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The Research of BIM in the Design Stage of Precast Concrete Structures

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Abstract: This paper presents a study on the application of BIM (Building Information Modeling) technology based on CDM (Component Data Model) theory in the design stage of precast concrete structures from three aspects of standard formulation, designing by filling numbers and software development, which is used to solve the problem that IFC（Industry Foundation Classes) cannot be implemented in the traditional mode. BIM technology, with its advantages of visualization, parameterization and integration, is widely used in the full life-cycle of prefabricated buildings. Initially, this paper analyzes the disadvantages of traditional BIM technology based on IFC format, such as the defect in developing IFC plug-ins and low data interaction efficiency for the lost of a large amount of data in the model. Then the process of BIM technology based on CDM theory is introduced for the design stage of precast concrete structures and from the comparative analysis of CDM theory and IFC theory, we can find that CDM theory can break the data island in the process of project design and improve the efficiency of data interaction among each BIM software. Finally, the feasibility of the proposed technical route is verified by a practical prefabricated engineering case, and this method can be universally applied to the full life-cycle management of the project construction.

Keywords: Building Information Modeling, Industry Foundation Classes, Component Data Model, Precast Concrete Structures

1. Introduction

At present, in each stage of project construction, information exchange between BIM (Building Information Modeling) software is mainly through IFC (Industry Foundation Classes) format. However, in this mode, there are many unavoidable and difficult problems in information interaction. Such as a large amount of data in the model is lost, resulting in low data interaction efficiency, and software developers generally do not have the ability to develop IFC plug-ins. Aiming at the disadvantages of IFC format, Lai Huahui et al. [1] proposed a technology route of BIM data sharing and exchange based on IFC standards, and imported the data into SJTUBIM platform for integrated management. Wang yong et al. [2] proposed the method of automatic model transformation in architectural structure design, and studied the automatic transformation among architectural model, structural model and computational model based on IFC standard. Saeed et al. [3] believed that the current construction industry lacks industrial component standards based on BIM Technology, specific frameworks and standards need to be developed and embedded in BIM software to integrate industrial buildings with BIM. Gao Qiuya et al. [4] proposed the production information model of prefabricated components based on IFC standard, and divided the information of the prefabricated components in the production stage into product information, process information, resource information, cost information and site information. The above study has initially solved the problem of data sharing in the full life-cycle of buildings from the perspective of optimizing IFC format, but it has not fundamentally solved the difficulty in implementing IFC standards [5].

CDM (Component Data Model), was proposed by Huang

Qiang, Chairman of China BIM Union, to realize open and interoperable information exchange by establishing component database needed for engineering construction and engineering management [6]. This paper applies BIM technology based on CDM theory to the design stage of precast concrete structure, solves the problem of internal differences of IFC format files in different BIM software, breaks the data island, and truly realizes data interaction and sharing. At the same time, based on the research building of prefabricated parts production base in Chizhou, Anhui Province, this paper demonstrates the advantages of CDM technology in the design stage of precast concrete structures through the formulation of CDM standards and the development of CDM software.

2. BIM Architecture Analysis Based on IFC Standard

2.1. IFC Standard

IFC (Industry Foundation Classes) standard is an object-oriented data model standard developed by BuildingSMART. As an open specification for building information modeling (BIM), IFC aims to support data transfer and sharing among project participants in building construction and facility management [7]. It consists of data represented as an EXPRESS schema and reference data represented as an XML (Extensible Markup Language) schema [8].

2.2. Data Analysis and Transfer Under IFC Standard

Currently, there are many mainstream BIM software, both domestic and foreign, that can support IFC standard format, and can generate IFC data interchange and read imported IFC data [9]. However, in the actual project application, a large amount of information is lost when IFC files between different software are exchanged. Even if they are exported in the same software and then imported, the information is lost and the transformation is incomplete [10]. For example, IFC_{21} files passed from Software 1 to Software 2 may lose entity types, IFC_{31} files passed from Software 1 to Software 3 may lose attribute information, and Software 1 cannot pass IFC files to Software 4, etc. (Figure 1). There are many reasons, such as different classification standards at home and abroad, differences in the definition of engineering behavior description, and the fact that BIM software vendors do not make IFC interfaces according to IDM (Information Delivery Manual) standards for their own interests [11]. Therefore, in the development of IFC standards for more than 20 years, there are still many problems in the application of engineering. Under such circumstances, it is difficult for China to realize the application of BIM based on IFC model, and a large number of differentiation problems at home and abroad need to be solved [12].

