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Developing an IFC-based database for construction quality evaluation

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Abstract: Quality evaluation and control represent increasingly important concerns for construction quality management. There is an evident need for a standard data model to be used as the basis for computer-aided quality management. This study focuses on how to realize evaluation of construction quality based on BIM and database technology. In this paper, the reinforced concrete main structure is taken as an example, and the BP neural network evaluation model is established by inquiring current construction quality acceptance specification and evaluation standard. Furthermore, IFC standard is extended to integrate quality evaluation information and realize the mapping of evaluation information in BIM model, contributing to the visualization and transfer sharing of evaluation information. Furthermore, the conceptual entity model is designed to build quality evaluation database, and this paper select MySQL workbench system to achieve the establishment of the database. This study is organized to realize the requirement of visualization and data integration on construction quality evaluation which makes it more effective, convenient, intuitive, easy to find quality problems and provide more comprehensive and reliable data for the quality management of construction enterprises and official construction administratiors.

Key words: BIM, BP neural network, Construction Quality evaluation, Visualization

1. Introduction and background

Quality evaluation and control represent increasingly important concerns for project managers. Defects or failures in constructed facilities can result in very large costs. Even with minor defects, re-construction may be required and facility operations impaired. Quality evaluation in construction typically involves insuring compliance with minimum standards of material and workmanship in order to insure the performance of the facility according to the design. For the purpose of insuring compliance, random samples and statistical methods are commonly used as the basis for accepting or rejecting work completed and batches of materials. Rejection of a batch is based on non-conformance or violation of the relevant design specifications. Good project managers try to ensure that the job is done right the first time and that no major accidents occur on the project.

BIM usage in design and construction phases is being used for identifying design coordination issues through clash detection and for identifying construction schedule feasibility issues through 4D analysis [1]. There is an evident need for a standard data model to be used as the basis for computer-aided quality management [2]. Building Information Modeling (BIM) is emerging as a method of creating, sharing, exchanging and managing the information throughout the lifecycle to tackle the problems related to interoperability and information integration [3]. The use of BIM has provided a means of increasing total construction quality [4]. It improves design quality in the following ways: ① Increases efficiency and precision and improves design evaluation and communication [5,6]; ② reduces errors due to better coordination between documents and the entire team, thus minimizes conflicts [7,8]; ③ simulation and optimization can be conducted for better performance, lower costs, and shorter lead times [9]; ④ mines implicit 3D modeling patterns from unstructured temporal BIM text data [10]; ⑤ reduces maintenance costs and time by providing timely and relevant information to facility management (FM) as early as the design stage [11]. However, there is still a great potential in using BIM and database for quality evaluation.

The Industry Foundation Classes (IFC) standard developed by Building SMART Alliance (BSA) (formerly known as International Alliance of Interoperability (IAI)), has matured as a standard BIM in supporting and facilitating interoperability across the various phases of a building lifecycle [12]. IFC is an object-oriented, non-proprietary building data model. However, modelling all possible objects related to the construction project is extremely complex. Therefore, the BSA introduced an incremental development of the IFC model by providing an extensible architecture for extending IFC in various domains. There are three mechanisms to extend IFC:① by defining new entities or types, ② by using proxy elements, and ③ by using the property sets or types [13].

Construction quality evaluation is a commitment to quality expressed in all parts of a project and typically involves many elements. The purpose of this study is to extend the interoperability of construction quality database in evaluation process by employing the Industry Foundation Classes (IFC) data model. To achieve this, by referring to construction quality inspection and acceptance specification, we connect IFC data and BP neural network algorithm to construction quality evaluation to improve the efficiency and accuracy of evaluation. Considering the large number of quality evaluation databased created in BIM dormain, we focus on two scenario analysis process: ① to realize specifically the IFC data mapping in construction quality domains which includes evaluation indicators, quality score and quality grade. ② to realize all quality data involved in evaluation need to be classified and unified encoded to construct the quality evaluation database. Then we try to discuss the logical framework and physical structure design of the database to integrate the heterogeneous construction quality data. Finally, we use a case study to verify the methods proposed in this study. This study is organized to realize the requirement of visualization and data integration on construction quality evaluation which makes it more effective, convenient, intuitive, easy to find quality problems and provide more comprehensive and reliable data for the quality management of construction enterprises and official construction administrators..

2. Methodology

Before looking at how the mapping works it is important to understand why the mapping is needed in the first scenario analysis process. In previous studies, researches have developed their own approaches to obtain the quality data of construction projects. Some studies focus on limited elements such as doors, windows and spaces with corresponding descriptive information. Many of these approaches are practice specific. However, for BIM projects there is a need to create quality data for pretty much all model elements and to create it to standards that allow structured data to be utilized efficiently and reliably by the evaluation process. In this study, we move away from placing data in IFC-based parameter fields and begin placing data directly into IFC and BP models. This meant we aligned evaluation information output with open international standards IFC (ISO 16739:2013) according to which the BP neural network model can be trained and tested as expected, then the approved model can be used to predict the construction quality score. This process has the potential to reduce the need for collect manually big data of construction projects, particularly as more design softwares adopt open principles. Finally, this approach obtains the quality score and grade according to the open data to be mapped.

We created a workflow (in Figure 1) which illustrates the prototypical framework to build a construction quality database with the essential data source in distinct form of graphical evaluation, parameter evaluation, IFC model, construction field data collection and user information. The main issues are that in order to create reliable data it relied on the effective IFC file extention for construction quality and adding a description to the construction site which support the corresponding operations (extract, transform and load) by users. Therefore, the mapping adds the ability to take a piece of structured data that already exists in BIM model and put into a unified field related to construction quality. So this means any piece of IFC data can automatically be placed into a corresponding evaluation program. Furthermore, the paper discusses the design of classification and encoding approach on the input data of the evaluation database which uses conceptual, logical and physical model proposed in this study for modeling the input data required and produced by the previous stage from construction quality angle to achieve an integrated management of construction quality.

