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Research Article

Application Study on Building Information Model (BIM) Standardization of Chinese Engineering Breakdown Structure (EBS) Coding in Life Cycle Management Processes

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The successful adoption of building information modelling (BIM) technology has led to an ever-increasing need for improving management practices in both construction and operation stages of highway project engineering. The most significant aspect of applying BIM technology is establishing the rationality and concise engineering breakdown structure (EBS) coding. However, China has no uniform EBS coding standard for highways, which limits BIM technology development in different construction projects and at different stages of the same construction project. The purpose of this study is to propose an EBS standard that embodies a coding system for highways and at the same time meets the requirements of BIM management, project management (PM), and operation management (OM) in life cycle management process. This paper presents an EBS standard based on three classifications: (1) project-level construction, (2) project-level operation, and (3) network-level operation. A case study is given to illustrate the proposed EBS standard's coding system. The new EBS system will have better adaptability in both the design and construction stages. The proposed EBS coding system has been applied in many projects and is undergoing both improvement and standardization in China. The presented EBS coding standard provides successful implementation references for the future adoption and use of BIM on PM and OM in highway projects.

1. Introduction

More and more highway projects apply BIM to improve the effectiveness and production efficiency of life cycle design and management [1, 2]. In China, many engineers use BIM to improve highway project management including design, construction, and operation. Its popularity is especially noticeable in its application to long-span bridges [3, 4]. BIM extends traditional building design beyond 2D technical drawings and beyond 3D modelling by adding 3D with time as 4D modelling and by adding cost as 5D modelling [5]. Therefore, BIM includes more than just 3D geometry. It also covers spatial relationships, geographic information, quantities, and properties of building components [6]. 4D modelling includes project management information in life cycle processes, such as quality, cost, and risk management in the construction stage as well as maintenance management in the operation stage [7, 8]. 5D augmented cost management improves the level of life cycle management [9, 10]. Manager priorities are less cost and high quality in both the construction and operation stages [11]. At the same time, the implementation of the BIM technique must consider the factors relating to 4D to improve the quality of project management and consider the factors relating to 5D to reduce the cost while ensuring project quality.

Some useful attempts at applying BIM technology to life cycle management can be found in the results of related literature research [12, 13]. Typical applications include conceptual design optimization, detailed design optimization, construction quality management, construction scheduling management, risk management, and maintenance interval management [14, 15]. Liu et al. [16] used a case study involving a long-span steel-box arch bridge project to demonstrate the effectiveness of the BIM-aided approach in the design and construction stages. Wei et al. [17] proposed a BIM-based method for calculating the auxiliary materials required for housing construction. Donato [18] extracted spatial relationships from a BIM, used them to assemble a topology graph, and then imported them into numerical analysis software to calculate numerical values through a customized tool. In the construction stage, Shalabi and Turkan [19] developed and validated implementing industry foundation classes (IFC) in BIM to link and present alarms reported by facility management (FM) systems. Chong et al. [20] analysed and compared the adoption and use of BIM in infrastructure projects, particularly in constructing major road projects in Australia and People's Republic of China. They discussed road design and planning simulation, web-based interface for the BIM, integration of BIM with geographic information system (GIS), construction progress tracking and updating the BIM, integration of BIM and laser scanning, and 3D model printing. Kim and Cho [21] proposed a geometric reasoning system that analyses geometric information in building designs, derives construction-specific spatial information, and uses the information to assist in construction planning. Kosandiak and Atkin [22] reported a new code of practice on how to reinforce the links between design, delivery, and operation of infrastructure assets through BIM. Wetzel and Thabet [23] presented a BIM-based framework to support safe maintenance and repair practices during the FM phase, through safety attribute identification, data processing, and rule-based decision-making, as well as a user interface. Kang and Hong [24] proposed software architecture for the effective integration of BIM into a GIS based FM system. Lin and Su [25] proposed a BIM-based facility maintenance management system for maintenance staff in the operation and maintenance phase.

To achieve quality management, risk management, and cost management, each component of a 3D model should be managed effectively with a unique ID in the computer [26–28]. Current BIM software is used by individuals, businesses, and government agencies who plan, design, construct, operate, and maintain highway facilities. The significant character of BIM software is that the BIM must carry each model's geometry, relations, and attributes. Each model element's attributes can be selected and ordered automatically and are used for quality management as well as cost control. The effective BIM codes must be defined to avoid confusion in life cycle management.

