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The Standardization Method and Application of the BIM Model for Interchanges

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Abstract: Research on the standardization of interchange BIM components is required to encourage the use of BIM technology in interchange and quicken the development and improvement of relevant standards and specifications. The depth level of the model, classification, and coding of interchange BIM components, and the design and administration of the component library are the main topics of this work. First, the concept and main research content on the standardization of interchange BIM components were proposed. Second, the common forms of interchange were summarized. The basic components of interchanges include through lanes, ramps, connections, overpass bridges, and traffic safety facilities, and can be divided into 14 second-level components, such as the main line, the minor cross highway, the speed-change lane, etc. On this basis, a method for interchange BIM components classification based on faceted classification and a coding method based on a combination code was proposed. The model depth grading of the BIM component of the interchange was studied, and grading was carried out considering three aspects: the level of detail (LOD), geometric accuracy, and information level. Finally, the process of creating interchange BIM component libraries was proposed. The results showed that the interchange BIM components can adopt a three-level coding method, namely "the overall spatial code–classification code–instance code", and the LOD, geometric accuracy, and information level of the interchange BIM components can be divided into four levels. Additionally, interchange BIM component libraries can be created using five steps: an overall plan of component resources, standard determination, component creation, component audit, component storage, and application.

Keywords: road engineering; standardization; faceted classification; BIM; interchanges; components

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1. Introduction

Once the concept of BIM was introduced in the 1970s, it was rapidly developed, popularized, and applied [1]. The introduction and development of BIM technology in the transportation field came later than in the construction industry, and BIM in China's transportation field is still in its initial stages. The relevant standards and specifications are still being formulated and are not complete; they are especially lacking interchange-related content. As the smallest particle size in the application of BIM technology, BIM components in interchanges are characterized by a large variety and mixed information. Thus, it is necessary to study the standardization of BIM components to promote the application of BIM technology in interchanges and to accelerate the development and improvement of relevant standards and specifications.

Robert Agren and Robert D. Wing [2] proposed that the industrialization of construction should go through several important stages, such as early component prefabrication, component module standardization, large-scale production, and information management. The standardization of BIM components is the key to the development of BIM technology. Foreign research on the standardization of BIM components started earlier, and most of the research results are presented in the form of promulgating BIM standards, such as the BIM international standards led by the International Organization for Standardization ISO, and the BIM national standards led by the United States, Singapore, South Korea, Japan, and other countries, which are quite mature [3–7]. So far, as the IFC standard released by the International Collaboration Consortium in 1997 has provided a standard data model for the field of construction engineering, the BIM standards promulgated in various countries were formulated on this basis to achieve information exchange and sharing [8]. In recent years, some foreign scholars have shifted the direction of BIM research towards practical research. Weisheng Lu et al. [9] used social network analysis to compare the impact of BIM on the organization of construction projects and elucidated the ways to produce this impact. Emad Al-Qattan et al. [10] used physical computing systems to associate physical objects with their digital design information in digital and physical methods. Some other scholars [11–14] have studied the difficulties of BIM building design coordination.

The research work on BIM standardization in China has only been carried out recently, and the research on BIM standardization in highway engineering has just started. Some scholars have studied BIM components. Zhu Wenjie et al. [15] created a standard component library platform according to the current situation of BIM component application management in railway construction enterprises. Wang Wanqi et al. [16] proposed a clustering method for BIM components and a component library according to the amount of attribute information. As for highway engineering, domestic scholars have mainly focused on the applications of BIM. Wang Yu [17] studied the application of BIM in interchange based on the Autodesk platform. Zhu Jianqing [18] studied the modeling steps and parameter output method of BIM technology in the design process of interchange based on Autodesk's BIM software. Wang Ru et al. [19] discussed the rapid construction method of the terrain model, main structure model, and subsidiary facilities model by using the visual programming plugin Dynamo in combination with BIM. Zhang Wensheng et al. [20] combined BIM and the point cloud model for rapid modeling of tunnels. Zhang Feng [21,22] proposed that the delivery standard system and classification coding system could be applied to highway engineering projects by studying the standard framework at home and abroad in combination with the characteristics of highway engineering projects. Hu Honglong [23] extended the coding structure of BIM components to six layers from the perspective of the actual needs of highway maintenance. In recent years, the Ministry of Transport, various localities, and enterprises have also carried out road engineering BIM standardization work [24]. Although some standard specifications for road engineering BIM at various levels have been developed, there are still problems, such as the lack of comprehensive content for specification provisions and poor compatibility between different levels.

It can be concluded from the above research status that the current BIM research on highway engineering is mainly application oriented. Some scholars have studied the standardization of highways and interchanges; however, most of them have extended definitions based on construction standards, and most are macro-conceptual regulations, lacking specific unit expressions. As an important control point of highway projects, interchanges are also large projects with distinctive characteristics of highway engineering and certain construction projects, and their standardization cannot be defined simply from highway engineering components.

This paper first introduces the concept and main research contents of interchange BIM component standardization. Secondly, the common forms of interchange and the component units of interchange are summarized and classified, and based on this, the classification and coding of interchange BIM components are studied in terms of both principles and methods. Then, the information classification of the components is studied in terms of the detail level of BIM components, the geometric expression accuracy of BIM components, and the information depth of BIM components. Finally, the concept, creation process, and management method of the BIM component library for interchanges are introduced, and the standardization of BIM components for interchanges is visualized through example applications. This study provides a theoretical basis for the classification and coding of BIM components for interchanges, the classification of BIM models, and the creation and management of component libraries. It provides a reference for applying BIM technology to interchanges and improving related standards and specifications.