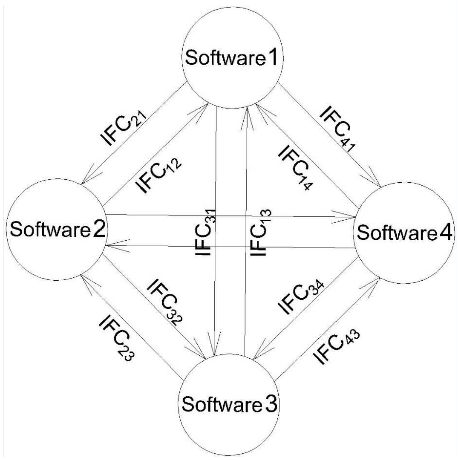


Figure 1. *Transmission method of IFC.*

2.3. IFC - BIM Disadvantages

1) At different stages of the project, information between BIM software is basically transmitted through the IFC format. However, due to the disadvantages of redundancy and information loss, the model cannot be reused in all stages of the project, and often needs to be re-modeled to continue the work, which greatly increases the repeated workload of engineering personnel.

```
IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body','Model',*,*,*,*,#65,$,.MODEL_VIE
W.,$);
#138= IFCDIRECTION((1.,0.));
#140= IFCCARTESIANPOINT((0.,0.));
#142= IFCAXIS2PLACEMENT2D(#140,#138);
#143= IFCRECTANGLEPROFILEDEF(.AREA.,'',#142,800.,800.);
#144= IFCDIRECTION((1.,0.,0.));
#146= IFCDIRECTION((0.,0.,1.));
#148= IFCCARTESIANPOINT((0.,0.,0.));
#150= IFCAXIS2PLACEMENT3D(#148,#146,#144);
#151= IFCDIRECTION((0.,0.,1.));
#153= IFCEXTRUDEDAREASOLID(#143,#150,#151,3500.);
#154= IFCSHAPEREPRESENTATION(#136,'Body','SweptSolid',(#153));
```

Figure 2. *Frame column IFC file.*

2) It is difficult for engineers to understand the complicated IFC format (Figure 2), and different software vendors have different interpretations of the IFC format, making it difficult for engineers to find and modify relevant error

information in the IFC format [13].

3) In the design phase, due to the great differences between kinds of BIM software, makes the establishment of the model often require multiple software, such as Revit, TEKLA, CATIA, and plug-ins based these software [14], which requires designers to master a large number of design software for integration design. This greatly increase the cost of software acquisition, personnel training and the difficulty of software modeling.

It can be seen that these disadvantages make it difficult to implement the BIM technology based on IFC format in engineering application.

3. BIM Architecture Analysis Based on CDM Theory

3.1. CDM Theory

CDM (Component Data Model) is Chinese BIM solution to realize BIM landing. The aim of the CDM standard is to provide the construction industry with an intermediate data standard that doses not depend on any specific software and connects the design to the operation and maintenance of the construction process, suitable for the information creation during the construction process and the information exchange during the full life-cycle of the project.

CDM parameter coding rules are composed of the form HcdmClass and HcdmNumber (Figure 3), where the HcdmClass format is AXYYY (A stands for construction project; X is the professional distinction code: 1 Foundation, 2 Structure, 3 Electrical, 4 Interior Trim, 5 Exterior Trim, etc. YYY stands for each component type). For example, A2001 stands for CDM standard of prefabricated rectangular column and A2002 stands for CDM standard of prefabricated circular column; The format of HcdmNumber is XX-FYY-ZZZ (XX represents the component category; FYY represents the floor; ZZZ represents component serial number), such as A2001-01-F12-002 stands for CDM standard for layer 12, Number2 prefabricated rectangular column with size 400×400.