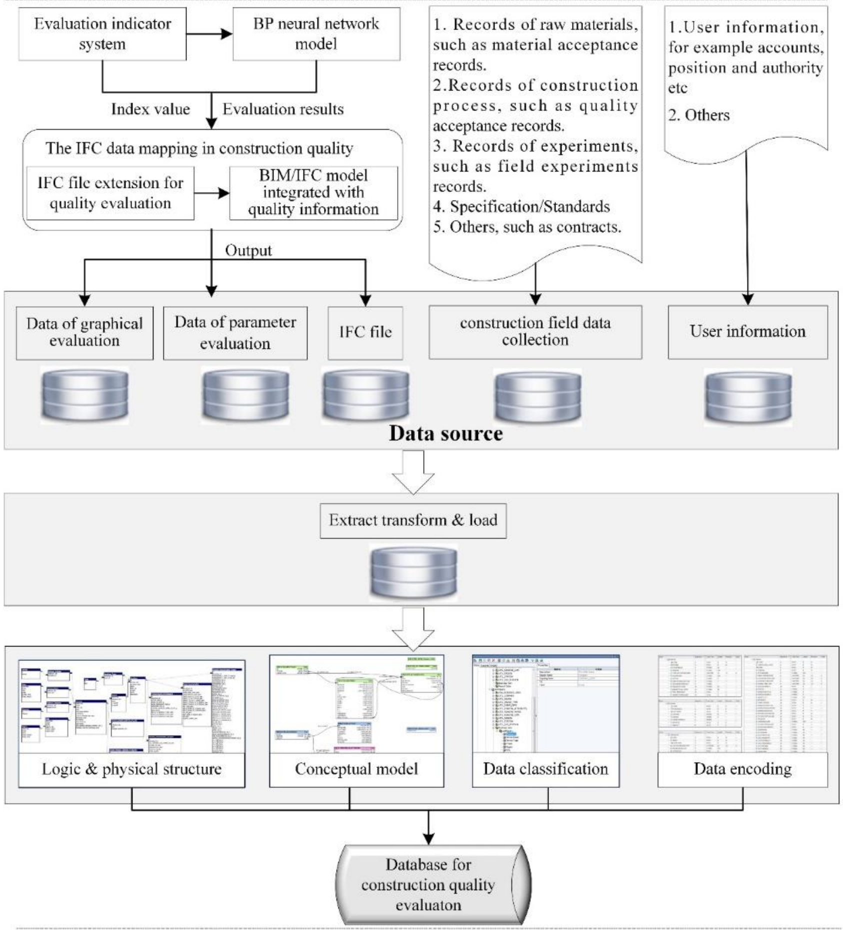

Figure 1: The method proposd in this study

3. Quality oriented evaluation model based on IFC and BP neutral network

The model is intended to provide for a construction project and a work routine to be used by a multi-disciplinary strakeholders throughout the process of assessing and managing the implementation, utilization and follow up of the construction. The evaluation presents a gross result.

3.1. Selection of construction quality evaluation index

In order to compute quantitatively the value of quality content, it is of importance to establish the evaluation indicator system in consideration of performance test, quality record, allowable deviation and appearance quality. As quality has no specific definition, it is vitally important that briefing documents set out clearly the level of quality that is required. Specific documents, standards and specification can help in the appraisal of construction entities. Taking the cast-in-place steel-concrete structure as an example, referring to Acceptance Standard for Construction Quality of Constructional Engineering (GB 50300-2013), Acceptance Specification for Construction Quality of Concrete Structure Engineering (GB 50204-2015), Evaluation criteria for Construction Quality of Constructional Engineering (GB/T 50375-2016) and the related literature, 16 quality evaluation indicators have been determined to reflect the overall appraisal of construction quality as the 17th indicator from four aspects: performance test, quality record, allowable deviation and appearance quality, shown in table 1.

Table 1: Evaluation index for the construction quality of reinforced concrete main structure

No.	Evaluation Indicator	Structural element	Evaluation Item	Description of Indicator

1	concrete strength	Beam, slab, column, wall	Performance Test	The concrete strength of the structure entity shall be reflected to meet the specifications and design requirements.
2	reinforcement cover thickness deviation	Beam, slab, column, wall		The measured deviation value of the cover thickness of longitudinal carrying bars in the structural entity is within the range of ±5mm.
3	column cross-section dimension	column		The measured deviation value of the sectional dimension of cast-in-place reinforced concrete columns should be within the range of (+10, -5) mm.
4	wall thickness deviation	wall		The measured deviation value of wall thickness of cast-in-place reinforced concrete should be within the
5	beam depth/width deviation	Beam		The measured deviation value of the beam depth and width of cast-in-place reinforced concrete shall be
6	Plate thickness deviation	slab		The measured deviation of slab thickness of cast-in-place reinforced concrete shall be within the range of (+10, -5) mm.
7	completeness of raw material record	Beam, slab, column, wall	Quality Records	The material qualification certificate, the incoming acceptance record and the reexamination report shall be complete.
8	completeness of construction record	Beam, slab, column, wall		The record of the working performance of premixed concrete, the concrete construction record, the reinforcement installation record and the construction quality check and acceptance record shall be complete.
9	completeness of test record	Beam, slab, column, wall		The test report of concrete mix proportion, the strength report of concrete specimen and the test report of steel joint connection should be complete.
10	axis deviation	Beam, column, wall	Allowable deviation	The measured deviation value of the axis position of structural element should not exceed 8mm.
11	elevation deviation	Beam, slab, column, wall		The measured deviation value of storey height elevation shall be within the range of ±10mm.
12	verticality deviation	Column, wall		The measured deviation value of height and verticality of component should not exceed 10mm.
13	planeness deviation	Beam, slab, column, wall		The measured deviation value of the surface evenness of the component shall not exceed 8mm.
14	Crack	Beam, slab, column, wall	Appearance quality	Any cracks that affect the structure, performance, or function shouldn't exist in the main boday.
15	Joint reliability	Beam, slab, column, wall		Any defects that affect the transmission performance of the structure shouldn't exist in joints of the entity
16	Exposed reinforcing steel	Beam, slab, column, wall		Any serious internal steel exposure shouldn't exist in the structure entity.
17	Overall appraisal			Integrate 16 indicators to evaluate construction quality

