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香港建築業物料聯會有限公司
HONG KONG CONSTRUCTION MATERIALS ASSOCIATION LIMITED

BIM-based Rebar Design Optimization and Prefabrication Automation



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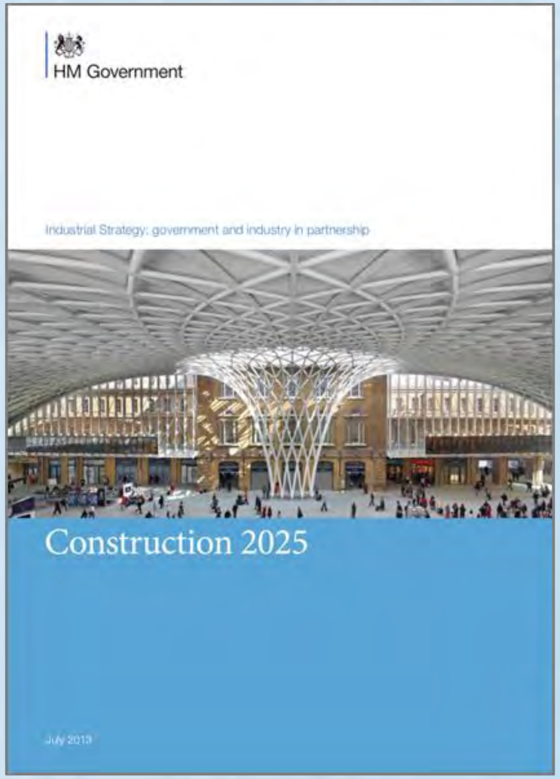
Technical Seminar
Webinar on Experience Sharing of a Showcase using Prefabricated Rebars Cum Research on BIM-based Rebar Design Optimisation & Automation
21 August 2020

Background of the Project

- Growing academic and industry interests on offsite construction
- Innovative technologies for industry transformation:

1. Standardized and prefabricated components
2. (Semi-)automated construction



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Background of the Project

- Hong Kong has policy to support offsite prefabrication.
- This project echoes with the Policy Address, adoption of technology and innovative construction methods to improve productivity and cost-effectiveness.
- Prefabricated steel reinforcement components are encouraged.

The Hong Kong Special Administrative Region of the People's Republic of China

The Chief Executive's 2017 Policy Address

III. Diversified Economy

113. The construction industry has been facing the challenges of high construction costs and labour shortage in recent years. Hence, the Government is proactively promoting the adoption of technology and innovative construction methods to improve productivity and cost-effectiveness. For instance, the Government is assisting the industry in establishing large-scale and highly automated steel reinforcing bar prefabrication plants for the production of prefabricated steel reinforcement components for use in construction projects. We will also adopt Building Information Modelling technology in the design and construction of major government capital works projects that are scheduled to start in 2018, and promote the use of this technology in private construction projects. Besides, the new Construction Innovation and Technology Application Centre of the Construction Industry Council will be in operation by the end of this year to provide the latest information on local and overseas construction technologies and to support their adoption by small and medium enterprises.

Background of the Project

- Echo with the Policy Address, adoption of technology and innovative construction methods to improve productivity and cost-effectiveness.
- Prefabricated steel reinforcement components are encouraged.

> recent years. Hence, the Government is proactively promoting the adoption of technology and innovative construction methods to improve productivity and cost-effectiveness. For instance, the Government is assisting the industry in establishing large-scale and highly automated steel reinforcing bar prefabrication plants for the production of prefabricated steel reinforcement components for use in construction projects. We will also adopt

- Traditionally, structural engineers (SE) do not prepare full rebar details for construction.
- Structural analysts only serve the purpose of structural stability and rebar detailing should refer to general detailing drawings, actual rebar details would be pending until construction stage.
- Rebar quantities are provisional quantity and subject to future re-measurement, normally it would be finalized upon structural works completed.

Background of the Project - Wishes

- During the design stage, once structural framing plan completed, rebar models can be generated by automation plug-in
- Rebar details design can be prepared earlier. Rebar drawings can be generated conveniently.
- Rebar bending schedule and rebar quantities can be prepared in BQ in post-tendering stage. No more provisional quantity. It can reduce the re-measurement efforts and argument on final account.
- Rebar models are directly passed to contractors and rebar factories for prefabrication.
- Enhance productivity, effectiveness, quality control, and wastage reduction on site

Human error in manual rebar fabrication

"BIM-based Rebar Design Optimization and Prefabrication Automation" – Jack Cheng, CM Chan, Vincent Gan

