Concrete Reinforcement Modeling with IFC for Automated Rebar Fabrication

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Abstract: Automated rebar fabrication, which requires effective information exchange between model designers and fabricators, has brought the integration and interoperability of data from different sources to the notice of both academics and industry practitioners. Industry Foundation Classes (IFC) was one of the most commonly used data formats to represent the semantic information of prefabricated components in buildings, whereas the data format utilized by rebar fabrication machine is BundesVereinigung der Bausoftware (BVBS), which is a numerical data structure exchanging reinforcement information through ASCII encoded files. Seamless transformation between IFC and BVBS empowers the automated rebar fabrication and improve the construction productivity. In order to improve data interoperability between IFC and BVBS, this study presents an IFC extension based on the attributes required by automated rebar fabrication machines with the help of Information Delivery Manual (IDM) and Model View Definition (MVD). IDM is applied to describe and display the information needed for the design, construction and operation of projects, whereas MVD is a subset of IFC schema used to describe the automated rebar fabrication workflow. Firstly, with a rich pool of vocabularies practitioners, OmniClass is used in information exchange between IFC and BVBS, providing a hierarchy classification structure for reinforcing elements. Then, using International Framework for Dictionaries (IFD), the usage of each attribute is defined in a more consistent manner to assist the data mapping process. Besides, in order to address missing information within automated fabrication process, a schematic data mapping diagram has been made to deliver IFC information from BIM models to BVBS format for better data interoperability among different software agents. A case study based on the data mapping will be presented to demonstrate the proposed IFC extension and how it could assist/facilitate the information management.

Key words: Building Information Modeling, Construction Automation, Industry Foundation Class, Prefabrication, Steel Reinforcement

1. Introduction

Reinforced concrete (RC) has always been one of the most often used materials in buildings and occupies a large part of the total costs of the construction projects. In Hong Kong, other types of structure like steel-framed structure only occupy less than 2% of all construction costs.[1] In order to meet time-saving performance and avoid error-prone manual intervention, automated rebar fabrication is promoted by government and the construction industry due to limited space and high labor costs in construction sites especially in metropolitan urban regions like Hong Kong. Many innovative fabrication

technologies with larger freedom for designers could help to open the mass market of digital fabrication.[2]

The usage of Building Information Modeling (BIM) contributes to improving the quality and integrity of the automated rebar fabrication, for its capability to store information of building elements and facilitate the workflow of fabrication and procurement. [3,4] And 3D coordination view in BIM tools could help to maintain the consistency of rebar design and fabrication. But very few researches have been studied on the implementation of BIM platform to achieve more potential functions.[5] As one of the very few public and internationally recognized standards (ISO/PAS 16739:2005) for exchange of information in the Architecture, Engineering & Construction (AEC) domain[6], Industry Foundation Class (IFC) is one of the most used data formats, currently utilized to carry semantic information of reinforcement elements among multiple types of BIM-based software agents. IFC can provide most of the parameters needed for fabrication. Except for IFC, Omniclass, which is frequently used in facility management, could be utilized as well for its hierarchy classification structure for reinforcing elements. And the International Framework for Dictionaries (IFD) could offer a consistent definition for the usage of each specific attribute by assigning a Globally Unique Identifier (GUID) to each element.[7] Thus, it will be helpful if reinforcement information could be exchanged seamlessly from BIM-authoring software to the rebar cutting and bending machines through IFC.

Currently the data format adopted by most types of rebar machines is BundesVereinigung der Bausoftware (BVBS). It is a numerical data structure developed and readable for most types of fabrication machines to perform rebar cutting and bending, with reinforcement information stored and exchanged through ASCII encoded file. [3] The details of BVBS is introduced in the following section. However, not all attributes needed in BVBS could be found in IFC files of BIM models because it mainly focuses on geometrical and semantic information of two-dimensional rebars. Thus, it's necessary to ensure the smooth data format conversion and improve the interface which allows characters from different construction phases to collaborate with each other and perform data interoperability effectively.

This study aims to present an extended IFC schema to address and compensate for the missing information within the data conversion for better data interoperability. The software and data interoperability could promote the collaboration of different phases in the whole life cycle of construction to achieve certain functions like clash detection and BIM-based quantity take-off. [8] A schematic data mapping diagram is made to expose the relationship between them in order to achieve a more efficient data interoperability performance with the aid of Information Delivery Manual (IDM) and Model View Definition (MVD). And a use case is presented to illustrate the extended IFC schema.