3.2. Overall appraisal of construction quality in BP neural network model

(1) Evaluation model structure

A single hidden layer neutral network is adopted in this paper which means that the evaluation model includes input layer, single hidden layer and output layer. The index values set in Table 1 can be used as the input parameters of the BP neural network model, so the number of nodes in input layer is 16. The quality scores (hundred-mark system) of steel-concrete structure can be obtained through the evaluation model, so the number of nodes in output layer is 1. The number of nodes in the hidden layer is usually determined by a formula , here L is the number of nodes in hidden layer (positive integer), m and n are respectively the number of nodes in input and output layer, and a is a constant between 0 and 10. According to the formula above, the number of nodes in the hidden layer of the BP neural network model is a constant between 5 and 14. The constants in this range need to be tested, and the constant which corresponds to the optimum training result is selected to be the number of nodes.

(2) Sample data classification

Classification is based on the initial value of each indicator, as shown in Table 2. The first-level indicators are marked in ten-point system by experts' opinions. The indicator values of the 2nd level can be obtained from Construction quality acceptance records of the inspection lot in steel-concrete structure. The indicator values of the 3rd level represent the appearance quality of structural entities which can be obtained from Construction appearance-quality acceptance records of the inspection lot. In consideration of construction quality acceptance, observation methods are normally used to check if the evaluation indicators satisfy specifications and design requirements. The 17th indicator "overall appraisal" usually describe inspection results with Good or General. This paper utilizes the percentage that the number of inspection sites with Good result occupies all sites to achieve quantitative description.

Table 2: The Classification of construction quality evaluation indicators

Category	Index	Iterm
First category	Concrete strength	Performance test
	completeness of raw material record, completeness of construction record, completeness of test record	Quality Records
Second category	Reinforcement cover thickness deviation, column cross-section dimension deviation, wall thickness deviation, beam depth/width deviation, Plate thickness deviation	Performance test
	Axis deviation, elevation deviation, verticality deviation, planeness deviation	Allowable deviation
Third category	Crack, Joint reliability, Exposed reinforcing steel	Appearance quality

Table 3: BP neural network sample data

Evaluation index	concrete strength	reinforcement cover thickness deviation	column cross-section size deviation	wall thickness deviation	depth of beam, width deviation	Plate thickness deviation	Raw material record completeness	construction record completeness	Test record completeness	Axis position deviation	Story height elevation deviation	Story height vertical deviation	surface evenness deviation	Crack	Joint part reliability	Exposed reinforcing bar	Construction quality score of main body structure
1	10	3.07	4.82	6.6	5.4	5.33	10	10	10	3.77	3.95	4.91	3.68	1	1	0.9	96.3
2	10	2.94	4.5	5.92	5.1	5.29	9	10	9	3.42	2.6	4.55	5.11	0.95	0.9	1	94.9
3	8.5	3.88	6.27	5.5	7.19	5.5	8.5	8	8.5	5.26	6.1	7.33	6.54	0.8	0.85	0.8	83
4	8.5	4.17	6.4	7.39	6.4	6.96	7	8.5	8	4.92	5.97	8.5	7.29	0.8	0.92	0.8	79.75
5	7	4.28	6.97	7.21	6.99	8.1	8	8	7	7.2	8.9	8.94	7.11	0.84	0.9	0.95	76.7
6	7.5	4.05	7.83	5.5	7.93	5.22	7	9	8.5	6.91	9.22	9.59	7.36	0.82	0.88	0.8	77.75
7	8	4.39	7.1	8.87	8.2	9.24	8.5	8	7	7.09	8.36	8.91	6.8	1	0.91	0.95	79.05
8	10	2.97	5.15	4.2	4.96	5.52	9	9	9	3.42	4.22	3.88	4.07	0.8	0.95	0.9	93.15
9	9	4.05	7	7.27	6.9	6.08	8	9	7	6.18	7.01	9.12	7.03	0.9	0.84	0.8	80.1
10	10	3.31	4.91	6.11	4.92	8.34	9	10	10	3.81	4	6.21	5.7	0.85	0.9	0.86	92.3
11	8.5	4.02	5	6.6	4.37	5.13	8.5	9	8.5	5.3	6.12	7.52	6.21	0.8	0.8	1	85.15
12	7	4.67	7.44	5.59	7	7.19	7	8	7	7.1	8.76	9.71	7.6	0.85	0.9	0.9	73.9
13	9	3.04	5.11	4.9	5.34	4.98	8.5	10	8.5	4.05	2.92	5.8	4.5	0.82	0.85	0.8	89.95
14	8.5	3.95	6.44	3.92	7.02	5.71	9	10	10	4.3	6.97	7.17	6.22	0.9	0.9	0.8	87.65
15	9	4.01	6.67	5.5	5.41	7.32	7.5	8.5	8.5	3.59	6.16	6.93	5.63	0.95	0.94	0.85	86.15
16	10	3.4	5.66	4.74	6	7.99	10	10	9	4.89	5.05	5.3	4	0.85	0.8	0.9	91.5
17	9	3.25	7	8.81	5.03	6.77	9	10	8.5	7.29	8.17	8.69	7.6	0.8	0.95	0.85	85.35
18	10	3.5	7.83	5	7.95	5.2	10	9	9	4	5.26	5.61	3.9	0.9	0.9	1	91.85
19	10	3.44	5.16	6.11	6.81	4.73	10	10	10	6.5	9.73	9	7.4	0.8	0.82	0.8	88.3
20	8.5	4.1	5.55	5.45	5.17	6.59	9	10	9	6.11	6	7.95	7.03	0.85	0.8	0.95	85.35
21	9	4.34	6.77	6.65	7	8.09	10	10	10	6.08	9.29	9.19	7.83	0.9	1	0.9	86.6
22	10	3.91	6.71	8.19	7.22	4.54	10	10	9	4.07	3.87	4.96	6.6	0.85	0.8	0.9	89.8
23	9	3.19	6.9	4.15	5.02	5.54	10	10	9	5.01	8.8	8.36	7.73	0.85	0.8	0.8	87
24	8.5	3.02	3.95	5.9	5.06	7	9	10	9	5.5	8.14	7.9	7.11	0.93	0.85	0.9	86.15