In USA, Construction Operations Building Information Exchange (COBie) was approved by the US-based National Institute of Building Sciences as part of BIM standard in December 2011. It is closely associated with BIM approaches to design, construct, and manage built assets, and it has been incorporated into related software. COBie documentation together with BIM implementation promotes an opportunity for improved data handover for facilities managers and building owners [29]. Research findings reveal that further development of COBie is required to mitigate software inflexibility and augment automation of semantic data transfer, storage, and analysis. Future work will validate the Application Programming Interface (API) plug in via user experience and integrate additional databases such as post-occupancy evaluations (POE) [14]. In fact, using an engineering breakdown structure (EBS) is an effective approach to operating the BIM in life cycle management processes. Almost all highway construction projects in China have used BIM technology since 2014 to manage the construction and operation processes. BIM technology is applied by government, institutes, design institutes, and consulting companies in different provinces and regions. Therefore, no consistent EBS coding standard exists; several BIM management systems are incompatible. When different EBS coding data and information are applied in different projects, they cannot be shared. This is contrary to the original intention of BIM technology application. A complete Chinese EBS coding system applicable to all cities and provinces is urgently needed in China. Researching and creating this complete EBS coding system is the purpose of this study.

To operate the BIM effectively, the most significant work is establishing the rationality and concise EBS coding. Furthermore, in different construction projects and at different stages of the same construction project, it is important to operate the BIM and transfer information in life cycle management processes. Therefore, a uniform EBS coding standard used for BIM management, project management, and operation management in life cycle management process of highways is needed urgently. This paper presents a new and complete EBS coding standard system with three classifications: (1) project-level construction, (2) project-level operation, and (3) network-level operation. The application practices of many BIM technology projects of the authors' institute provided a useful reference for the formulation of standards. For different stages and different projects, the encoding structure needs to be adjusted. An overview of the EBS coding standard system is shown in Table 1.

The first EBS coding classification has eight coding districts represented by numbers or letters. It is suitable for BIM management and construction project management in both the design and construction stages. The second EBS coding classification adds maintenance work behind the first EBS coding classification due to its use in the operation stage. The third EBS coding classification adds the naming and numbering of highway network before the second EBS coding classification since it is suitable for network-level work in the operation stage. The basic flowchart for EBS coding of standards is shown in Figure 1. The use of the EBS coding standard in many projects demonstrated an increase in effectiveness and production efficiency due to BIM technology. Those results were further confirmed by many BIM project practices that were based on the new EBS coding standard requirements.

Table 1: EBS coding standard system.

Classification	Purpose	Level	Stage
First	BIM management and project management (PM)	Project	Construction
Second	BIM management and operation management (OM)	Project	Operation
Third	BIM management and operation management (OM)	Network	Operation

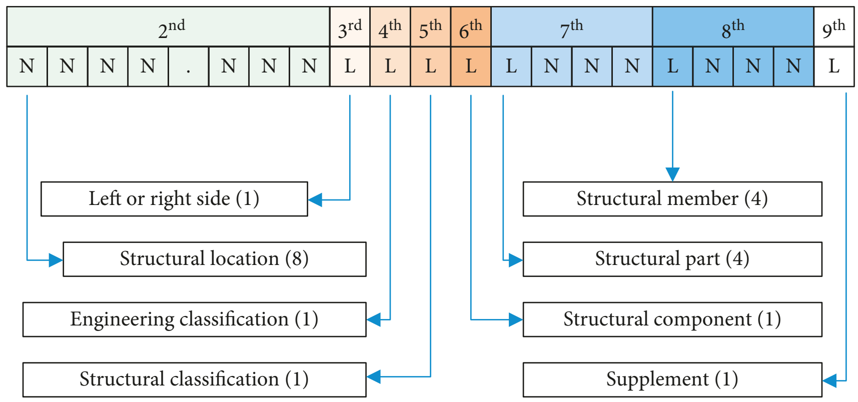

Figure 1: The basic flowchart for EBS coding of standards. Top row 2nd–9th districts are labelled according to letter or number. L refers to abbreviation of "letter" (from A to Z). N refers to abbreviation of "number" (from 0 to 9). The description of breakdown of structure components: structural location, left or right side, engineering classification, and characteristics pertaining to structures.