2. Methodology

BIM has several open specifications such as IFC and openBIM standard which can assist the process to convey information. IFC carries the semantic information of reinforcing steel and is utilized to enhance the data interoperability among different software programs, whereas the data format recognized by rebar machines is BVBS. BVBS specification can be applied in Computer Numerical Control (CNC) bending machines or Production Planning and Scheduling (PPS) software[3], transferring data of reinforcement in cast-in-place concrete structures such as bar length, diameter, and steel grade. More details of BVBS data format are shown in Figure 1.
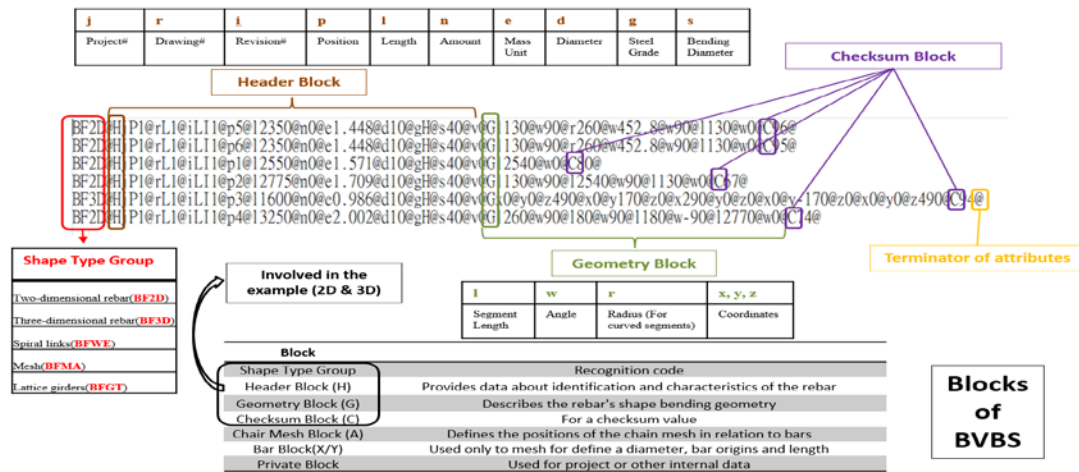
Figure 1. Details of BVBS data format

IDM is adopted to offer a reference database to reveal the information required by different processes in construction and execution[9], and to bring together various types of information into a single operating environment to reduce the repetition of paper documents. In this study, the information needed to be exchanged between BVBS and IFC is determined referred to IDM, and IFC entities related to key parameters of rebar are extracted and inspected within the process map, exchange requirements and function parts. MVD, a data-centric subset of the IFC schema, is applied to narrow down the broad scope of the overall IFC schema according to the required function, since not all phases in construction like design, procurement, fabrication and operation, need the same entities in each specific domain. In this study, rebar MVD, shown in Figure 2, is used to display and describe the data exchange process in the automated rebar fabrication workflow. Within the conversion from IFC to BVBS specification, data loss occurs and leads to mistakes in cutting and bending, making it necessary to conduct an extended IFC schema through parsing BVBS specification with the IFC schema of the most updated version so that newly added and removed entities or attributes will be considered to address missing information and improve the data interoperability. This extended IFC schema could cover more types of reinforcing elements than the existing one and provide enough information needed for fabrication.
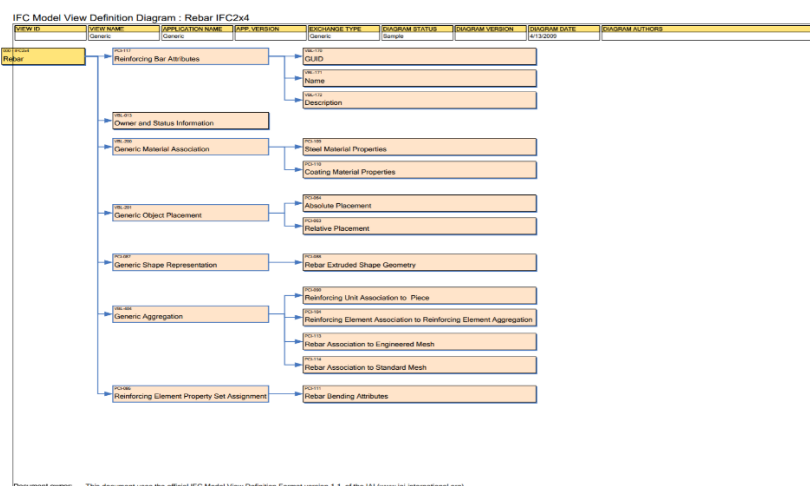