2. Standardization of BIM Components for Interchanges

2.1. Concept of Standardization of Interchange BIM Components

Interchange BIM components are the reusable, irreplaceable, and functional components of an interchange in the BIM model, and they are the smallest particle size in the BIM model. The components of interchanges in highway engineering are complex and diverse. Their construction includes not only the professional engineering contents of highway engineering, but also the unique professional components of interchanges. To manage the various components of interchanges in a reasonable and orderly manner, regulate their production, use, and maintenance, and improve their efficiency, the standardization of BIM components for interchanges is recommended. Standardization of BIM components for interchanges is defined as, at a certain stage of BIM development, improving the efficiency of all stages of the life cycle and reducing the cost of BIM implementation, standardizing all aspects of BIM components for interchanges, and unifying the repetitive items in the creation, use, and maintenance of interchange, so that all types of BIM components in interchanges can obtain the best performance based on their functionality, reusability, and expandability. The BIM components of interchanges are designed to be functional, reusable, and extensible.

2.2. Content of Interchange BIM Component Standardization

The creation of internal information attributes is the main content of the interchange BIM component standardization process, which includes the classification and coding of interchange BIM components, the determination of the information depth level of interchange BIM components, and the creation of the interchange BIM component library [25], as shown in Figure 1.

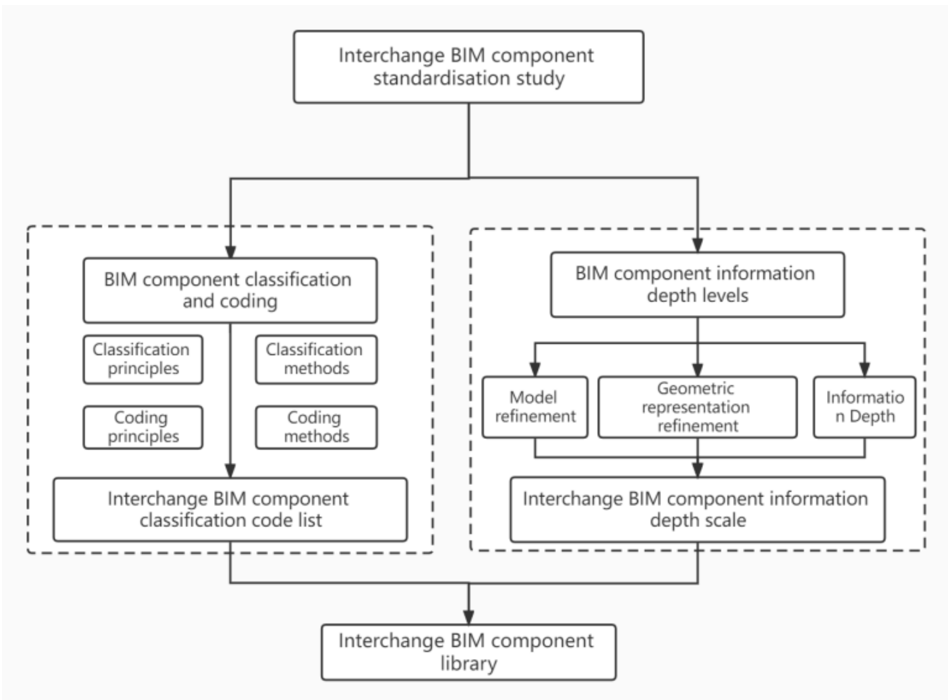

Figure 1. The process of interchange BIM components standardization.

An interchange is a complex project, involving many disciplines such as roads, bridges, and traffic safety facilities, and its BIM components, therefore, have various types. The design and construction of an interchange include multiple phases, and the demand for information stored in the BIM components is different in different phases. The creation of an interchange BIM component library is not only an important vehicle for the transformation of standardization results, but also facilitates the maintenance and modification, updates and iterations, and further improvements of BIM components.

3. Classification and Coding of BIM Components for Interchanges

The classification and coding of interchange BIM components are core tasks in the standardization process. Whether the classification standard is scientific, and the information coding is standardized will directly affect the management level and application efficiency of interchange BIM components. Therefore, in the process of standardizing BIM components for interchanges, scientific principles of component classification and coding should be proposed, and appropriate component classification and coding methods should be developed in consideration of the characteristics of interchanges.

3.1. Components of an Interchange

The interchange keeps two roads spatially separated and uses ramps to make the two roads interchangeable, reducing the number of conflict points, and it has a large capacity, safe traffic flow, complex structure, and large land area. Although an interchange is a complex project, the basic units that make up an interchange have a good consistency. Interchanges are generally composed of a mainline, ramps, ramp connections, crossline structures, and other traffic engineering and facilities along the route [26]. Depending on its grade, form, and function, each basic unit can be further subdivided, as shown in Figure 2.