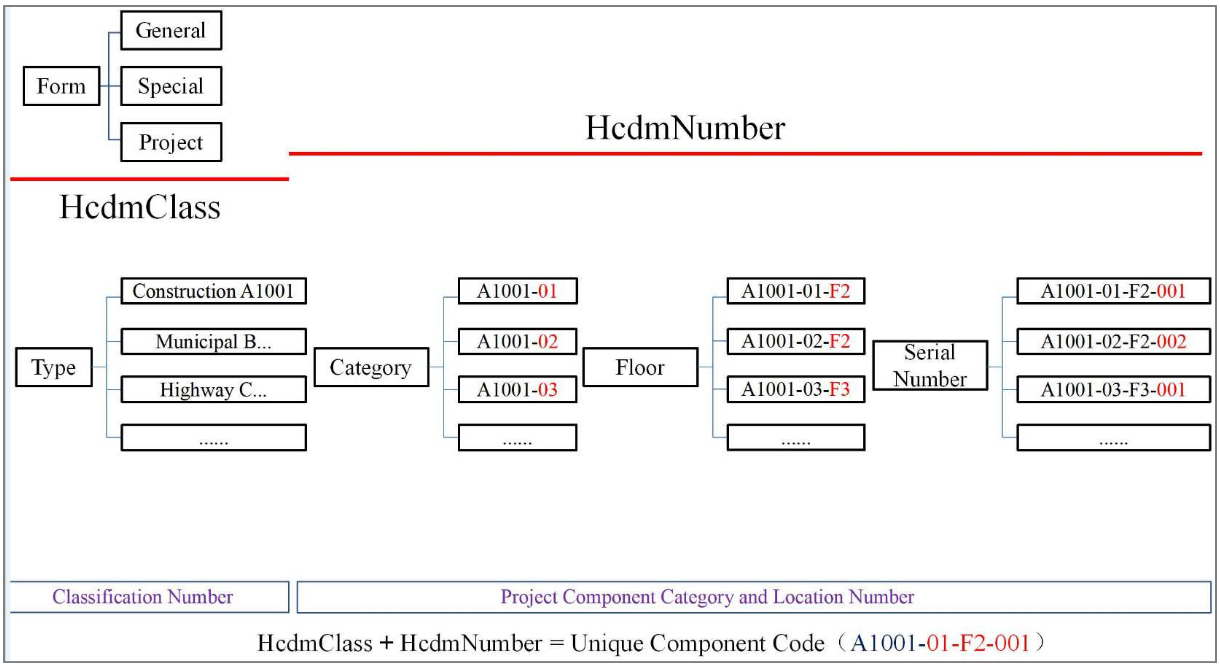


Figure 3. *CDM coding rules.*

3.2. Data Analysis and Transfer Under CDM Theory

Based on CDM theory, the data creation and interaction of the full life-cycle of the construction project only need to pass through:

1) Establish CDM standards for each component.
2) Design by filling in Numbers.
3) Develop CDM data software.
4) The CDM standard automatically forms the data model after the CDM data is read by the CDM data software.
5) Transfer CDM standards from the current phase to the next phase of the project.

3.2.1. Establish Component CDM Standards

According to the property characteristics of components and relevant provisions in the flat atlas, establishing component CDM standards. Taking CDM standard of prefabricated rectangular column in design stage as an example, the longitudinal information of standard table includes External Parameters, Coordinates and Surface Geometry Parameters, Reinforcement Relation Parameters and Reinforcement Design Parameters. And the horizontal information includes Instructions, Field coding, Field name, Unit and Field values (Figure 4-Figure 7).

