 20 main categories, such as beams, columns, slabs, walls, stairs, and balconies. To enhance the readability of the major category information for humans, a two-letter uppercase code is adopted for encoding, which consists of the first letter of the Chinese pinyin of the component main category name (with "U" as the default letter for missing pinyin). The component part major category codes are shown in Table 8.

**Table 8.** Descriptive statistics of the observed data for the encoding information categories.

| Component Part Category Name | Major Category Codes | Component Part Category Name | Major Category Codes | Component Part Category Name | Major Category Codes |
|---|---|---|---|---|---|
| Beam | LU | Window | CU | Canopy | YP |
| Column | ZU | Bathroom fixture | WY | Support | ZC |
| Slab | BU | Electrical equipment part | DQ | Purlin | LT |
| Wall | QU | Kitchen and dining part | CC | Truss | HJ |
| Stair | LT | Storage cabinet part | CG | Embedded component | YM |
| Balcony | YT | Wall cladding part | QZ | Others | QT |
| Door | MU | Flooring part | DZ | | |

(2) Component Part Subcategory Code

The component part subcategory represents a further classification based on the component part major category. To ensure a comprehensive classification of subcategory information, the detailed subcategory system within the China Civil Engineering Society standard was employed for design reference [12]. The subcategory code is encoded incrementally using "two digits" to represent the component part sequential number. As such, the subcategory code acts as the dependent code of the major category code, and its code range structure is flexible, with the number of code ranges varying with the major category, and the length of each code range changing based on specific classifications. Furthermore, the subcategory code does not possess any intrinsic meaning and must be read or searched in conjunction with the major category code to obtain complete category information. Examples of subcategory codes for beams, columns, and slabs can be found in Table 9.

**Table 9.** Examples of subcategory codes for beams, columns, and slabs.

| Major Category (Codes) | Component Part Subcategories | Subcategory Codes |
|---|---|---|
| Beam (LU) | Frame beam | 01 |
| | Foundation beam | 02 |
| | Cantilever beam | 03 |
| | Circular beam | 04 |
| | Passing beam | 05 |
| | ...... | ...... |
| Column (ZU) | Frame column | 01 |
| | Truss column | 02 |
| | ...... | ...... |
| Slab (BU) | Reinforced truss prefabricated slab unidirectional slab | 01 |
| | Reinforced truss prefabricated slab bidirectional slab in the middle | 02 |
| | Reinforced truss prefabricated slab bidirectional slab on the edge | 03 |
| | Reinforced truss prefabricated slab bidirectional whole slab | 04 |
| | Prestressed circular hole slab | 05 |
| | Double-T slab | 06 |
| | PK prestressed concrete composite continuous slab | 07 |
| | PK prestressed concrete composite simply supported slab | 08 |
| | ...... | ...... |

#### 4.2.2. Design of Project Information Codes

The project information is classified into four categories: project code, building code, floor code, and location code for component parts. These categories are hierarchically related in space, which can more accurately represent the location information of the construction and operation of component parts.

(1) Project Code

Considering the universality of the code, the structure of the project code can be designed as "region code + partial project number". The region code can use the administrative division code of the province, such as 11 for Beijing and 12 for Tianjin, as shown in Table 10. The partial project number can use the last four digits of the project number filed by the construction project approval management department in various regions (such as the provincial engineering construction project approval management system) where the component parts are located. This form can use a relatively short character string to ambiguously locate one or more engineering construction projects.

**Table 10.** Administrative division code of the province in China.

| Region Code | Region | Region Code | Region | Region Code | Region |
|---|---|---|---|---|---|
| 11 | Beijing | 35 | Fujian Province | 53 | Yunnan Province |
| 12 | Tianjin | 36 | Jiangxi Province | 54 | Tibet Autonomous Region |
| 13 | Hebei Province | 37 | Shandong Province | 61 | Shaanxi Province |
| 14 | Shanxi Province | 41 | Henan Province | 62 | Gansu Province |
| 15 | Inner Mongolia Autonomous Region | 42 | Hubei Province | 63 | Qinghai Province |
| 21 | Liaoning Province | 43 | Hunan Province | 64 | Ningxia Hui Autonomous Region |
| 22 | Jilin Province | 44 | Guangdong Province | 65 | Xinjiang Uygur Autonomous Region |
| 23 | Heilongjiang Province | 45 | Guangxi Zhuang Autonomous Region | 71 | Taiwan Province |
| 31 | Shanghai | 46 | Hainan Province | 81 | Hong Kong Special Administrative Region |
| 32 | Jiangsu Province | 50 | Chongqing | 82 | Macao Special Administrative Region |
| 33 | Zhejiang Province | 51 | Sichuan Province | | |
| 34 | Anhui Province | 52 | Guizhou Province | | |

(2) Building Code and Floor Code

In terms of building codes and floor codes, their own numerical information can be used for encoding. Considering the size of certain construction projects, using a two-digit number format of 01–99 for coding may lead to insufficient code capacity. Therefore, a mixed format of two characters is adopted for coding, with priority given to the two-digit numeric format code. When the number of buildings or floors is between 1 and 99, a two-digit number format of 01–99 is used. When the number of buildings or floors is 100 or above, a mixed format of letters and numbers is used. A is designated as “10”, B as “11”, C as “12”, and so on, with A0 representing the 100th floor and C3 representing the 123rd floor. Meanwhile, considering the situation of underground floors, “1X” represents the first underground floor, “2X” represents the second underground floor, and so on.