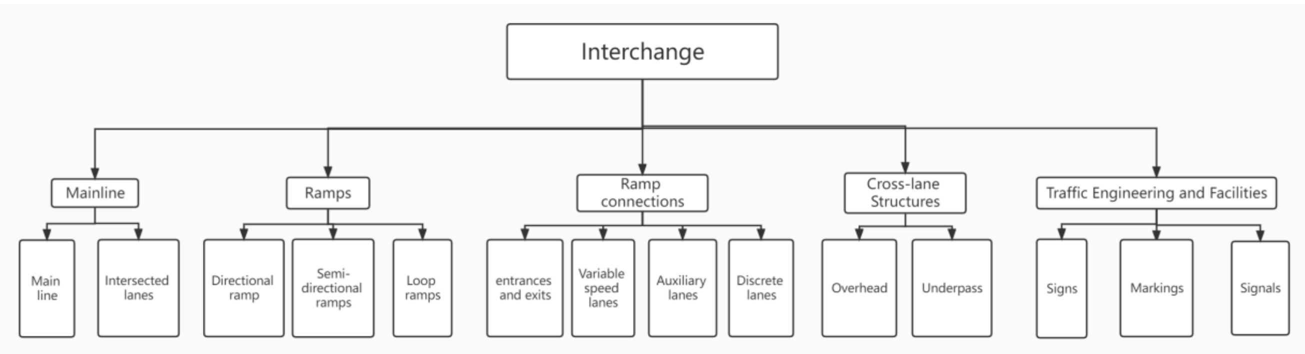

Figure 2. Classification of interchange components.

As shown in Figure 2, the component units of the interchange are distinguishable and can be studied separately for different component units. This feature also provides the basis for the classification and coding of the interchange BIM components.

3.2. Method of Classification of Components

Scientific and reasonable classification of interchange BIM components can standardize and provide an orderly count of the various components of interchanges, and greatly improve the process of standardization of interchange BIM components. The classification of interchange BIM components should not only be based on the attributes and characteristics of the information contained in the component model, but also should be associated with the BIM level. Combined with the characteristics of interchanges, the BIM components of interchanges should include the following: ramp components, variable speed lane components, auxiliary lane components, collector components, interweaving area components, nose end construction components, ramp end planar intersection components, etc., as shown in Table 1.

Table 1. Interchange BIM components.

Specialties	Structural Systems	Functional Systems Primary Structures	Functional Systems Primary Structures
Interchange	Ramp components/variable speed lane components/auxiliary lane components/collector components/interweaving area components	Road surface	Road surface structures Appurtenances
		Road base	General road base Special foundations
		Support	Surfacing Retaining walls
		Drainage facilities Traffic safety facilities	Drainage ditches and pipes Traffic facilities
	Nose construction elements	Road surface Road base Support	…… …… …… …… …… ……
	Ramp end planes	Crossing elements inflow islands Separation islands	…… …… …… ……

To distinguish and categorize interchange BIM components more systematically, it is also necessary to choose a suitable classification method. Information classification mainly includes three basic methods: line classification, surface classification, and hybrid classification [27]. The line classification method gradually classifies the classification object into several hierarchical categories according to the attributes or characteristics of the classification object, and finally into a hierarchical and gradually unfolded system. The surface classification method selects several attributes or characteristics to divide the classification object into categories without affiliation, and then continuously divides the selected categories into a mutually independent classification system. The mixed classification method combines the above two methods. The mixed classification method generally uses one of the above two methods as the main means of classification and the other method as a supplementary classification method.

In interchanges, a BIM component often contains multiple attributes or features. For example, an auxiliary lane in an interchange usually contains multiple aspects, such as design speed, cross-section type, and geometric indicators, which are suitable for classification using the surface classification method. At the same time, considering the principle of compatibility in the classification of components, the classification method of interchange BIM components should be consistent with the classification methods in the existing relevant national standards. The use of the facet classification method is beneficial because of the addition of interchange component attributes and features, without the need to determine the final grouping in advance, and the later completion is also convenient for computer retrieval and suitable for computer management.

3.3. Method of Coding Components

Compared with BIM components of other professions, interchange BIM components are more diverse, and the articulation between different components is more complex, making classification more difficult. Moreover, the same types of components are repeatedly used in different ramps, making identification more difficult. Commonly used code types are described in Basic Principles and Methods of Information Classification and Coding [27]. Combining the analysis with the application requirements and the characteristics of interchanges, hierarchical codes and combination codes are the most suitable code structures for interchange BIM components. Hierarchical codes classify the code object into several segments according to the hierarchy, with each segment representing the hierarchy of the code object. Combined codes are a combination of different code segments, which are interdependent but different from each other.

The relevant national specification standards adopt the method of hierarchical codes for coding, but there are problems, such as poor flexibility of the classification structure and difficulties in subsequent changes. To increase the application capability of interchange BIM component coding and increase the classification flexibility, it is more appropriate to adopt the method of combination codes for coding. The coding content further extends the classification code of highway engineering components [28]. The interchange classification code is 08, in addition to the space code and example code [29], a total of 21 bits (excluding hyphens), and the code composition is shown in Figure 3.

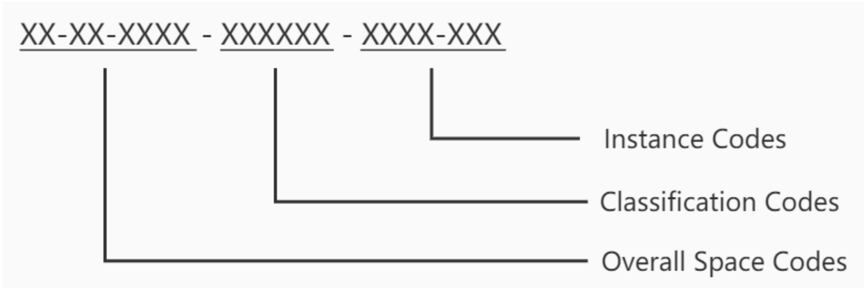

Figure 3. Interchange BIM components coding.