Figure 2. Rebar MVD [10]

3. Data mapping

Most of the BVBS-relevant information can be collected from IFC files according to IFC4Add2 (Version 4.0 Addendum 2) exported from authoring BIM software. Thus, a mapping chart (Figure 3) and a data mapping diagram (Figure 4) have been made in order to reveal the correlation between the two data sets more clearly and precisely.

BVBS		IFC			
		IFC4Add2-TC1		**IFC4 RV& DTV from Revit**	
Attributes	**Block**	Entity	Attributes	Entity	Attributes
Two-dimensional rebar(BF2D)	**Shape Type Group**: recognition code	Mainly 2D rebars and Specific to Rebar Shapes		Mainly 2D rebars and Specific to Rebar Shapes	
Three-dimensional rebar(BF3D)					
Spiral links(BFWE)					
Mesh(BFMA)					
Lattice girders(BFGT)					
Project Number(j)	**Header Block (H)**: provides data about identification and characteristics of the rebar	External Document		External Document	
Drawing Number(r)					
Revision Number Index(i)					
Position(p)		IfcElement	Tag	\	\
Length(l)		IfcReinforcingBarType	BarLength	IfcReinforcingBar	Bar Length(Optional)
Amount(n)		IfcElementQuantity	Quantities		
Mass Unit(e)		Derived from and Specific to Rebar Shape and Steel Grade			
Diameter(d)		IfcReinforcingBarType	NominalDiameter	IfcReinforcingBar	NominalDiameter(Optional)
Steel Grade(g)		IfcReinforcingElementType	HasAssociation	IfcReinforcingBar	SteelGrade(Optional)
Bending Diameter(s)		IfcReinforcingBarType	BendingParameters	\	\
Leg Length(l)	**Geometry Block (G)**: describes the rebar's shape bending geometry	IfcReinforcingBarType	BendingParameters	\	\
Angle of Following Bend(w)		IfcReinforcingBarType	BendingParameters	\	\
Encoding needed	**Checksum Block (C)**: for a checksum value				
	Chair Mesh Block (A): defines the positions of the chain mesh in relation to bars				
	Bar Block(X/Y): used only to mesh for define a diameter, bar origins and length				
	Private Block: used for project or other internal data				

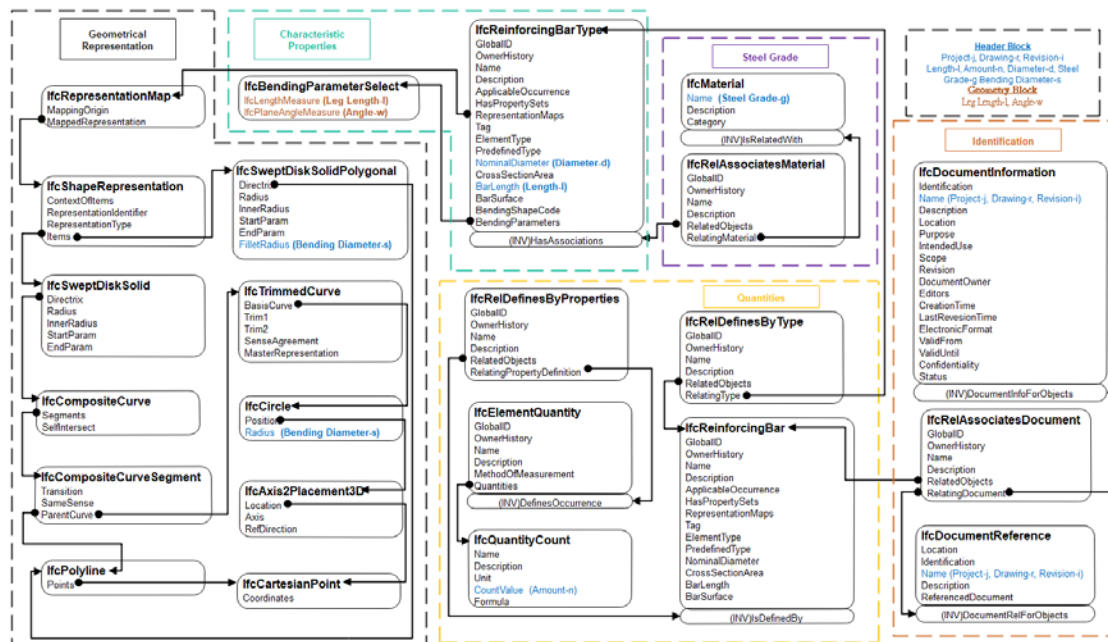**Figure 3.** Data mapping between BVBS and IFC4