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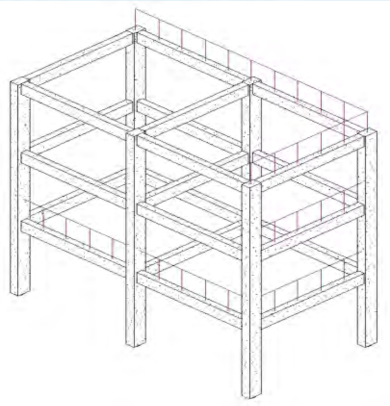
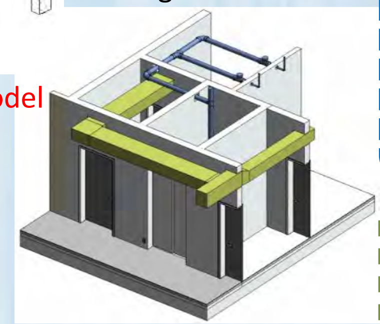
Overview of the Project

1. To develop an **innovative approach** for **automated clash-free steel reinforcement design optimization.**
2. To develop an **automated BIM-based framework** to generate the **rebar bending schedule**, **detail drawings**, and **factory machine codes** for rebar prefabrication.

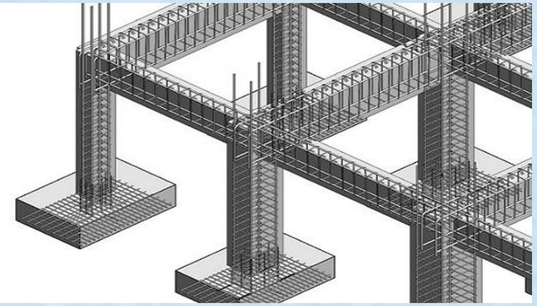
3D architectural BIM model

- Geometry details
- Material properties
- Holes for MEP

DATA

Optimization

Loading
Structural analysis
Design code



Structural BIM model

- Rebar number & diameter
- Layout details of rebar

Revit, Tekla, IFC

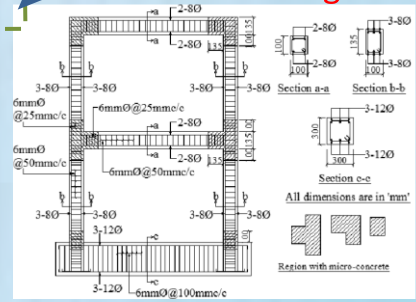
DATA

Rebar schedule

Host	Rebar Number	Bar Diameter	Shape	Quantity	Shape Image
T3					
TL.W06	07	20 mm	00	31	
TL.W06	07	20 mm	00	31	
TL.W06	08	16 mm	25	21	
TL.W06	08	16 mm	25	20	
TL.W06	10	14 mm	21	31	
TL.W14	07	20 mm	00	31	
TL.W14	07	20 mm	00	31	

DATA

Rebar drawings



DATA

BVBS

Rebar fabrication code

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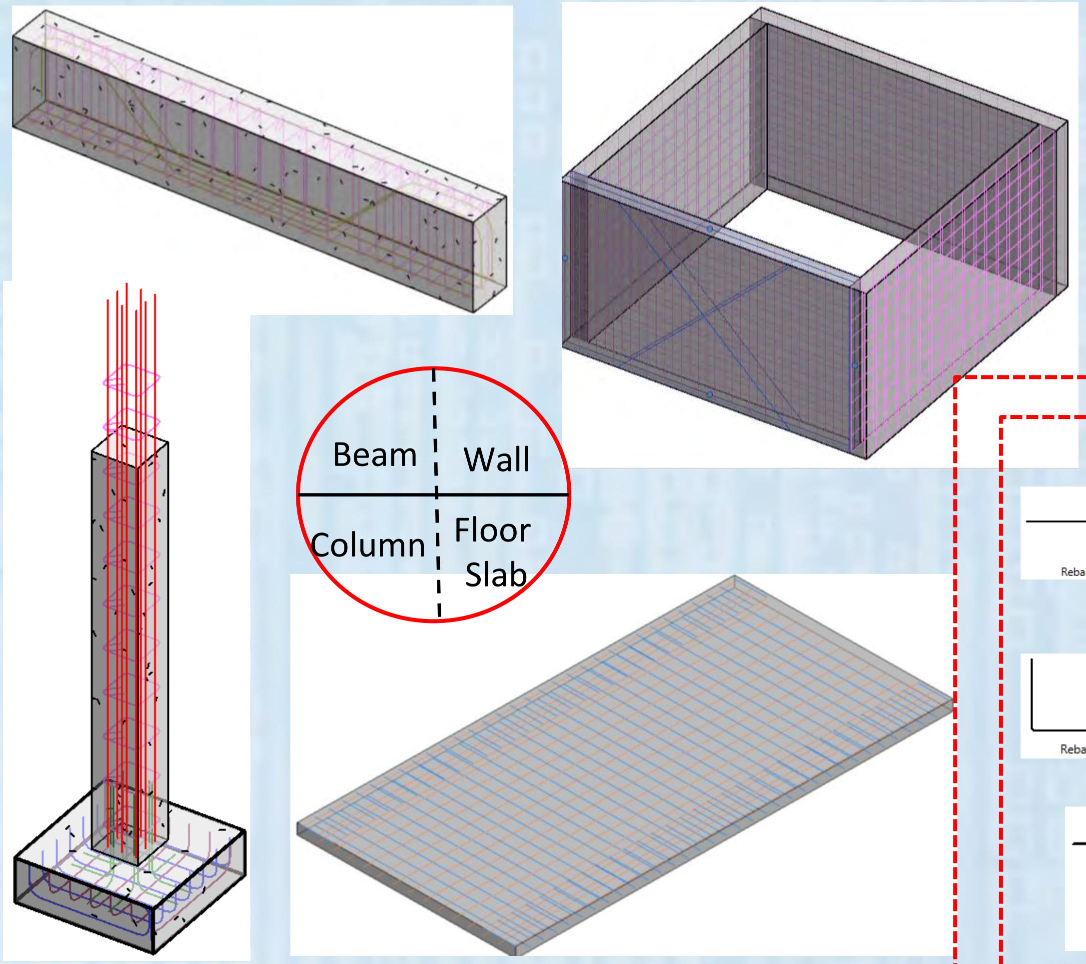
June 2019 – Dec 2020