The coding of interchange BIM components using the combination code approach does not violate the normative principles of coding in essence, but it is a further extension of the coding rules based on the norms. To increase the application capability of the code, the overall spatial code and the example code are added in full combination with the interchange's characteristics.

The overall spatial code is divided into three levels, which are used to characterize the project name, project section, and unit works, respectively, using the coding rules of sequential codes to indicate the spatial information of the project. The classification code adopts the coding rules of hierarchical code, based on the classification of interchange BIM components, and is mainly used to characterize the categories of components. The example codes are coded using unordered codes to indicate each specific component of the project, and to distinguish each component to ensure its uniqueness.

4. Model Depth Grading of BIM Components for Interchanges

An important task in the process of standardization of interchange BIM components is to standardize and classify the information in BIM components, and the basic principle to be followed in the division is the "moderate principle" to adapt to the demand of BIM model depth in different engineering stages [30]. However, interchanges have the characteristics of both point projects in the construction field and strip projects in the road engineering field, so it is necessary to classify the component model levels according to the characteristics of interchanges.

4.1. Model Granularity of BIM Components

In traditional highway design, the design information of interchanges is described in separate drawings for each type of interchange. Both China and the USA divide the construction phases of highway projects and specify the main work content for each phase, as shown in Table 2.

Table 2. Comparison table of highway construction stages in China and the United States.

American Road Construction Phase	Main Work Content	China's Road Construction Phase
Planning	State transport departments, urban planning departments and local governments identify projects depending on the potential for investment	Engineering stage Preliminary design stage
Project development	Engineering projects are clearly defined. Alternative route corridor zones and design criteria (indicators) are developed, and recommended options are presented.	
Detailed design	Detailed design, preparation of detailed design drawings, calculation of quantities and project budgeting	Construction design stage
Land acquisition	Purchase of the land required for the acquisition of the project	Construction phase
Construction	Selection of contractor and start of construction building	

According to the analysis in Table 2, there are commonalities between China and the USA in the division of road construction stages. Although the designation of each engineering stage is different, the requirements and contents of each stage are the same. Compared with the work content and the need for project information, "planning" and "project development" are the same as the "feasibility stage" and "preliminary design stage" of Chinese engineering projects. "Detailed Design" is equivalent to the "Construction Design Stage", with the main work being the detailed design of the project.

Depending on the stage of the project, the content and description focus of the drawings vary. As for the definition of the engineering stage in China, too complex information about BIM components in the engineering stage will bring a lot of ineffective work and reduce efficiency, while too simple information about BIM components in the construction drawing design stage will not meet the demand of construction application. Therefore, this paper proposes the correspondence between the model depth level of BIM components and the engineering stages of design, construction, operation, and maintenance, based on the Chinese design specifications and guided by the information requirements of the design stage.

With the continuous progress of engineering stages, the information demand of the BIM model changes, and there may be a situation where the actual depth level of the BIM model does not match the evaluation level. To solve this problem, the number of information covered by the BIM model, geometric expression accuracy level, and information depth should be judged at each engineering stage change node, with the information demand of the engineering stage as the judgment standard. For example, when the project is in the linkage between the preliminary design stage and construction drawing design stage, the model depth level required in the construction drawing design stage should be used as the basis to supplement and improve the current information to ensure that the information content change is synchronized with the engineering stage. However, in different design stages, the appointing party may put forward too high information requirements, resulting in unnecessary labor for the designers. To avoid this situation, designers and managers should communicate several times to clarify the actual project information requirements to ensure the effectiveness of the BIM model depth level evaluation at each stage.

4.2. Model Granularity of BIM Components

The BIM components of interchanges are often made up of multiple model units due to their large footprint and complex structure. Depending on the model fineness, these model units can be divided into four levels: overall level, functional level, component level, and part level, with the model units concentrated in the engineering stages of design, construction, operation, and maintenance. The model is divided into four different detail levels, LOD1.0 to LOD4.0, according to the depth of application, as shown in Table 3, and can be extended between the basic levels of detail, such as LOD1.X, according to the needs of the project.

Table 3. Classification of BIM components LOD.

Level	Description	Corresponding Minimum Model Unit	Engineering Phase
LOD1.0	Project scheme level representation. Includes the main engineering model of the interchange's extensive topography, nearby towns, major road and water networks, and the route, roadbeds, and bridges in a holistic form.	General level model units	Engineering phase
LOD2.0	The initial representation of the model. This includes the measured topography of the interchange area, the main geological areas, the object models of the route, roadbeds, bridges, and traffic engineering by function, and the main model of the intersected road.	Functional level model units	Preliminary design phase
LOD3.0	Enables accurate representation of the model. This includes a large-scale topographic survey, the improvement of important features, detailed adverse geology, the model of the intersected road, and the object model of the route, road base and road surface, bridges, culverts, traffic signs, and markings, etc., divided by their components.	Component level model units	Construction drawing design phase
LOD4.0	Achieves accurate representation of the model, including temporary sites, object models of routes, roadbeds, bridges, culverts, flyovers, access roads, traffic signs and markings, service facilities along the route, temporary facilities, etc., divided by processing and construction.	Part level model units	Construction O&M phase

4.3. Accuracy of the Geometric Representation of BIM Components

The geometric expression accuracy specifies the degree of realistic and detailed response of the geometric information of the BIM model. For the interchange model units, it is recommended they are divided into four different levels from G1 to G4, and the specific division principles are shown in Table 4.