Figure 4. Schematic data mapping diagram between BVBS and IFC4Add2

3.1. Identification representation

Identification information is a vital element for fabricators to track and categorize rebars from different projects. There's no perfectly matched identification-related data in IFC that could be extracted for project number (j), drawing number (r) and revision index (i), as required in BVBS specification. In order to satisfy identification parameters in Header Block of BVBS, external documents could be involved to provide these data. Under this circumstance, the object level entity *IfcReinforcingBar* is linked with *IfcDocumentInformation* or *IfcDocumentReference* through *IfcRelAssociatesDocument*, and under either of these two entities, the corresponding number and index could be obtained through the attribute *Name*.

3.2. Geometrical representation

IfcSweptDiskSolid is one of the most used ways of constructing a three-dimensional solid, by sweeping along the directrix which can be defined by *IfcCompositeCurve*. This *IfcCompositeCurve* is composed of one or more *IfcCompositeCurveSegment* and they all originate from *IfcPolyline*, the end points are defined by the cartesian points assigned. And *IfcSweptDiskSolidPolygonal*, the subtype of

IfcSweptDiskSolid, is another method where the source of attribute directrix can only be *IfcPolyline*. In this way, an optional attribute *FilletRadius* under *IfcSweptDiskSolidPolygonal* could be applied to denote bending diameter in BVBS format.

3.3. Characteristic properties

Bar diameter and length are directly provided by attributes *NominalDiameter* and *BarLength* under *IfcReinforcingBarType*. In previous IFC schema before IFC4, there is no bending-related entities or attributes, but *BendingShapeCode*, and *BendingParameter* were added in this update to fill the gap.

BendingShapeCode indicates a shape code from some certain standard that can be referenced from *IfcDocumentReference* using external resources. Related to *BendingParameters*, *IfcBendingParameterSelect* can obtain the value of segment length and angle following bends, the specific description of which is defined by *BendingShapeCode*.

3.4. Quantities

There is no usable attribute under *IfcReinforcingBarType* or *IfcReinforcingBar* to define the amount of reinforcement, but we can deduce it from the number of reinforcement entities or acquire it from one quantity set named *Qto_ReinforcingElementBaseQuantities* which can measure count, length, and weight. Quantities of reinforcement can be offered as well by the attribute *CountValue* under *IfcQuantityCount*, the attributes of which could be inherited from *IfcElementQuantity*, the objectified relationship between *IfcReinforcingBar* and which could be indicated by *IfcRelDefinesByProperties*.

3.5. Steel grade

Steel grade was previously represented by attribute *SteelGrade* under *IfcReinforcingElement* but this attribute has been deprecated in the recent update. Instead, it can be provided in attribute *Name* under *IfcMaterial* which is associated with *IfcReinforcingElementType* by *IfcRelAssociatesMaterial*. And the parameter of strength such as Young's Modulus and Shear Modulus can be provided by the property sets for object template named *Pset_MaterialMechanical*. And we can obtain general properties like mass density from *Pset_MaterialCommon* as well so that we can calculate the mass unit required by BVBS specification accordingly.

4. Extension of IFC schema

4.1. Extended entities

Three out of five types of reinforcement shapes required by BVBS could be found in IFC: two-dimensional rebar (BF2D), three-dimensional rebar (BF3D) and reinforcing mesh (BFMA). Among them, represented only in Cartesian points, 3D rebar is special and hard to be distinguished, not to mention spiral links (BFWE) and lattice girders (BFGT), which are even harder to be defined. Therefore, it's necessary to propose new entities in type level for 3D rebar, spiral links and lattice girders.