2. EBS Coding System Standard

2.1. The Structure of the EBS Coding System. The application of BIM technology goes beyond the planning, design, and construction stages of the project, extending throughout the highway facility life cycle, supporting processes such as cost management [30], construction management [31], PM, and facility operation [32, 33]. Several data transfers occur throughout the different stages, e.g., from the design stage to the construction stage and from the construction stage to the operation stage. The significant data transferred not only include the 3D BIM but also the EBS coding of BIM members. The 3D-BIM member can represent the construction project management media or the operation management media. BIM members must be effectively managed; therefore, a unique code is assigned to each BIM member. EBS coding plays this vital role in the BIM technology process.

As a significant BIM database, EBS can be used to manage the 3-D BIM in both the construction stage and operation stage. Moreover, the project management (PM) and operation management (OM) for highways can be realized by using EBS coding directly. In the construction stage, work breakdown structure (WBS) coding besides being used to describe the work of a project is also used as a basis for estimating and reporting costs, allocating manpower and scheduling tasks [34]. Actually, WBS coding are applied to PM in the construction stage but not applied to OM in the operation stage. In order to achieve life cycle management using BIM technology, the effective approach for carrying out project management is that EBS coding is mapping WBS coding in the construction stage. EBS extends the life cycle management of facilities including roads, bridges, tunnels, intersection of routes, traffic interchanges, traffic engineering, roadside facilities, environmental conservation areas, and mechanical equipment. The life cycle management not only refers to BIM management but also relates to PM in the construction stage and OM in the operation stage. Therefore, the EBS coding standard system was established according to different purposes, levels, and stages. The author proposes a new EBS coding standard system for life cycle highway management. There are three EBS coding standard classifications: purpose, level, and stage, as shown in Table 1.

2.2. The Basic Structure of EBS Coding Standard. We define the first classification as the basic structure of the EBS coding standard, and the second and third classifications are expanded from its basic structure. Several factors such as the structural location, left or right side, engineering classification, structural classification, structural component, structural part, and structural member are considered in the basic structure of EBS coding standard. The objective of EBS coding is twofold: (1) to create a unique ID for managing the BIM member in the life cycle analysis and (2) to provide object for PM during life cycle management. Therefore, the final EBS coding standard needs to have some significant characteristics, such as uniqueness and functional information. The goal was to make it as simple as possible.

There are eight districts in the basic structure of EBS coding standard which define eight districts, beginning with the second district and ending with the ninth district. In each district, specific meanings are given to each letter or numbers. The second district defines the structural location through 8 numbers. We recommend the location be denoted by hub stakes, such as bridge and tunnel hub stakes, or main body of the road hub stake. The third district denotes that this EBS coding denoted structure is located on the left or right side. L denotes the left side, R denotes the right side, and N denotes the whole structure without reference to either left or right side. The fourth district denotes engineering classification such as main body of road (thoroughfare), surface, bridge, tunnel, intersection of routes, traffic interchange, and traffic engineering. The detailed rule of the fourth district EBS coding is shown in Table 2.

The fifth district coding denotes structural classification according to the engineering classification. For example, if the fourth district EBS coding is C which denotes a bridge, we can designate the type of bridge as a beam bridge, cable-stayed bridge, suspension bridge, or arch bridge in the fifth district. Due to the EBS coding emphasis on life cycle management, a reasonable account of the decomposition in structural components is required, which can also be defined as key problems in either the construction or operation stage. Typical EBS coding rules pertaining to the main body of the road, surfaces, and bridges are shown in Tables 3–5.

These EBS coding illustrated in Tables 3–5 are based on many current standards such as "Technical Standard of Highway Engineering" [35], "Standards for Technical Condition Evaluation of Highway Bridges" [36], and "Code for Maintenance of Highway Bridge and Culverts" [37]. Such EBS coding structure is convenient for project management in the construction stage and maintenance management in the operation stage. The ninth district of EBS coding refers to supplemental information when it is needed to support external information such as structural location or structural classification and to distinguish duplicate EBS coding. The ninth district code is optional. If no supplemental information is needed, the ninth district should be replaced by the pound sign, "#."

From the above introduction, the basic EBS coding for structures is established. This classification of EBS coding is used for PM in the construction stage of the project level. This type of EBS coding is becoming more popular and successful.