(3) Location Code

Considering the simplicity and applicability of the location code, a four-character mixed format is used to encode it, taking into account the axis information in the construction plan. The first two characters are in letter format, indicating the horizontal axis where the component part begins. The axes are numbered from bottom to top, starting with A (the default position is represented by the letter “U”). If the number of axes exceeds 26, the numbering continues with AA, AB, AC, and so on. The last two characters are in numerical format, indicating the vertical axis where the part/component begins. The axes are numbered from left to right, starting with 1 (the default position is represented by the digit “0”). For example, “CU05” represents the horizontal axis of C and the vertical axis of 5 for the starting position of the component part.

#### 4.2.3. Design of Other Information Codes

The other information is divided into two types: the serial code and the extended code for component parts. The serial code is a commonly used code format on the production line, which is used to distinguish and limit the number of products produced and facilitate identification and checking. The extended code is often used to represent additional feature information beyond category and project information. The specific information represented by the extended code is often accompanied by supplementary explanations in parentheses. It is not difficult to see that there is a significant difference in the design of the extended code compared to the category and project information. When designing category and project information, the coding information category has usually already been defined, and only code character design is necessary. In contrast, the elements contained in the extended code are difficult to define completely, which results in poor concision and standardization of extended code coding. Most regional standards in China have designed a considerable number of other information for coding, such as 55 additional attribute types specified in the local standard of Hunan Province [17] and comprehensive attribute code information designed in the local standards of Yunnan Province and Guangxi Zhuang Autonomous Region, with a total length of 371 characters [18,19]. This easily leads to code redundancy, which does not comply with the principle of concise information coding and results in poor readability of the code by humans.

In today’s highly digitized era, with the issue of code readability and attribute inclusion becoming more significant, other information codes are designed to only carry out the function of unique identification, while the remaining information is expressed through attributes. Therefore, it is necessary and feasible to introduce meaningless code forms in the code design of other information. This is because, on the one hand, for the entire component part code structure, category information and project information cover more important information categories, and meaningful codes have been used for their code segment design, resulting in stronger human readability of important attribute information. On the other hand, defining other information in its entirety presents significant difficulties, and using meaningful codes may result in character redundancy and weaker human readability. In contrast, using meaningless codes for coding is relatively straightforward, easy to expand, and convenient to use.

When designing the code for other information, this paper adopts a fixed six-character alphanumeric code structure. This design balances the needs of security and user experience as it does not convey any meaning and serves only as a unique identifier. Therefore, it can be referred to as an “implicit code”. By combining 24 alphabetic characters and 10 numerical digits, the capacity of this code segment is, $C = (24 + 10)^6 \approx 1.54 \times 10^9$. This design meets the coding needs of a certain number of parts and components, ensuring “one item, one code” to avoid confusion in lifecycle management. Additionally, establishing the mapping relationship between the “implicit code” and the information of parts and components [2,38,39], i.e., a unique “implicit code” corresponds to a specific part or component, and integrating this mapping relationship into a universal database for component parts codes, can facilitate information queries and retrieval.

### *4.3. Structure and Examples of Component Part Codes*

In summary, based on the analysis of the readability of component part codes by humans, this study has designed a code structure for prefabricated building component parts, as shown in Figure 2.

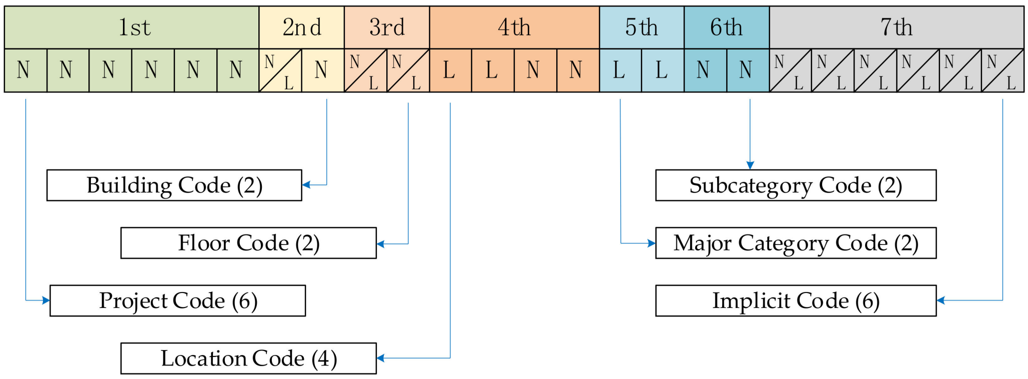


**Figure 2.** Code structure of prefabricated building component parts. The top row consists of 7 segments labeled with letters or numbers. L is an abbreviation for “letter” (from A to Z), and N is an abbreviation for “number” (from 0 to 9). It should be noted that to avoid potential confusion with the letters I and O, the implicit code employs 24 alphanumeric characters and 10 numerical digits.