The shape definition of 2D rebar is formed by *IfcPolyline* which could also be applied to three-dimensional solid. Thus, both 2D rebar and 3D rebar could share this entity but an identifier may be needed in the beginning to distinguish 3D from 2D. In terms of spiral links, the spacing of stirrups is one of the crucial parameters apart from basic ones like diameter and steel grade. Another essential one depends on the perimeter of the cross-section of building element: a circular one needs the radius; but for a square one, a side length will do. As for lattice girders, more distinctive attributes are utilized since it's a combination of bars at different locations. The diameter of the upper chord, lower chord and diagonal chord, length, pitch and height are all compulsory parameters required in prefabrication. The diagram of extended IFC entities is shown in Figure 5.
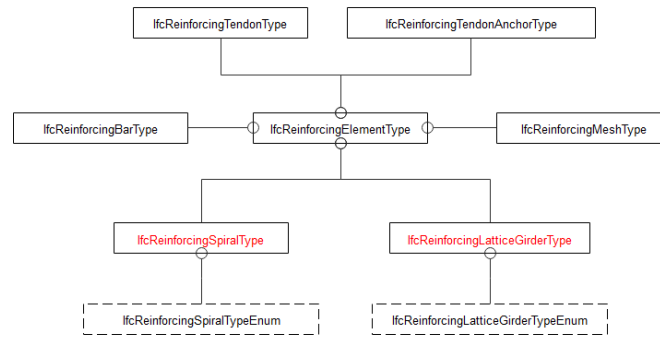
Figure 5. Express-G diagram for extended IFC entities

4.2. Extended parameters under existing entities

4.2.1. Mark Number

In response to the *Position* in BVBS format which can be regarded as bar mark in prefabrication, there is no perfectly fit attribute in reinforcement related IFC entities. There is a *Tag* attribute under entities in type-level. However, since one element type may be utilized in various locations in the same project, *Tag* in type-level may not be appropriate enough. An added *BarMark* attribute under entities in type-level like *IfcReinforcingBarType* and *IfcReinforcingMeshType* can fill this gap by marking those reinforcing elements which possess the same parameters in the same phase, making it more convenient to conduct prefabrication and transportation.

4.2.2. Mass Unit

The definition of mass unit of reinforcement is mass per item, and this should be a derived parameter, the acquisition of which involves calculation based on density, length, and diameter. However, there are no such attributes in IFC, making it more inconvenient to perform cost estimation and quantify reinforcement production, which is particularly essential to decision making and evaluation of the structural design. Thus, a new attribute *MassUnit*, the value of which can be obtained through arithmetic operations, is supposed to be appended in the current list of entities at type level like *IfcReinforcingBarType* instead of instance-level to avoid time wastage due to the increased size of models.

4.2.3. Hook Type

There are 5 separate hook types in Revit: two standard hooks 90 deg/180 deg, three stirrup/tie hooks 135deg/90 deg and stirrup/tie seismic hook 135deg. But there is no hook related IFC entities, and hooks are represented as segments and angles. For instance, the hooks are represented by *IfcCircle* plus *IfcPolyline*, which is not distinctive enough and the size of models will be enhanced, which is surely a wastage. Proposed attributes *HookAtStart* and *HookAtEnd* under type-level entities like *IfcReinforcingBarType* will make the entity simpler and more readable, saving storage space for IFC file as well.

5.   Use case

Examples of the reinforcing bar information represented by the extended IFC are shown. The attributes (Figure 6 and 7) in *IfcReinforcingSpiralType* and *IfcReinforcingLatticeGirderType* are proposed according to the geometrical and semantic parameter as well as the attribute heritance of *IfcReinforcingBarType* and *IfcReinforcingMeshType*. [11] Except for fixed attributes including *PredefinedType*, *BendingShapeCode* and *BendingParameters*, geometrical attributes are proposed corresponding to each type.