2.3. EBS Coding System Standard and Life Cycle Management in BIM. Life cycle management relates to design, construction, and operation stages. The solutions addressing life cycle management are different in each stage. The design stage focuses on an optimized design plan, the construction stage focuses on quality and risk management, and the operation stage focuses on maintenance and reinforcement management. We need to establish the different EBS coding standard in different stages. At the same time, the EBS coding in different stages should have connections that can show how planned solutions relate to each other. For this purpose, we proposed life cycle EBS coding system as is shown in Table 1. The second and the third classifications of EBS coding standards are based on the basic structure of EBS coding and are introduced as follows.

Figure 2 illustrates the application process of EBS coding in life cycle management. Generally, the BIM is built in the design stage or in the construction stage with commercial software. Once a BIM is obtained, many BIM technology applications such as drawing review, engineering quantity accounting, construction simulation, and construction planning can be implemented. Clearly, these applications are based on the 3D model and are not related to BIM project management, so at this point, the EBS coding is not necessary. To apply the collaborative management platform, EBS coding must be correlated with the BIM. Based on EBS coding, the project collaborative management platform is developed. The functions of this platform include quality management, schedule management, risk management, measurement-based payment, personnel management, and equipment supplies management. These functions are dependent on the EBS coding system, not only in the construction stage but also in the operation stage.

Table 2: Rules of the 4th district EBS coding.

Engineering classification	Coding
Main body of road	A
Surface	B
Bridge	C
Tunnel	D
Intersection of routes	E
Traffic interchange	F
Traffic engineering	G
Roadside facilities	H
Environmental conservation	I
Mechanical equipment	J
Other engineering	K

For this purpose, we established a three-classification EBS coding system. The first classification is illustrated above. Because the second classification of EBS coding is used for BIM management and maintenance management in the operation stage, maintenance work is added based on the first classification of EBS coding. We recommend making the following improvements according to the first classification of EBS coding: (1) add standard maintenance work to the tenth district and (2) modify the second district by converting it to an operation hub stake. This modification allows for the differences in the construction hub stake and operation hub stake. The details of the second classification of the EBS coding of a standard structure are shown in Figure 3.

Table 1 demonstrates that the third classification of EBS coding is used for network level of highway operation. Therefore, we should obtain the third classification of EBS coding based on improving the second classification of EBS coding. Naming and numbering of the highway is added in the third classification of the EBS coding. The details of naming and numbering rules are shown in Table 6. The flowchart of EBS coding for a third classification of EBS structure are shown in Figure 4.

3. Case Study

3.1. Engineering Background. Ou River Estuary Bridge is the first large bridge in China with three towers and a four-span suspension bridge. The main span is composed of four spans, 230, 800, 800, and 348 m, the north approach span is the box beam bridge with a length of 3,219 m, and the south approach span is the box beam bridge with a length of 2,603 m.

Table 3: Main body of road EBS coding (from the 5th to 8th district).

The 5th district		The 6th district		The 7th district		The 8th district	
Structural classification	Coding	Structural component	Coding	Structural part	Coding	Structural member	Coding
Subgrade structure	A	Roadbed	A	No breakdown structure	N###	No breakdown structure	N###
		Embankment	B				
		Subsoil	C				
		Soil improvement	D				
Verge	B	Soil surfaced road	A				
		Hard shoulder	B				
Side slope	C	Fill slope	A				
		Cut slope	B				
		Plain stage of slope	C				
		Berm	D				
Lane separator	D	Plants	A				
		Curbstone	B				
		Water draining	C				
Water draining system	E	Side drain	A				
		Water-diversion ditch	B				
		Cut-off ditch	C				
		Chute drop	D				
Road embankment wall	F	Wall	A				
		Basement	B				
		Shrinkage and tension joint	C				
		Drain hole	D				
Cut slope wall	G	Wall	A				
		Basement	B				
		Shrinkage and tension joint	C				
		Drain hole	D				
Road shoulder wall	H	Wall	A				
		Basement	B				
		Shrinkage and tension joint	C				
		Drain hole	D				

Both the main body of the roads and surfaces in the seventh and eighth districts are empty due to structural simplicity. In such circumstances, we should use the letter and pound sign "N###" to indicate that the EBS coding is complete.

Table 4: Surface EBS Coding (from the 5th–8th district).