Supported by CIC Research Fund

"BIM-based Rebar Design Optimization and Prefabrication Automation" – Jack Cheng, CM Chan, Vincent Gan

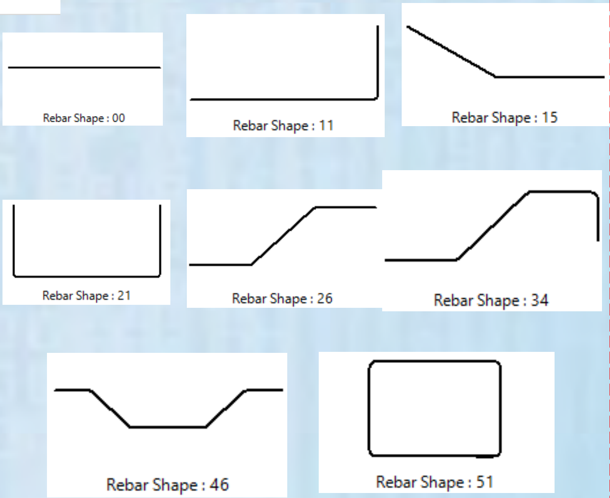
Scope of the Project



Common RC components

Frequently-used rebar shapes

BS 8666



Project Progress

Official Start Date: 17 June 2019

1st progress report (Month 4) | 2nd progress report (Month 6) | 3rd progress report (Month 8) | 4th progress report (Month 10) | 5th progress report (Month 14) | Final report Summary report (Month 18)

Month	2	4	6	8	10	12	14	16	18
1st Milestone – novel clash-free rebar design optimization									
1.1 BIM model extraction									
1.2 Rebar design optimization									
1.3 Rebar BIM model generation automation from external programs									
1.4 Rebar BIM model generation from optimal design									
2nd Milestone – automated generation of rebar drawings and fabrication machine codes									
2.1 Automated BIM-based generation of rebar drawings*									
2.2 Rebar schedule compliant with BQ standard*									
2.3 Automated generation of rebar fabrication machine code									
3rd Milestone - pilot project to test and modify the BIM-based development									
3.1 Case study on a typical RC building structure									
3.2 Relevant modification and tuning of the development									

**Note: Tasks 2.1 and 2.2 need a little more time as the team tries to incorporate the new CIC Standards*

Deliverables

- A **plug-in program interfaced within BIM system** to be developed for **automated clash-free design optimization** of steel reinforcement

Deliverables

- A **BIM-based plug-in tool** to be developed to prepare the **rebar schedule**
- An **automated drawing generation tool in BIM** to be developed to automatically generate the **rebar detailing drawings**
- A **customized program** to be developed to generate the **factory machine codes (BVBS)** for rebar fabrication