4.4. Information Depth of BIM Components

The information in the interchange BIM component model should include both geometric and non-geometric information, and the depth of information specifies the level of detail of the attribute information carried by the interchange model. Combined with the characteristics of interchanges, it is recommended to divide them into four different information depth levels from N1 to N4. The specific division principles are shown in Table 5.

Table 4. Classification of BIM components' geometric accuracy.

Grade	Grade Requirements	Stage
G1	Schematic representation of the model unit, the form, scale, and microtopography of the interchange, including rough dimensions inferred from experience, similar projects, etc.	Engineering stage
G2	Approximate representation of the main geological feature outline of the interchange, reflecting the approximate geometric characteristics of the interchange's specialist objects, including the structural form and main structural dimensions.	Preliminary design stage construction design stage
G3	Accurate representation of the model unit, with high precision contour details of the local topography, geology, and features of the interchange, reflecting the actual shape of the interchange's specialist objects, including all dimensions.	Construction phase
G4	Accurate representation of the model unit, with details of each specialist object within the scope of the interchange that reflects the precise detail dimensions of the object, installation dimensions, and details that meet the needs of high precision identification, such as manufacturing and processing preparation.	/

The geometric fineness level of the model corresponding to each engineering stage in the figure is only the minimum requirement; if the dimensions need to be measured, the geometric expression accuracy should be increased by one level.

Table 5. Classification of BIM components' information level.

Level	Information Requirements	Stage
N1	Contains basic information about the interchange project, and non-geometric information about nearby towns, rivers, road networks, etc.	Engineering stage
N2	It is desirable to include N1, adding design information required for the preliminary design, including design information such as physical information of the main works and other technical and economic indicators for the preparation of the project estimate.	Preliminary design stage
N3	It is desirable to include N2 to further improve and enrich the design information, including design information on materials and properties required for the project, and to add information on the construction and installation of interchanges and other technical and economic indicators used for the preparation of the project budget.	Construction design stage Construction phase
N4	It is desirable to include N3, with design information improved to include details of dimensions and processes of each specialist object, and management information added to the construction process, such as progress, quality, safety, environmental protection, interchange asset information, and maintenance information.	Operation and maintenance stage

The geometric fineness level of the model corresponding to each engineering stage in the figure is only the minimum requirement.

5. Creation of a BIM Component Library for Interchanges

The BIM component library is an important part of the standardization of BIM models for interchanges. The creation of a BIM component library should first ensure that the components are classified in an orderly manner and that each category has a unique identifier. Secondly, the BIM components created by different people have a personal touch, so the information contained in the BIM components should also be standardized. The classification and coding of BIM components and the study of information depth levels all contribute to the creation of a BIM component library for interchanges.

5.1. The Process of Creating a Component Library

The BIM component library integrates the results of interchange BIM component standardization, facilitates the invocation of interchange standardized BIM components, enables digital delivery of the results, and is an important resource and tool for interchange BIM forward design work. As a complex project, the interchange contains a wide range of disciplines and therefore a wide variety of BIM components. First, scientific and reasonable classification of interchange BIM components is required, followed by the production of BIM components according to the model level, and finally, a strict audit. Thus, it can be concluded that the process of creating the interchange BIM component library should include five steps: overall planning, standard determination, component production, component audit, and component library application [31], as shown in Figure 4.