The 5th district		The 6th district		The 7th district		The 8th district	
Structural classification	Coding	Structural component	Coding	Structural part	Coding	Structural member	Coding
Surface course	A	Asphalt pavement	A	No breakdown structure	N###	No breakdown structure	N###
		Cement concrete pavement	B				
		Sand-gravel surface	C				
		Block pavement	D				
Base course	B	Cement-modified aggregate	A				
		Cement-stabilized soil	B				
		Soil-lime-fly ash	C				
		Lime-fly ash mixture	D				
		Cement-bound granular materials	E				
Bed course	C	Sand gravel	A				
		Cement-stabilized soil	B				
		Soil-lime-fly ash	C				
		Lime-stabilized soil	D				
		Cement-stabilized soil	E				

Table 5: Bridge EBS coding (from the 5th–8th district).

The 5th district		The 6th district		The 7th district		The 8th district	
Structural classification	Coding	Structural component	Coding	Structural part	Coding	Structural member	Coding
Beam bridge	A	Substructure	A	Pier	ANNN	Pier shaft	ANNN
						Tie beam	BNNN
						Pile cap	CNNN
						Cover beam	DNNN
						Check block	ENNN
						Spacer	FNNN
				Abutment	BNNN	Abutment capping	ANNN
						Abutment shaft	BNNN
				Bridge foundation	CNNN	Pile foundation	ANNN
						Open caisson foundation	BNNN
		Superstructure	B	Bearing structure	ANNN	Trapezoidal girder	ANNN
						Box girder	BNNN
						Concrete slab	CNNN
						Hollow slab	DNNN
						Steel truss	ENNN
						Steel beam	FNNN
						Cast-in-situ structure	GNNN
				General structure	BNNN	Diaphragm	ANNN
						Wet joint	BNNN
		Bridge deck system	C	Bridge deck pavement	ANNN	Concrete	ANNN
						Asphalt concrete	BNNN
						Waterproof layer	CNNN
				Shrinkage and tension joint	BNNN	No breakdown structure	N###
				Strapped joint	CNNN		
				Sidewalk	DNNN		
				Balustrade	ENNN		
				Drainage system	FNNN		
				Illumination	GNNN		
Cable stayed bridge	B	Reference beam bridge coding standard					
Suspension bridge	C	Reference beam bridge coding standard					
Arch bridge	D	Reference beam bridge coding standard					
Culvert	E	Reference beam bridge coding standard					

Notes: NNN denotes the serials number of structural part in the 7th district or structural member in the 8th district. It arranges from 001 to the total number of structural part or member.

BIM technology is used in its life cycle management. The BIM was built in the design stage, and a project collaborative management platform was applied during construction such as quality management, risk management, and cost management. The maintenance and management system based on BIM will be applied after completion (scheduled for 2021). Figure 5 shows the Ou River Estuary Bridge arrangement of the main span and approach span.

3.2. Application Results. According to the characteristics of Ou River Estuary Bridge, the first classification of EBS coding has been defined along with building BIM modelling at the same time. Typical EBS coding results of the Ou River Estuary main span bridge and details of two members are shown in Figure 6. The first member is a steel beam with EBS coding 0276.020RCCBA023F001#. Each district of this EBS coding has a special meaning. The first 7 digits "0276.020" denote the hub stake of the main span bridge; the third district letter "R" lets us know that this steel beam is located on the right-hand side; the fourth district letter "C" denotes the engineering bridge classification according to Table 2; the fifth district letter "C" denotes the structural classification of the suspension bridge according to Table 5; the sixth district letter "B" denotes a structural component superstructure according to Table 5. The seventh district is a letter-number set "A023" denoting a bearing structure with a number of 023 according to Table 5. The eighth "F001" district denotes a steel beam structural member with a number of 001 according to Table 5. The ninth district "#" denotes there is nothing to supply for this member's EBS coding. The EBS coding of the main span bridge pier is also demonstrated in Figure 6. Likewise, Figure 7 shows the EBS coding of the box girder and pile foundation located on the Ou River Estuary Bridge's southern approach to the span bridge. Each coding has special meanings according to proposed EBS coding standard.