In the code structure diagram, the first six sections of the top row use meaningful codes, which we refer to as “explicit code segment”, and their code names have been standardized as project code, building code, floor code, location code, major category code, and subcategory code, respectively. The information contained in these codes is either intuitively readable or can be found through relevant standards and specifications. The seventh section of the top row uses meaningless codes, including implicit codes, and is thus referred to as the “implicit code segment”. The implicit codes do not convey specific information in their form but can be queried and retrieved through information mapping and data integration in the “Component Part Universal Code Database” established for building component parts. An example of a component code is shown in Table 11.

**Table 11.** Example of component part coding.

| Code Type | Project Code | Building Code | Floor Code | Location Code | Major Category Code | Subcategory Code | Implicit Code |
|---|---|---|---|---|---|---|---|
| Segmented Code | 432994 | 01 | 03 | CU05 | LU | 01 | CXZG39 |
| Complete Code | 4322940305CU05LU01CXZG39 | | | | | | |
| Code Meaning | The frame beam is located on the third floor of Building 1, Hope Livable Industrialization Project in Hunan Province, with the starting point of the horizontal axis as C-axis and the starting point of the vertical axis as 5-axis, its “Implicit Code” is CXZG39. | | | | | | |

### *4.4. Deepening the Design of the Implicit Code*

In the context of the concept of building whole-life management, the information covered by the prefabricated building component parts should encompass the five stages of design, production, transportation, construction, and operation, including quality, cost, and risk management in the construction stage, as well as maintenance management in the operation stage [40–42]. In the preceding text, the importance of coding information categories was identified, and their codes were designed. The "explicit code segment" contains the category and project information of the component parts, which are the most important information categories in the whole life cycle of the building. The "implicit code segment" contains implicit codes that do not express specific information in the form but can be queried and retrieved through the established "universal component part code database" via data integration. Through literature research and combined with the concept of prefabricated building whole-life management, the information categories contained/mapped by the implicit codes were further classified, as shown in Table 12.

**Table 12.** Information classification for the lifecycle management of prefabricated building component parts.

| Code Segments | Phase | Information Contained (Or Mapped) in the Segment |
|---|---|---|
| Explicit Code Segment | / | Project code, Project building number, Project floor number, Component location, Component part major category, Component part subcategory. |
| Implicit Code Segment | Design and Production Phase | Serial number, geometric information, material type/specification, steel bar information, design-related standards, design personnel, manufacturer, production location, production batch, maintenance conditions, inspection items, inspection personnel, inspection time, allowable error of the component, actual error of the component, time of storage in warehouse, time of delivery from warehouse, photographs of this phase, etc. |
| | Transportation and Construction Phase | Off-site transportation plan, entry time, yard time, on-site transportation time, on-site transportation requirements, lifting requirements, installation time, installation method, installation machinery used, installation tools, connection nodes, connection methods, supervisor, acceptance time, acceptance criteria, acceptance personnel, photos for this stage, etc. |
| | Operation and Maintenance Phase | Installation unit, start-up date, service life, maintenance period, maintenance unit, operation unit, usage condition, number of inspections conducted, last inspection time, planned inspection time, inspection personnel, photos taken during this phase, etc. |

## 5. Applications of the Semi-Explicit Practical Coding Method for Prefabricated Building Component Parts

Based on the importance identification of coding information categories, the analysis of code readability by humans, and the code design, this study aims to summarize the coding and information data integration processes in the field of prefabricated building component parts. In addition, a case study of a prefabricated office building project with a framed structure is presented to illustrate the application of the newly proposed coding method for prefabricated building component parts.

### *5.1. Business Process for Component Parts Information Coding*

Information serves as the cornerstone of implementing Building Information Modeling (BIM). It is a ubiquitous component that spans the entire lifecycle of a project, and its quality has a direct impact on the successful implementation of the project. To ensure the effectiveness of the information coordination and construction, it is imperative to establish a standardized and normalized information classification and encoding system. Moreover, it is important to note that different components may have distinct information-sharing requirements, which may vary from complete sharing, partial sharing, only sharing within the model, or refusal to share. In this study, as described in Figure 3 and with reference to [43], a business process for encoding component information is presented to highlight the various stages of information collection, classification, encoding, storage, and transmission paths. A comprehensive analysis of the information status during different project implementation stages is also provided.