(3) MATLAB implementation of the evaluation model

In this study, 24 groups of sample set data are collected through investigation and survey, as shown in Table 3. Matlab R2016b software is employed to establish the construction quality evaluation model based on BP neural network. The training situation and graphic outputs are shown in Figure 2. The processing time of the neural network is 15 seconds, and it achieves the optimum in 10706 times of training, with the mean square error (MSE) is 9.99*e-9, the gradient is 3.49*e-5, the degree of fitting reaches 0.99642. The prediction results are shown in Figure 3. The expected values of the test samples are respectively 86.15, 91.50, 89.80 and 96.30 and the predicted results are 86.33 93.02, 93.04, and 95.60. The absolute error distributes in the range of -0.7~3.2, and the error rates are 0.21%, 1.66%, 3.61% and -0.73%. The absolute value is less than 5%. The prediction results are satisfied with the precision requirements. According to Evaluation criteria for Construction Quality of Constructional Engineering (GB/T 50375-2016), it is accepted that the overall appraisal of structural quality reaches 85 and above should be rated as Good.

3.3. IFC data mapping in construction quality domain

In this work, a formalization structure is suggested for database tables to enable exchange of IFC-based evaluation indicator information by information provider (quality related information stored in IFC model) and information receiver (the heterogeneous database integration system). All quality evaluation data is uniquely identified via unit ID which maintain information exchange between IFC model and database tables. In this condition a need for a new type of ID is observed as well to obtain mapping between process resources and IFC objects to support exchange of cost information. Therefore, IFC data mapping and extension is a primary step to link evaluation information generated in IFC model and database tables.

IFC data mapping in construction quality domain need to be achieved in the standard level and application level as shown in Figure 2. In term of standard level, quality evaluation information need to be extended and expressed normalized on the basis of IFC standard. In term of application level, in this paper Revit software for BIM is employed to link the evaluation information based on IFC's standardized description with BIM model, and this meanwhile realizes the integration of evaluation information in IFC documents, which can be viewed throguh exported IFC validation document.

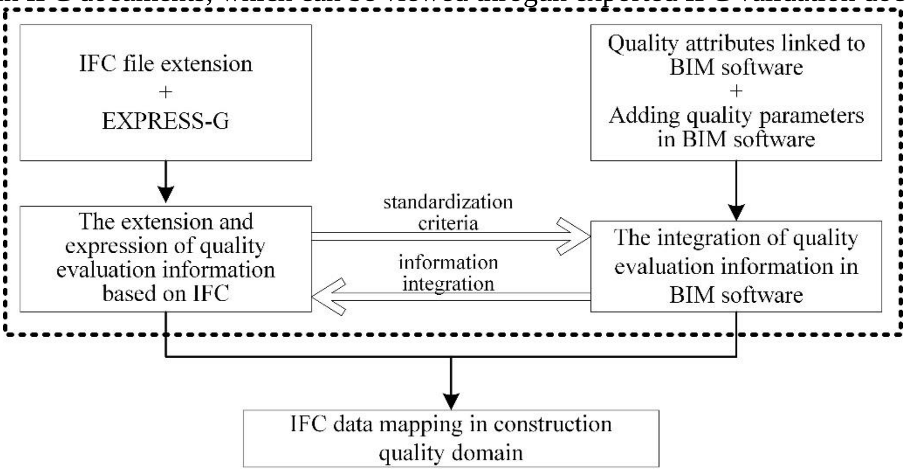

Figure 2: Implementation of IFC data mapping

(1) IFC extension process based on PropertySet of construction quality

The evaluation information of construction quality based on IFC file extension is to describe the quality of beam, plate, column and wall which can be regarded as the entity in IFC model while the evaluation information is equivalent to the attribute of entity characteristics described by IFC standard. The existing IFC4 standards already include the standardized definitions of entities of beams, plates, columns and walls. In this paper, the extension mechanism based on PropertySet is utilized to extend the quality attributes. The property set is a container class that holds specified properties within an IFC resource file. The reason to adopt this extension approach is not only that it is unnecessary to change the system structure of the original IFC standard, but it also satisfies the requirements of putting evaluation information into the IFC standard, which makes it convenient and feasible, and the specific extension process is as shown in Figure 3. First of all, the corresponding entity, attribute and their relationship in the IFC standard need to be determined according to the characteristics of quality evaluation in structure construction. Secondly, attribute sets need to be categorized according to different characteristics of the entities. Finally, defining attribute sets and attribute on construction quality to complete the extension process of evaluation information based on IFC.