This EBS coding includes more completely information that is conducive to management. The code generation and

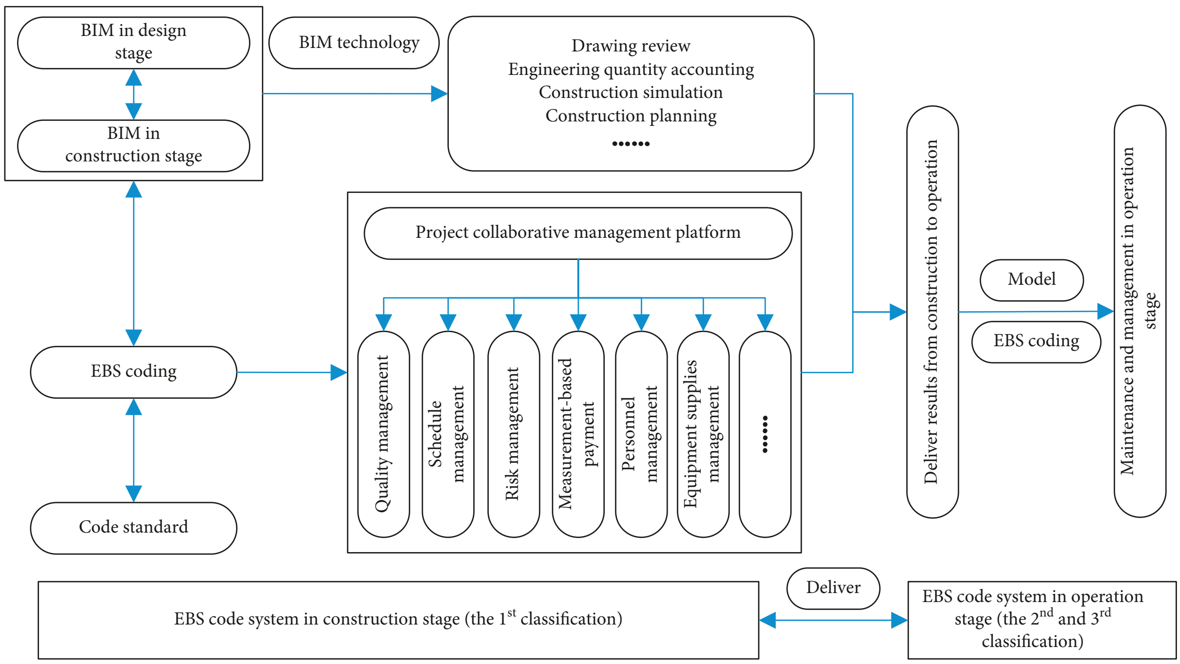

Figure 2: The application process of EBS coding.

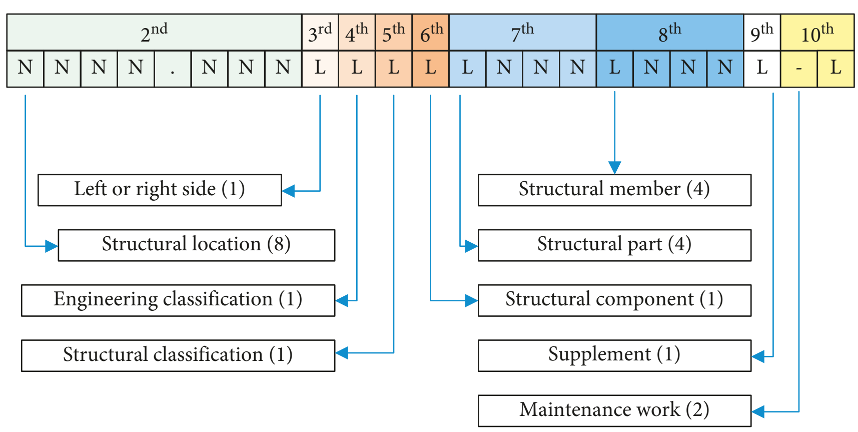

Figure 3: The second classification of EBS coding of a standard structure. Top row 2nd–10th districts are labelled according to letter or number. L refers to abbreviation of "letter" (from A to Z). N refers to abbreviation of "number" (from 0 to 9). The description of breakdown of structure components: structural location, left or right side, engineering classification, and characteristics pertaining to structures.

Table 6: The rule of naming and numbering of highway.

Level	Coding
Expressway	A
A road	B
2nd class highway	C
3rd class highway	D
4th class highway	E
Other	F

compilation in the BIM is defined in the model building process. In order to increase efficiency and accuracy, a simple conversion program is developed to use in Ou River Estuary bridge's BIM management. This conversion program is being improved to accommodate different kinds of BIM modelling software.

The EBS coding system was established to allow the EBS coding to become a part of the BIM. Based on BIM and EBS coding, the Ou River Estuary bridge project collaborative management platform is developed to achieve many functions such as quality management, schedule management, risk management, measurement-based payment, personnel management, and equipment supplies management. These functions are dependent on the EBS coding system, not only in the construction stage but also in the operation stage. The application of the Ou River Estuary Bridge when using EBS coding was well received by project management because it achieved good results.