#	Attribute	Type
10	PredefinedType	IfcReinforcingSpiralTypeEnum
11	SpiralLength	IfcPositiveLengthMeasure
12	SpiralDiameter	IfcPositiveLengthMeasure
13	LongtudinalBarNominalDiameter	IfcPositiveLengthMeasure
14	TransverseBarNominalDiameter	IfcPositiveLengthMeasure
15	LongtudinalBarCrossSectionArea	IfcAreaMeasure
16	TransverseBarCrossSection	IfcAreaMeasure
17	Pitch	IfcPositiveLengthMeasure
18	BendingShapeCode	IfcLabel
19	BendingParameters	IfcBendingParameterSelect
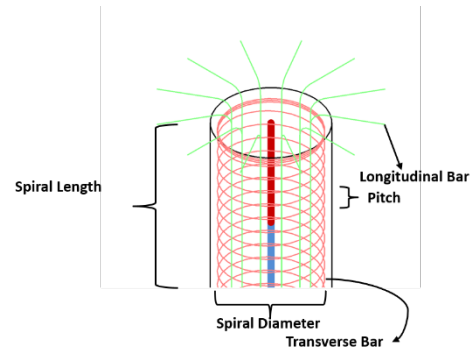
Figure 6. Proposed attributes of IfcReinforcingSpiralType with reference to IFC4Add2 Documentaion [12]

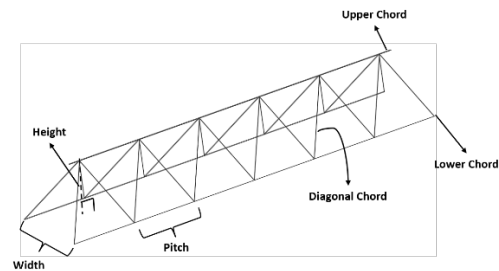| #	Attribute	Type
10	PredefinedType	IfcReinforcingLatticeGirderTypeEnum
11	UpperChordLength	IfcPositiveLengthMeasure
12	LowerChordLength	IfcPositiveLengthMeasure
13	DiagonalChordLength	IfcPositiveLengthMeasure
14	Width	IfcPositiveLengthMeasure
15	Height	IfcPositiveLengthMeasure
16	UpperChordDiameter	IfcPositiveLengthMeasure
17	LowerChordDiameter	IfcPositiveLengthMeasure
18	DiagonalChordDiameter	IfcPositiveLengthMeasure
19	UpperChordCrossSection	IfcAreaMeasure
20	LowerChordCrossSection	IfcAreaMeasure
21	DiagonalChordCrossSection	IfcAreaMeasure
22	Pitch	IfcPositiveLengthMeasure
23	BendingShapeCode	IfcLabel
24	BendingParameters	IfcBendingParameterSelect

Figure 7. Proposed attributes of IfcReinforcingLatticeGirderType with reference to IFC4Add2 Documentaion [13]

Under *IfcReinforcingBarType*, four new attributes are added: *MarkNumber*, *MassUnit*, *HookAtStart*, and *HookAtEnd* (Figure 8). *MarkNumber* is used to indicate the serial number of rebars with the same parameters so that it will be easier to categorize and track them while converting them into BVBS file. Required by fabrication machines, *MassUnit* presents the mass per reinforcing bar. In terms of *HookAtStart* and *HookAtEnd*, the type is defined to be *IfcReinforcingBarHookTypeEnum*, under which there are five types of hooks: Standard 90, Standard 180, Stirrup/Tie 135, Stirrup/Tie 90 and Seismic 135. In the tree view of the IFC file (Figure 9), the attributes including extended ones are listed in the brackets after IFCREINFORCINGBARTYPE and added attributes are marked.

#	Attribute	Type
10	PredefinedType	IfcReinforcingBarTypeEnum
11	MarkNumber	IfcReal
12	NominalDiameter	IfcPositiveLengthMeasure
13	CrossSectionArea	IfcAreaMeasure
14	BarLength	IfcPositiveLengthMeasure
15	MassUnit	IfcPositiveLengthMeasure
16	BarSurface	IfcReinforcingBarSurfaceEnum
17	HookAtStart	IfcReinforcingBarHookTypeEnum
18	HookAtEnd	IfcReinforcingBarHookTypeEnum
19	BendingShapeCode	IfcLabel
20	BendingParameters	IfcBendingParameterSelect

Figure 8. Extended attributes in IfcReinforcingBarType [10]