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R&D Progress

1. Clash-free steel reinforcement design:

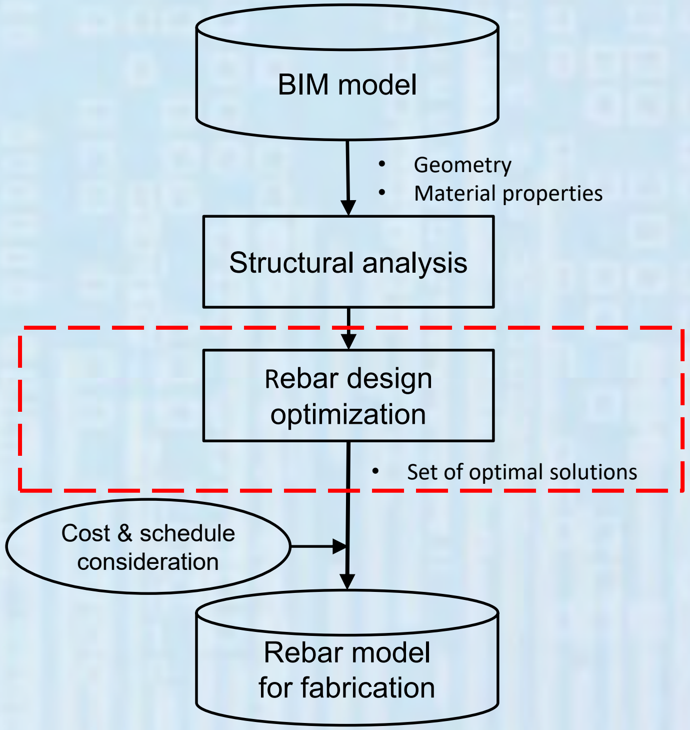
1.1. Optimal design formulation
1.2. Rebar design optimization
1.3. Parametric clash avoidance solver

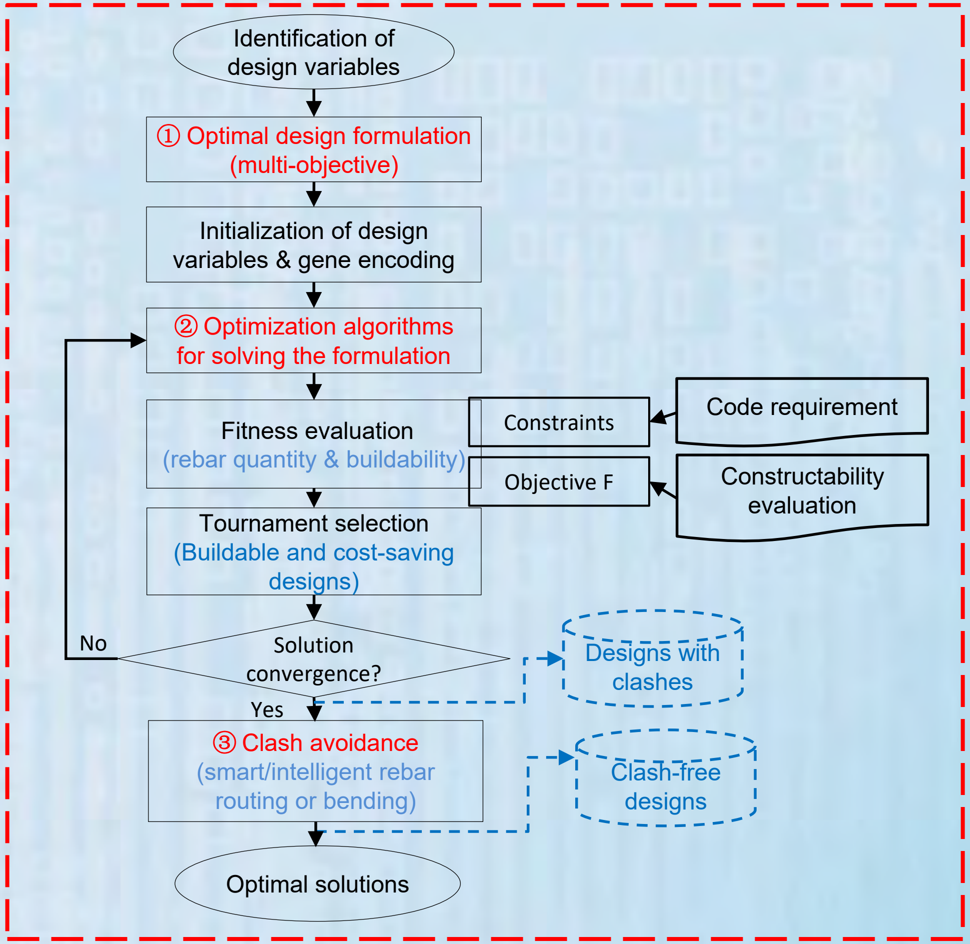
2. Automatic rebar prefabrication:

2.1. Generation of BVBS
2.2. Generation of rebar detail drawings and schedule
2.3. API for automated drawing generation

1. Procedure of Design Optimization

- A holistic approach is proposed to optimize the rebar design:





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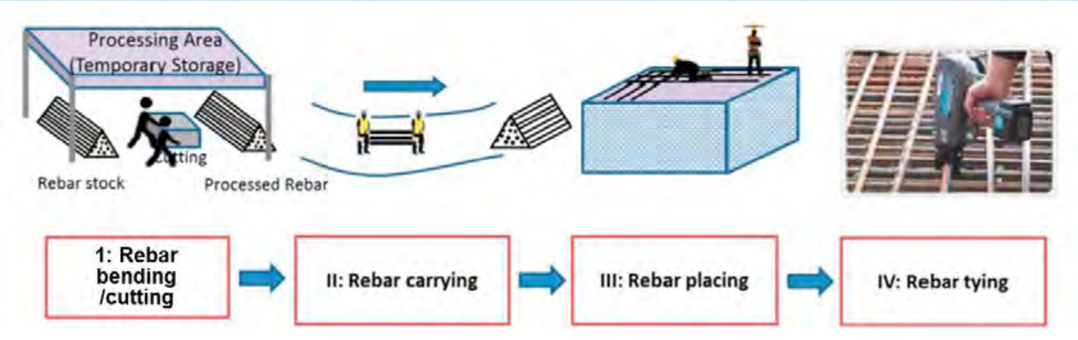
1.1. Optimal Design Formulation

- Rebar installation operation process



Buildability optimization:

Minimize	$Q_{frame}\,(\mathrm{dm}^3) = \sum (L_i A_i) + \sum (L_j A_j)$	Material consumption
Minimize	$C_{frame}\,(\mathrm{min}) = \sum T_{placing} + \sum T_{fixing}$	Placement and typing time

Subject to a set of design constraints from the Code of Practice for Structural Use of Concrete 2013, e.g., strength, bar spacing.

1. Bar spacing is checked for each candidate solution generated
2. The strength is also formulated as a code-stipulated constraint
3. Other detailing requirements of the reinforcement, such as steel ratio and minimum number of bars, are also satisfied

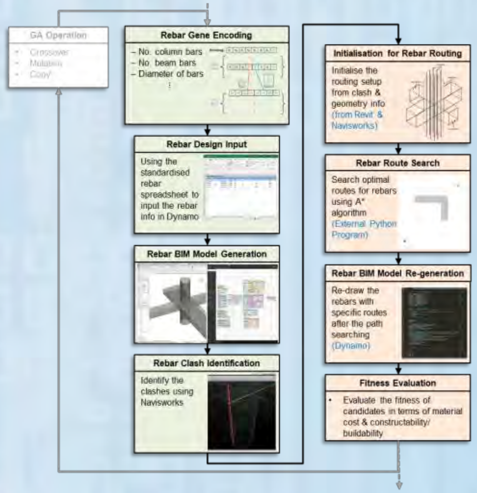
Smaller-sized bars

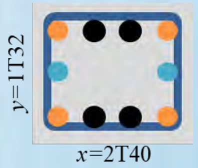
➔ Material weight (↓)

➔ Time for typing (↑)

Weight-aggregation:

$$f(w \times Q_{frame} + (1\text{-}w) \times C_{frame})$$





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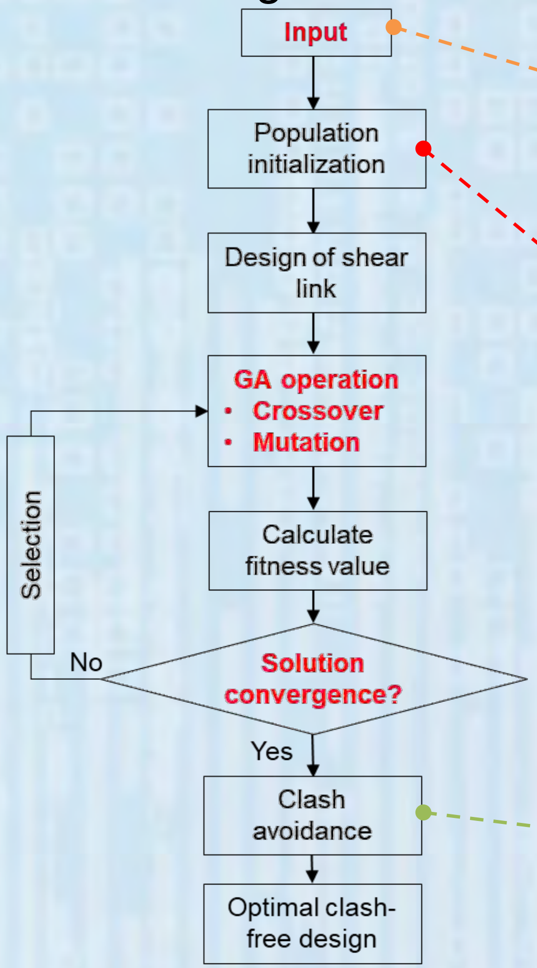
1.2. Rebar Design Optimization