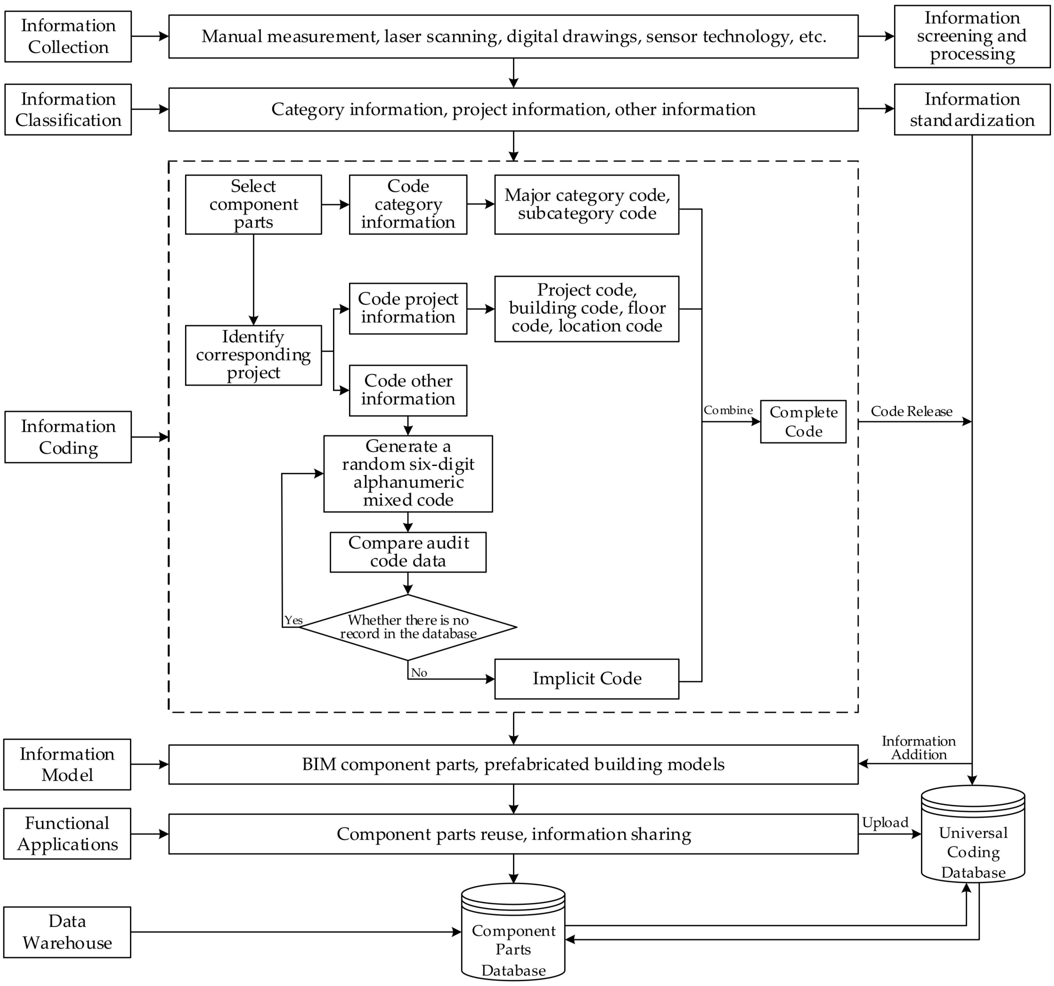


**Figure 3.** Business process for component parts information coding.

At the outset of the encoding process that corresponds to the encoding method proposed in this paper, when selecting component parts, their category information is determined and a parameterized model is created, which associates the component parts with their major category and subcategory codes. Secondly, after the component parts are associated with the project, the remaining coding information is generated, which includes the project code, building code, floor code, and location code. These codes are linked to the corresponding component parts belonging to the project. In addition, a randomly generated six-digit "implicit code" is associated with the component parts after being audited by the universal coding database to ensure uniqueness. Finally, the various code segments are combined to generate the complete code, which is recorded in the universal coding database.

### *5.2. Data Integration Process for Component Parts Coding*

In the construction industry, the information-intensive nature of projects requires stakeholders to access various project documents, such as design drawings, specifications, contracts, change orders, site reports, requests for information, and parametric models [44]. To meet the requirements of building lifecycle management, as identified in Table 10, data tables for component part information are established for the design and production, transportation and construction, and operation and maintenance phases. The necessary fields for each data table are created, and the component part codes are set as the primary key to ensure the uniqueness of each information record. Preset data information is obtained through BIM software, generating a detailed list or external plug-in to import data into the database after passing code compliance checks [45–49]. Additionally, an open data table is created to allow project stakeholders and users to define and input customized information entries and corresponding data. The integrated process for part and component information design is shown in Figure 4, as described in reference [50].