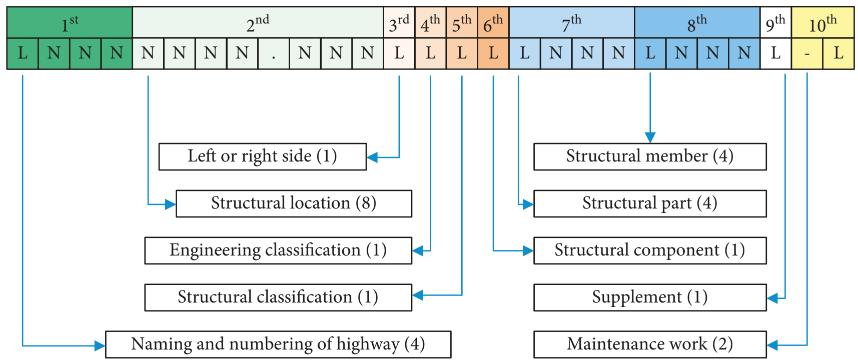

FIGURE 4: The third classification of EBS coding of a standard structure. Top row 2nd–10th districts are labelled according to letter or number. L refers to abbreviation of "letter" (from A to Z). N refers to abbreviation of "number" (from 0 to 9). The description of breakdown of structure components: structural location, left or right side, engineering classification, and characteristics pertaining to structures.

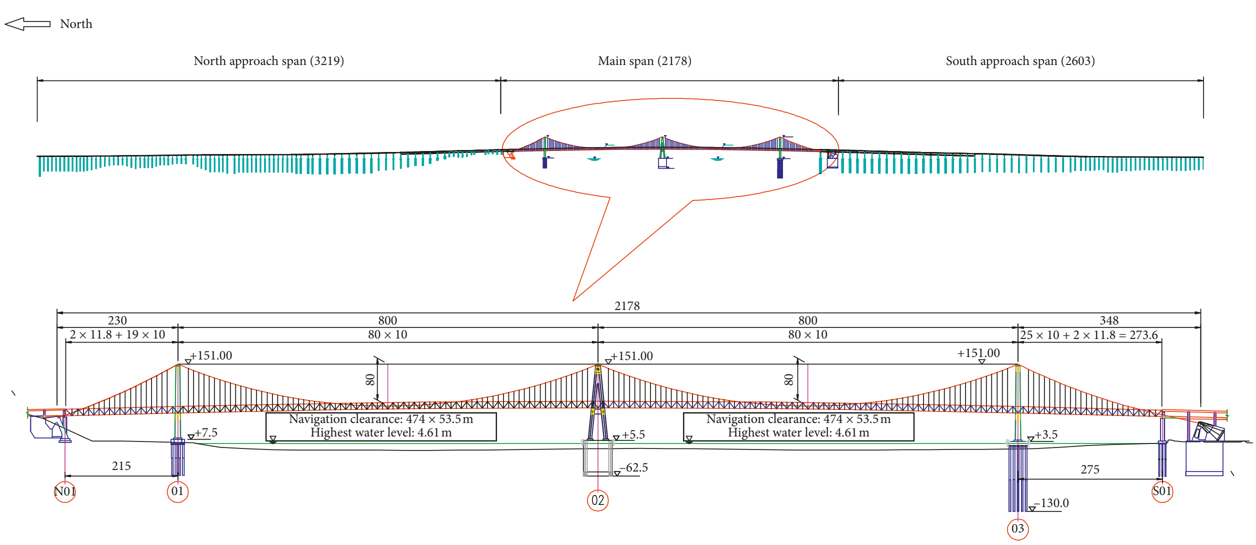

FIGURE 5: Ou River Estuary Bridge arrangement of main span and approach span (units: m).