- GA-based optimization algorithm is developed to solve the formulation:



- **Information extracted from BIM model:**
  - Elements' diemensions
  - Structural analysis result
  - Available rebar diameter
  - Stirrup diameter
  - Spacing requirement
  - Cover layer

- **GA population initialization:**

1) Calculate maximum number of rebars in one layer;
2) Calculate the minimum number of layers required for each area;
3) Automatically establish the database containing practical layouts;
4) Generate the initial population by choosing rebar combination in the database (constraints are met)

- **Parametric clash solver:**

1) Joint classification (beam-column joints, etc.; T joints, etc.)
2) Try different strategies, such as repositioning, bending or both.

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1.2. Rebar Design Optimization

- **Recap of the column rebar design**
  - **Assumption**
    1. Only one layer of rebar is considered for each side of column
    2. Only one type of diameter is used for each side of column (the corner bar is not included)
  - **Workflow**
    1. Establish a database consisting of practical layouts (number of rebars, diameter, steel area)
    2. Select a layout for each side (*Asx, Asy*)
    3. Select the diameter of the corner bars (*Asc*)
    4. Conduct shear link design according to the layout of longitudinal rebars

GA encoding

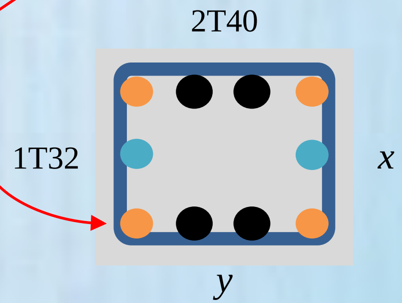
SideX	SideY	DiaC

3 basic variables (the first two -- combination index number)

Example

4	10	40

5 basic variables to describe the longitudinal rebar layout for a rectangular RC column: n_x, d_x, n_y d_y, d_c



CombListLC

	Number of rebars	Diameter	Steel area
1	1	16	201.0619
2	1	20	314.1593
3	1	25	490.8739
4	1	32	804.2477
5	1	40	1.2566e...
6	2	16	402.1239
7	2	20	628.3185
8	2	25	981.7477
9	2	32	1.6085e...
10	2	40	2.5133e...
11	3	16	603.1858
12	3	20	942.4778
13	3	25	1.4726e...
14	3	32	2.4127e...
15	3	40	3.7699e...
16	4	16	804.2477
17	4	20	1.2566e...
18	4	25	1.9635e...
19	4	32	3.2170e...
20	4	40	5.0265e...

Database

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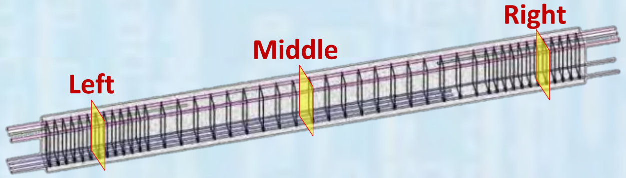
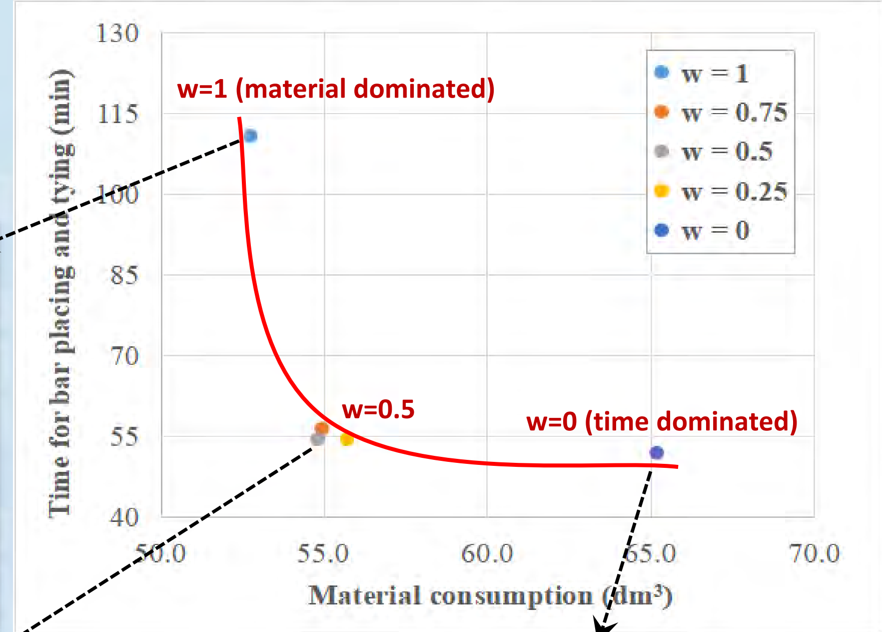
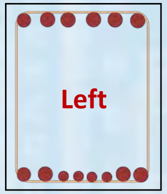
1.2. Rebar Design Optimization