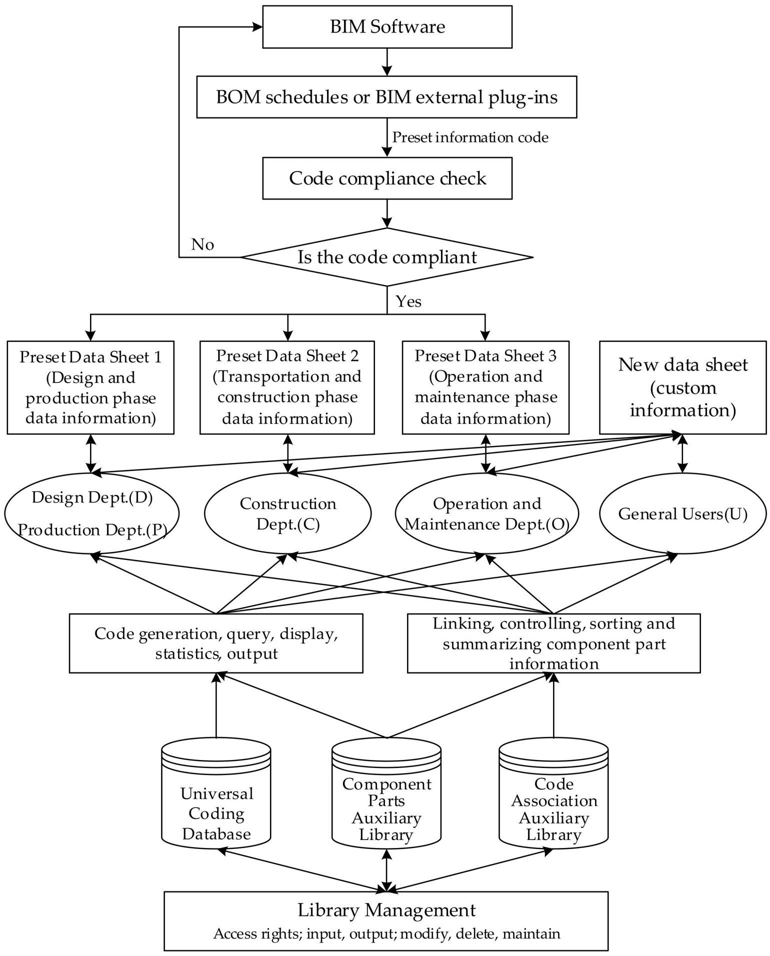


**Figure 4.** Data integration process for component parts coding.

### *5.3. Application in BOM Tables*

This article applies coding and data integration to the parametric model of a prefabricated frame office building project in Hunan province, China. After completing the split design of prefabricated beams, columns, and slabs, the associated category and project information of these components were coded and combined with a hidden code to obtain their complete code. In this phase, thousands of prefabricated components were coded and entered into a database to form a Bill of Materials (BOM) table, which supports subsequent processes such as computer-recognized materials and material traceability, and improves production planning, design, and production efficiency [2]. The BOM table containing the codes of prefabricated components is shown in Table 13.

**Table 13.** Bill of Materials (BOM) for Recording Component Codes (BOM of Composite Beams).

| Serial No. | BOM Version | Product Category | Component Part Code | Length /mm | Width /mm | Height /mm | Area /mm$^2$ | Volume /mm$^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | B | Stacked beam | 4329940102AU01LU06CXL001 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 2 | B | Stacked beam | 4329940102AU02LU06CXL002 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 3 | B | Stacked beam | 4329940102AU03LU06CXL003 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 4 | B | Stacked beam | 4329940102BU01LU06CXL004 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 5 | B | Stacked beam | 4329940102BU02LU06CXL005 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 6 | B | Stacked beam | 4329940102BU03LU06CXL006 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 7 | B | Stacked beam | 4329940102BU03LU06CXL007 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 8 | B | Stacked beam | 4329940102BU03LU06CXL008 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 9 | B | Stacked beam | 4329940102BU04LU06CXL009 | 3730 | 380 | 200 | 1.417 | 0.283 |
| 10 | B | Stacked beam | 4329940102BU04LU06CXL010 | 3730 | 380 | 200 | 1.417 | 0.283 |
| | | | …… | | | | | |

### *5.4. Examples of Component Part Code Diagrams*

The component part codes are required to be represented in the form of physical graphical symbols and labels, and attached to or embedded within the component parts, as illustrated in Figure 5, to facilitate the transmission of information.

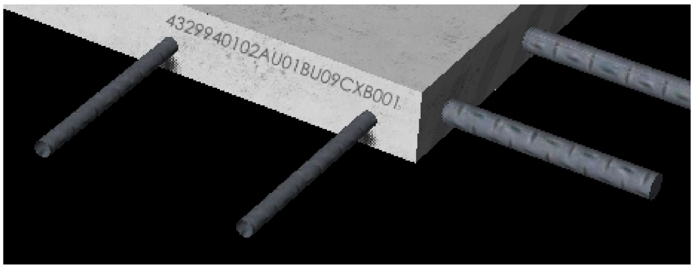


**Figure 5.** Example of component part codes (a composite panel).

### *5.5. Application in Component Database Platforms*

Considering the limitations of the database platform for project stakeholders and ordinary users, the editing and modification of component part codes may be inconvenient. Therefore, it is possible to expand the database platform to the web and client sides and establish a universal component part code system that is compatible with the database. Users can input a six-digit "Implicit Code" to query the component part and obtain information about the component part in various stages, which is highly convenient. In addition to code search, the universal component part code system should also provide multiple retrieval methods such as project search, category search, and advanced search. The interface layout of the universal component part code system is shown in Figure 6.