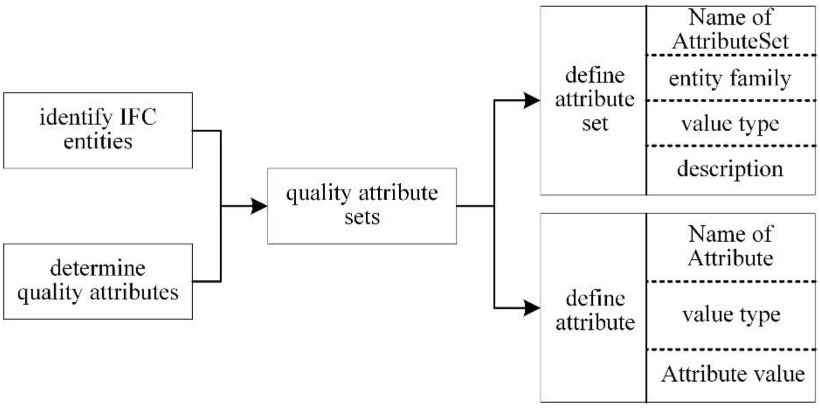

Figure 3: IFC extension process based on PropertySet

In IFC standard, major entities of stucture element including columns, walls, beams, and plates have been separated into a general definition and a specific specialization to represent the standard entities for a parametric exchange of its shape, material and underlying element type [14]. On the other hand, some property sets, for example the 17 quality attributes designed in Table 1, are excluded in the IFC specification and lack of a predefined set of properties indicated by assigning the structure elements. The definition of an IfcPropertySet includes name, entity family, the applicable type of value, and description. A definition and illustration of how IFC properties can be used to structure external library quality information is shown in Figure 4, in which the property type and value are determined by the quantized results of quality evaluation indicators in Table 3. In this example an onsite reinforced concrete model is structured as an instance of IfcPropertySet and its properties as instances of the subclasses of IfcProperty. The reference to the property value is through IfcObjectReference and IfcLibraryReference.

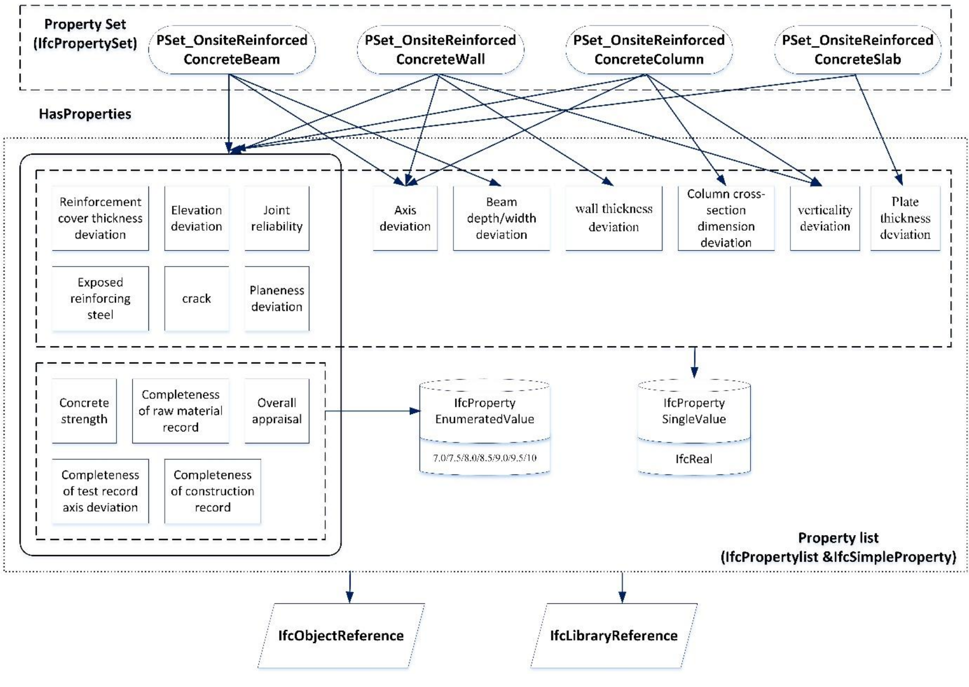

Figure 4: An instance model of IfcPropertySet

(2) The expression of quality evaluation information based on IFC

After finishing IFC extension on quality evaluation information, it is necessary to further describe the quality information. EXPRESS-G is a graphical modeling notation developed within STEP and used for IFC definition. In this study it is used to identify data attributes of IFC quality classes and the relationships that exist between classes as shown in Figure 5 [15-18]. Considering five entity classes comprised of IfcProduct, IfcElement, IfcBuildingElement, IfcPropertySetDefinition and IfcPropertySet, an inheritance relationship is expressed by thick lines between two adjacent entity classes, and with circles directing to its subclasses. The relationship between IfcPropertySet and

IfcEntity is established by IfcPropertySetDdfinition, thus the construction quality condition of IfcEntity can be expressed by the construction quality information contained in IfcProperty. IfcProperty covers two subtype classes including IfcComplexProperty and IfcSimpleProperty, of which IfcSimpleProperty includes six subtype classes. The contents in the elliptical dashed box in Figure 5 are the quality properties as defined previously, which are linked to PropertySet OnsiteReinforcedConcreteBeam/Column/Slab/Wall through thin full lines as explicit properties, and the properties are assigned with enumerated values or simple values which are forcibly connected to PropertySet in thin full lines.