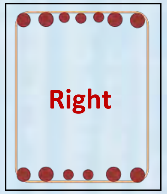
- Rebar design optimization for a beam example
- Predefine a set of weighting factor (w) and generate candidate solutions, as follows:

$$f(w \times Q_{frame} + (1-w) \times C_{frame})$$

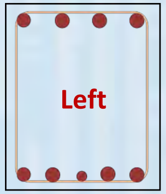


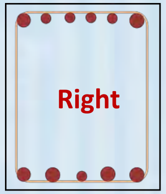






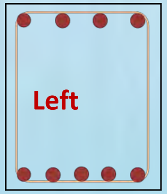
Configurations			Area (mm²)	
			Actual	Required
Top	L	6T16	1206	1100
	M	2T16 + 1T12	515	500
	R	4T16 + 3T10	1040	1000
Bottom	L	4T16 + 4T10	1118	900
	M	2T12 + 4T10	540	500
	R	4T16 + 2T10	961	900
SUM			5380	4900

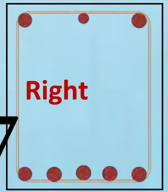




Configurations			Area (mm²)	
			Actual	Required
Top	L	4T20	1257	1100
	M	2T20 + 2T16	1030	500
	R	2T20 + 4T16	1432	1000
Bottom	L	4T16 + 1T12	917	900
	M	4T16 + 1T12	917	500
	R	4T16 + 1T12	917	900
SUM			6470	4900

Configurations			Area (mm²)	
			Actual	Required
Top	L	4T32	3217	1100
	M	2T32	1608	500
	R	2T32 + 1T20	1923	1000
Bottom	L	5T16	1005	900
	M	5T16	1005	500
	R	5T16	1005	900
SUM			9763	4900





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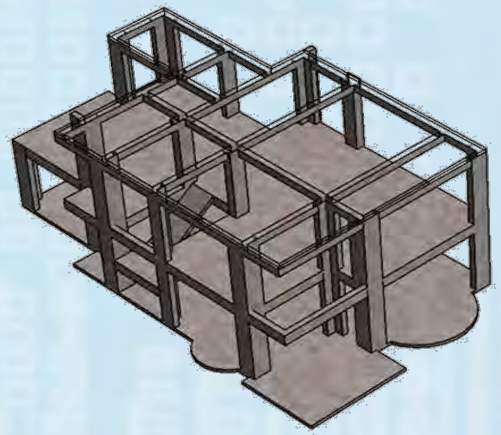
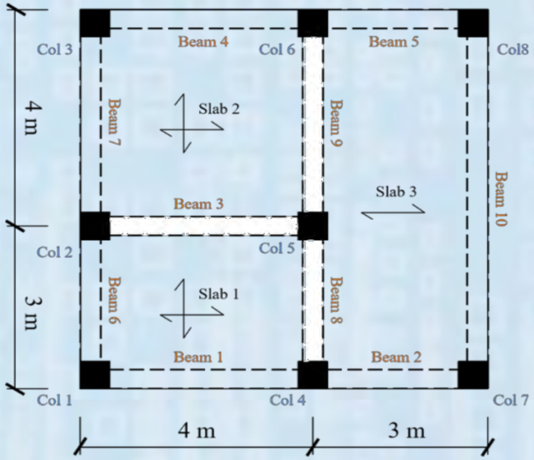
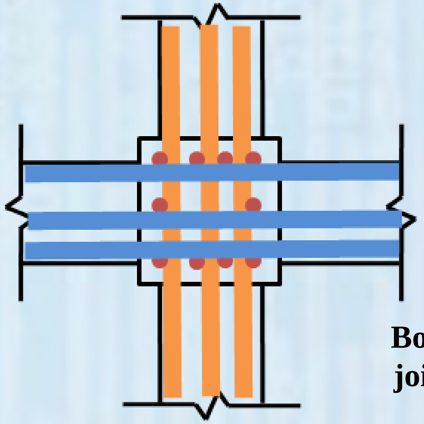
1.2. Rebar Design Optimization

- Implementation of automated steel reinforcement design for different types of structural elements





- An Inner GA algorithm is developed to check whether clash-free solution exists for each joint



Bottom-column joint (top view)