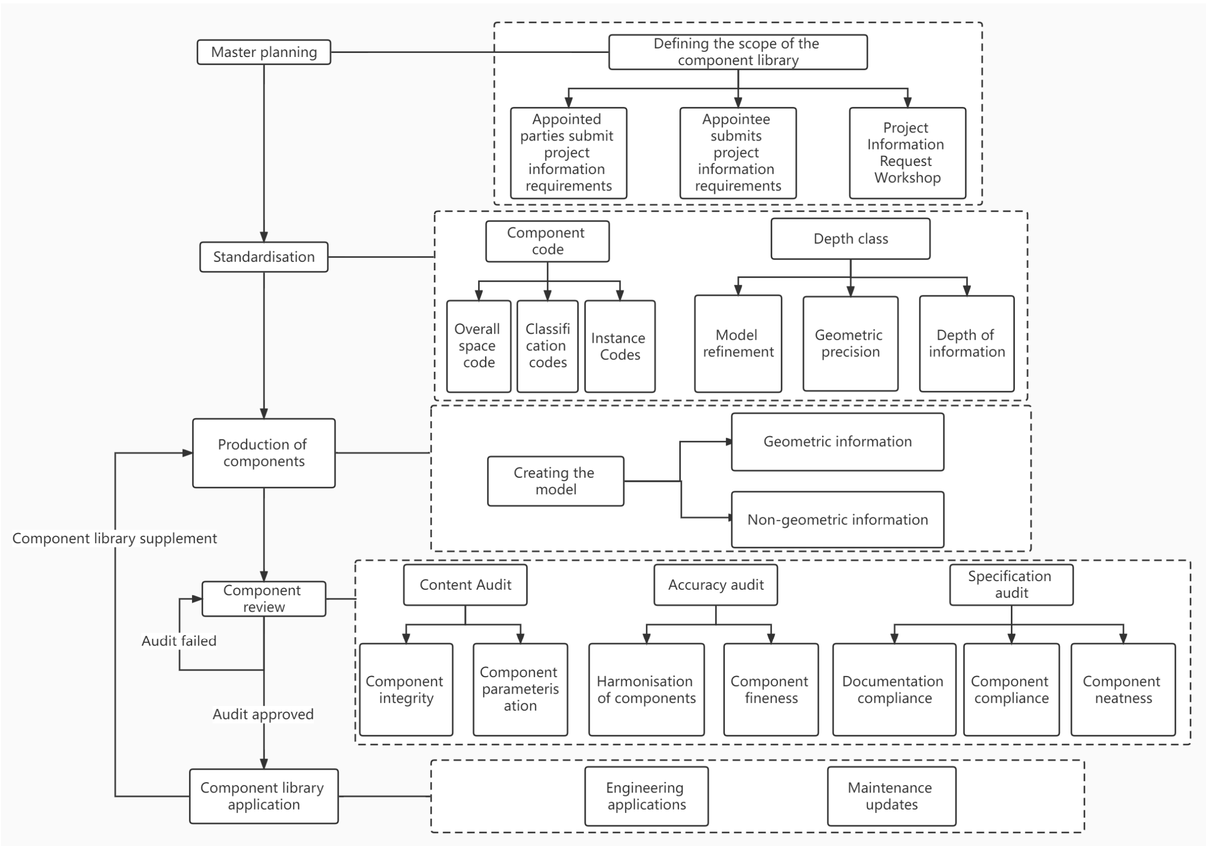

Figure 4. The process of creating interchange BIM libraries.

1. General Planning

As an important part of highway engineering, the interchange has the characteristics of wide topography and many professions involved in highway engineering. BIM component library should be created firstly by the appointed party and the appointed party to submit the project information requirements, carry out a project information seminar, and determine the BIM components needed in the library and the specifications to be met after the overall planning of the project, to facilitate the comprehensiveness and standardization of the content of the BIM component library later.

2. Standard determination

The content and format of BIM components need to be standardized to facilitate the effective management of BIM components at a later stage. To improve the efficiency of management at a later stage, the BIM components of different projects, sections, and stages of interchanges need to be classified and coded in a standardized way. To improve the standardization of model creation, it is necessary to determine whether the depth of the model meets the requirements.

3. Component fabrication

The BIM model should be created in the appropriate BIM software platform, and the geometric and non-geometric information should be added to the BIM model according to the research results of the coding and information depth levels applied at different stages.

4. Component audit

The content of the composition audit includes three aspects: content audit, accuracy audit, and specification audit. The audit shall be jointly participated by the appointing party and the appointed party, and each party shall assign experienced professionals to check. The components that pass the audit shall be synchronized in the component library for retrieval and download; the audit results and modification opinions shall be given if they do not pass the audit, and the appointed party shall modify and add geometric and non-geometric information of the model according to the opinions. After completing the modification, submit the component again for review until the component passes the review.

5. Component library applications

The component library application includes two aspects: management and maintenance. Management means that the interchange BIM component library should be applied during the whole life cycle of design, construction, operation, and maintenance. As the project phase progresses, the management can submit the component library replenishment requirements to the appointed party and re-enter the component production and component review process at different decision points to improve the component library according to the project requirements. During the application period, the component library should be maintained and updated in real-time to meet the requirement of timeliness in the standardization work.

5.2. The Significance of Creating a Component Library

The creation of a BIM component library for interchange interchanges is of great significance to the standardization of components, which is reflected in the following three aspects.

1. Standardization of BIM components for interchanges is a process that includes several elements, such as component classification and coding and component information depth levels. The interchange BIM component library is an important carrier for the application of interchange BIM component standardization results to actual projects.
2. The interchange BIM component library is the final product of interchange standardization. It integrates all types of BIM components from the standardization process of interchange BIM components and enables a high degree of sharing and reuse during the whole life cycle of interchange design, construction, operation, and maintenance so that the advantages of the standardization work can be fully utilized.
3. The creation of the interchange BIM component library facilitates the management of BIM components, which is important for maintaining, updating, and improving the standardized results of interchange BIM components.

6. Example Applications

To visually demonstrate the results of interchange BIM component standardization, the classification and coding of interchange BIM components, the information depth level, and the specific application of the BIM component library are introduced, respectively.

6.1. Application of Classification and Coding

The BIM components for interchanges are classified into two categories: general components and special components for interchanges, as there are many different disciplines involved. In the process of classification and coding, the classification and coding system for common components is more complete, and some of them have already formed the relevant specification standards, which can be directly referenced, while the special components can continue to be written in the specification. Combining the characteristics of interchanges, the classification and coding of special components for interchanges could be completed, and the results are shown in Table 6.

Table 6. Classification and coding of special components for interchanges.