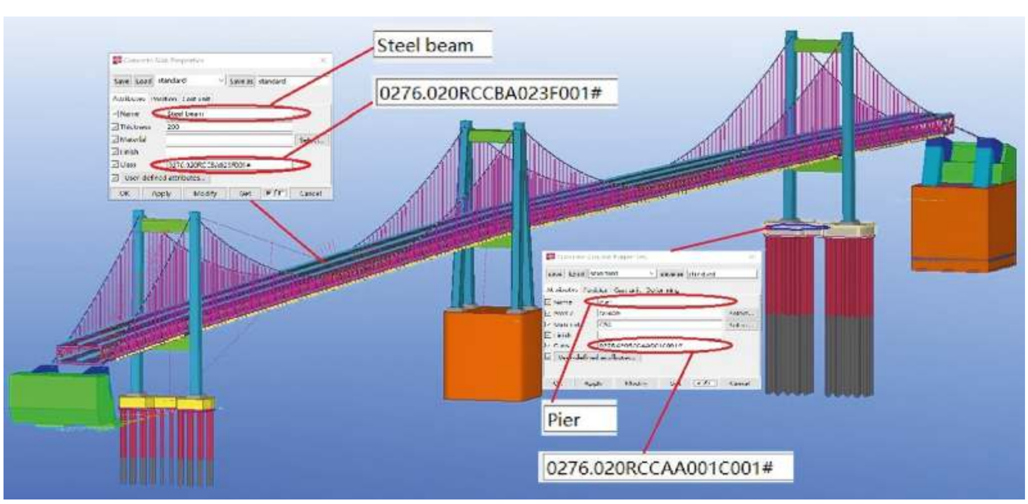

FIGURE 6: Typical EBS coding results of the Ou River Estuary main span bridge.

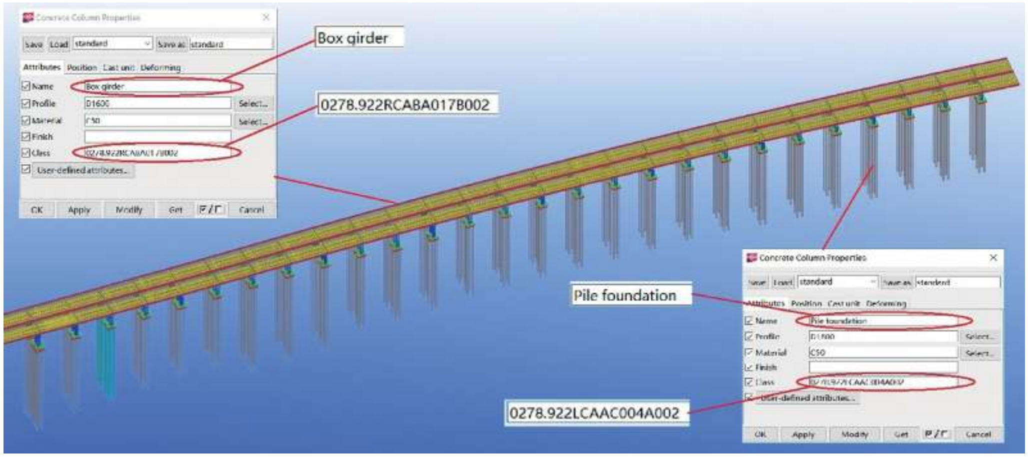

Figure 7: Typical EBS coding results of Ou River Estuary southern approach to span bridge.

4. Conclusions

This study achieved its primary task of providing an EBS standard to use as a way to provide coding for life cycle management. There are three classifications in the proposed EBS coding system that are needed to establish a BIM: management, PM, and OM. The establishment of this model led to the following conclusions.

The first EBS coding classification is suitable for BIM management and PM in the design and construction stages. This EBS coding classification includes primary information such as structural location, left or right side, engineering classification, structural classification, structural component and structural part, structural member, and supplemental information, which are found in the second to ninth districts. This is the basic EBS coding for highway structural members.

The second EBS coding classification is suitable for BIM management and OM with the project level. This EBS coding classification not only includes all the information of the first classification of EBS coding but adds maintenance works to the tenth district.

The third classification of EBS coding is used for BIM management and OM with network level in operation stage. On the basis of second classification of EBS coding, the naming and numbering of highway is added on the first district.

The rationality and concise uniform EBS coding standard is established to the benefit for the use of BIM technology on PM and OM in highway projects since significant information was transferred through EBS coding. A case study illustrates that the proposed EBS coding system plays a very significant role in the application of BIM technology. The application of many projects demonstrates that this EBS coding standard system is suitable for BIM management, PM, and OM for both project-level work and network-level work in both the construction and operation stages.

The proposed results of this study provide a useful method and an applicable approach for the use of EBS coding to manage BIM modelling as well as project-level and network-level management in life cycle management. The development and implementation of this EBS coding standard will greatly promote the application and development of BIM technology in China.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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