Component Standard Name			Prefabricated rectangular column	
Hcdmclass			A20203	
Hcdmclass+Number				
External Parameters				
Instructions	**Field coding**	**Field name**	**Unit**	**Field values**
	KZ001	Phase	Design	
	KZ002	Delivery date	DN	
	KZ003	Principal	Name	
	KZ004	Principal	ID number	
	KZ005			

Figure 4. *External Parameters.*

Coordinates and Surface Geometry Parameters				
Instructions	**Field coding**	**Field name**	**Unit**	**Field values**
	KZ021	Control points Xl	m	
	KZ022	Control points Yw	m	
	KZ023	Control points Zh	m	
	KZ024	Direction Angle β	°	
	KZ025	Column length X1	mm	
	KZ026	Column length Y1	mm	
	KZ027	Column high Z1	mm	
	KZ028	Keyway outside height e1	mm	
	KZ029	Keyway outside width e2	mm	
	KZ030	Keyway inside height e3	mm	
	KZ031	Keyway inside width e4	mm	
	KZ032	Keyway depth t1	mm	

Figure 5. *Coordinates and Surface Geometry Parameters.*

Reinforcement Relation Parameters				
Instructions	**Field coding**	**Field name**	**Unit**	**Field values**
①Rebar	KZ101	Angle rebar upper side head Δ1	mm	
	KZ102	Angle rebar lower side head Δ2	mm	
②Rebar	KZ103	h-Side rebar upper side head Δ3	mm	
	KZ104	h-Side rebar lower side head Δ4	mm	
③Rebar	KZ105	b-Side rebar upper side head Δ5	mm	
	KZ106	b-Side rebar lower side head Δ6	mm	

Figure 6. *Reinforcement Relation Parameters.*

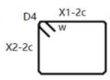
Reinforcement Design Parameters				
Instructions	**Field coding**	**Field name**	**Unit**	**Field values**
	KZ150	Concrete strength	Concrete grade	
	KZ151	Thickness of protective layer c	mm	
	KZ152	The main rebar grade	Rebar grade	
①Rebar Δ1 KZ027-Δ2	KZ153	Angle rebar diameter D1	mm	
②Rebar Δ3 KZ027-Δ4	KZ154	Number of h-Side rebar n1	root	
	KZ155	h-Side rebar diameter D2	mm	
③Rebar Δ5 KZ027-Δ6	KZ156	Number of b-Side rebar n2	root	
	KZ157	b-Side rebar diameter D3	mm	
④Rebar 	KZ158	The stirrups grade	Rebar grade	
	KZ159	First section stirrup densification area L1	mm	
	KZ160	Stirrup spacing in densified area S1	mm	
	KZ161	Second section stirrup densification area L2	mm	
	KZ162	Stirrup spacing in densified area S2	mm	
	KZ163	Stirrup spacing in non dense area S3	mm	
	KZ164	Stirrup diameter D4	mm	
	KZ165	Bending angle of stirrup	°	
	KZ166	Bending length of stirrup w	mm	
	KZ167	Limb of h-Side stirrup	limb	
	KZ168	Limb of b-Side stirrup	limb	
	KZ169	Sleeve height	mm	
	KZ170	Sleeve outer diameter	mm	

Figure 7. *Reinforcement Design Parameters.*

3.2.2. Design by Filling in Numbers

According to the actual component information of the project, fill in corresponding field values in the CDM table. Collect the CDM table of each component after filling the number, that is to form the CDM table set of the project: ∑CDM.

3.2.3. CDM Data Interaction

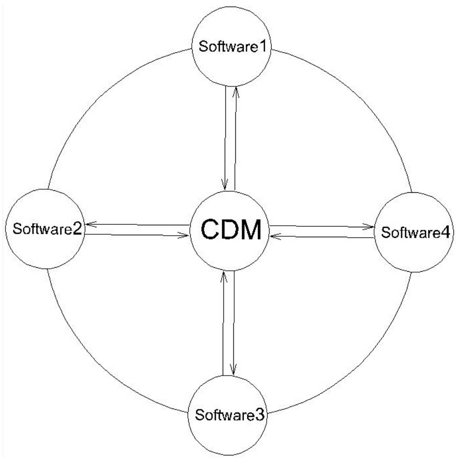


Figure 8. *Transmission Method of CDM.*

Research and development of data software based on CDM format, the software's functions include reading the CDM set after filling in numbers, delivering the CDM set to each BIM software for model display and deep application losslessly, exporting the models in each BIM software to CDM set, and realizing one-key calculation of quantities and one-key calculation of price based on CDM set. This software not only gets through the non-destructive transmission of data between BIM software, but also realizes the concept that BIM technology does not need to rely on any 3D software and only needs to fill the number in the EXCEL data sheet (Figure 8).