Code	Class	Code	Class
18-08.00.00.00	Interchange	18-08.03.00.00	Auxiliary lane components
18-08.01.00.00	Ramp components	18-08.03.01.00	Combined flow connection components
18-08.01.01.00	Directional ramp components	18-08.03.01.01	Single entry double exit components
18-08.01.02.00	Semi-directional ramp elements	18-08.03.02.00	Increase or decrease in the number of basic lanes
18-08.01.03.00	Loop ramp components	18-08.03.02.01	Basic lane increase
18-08.02.00.00	Variable speed lane components	18-08.04.00.00	Collector lane components
18-08.02.01.00	Acceleration lane elements	18-08.05.00.00	Interweaving zone elements
18-08.02.01.01	Single lane parallel elements	18-08.06.00.00	Nose construction elements
18-08.02.02.00	Reduced lane members	18-08.06.01.00	Diversion nose members
18-08.02.02.01	Single lane exit	18-08.06.02.00	Combined flow nose elements

This table is a preliminary layered coding table for the interchange-specific parts, while the overall space coding table should be coded according to the actual project and the example code table should be coded according to the project-specific components.

6.2. Application of Information Depth Levels

The information depth level of interchange BIM components is mainly used to ensure the integrity, continuity, and appropriateness of BIM component information in different design stages. The design and construction process of interchanges generally includes the design stage, construction stage, operation stage, maintenance stage, etc. The requirements of the BIM component information depth level are shown in Table 7 [32].

Table 7. Modeling level of BIM components at different stages.

Stage		Model Fineness Level	Model Geometric Fineness Level	Model Information Depth Level
Design stage	Engineering stage	LOD1.0	$\geq$G1	$\geq$N1
	Preliminary design stage	LOD2.0	$\geq$G2	$\geq$N2
	Construction design stage	LOD3.0	$\geq$G2	$\geq$N3
Construction phase		LOD4.0	$\geq$G3	$\geq$N3
Operation and maintenance stage		LOD4.0	$\geq$G3	$\geq$N4

The geometric fineness level of the model should be increased by one level if dimensions are to be measured.

With the depth level of the interchange and the BIM components combined with the main points of the interchange design, the depth level information of the interchange BIM components can be derived. The information of the model can be mainly divided into identification information, dimensional information, location information, and technical information, which meets the requirements in Tables 8 and 9.

6.3. Application of Component Libraries

The interchange BIM component library was applied to the interchange design, and the design results are shown schematically in Figure 5, with details of the interchange BIM components involved in the figure shown in Table 10.

Table 8. Level of interchange BIM components' general information.

Property Group	Property Name	Type	Unit	LOD1.0	LOD2.0	LOD3.0	LOD4.0	Remarks
Signage Information	Name of interchange	Text		△	▲	▲	▲	e.g., Interchange No. 1
	Classification code	Text		△	▲	▲	▲	
Location Information	Interchange Start point stake	Text		○	△	▲	▲	e.g., K1+000
	Interchange Start point coordinates	Text		○	△	▲	▲	x, y, z
	Interchange Endpoint stake	Text		○	△	▲	▲	e.g., K2+000
	Intersection Endpoint coordinates	Text		○	△	▲	▲	x, y, z
Dimension Information	Angle of intersection	Numerical value	°	○	△	▲	▲	
	The total length of the ramp	Numerical value	m	○	△	▲	▲	
	Land area	Numerical value	mu	○	○	△	△	
Technical Information	The total amount of fill	Numerical value	m^3	-	△	▲	▲	
	Total excavation quantity	Numerical value		-	△	▲	▲	
	Interchange classification	Text		○	△	▲	▲	General, junction
	Form of intersection	Text		○	△	▲	▲	e.g., trumpet-shaped
	Span relationship	Text		○	△	▲	▲	Mainline up span, mainline down through
				……				

"▲" in the table means "this attribute should be included under normal circumstances"; "△" means "this attribute is recommended to be included when conditions permit "; "○" means "this attribute can be included when conditions are available"; "-" means "this attribute may not be included".

Table 9. Level of interchange BIM components' unique information.

Name of Component	Property Group	Property Name	Type	Unit	LOD1.0	LOD2.0	LOD3.0	LOD4.0	Remarks
Ramp	Signage Information	Classification code	Text		-	○	△	▲	
	Location Information	Start stake number	Text		○	△	▲	▲	e.g., K0+215
		Start coordinates	Text		○	△	▲	▲	x, y, z
		Finish stake	Text		○	△	▲	▲	e.g., K0+452
		End point coordinates	Text		○	△	▲	▲	x, y, z
	Size information	Ramp widths	Numerical value	m	○	△	▲	▲	
		Ramp length	Numerical value	m	○	△	▲	▲	
	Technical information	Cross-sectional form	Text		△	▲	▲	▲	e.g., single lane in one direction
		Design speed	Numerical value	km/h	△	▲	▲	▲	

Table 9. *Cont.*

Name of Component	Property Group	Property Name	Type	Unit	LOD1.0	LOD2.0	LOD3.0	LOD4.0	Remarks
Variable speed lanes	Signage Information	Classification code	Text		-	○	△	▲	
	Location Information	Start stake number	Text		○	△	▲	▲	
		Start coordinates	Text		○	△	▲	▲	
		Finish stake	Text		○	△	▲	▲	
		End point coordinates	Text		○	△	▲	▲	
	Size information	Variable speed lane length	Numerical value	m	△	▲	▲	▲	
		Fade section length	Numerical value	m	△	▲	▲	▲	
		Fade rate	Numerical value	1/m	△	▲	▲	▲	
	Technical information	Lane type	Text		△	▲	▲	▲	e.g., acceleration lane, deceleration lane
……									

The meaning of "▲", "△", "○" and "-" in the table are the same as in Table 8.