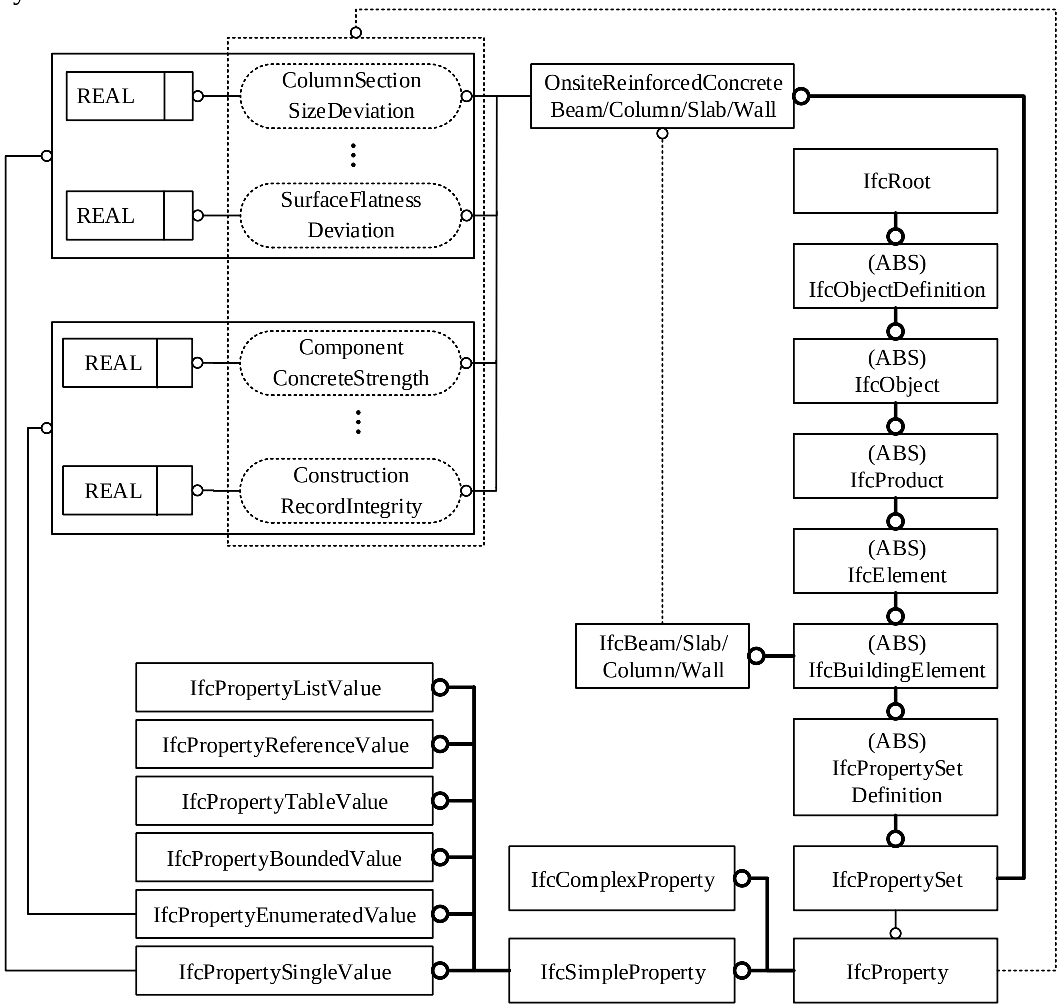

Figure 5: EXPRESS-G diagram for quality evaluation information

In this way an IFC-based quality-evaluation information library is constructed to support building element compositions to be mapped to IFC objects identified such as IfcWall, IfcSlab, IfcBeam and IfcColumn. In this study the IFC model was proposed to integrate with a quality-oriented database. A number of external libraries including structural elements and evaluation results were loaded into the database as IfcLibrary and IfcPropertySet instances. The quality information collected from acceptance records and inspection files with calculation results in BP neutral network were used as data source. So in the expression process, the cast-in-place reinforced concrete elements were defined as property sets (IfcPropertySet) and inspection and evaluation records as external product libraries (IfcLibrary). There are 17 properties such as concrete strength was defined as IfcSimpleProperty. The values of the properties were defined as selection by IfcPropertyEnumeratedValue or IfcPropertySingleValue.

4. Integrated database construction for construction quality evaluation

It is important to use various data accurately and effectively in order to enhance the ability to evaluate construction quality. If such data are integrated and visualized, a reality-based virtual database environment can be constructed, which can be used by evaluation simulator and construction manager. Besides the quantitative information discussed above mapping in BIM model, the database should also include unstructured data, such as BIM model (or drawings), site-quality documentations, image&video

records etc, which can be used to support visual display or auxiliary reference for construction quality evaluation. In order to classify the structure of evaluation data reasonably, it is necessary to identify the database composition according to the characteristics and functions of evaluation data. In general three categories are set in this study: ① graphical evaluation data as the basis of construction quality evaluation is normally obtained from the views (or drawings) in BIM model. ② parametric evaluation data refers to the parameterized information that BIM model can reflect on basic situation and quality status of structure entity, as well as the evaluation information which can be quantified in other construction quality record document or can be described in a simple text format. ③ other evaluation data involves raw materials certificates, on-site test records, construction quality acceptance record, contract documents, design documents and related standard quality records, as well as IFC document, pictures and video records, all of which can provide reference for construction quality evaluation.

Data classification is the process of organizing data into categories for its most effective and efficient use. With complex composition and wide range of sources, the visual evaluation data of construction quality consists of data with different storage structures. With many different storage structure, data can be divided into structured data, unstructured data and semi-structured data. Structured data refers to the data which has a certain structure, can be stored in a database and logically expressed through a two-dimensional relational table structure. Unstructured data refers is what has unfixed data structure, can not be directly stored by the relational database, and can only be stored in various forms of documents. Unstructured data can only be stored in a specific field to be browsed through the corresponding software which results it uneasy to be understood and unable to be standardized. Semi-structured data is a data form between structured data and unstructured data, and its structure form changes greatly. There is no obvious distinction when the structure and content of the data mix together. Besides, semi-structured data is commonly self-describing. According to the differences of storage structures of quality evaluation data, it can be classified into structured and unstructured data (there is no semi-structured quality evaluation data as discussed above) as shown in Figure 6. The graphical evaluation data belongs to the unstructured data. Parametric evaluation data can be expressed by two-dimensional logic relational table structure, which belongs to the structured data. Other evaluation data is usually stored in documents, pictures, audio and video form, which belongs to unstructured data.