3.2.4. CDM Data Transmission Method at Each Stage of the Project

In the precast concrete structure system, CDM data are transmitted in order of design stage, production stage, transportation stage, installation stage and other stages. Taking CDM standard of prefabricated rectangular column as an example, in the design stage, the designer fills the values of CDM set from KZ001 to KZ170. After the completion of the filling, the designer passes it to the engineer in the production stage for the filling in the field code of KZ201-KZ204, and then fills in the field code of KZ251-KZ258 in the transport stage (Figure 9). In this way, the disadvantages of IFC data transmission are solved.

Production parameters				
Instructions	Field coding	Field name	Unit	Field values
	KZ201	Required mold		Steel mold
	KZ202	Assembly process		
	KZ203	Concrete curing		Steam curing
	KZ204	Demoulding state		Good
Transport parameters				
Instructions	Field coding	Field name	Unit	Field values
	KZ251	Manufacturer		SH manufacturing factory
	KZ252	Date of manufacture		2020.11.11
	KZ253	Date of production		2020.12.12
	KZ254	Factory inspection		Qualified
	KZ255	Component weight		200KG
	KZ256	Vehicle Information		XXXXXX
	KZ257	Receiving Unit		SH construction
	KZ258	Component tracking and positioning		RFID001

Figure 9. *Transmission Process of CDM Data.*

3.3. CDM-BIM Advantages

1) Engineers do not need to master a large number of BIM software, and only need to fill in the form with numbers, realizing that BIM technology does not depend on any 3D software. Moreover, CDM data tables are in a format that engineers can understand without having to deal with the complicated IFC data codes.
2) By developing the API of each BIM software in CDM data software, the same CDM set can be imported into different software to generate the same model. The same model can be exported to the same CDM set in different BIM software. This method has high efficiency of data interaction and realizes the lossless transfer of data among software.
3) The data information of each stage of the project only needs to be transmitted through the CDM data table. With the extension of the project stage, the CDM standard will be filled in one by one, and there will be no data islands of a certain stage of the project. The downstream of the project can intuitively understand the

data from the upstream, so as to truly realize the the full life-cycle management of the project construction.

4. Application Case of CDM Theory in the Design Stage of Prefabricated Building

4.1. General Situation of the Project

The research building of prefabricated parts production base in Chizhou, Anhui Province, is located in Qianjiang Industrial Park. The construction unit is China Power Chizhou Construction CO., LTD., and the design unit is SINOHYDRO BUREAU 8 CO., Ltd.,. This building is a public office building with a structural form of integrated frame structure. This building has a design life of 50 years and a seismic grade of 6. And the building is 17.10m high with 4 floors and the building area is 5114.78m^2.

The precast components of the project include: precast sandwich exterior wall, precast exterior wall board, precast interior wall board, precast steel truss laminated floor, precast laminated beams, precast columns, precast balconies, precast air conditioning board and precast stairs, etc. Among them, there are 648 precast boards, 466 precast laminated beams, 132 precast columns and 16 precast stairs.

4.2. Engineering Solutions Based on CDM Theory

4.2.1. Establish CDM Standards for Each Component

In design phase, the project made the CDM Standard of precast rectangular column (A2001), the CDM Standard of precast circular column (A2002), the CDM Standard of precast laminated floor (A2003), the CDM Standard of precast stair (A2004), the CDM Standard of precast laminated beams (A2005) and the CDM Standard of precast polygon laminated floor (A2006) (Table 1).

Table 1. *Set CDM standard.*

HcdmClass	Standard Name
A2001	CDM Standard of precast rectangular column
A2002	CDM Standard of precast circular column
A2003	CDM Standard of precast laminated floor
A2004	CDM Standard of precast stair
A2005	CDM Standard of precast laminated beams
A2006	CDM Standard of precast polygon laminated floor

4.2.2. Design in CDM Standard by Filling in Numbers

According to the CDM standards formulated in this project and the actual design parameters of each component, the CDM field values of each component in design phase is filled (Figure 10), and the CDM set -∑CDM of project components is formed after the number is filled.