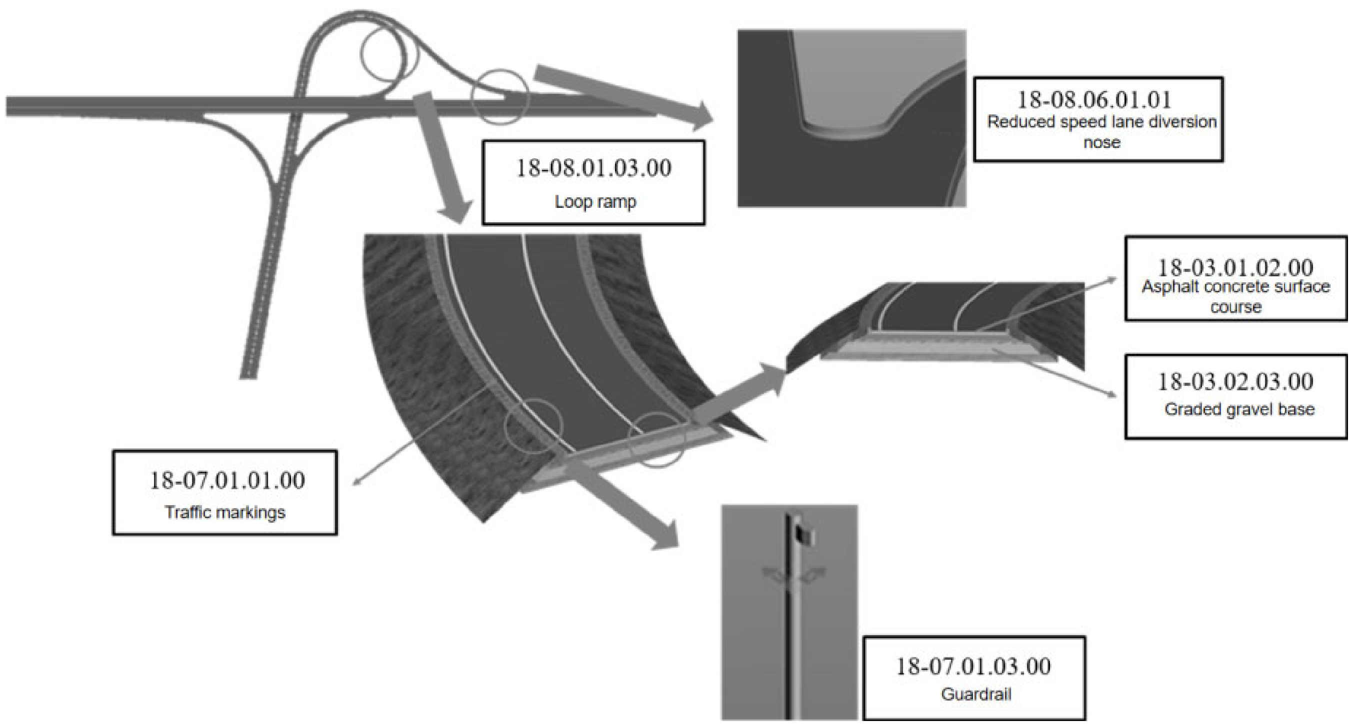

Figure 5. Design results using the BIM components library.

Table 10. Quantities of interchange BIM components.

Component Code	Component Name	Component Type	Component Location	Quantity
18-08.01.03.00	Ring ramp	Interchange-specific component ramp component	XX interchange Ramp B	1 pc
18-08.06.01.01	Reduced speed lane diversion nose-end	Interchange special component nose-end component	AK0+125/ CK0+125	2 pcs
18-03.01.02.00	Asphalt concrete surfacing	General component pavement elements	Ramp A/Ramp B/ Ramp C/Ramp D	2520 m^3
18-03.02.03.00	Graded gravel subgrade	General purpose component pavement elements	Ramp A/Ramp B/ Ramp C/Ramp D	2520 m^3
18-07.01.01.00	Traffic markings	General purpose traffic engineering and alignment components	Ramp A/Ramp B/ Ramp C/Ramp D	503 m^2
18-07.01.03.00	Guardrail	General purpose traffic works and facilities along the route	Ramp A/Ramp B/ Ramp C/Ramp D	717 m
……				

7. Conclusions

This paper takes interchange as the object, and through the study of the existing related standards and literature, the following milestones of BIM model standardization methods and applications are obtained.

1. From the characteristics of BIM components and interchanges, this paper proposed the concept of standardization of BIM components for interchanges and discusses how the main contents of the standardization of BIM components for interchange should include the classification and coding of BIM components, the model depth classification of BIM components, and the creation of a BIM component library.
2. The principles and methods of classifying and coding BIM components for interchanges were determined, and the "Classification and Coding Table for Interchange Specialized Components" was developed.
3. The process of creating a BIM component library for an interchange should include five steps: overall planning, standard determination, component production, component library operation, and component library application.
4. This paper mainly studied the standardization of interchange BIM components at the theoretical level, produced some interchange BIM components, and initially established the framework of the interchange BIM component library. A complete interchange BIM component library has not yet been established but will be gradually improved by future studies.
5. The findings of this paper clarify the various tasks involved in carrying out the standardization of BIM components for interchange interchanges and open up new ideas for the standardization of BIM component processing. It also illustrates the feasibility of this standardization approach, using the construction of an interchange component library in China as an example, which can be replicated in the design of interchanges in various countries. A foundation is laid for the application of BIM technology to interchanges and the improvement of relevant BIM standard specifications.

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