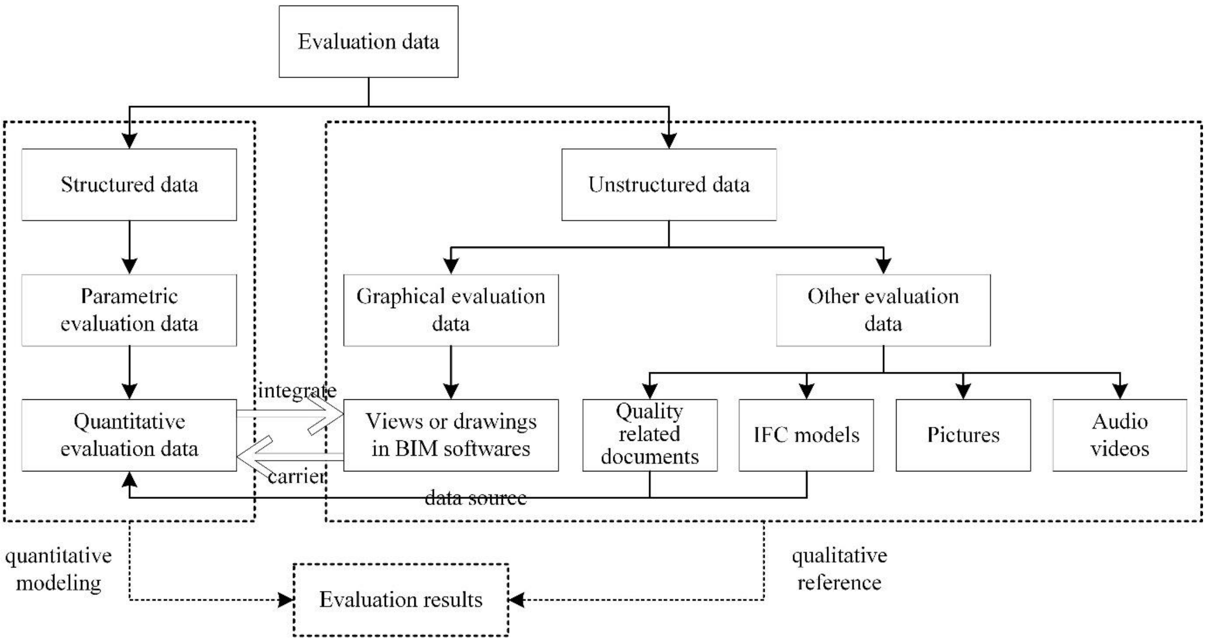

Figure 6: Data classification of quality evaluation

Referring to the visual requirements of construction quality evaluation and data characteristics in database, the entities and attributes are categorized into 5 entities including “fractional project”, “constituent project”, “inspection lot”, “IFC element” and “quality related files”. The first four entities including “fractional project”, “constituent project”, “inspection lot”, “IFC element” consist of structured data on construction components and workflow of quality acceptance. The entity attributes of “quality related file” can be viewed as unstructured data, which mainly include graphical evaluation data and others. After categorizing the entities and corresponding attributes, considering the relationship between the entities and adopting a bottom-to-up strategy to design the conceptual entity model in quality database, the global E-R (Entity Relationship) diagram is shown in Figure 7. The rectangle, ellipse and diamond box represents respectively entity, attribute and relation between entities in the diagram.

① One "fractional project" entity could be divided into "constituent project" entities which is illustrated as a 1:n (one-to-many) relationship between two these two entities. That is, one fractional project can be connected to multiple constituent projects while one constituent project only belongs to a specific fractional project.

② "constituent project" entity and "inspection lot" entity are connected in 1:n relation. That is, the evaluation of a constituent project needs to inspect and test multiple inspection lots while every inspection lot is set in exactly one constituent project.

③ One "fractional project" entity includes multiple "IFC element" entities which is shown as a 1:n (one-to-many) relationship. That is to say one "fractional project" consists of multiple structural elements with corresponding property attributes from IFC model while each structural element only belongs to one "fractional project" entity.

④ "inspection lot" entity and "IFC element" entity are connected in m:n relation. It means that one inspection lot needs to be examined by multiple evaluation indicators while one evaluation indicator will be utilized and inspected in multiple inspection lots.

⑤ "fractional project" (or "constituent project", "inspection lot", "IFC element") entity and "related files" entity are connected in 1:n or m:n relation. That is to say, the quality status of each fractional project (or constituent project, inspection lot, structural element, evaluation indicator) is recorded in one or multiple quality files while each file and can reflect the quality status of one fractional project (or multiple constituent project, inspection lot, structural element, evaluation indicator).