Reinforcement Design Parameters				
Instructions	**Field coding**	**Field name**	**Unit**	**Field values**
	KZ150	Concrete strength	Concrete grade	C40
	KZ151	Thickness of protective layer c	mm	20
	KZ152	The main rebar grade	Rebar grade	HPB400
①Rebar Δ1 KZ027-Δ2	KZ153	Angle rebar diameter D1	mm	28
②Rebar Δ3 KZ027-Δ4	KZ154	Number of h-Side rebar n1	root	2
	KZ155	h-Side rebar diameter D2	mm	28
③Rebar Δ5 KZ027-Δ6	KZ156	Number of b-Side rebar n2	root	2
	KZ157	b-Side rebar diameter D3	mm	3
④Rebar D4 X1-2c w X2-2c	KZ158	The stirrups grade	Rebar grade	HPB400
	KZ159	First section stirrup densification area L1	mm	900
	KZ160	Stirrup spacing in densified area S1	mm	100
	KZ161	Second section stirrup densification area L2	mm	800
	KZ162	Stirrup spacing in densified area S2	mm	100
	KZ163	Stirrup spacing in non dense area S3	mm	200
	KZ164	Stirrup diameter D4	mm	8
	KZ165	Bending angle of stirrup	°	135
	KZ166	Bending length of stirrup w	mm	50
	KZ167	Limb of h-Side stirrup	limb	4
	KZ168	Limb of b-Side stirrup	limb	4
	KZ169	Sleeve height	mm	450
	KZ170	Sleeve outer diameter	mm	60

Figure 10. *Number Design.*

4.2.3. CDM Software Development

Due to the superiority of TEKLA software in component assembly and the fact that all core functions of TEKLA have program instructions to correspond to, that is, to provide users with personalized interface handlers for TEKLA platform development [15]. This project adopts C# language to develops CDM software HUANG-CDM, and uses TEKLA API to display the model of data in TEKLA platform.

4.2.4. Model Generation

Through HUANG-CDM software and read in the CDM set, click the code name of any CDM component, and this component can be auto-generated on the Tekla platform (Figure 11). Then click the "Import all CDM data into TEKLA" button, the whole project model driven by CDM data can be formed on the TEKLA platform without any damage (Figure 12). Moreover, the 3D model dynamically corresponds to the CDM data in the HUANG-CDM software, that is, when any data is be added, modified and deleted in the CDM set, the model can automatically update this information without tedious operation by the designer in the 3D design software.

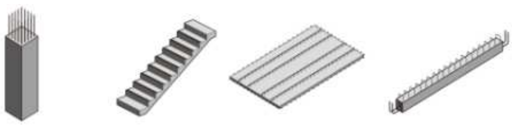


Figure 11. *Auto-Generate Component Models.*

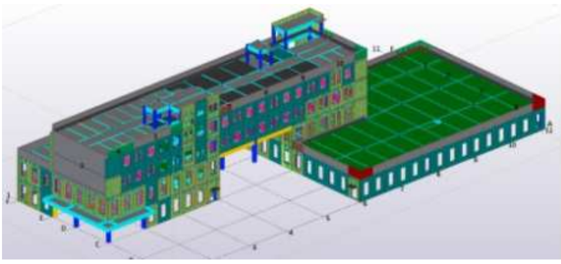


Figure 12. *Auto-Generate Project Model.*

5. Conclusion

This paper presents a study on the application of BIM technology based on CDM theory in the design stage of precast concrete structures from three aspects of standard formulation, designing by filling numbers and software development, which is used to solve the problem that IFC cannot be implemented in the traditional mode. And this method can be universally applied to the full life-cycle management of the project construction, so as to solve the problem that IFC-BIM cannot be implemented in the traditional mode. Finally, the feasibility of the proposed technical route is verified by the actual prefabricated engineering case, which solves the problems such as impassability of BIM data in the actual work and heavy repetitive workload of modelers, and greatly improves the application efficiency of BIM technology in the project.

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