Figure 9. Tree view of example for extended IfcReinforcingBarType

6. Automatic BVBS Code Generation for Rebar Fabrication

Provided the extended IFC schema, this study further develops a customized program based on the common BIM-authoring software (i.e., Autodesk Revit 2020) for the automatic generation of BVBS. As Figure 10 shows, the program was developed using Dynamo (a Python-based visual programming tool). It starts by reading the semantic and geometric information of each individual rebar in the BIM model. Based on the schematic data mapping between IFC and BVBS, the program then extracts the fabrication-related information from the rebar BIM model to automatically generate the BVBS.
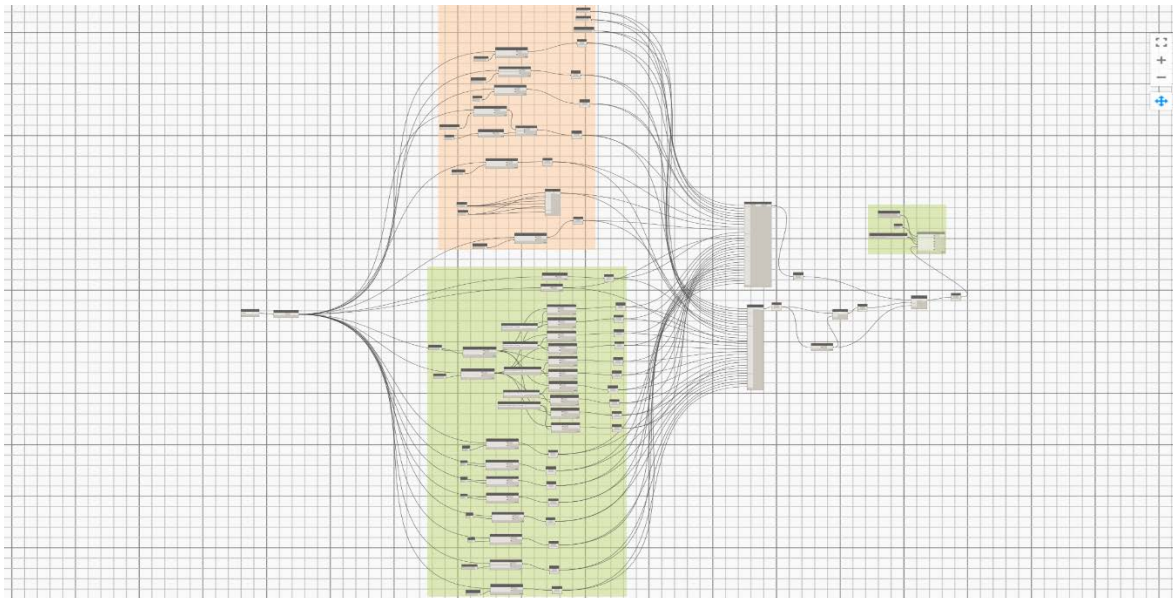

Figure 10. Overview of Dynamo program

So far, most of the attributes required in BVBS can be extracted from BIM models using the developed Dynamo program (by Python scripts customized by users). After the BIM model extraction, all required parameters in the Header Block can be acquired, except the project number, drawing number and revision index which need to be inputted manually according to practical situations. Regarding the geometry block, the team currently focuses on two-dimensional rebar. The program can provide the segment length in form of different capital letters that were assigned and customized in Revit-Rebar-Edit Family, and obtain the angle value through calculation based on Trigonometric function and segment length. The checksum block was also generated by the Dynamo program, the results of which could be utilized to check the correctness of BVBS string.