Through the authentication of project stakeholders and ordinary users, different permissions are assigned to enable the decentralized management of encoding information, including adding, deleting, querying, and modifying. During the design and production phases, the design and production parties can edit or add preset information. During the transportation and construction phases, the construction and supervision parties can manage the entry, installation, quality, and acceptance of the component parts through the system. In the operation and maintenance phase, the operation and maintenance party can not only inquire about the manufacturer, production, and installation time of the component parts but also update their operation and maintenance information in real-time. Additionally, the system also features data backup and recovery, system error recovery, and human error recovery.

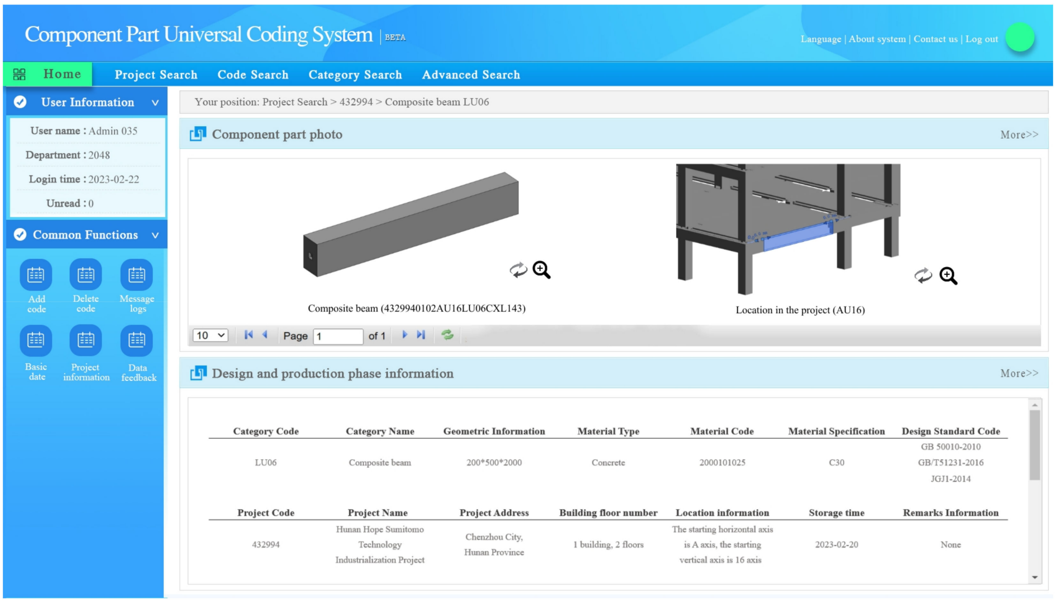


**Figure 6.** The interface layout of component part universal coding system.

## 6. Discussion

This study employed literature review and questionnaire survey methods to identify and select the categories of coded information. In both stages, eight information categories were found to be among the top ten in terms of frequency and importance scores. These eight categories can be classified into three types: category information, project information, and other information. (1) Category information serves as the foundation of coded information, with significant implications for material management, production management, and quality control in the field of prefabricated construction, providing support and guidance. (2) Project information is critical in distinguishing and linking coded information and can offer the necessary information support for the construction, installation, maintenance, and management of prefabricated buildings. (3) Other information supplements coded information, which can enhance the completeness and maintainability of coded information. They can facilitate the retrieval, management, and maintenance of coded information, while also promoting efficient usage and control.

These categories of coded information are of consistent interest to standard setters, scholars, and professionals in the prefabricated construction industry, although the degree of importance varies slightly. Therefore, in developing a coding method for prefabricated building component parts, this study comprehensively considered the needs and focus of all parties to ensure the comprehensiveness and practicality of the coding method.

### *6.1. Analysis of the Application of Semi-Explicit Coding Methods for Component Part Codes*

In practical engineering applications, a semi-implicit coding method can effectively improve the efficiency of identification and management of components in prefabricated construction. (1) The application of category information: The use of major category and subcategory codes for describing component part categories can improve the efficiency of the identification and management of a large number of component part types. For example, the same component part type may appear repeatedly on different floors of the same project. By using major category and subcategory codes, these identical component parts can be easily identified, avoiding misunderstandings and confusion in management. (2) The application of project information: Project code, building code, floor code, and location code describe the component part location and ownership information. By using these codes, component parts can be quickly located and managed. For example, when a component problem is found on a certain floor, it can be quickly located by using the floor code and location code, which facilitates problem resolution. (3) The application of other information: Implicit codes are auxiliary information that can be used to describe component part properties, such as material and specification. The use of implicit codes can further improve the efficiency of component part identification and management.