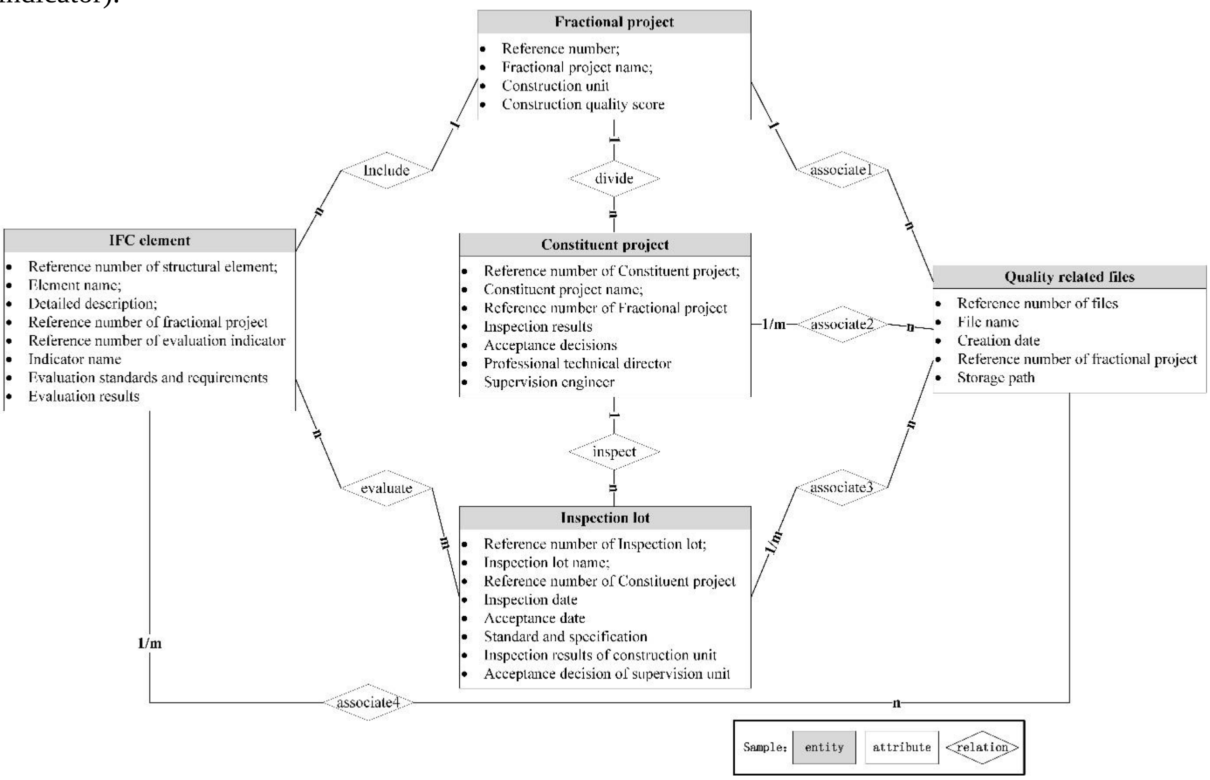

Figure 7: E-R diagram for quality evaluation database

5. Operating the IFC based database

A database comprised of several BIM models, or one BIM model by itself, can be used as a source of information for quality management techniques to identify useful evaluation attributes in data that could inform users, such as: the identification of key factors in construction quality constrol, causes for variations in the quality appraisal of beam construction, etc. Nowadays, taking into acount the

complexity of (especially) the large construction projects, it's quite important to set up a construction quality management system which acts as a distributed data store for BIM data. There is a need to maintain data consistency by updating and integrating the data on the quality management system.
Generally, similar to other BIM applications, the IFC-based construction quality management system is impacted by project organizational structure, working relationships, or even social networks, which are shaped by specific evaluation database. The operation of quality database cannot be disconnected with the model by which construction information is organized and illustrated in a particular standard like IFC. The prototypical framework is developed based on IFC extension and mathematical method (e.g. neural network model) for predicting the overall praisal, whereby indicator selection and database table design are normally organized in sequence. In an ideal situation, several 3D data collection techniques including scanning, photogrammetry, virtual modelling, 3D printing and rapid prototyping can be employed to capture quality information about construction projects. In the design stage IFC extension is developed to synthesize various evaluation mode, comes up with an optimal expression in geometric and evaluation definition, and constructs an entire building information model to be shared with the database developer, which can be perceived in Figure 8. The methmatical algorithms, BIM model building and the database are largely sequential. Users can access the quality database as a server through data sent by quality system client which is also fed back evaluation result stored in IFC model.

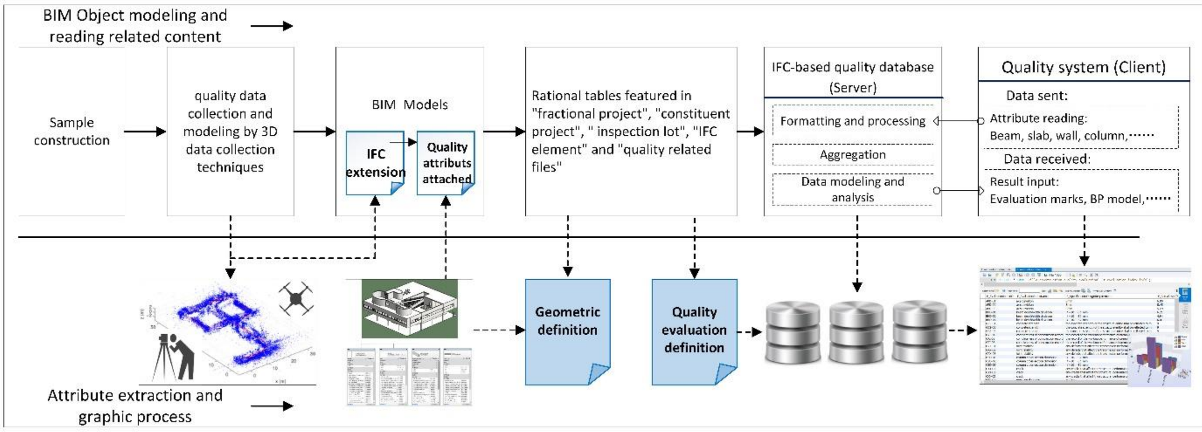

Figure 8: The workflow of quality database operation

6. Conclusion

The presented findings contribute to the understanding of the potential use of BIM in construction quality evaluation and fill an existing gap in data integration on the use of relational database. This paper explored the implementation of BIM in quality management and proposed integrated solutions to improve current quality management processes with assistance of an IFC based working environment. In order to better utilize the performance of BIM model and database on construction quality constrol, a variety of BIM-based evaluation frameworks have been proposed. Also this paper discusses how these IFC and neutral network models will work together to facilitate construction quality management. It helps the project participants to better understand the quality progress and to collaborate more effectively thanks to a visualized data format.

It can be concluded that the BIM and database-technology integrated construction quality evaluation method is suitable and helpful in quality compliance management. A quality system based on this approach proposed in this study could allow us to automate data acquirement and extraction from BIM model and produce evaluation information that can also be used by users of the quality system platform. Whilst there is a significant amount of time for us to implement the mapping of IFC element against evaluation results, the benefits to the user are they don't need to manually seek corresponding data which is attached to a BIM model as a database. The effort invested to create the mapping will allow us to ultimately move to being able to produce reliable IFC based quality database. Like any new feature there is always room for improvement, the reuqirement of more automation and new functionality generated with the development of quality system platform is a giant step towards massive open structured and unstructured data related construction quality.

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