The circular column joint given by CIC (Figure 11) was built in Autodesk Revit to test and verify the proposed IFC extension and the Dynamo program. After selecting all the steel reinforcement of any element like beam and column in the BIM model, the Dynamo program can be executed to automatically generate an output file in Excel Spreadsheet. As Figure 12 shows, the Excel Spreadsheet contains all the detailed geometric and sematic information for the steel reinforcement in BVBS format of beam in the model.
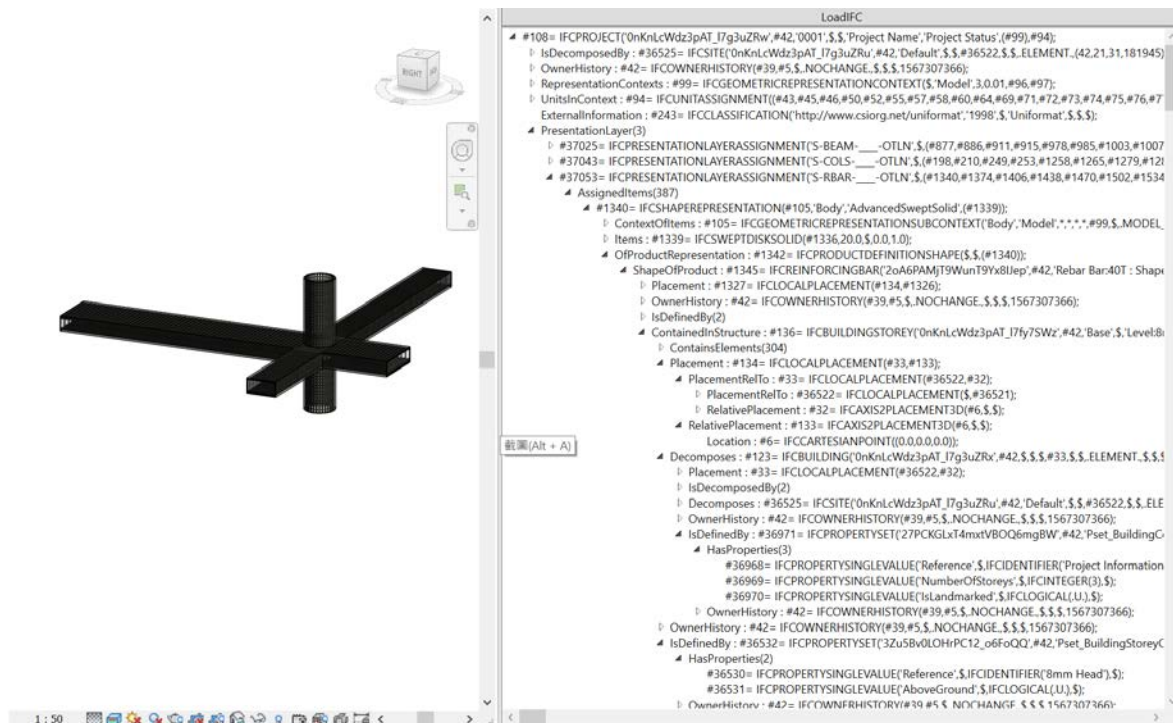
Figure 11. BIM model generated from clash-free solver

54	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
55	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
56	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
57	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
58	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
59	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
60	BF2D@HjP1@rL1@iLl1@p1@l3000@n1@e29.594@d40@g500@s280@Gl3000@w0@C84@
61	BF2D@HjP1@rL1@iLl1@p2@l4433@n1@e6.998@d16@g500@s32@Gr650@w360@w0@C81@
62	BF2D@HjP1@rL1@iLl1@p2@l4433@n1@e6.998@d16@g500@s32@Gr650@w360@w0@C81@
63	BF2D@HjP1@rL1@iLl1@p2@l4433@n1@e6.998@d16@g500@s32@Gr650@w360@w0@C81@
64	BF2D@HjP1@rL1@iLl1@p2@l4433@n1@e6.998@d16@g500@s32@Gr650@w360@w0@C81@
65	BF2D@HjP1@rL1@iLl1@p3@l4452@n1@e2.745@d10@g500@s20@Gr650@w360@w0@C81@

Figure 12. Part of output of Dynamo program

7. Conclusions and future work

In this study, openBIM standards are introduced along with some commonly used BIM specifications, and the parameters in BVBS specification are listed and parsed with the most updated IFC4Add2 schema in terms of semantic information of reinforcing elements. The data mapping between BVBS standard and IFC schema is made to address missing information in IFC, and in order to simplify the process of inputting reinforcement information into rebar cutting and bending machines, an IFC extension is proposed based on existing entities of reinforcing elements and incomplete conversion. With the aid of data mapping and IFC extension, the efficiency of reinforcing bar fabrication will be enhanced to a large degree and speed up the whole process to automation. However, some problems remain in the conversion in terms of Geometry Block in BVBS because different geometrical formulations are adopted for different shapes of reinforcing elements, which could be addressed and solved in the future along with more details of IFC extension. And for reinforcing elements other than bar and mesh, geometrical parameters of spiral links and lattice girders could be further modified instead of being determined just according to those of bar and mesh. The research plan also concerns the testing of the BVBS code generated from the developed Dynamo program in a local rebar factory to check the correctness of the code.

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