In summary, the selected coding information categories of this method have strong relevance, and their rationality and applicability have been reflected in specific engineering projects. It can improve the identification and assembly efficiency of prefabricated construction component parts, facilitate project progress and quality control, improve data sharing and collaborative efficiency. In addition, the introduction of implicit codes facilitates the traceability of component parts and maintenance of component part life cycle and usage, thus improving maintenance efficiency and service life.

### *6.2. Comparison of Semi-Explicit Part Coding Method with Other Related Coding Standards and Coding Methods*

The semi-explicit practical coding method proposed through designing the structure of the component part code using the aforementioned coding information categories can express the basic information of the components to some extent and meet their needs in various application scenarios. Compared with existing building product classification and coding standards, as well as other coding methods proposed in academic papers, this method has significant features and advantages:

#### 6.2.1. Comparison with International Building Product Classification and Coding Standards

In international classical building product classification and coding standards, OmniClass and ISO 12006-2 classification standards are more advanced, and the classification scope can also cover various aspects of building information, which can meet the higher requirements of informatization in the building industry. As mentioned earlier, OmniClass uses a mixed classification method, which divides building information into 15 classification tables (planes) and expands them in turn (lines) within each classification table. It can be said that the evolution from line classification coding to plane classification coding is a watershed in the transition of the building industry from traditional management to modern information management. However, these standards are more like a retrievable dictionary, which only provides a reference coding method for building information and does not provide a coding method for prefabricated building component parts. Therefore, they cannot be directly applied to the coding of building component part information.

#### 6.2.2. Comparison with Domestic Building Product Classification and Coding Standards in China

In China, the more mature building product classification and coding standard is the "GB/T 51269-2017 Standard for classification and coding of building information model", which is a more systematic standard that references OmniClass and makes localized adjustments based on the characteristics of the Chinese construction industry. Therefore, this standard still only provides classification tables and reference coding methods for building information and cannot be directly applied to the coding of prefabricated building component parts.

#### 6.2.3. Comparison with Domestic Society, Group, and Local Classification and Coding Standards for Prefabricated Building Component Parts in China

Among these domestic Chinese society, group, and local classification and coding standards, the society standard proposed by the China Civil Engineering Society is more normative and can serve as a reference for many regional coding standards, which often reflect the core ideas of the industry standards. However, these standards typically provide a large number of feature type codes and feature parameter codes, but do not provide guidance or explanations regarding the importance of feature codes or the number of coding information categories. This leads to a high degree of arbitrariness in the coding of building component parts, which can result in unstable code structures, uncontrolled code lengths, and poor code readability.

#### 6.2.4. Comparison with the Coding Method of Prefabricated Building Component Parts Proposed in Existing Academic Papers

The semi-explicit component part coding method proposed in this paper takes into account the importance and readability of coding information categories, which is lacking in other literature studies.

In terms of the design principles of the coding method, this paper and other related academic papers share a common approach that is based on building product information classification and coding standards both domestically and abroad, China's current prefabricated building atlas information, as well as relevant standards, regulations, and information technology for the design of the coding system. In terms of design principles, both are tailored to the characteristics of the Chinese construction industry while maintaining compatibility with existing international standards, ensuring rationality, conciseness, applicability, and expandability, while also considering connectivity with computer systems.

Regarding the research objectives and research objects, this paper is similar to other related academic papers in terms of combining and arranging coding information categories. However, this paper places greater emphasis on identifying and screening the importance of coding information categories, as well as exploring the readability of code from a human perspective, thus completing the coding method design. Therefore, this paper can serve as a supplement and extension to other studies and further improve and enrich the research results in the field of component and part coding.

Regarding the research methods, this paper is to some extent groundbreaking as existing academic papers lack research on the importance and readability of coding information categories. In terms of data sources, this paper is based on relevant coding standards and coding methods in the construction industry, which provides comparability and repeatability, and can be compared and verified with other studies.

Regarding the research results and conclusions, this paper proposes a semi-explicit coding method for component parts, which uses a mixed structure of semantic and non-semantic parts in the coding structure, making it a form of innovation to some extent. In the semantic part, the selected coding information categories for component parts are of high importance; therefore, the proposed coding method and corresponding coding structure have sufficient credibility and reliability, further supporting and validating the research results in the field of component part coding.

#### 6.2.5. Features and Advantages of the Semi-Explicit Coding Method

(1) Practicality: In response to the lack of recommendations or explanations on the importance and number of encoding information categories in domestic Chinese society, group, and local coding standards for building component parts, this paper identifies and filters the importance of encoding information categories and considers the readability of the code to encode information that is of high importance. In other words, the code structure proposed in this paper contains information that has been filtered and is of high importance in the explicit code segment.

(2) Semi-explicit: In response to the problem of excessively long building component part codes and redundant code structures caused by excessive coding requirements in some regions' coding standards, this paper divides the code structure into explicit and implicit code segments. Building component part information that is of great concern to the prefabricated building industry practitioners is encoded in the explicit code segment, while other information is encoded in the implicit code segment, and users can obtain the required information through information mapping and data integration into a universal coding system. This design shortens the length of building

component part code characters, enhances readability, and reduces the cognitive load to some extent while reflecting important building component part information.

(3) Sufficient room for expansion: This paper fully draws on the ideas of mixed classification and divides encoding information into three categories: category information, item information, and other information, and then encodes them in turn. While encoding category and item information explicitly, other information is encoded implicitly, establishing an information mapping relationship and using a six-character alphanumeric mixed code for representation. The capacity of the implicit code segment is over $1.54 \times 10^9$, which is sufficient for the billion-level, and supports project-related parties and user-defined information for continuous improvement of the required building component part information categories.

## 7. Conclusions and Future Directions

Component parts are the fundamental units of prefabricated buildings and serve as an important carrier for the study of prefabricated buildings during the entire life cycle. The precipitation and analysis of information related to component parts are of vital significance to the development of prefabricated buildings. The study of information categories and coding methods for prefabricated building component parts enables the preservation and accumulation of entity and parameterized information, as well as project engineering information. It also provides powerful support for the optimization and development of prefabricated buildings by enabling research at the smallest scale.

Therefore, based on the existing problems and challenges of component part coding in Chinese prefabricated buildings, this paper conducts importance recognition of coding information categories for prefabricated building component parts by employing literature review and questionnaire survey methods, which is currently lacking in existing research, and selects eight important coding information categories that can fully describe the basic information of component parts to some extent. The coding standard developers, relevant scholars, and industry practitioners pay higher attention to these coding information categories in the code structure and have a good consistency. Considering the readability of codes, this paper proposes a practical semi-explicit coding method for prefabricated building component parts, which has strong flexibility and wide applicability. This method has strong reference value for the development of prefabricated building component part coding standards in different countries and regions. The component part codes are divided into explicit code segments and implicit code segments, and semantic coding and non-semantic coding are conducted. The explicit code segments can fully represent the more important information categories of the building's entire life cycle, and project information and category information can be directly obtained through this code segment. The implicit code segment does not represent specific information in a form but can query and retrieve other information through information data integration. Therefore, this coding structure and coding method have sufficient credibility and reliability and can further support and prove the research results in the field of component part coding. In addition, considering the limitations of database platforms for users, a component part universal coding system is designed to be compatible with this coding system. By assigning different permissions to various stakeholders and users in the project, this system can achieve decentralized management of prefabricated building component coding data and support the information management of prefabricated building component parts throughout the entire life cycle and the promotion and application of prefabricated buildings.

One of the limitations of this paper is that it focuses on the perspective of China's prefabricated construction industry and explores the importance and readability of coding methods for building component parts. Consequently, the proposed coding method may face compatibility and applicability issues outside of China, which require further localized research by scholars in relevant fields from different regions. In addition, this paper has not yet developed a comprehensive list of coding categories for building component parts. The development of a complete coding system for prefabricated construction components is a "top-down" process that requires higher-level coordination and standardization, as well as participation from experts in various fields to provide collective wisdom and practical testing. Furthermore, this paper proposes a semi-explicit coding method for prefabricated building component parts, which may have strong reference value in other fields besides civil engineering. However, this study has not yet formed a universal coding design model that has sufficient applicability and compatibility. The coding methods for other products in different fields may involve the particularity of the design, production, operation processes, etc. Therefore, future research should focus on the study of coding methods for products in fields such as mechanical and electronic engineering and abstracting a general coding method applicable to various fields.

**Author Contributions:** Conceptualization, L.Q. and C.H.; methodology, D.F.; software, D.F. and C.H.; validation, L.Q., Y.L. and Z.S.; formal analysis, D.F. and L.Q.; investigation, Y.L. and C.H.; resources, Z.S.; data curation, D.F. and Y.L.; writing—original draft preparation, D.F. and L.Q.; writing—review and editing, Z.S.; visualization, D.F. and Y.L.; supervision, Z.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Natural Science Foundation of China (U1934217), Science and Technology Research and Development Program Project of China Railway Group Limited (Major Special Project, No. 2020-Special-02; Major Project, No. 2021-Major-02; Key Project, No. 2021-Key-10), and the China Energy Investment Corporation Limited (SHGF-18-50).

**Data Availability Statement:** The data used to support the findings of this study are included.

**Acknowledgments:** We would like to express our gratitude to the 154 professionals from the prefabricated construction industry who participated in our survey on the importance of different categories of coded information for prefabricated building component parts. Without their valuable input, this research could not have been possible.

**Conflicts of Interest:** The authors declare no conflict of interest.

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