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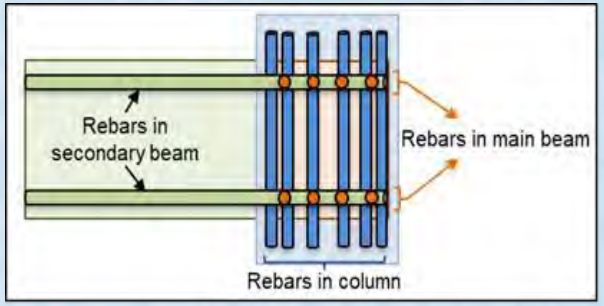
1.3. Parametric Clash Avoidance

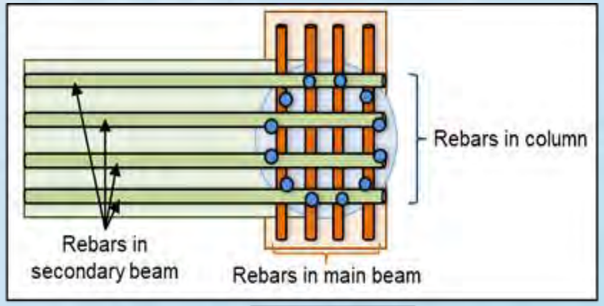
- Generalisation and parametrisation of clash avoidance:
- Vertical avoiding approach: (a) Repositioning, (b) bending of rebars, or (c) both
- Horizontal avoiding approach: (a) Repositioning, (b) bending of rebars, or (c) both
- Vertical avoiding distance: repositioning distance of rebars
- Horizontal avoiding distance: repositioning distance of rebars

To be optimised for the best option

(a) before clash avoidance

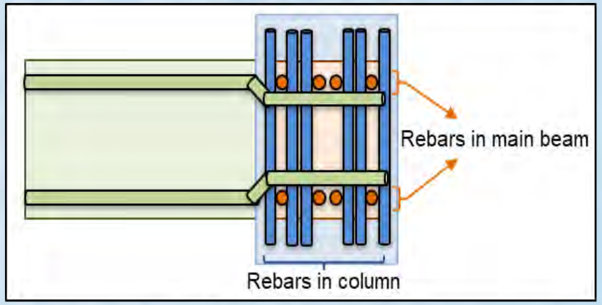


Elevation view

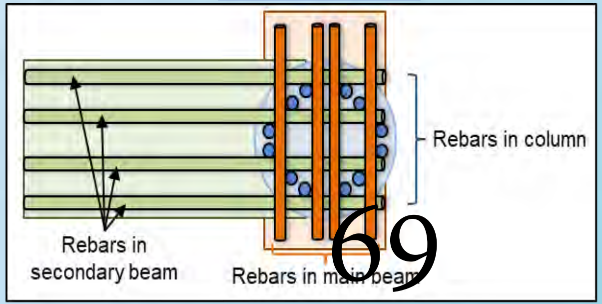


Plan view

(b) after clash avoidance



Elevation view



Plan view

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1.3. Parametric Clash Avoidance

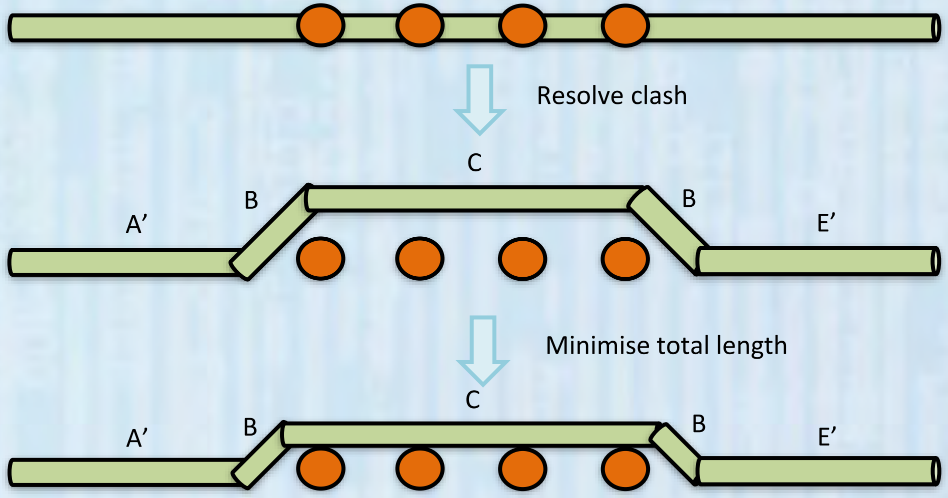
- **Generalised and parametrised clash avoidance – bending rebar shape**
- With given the starting and ending position of rebars,

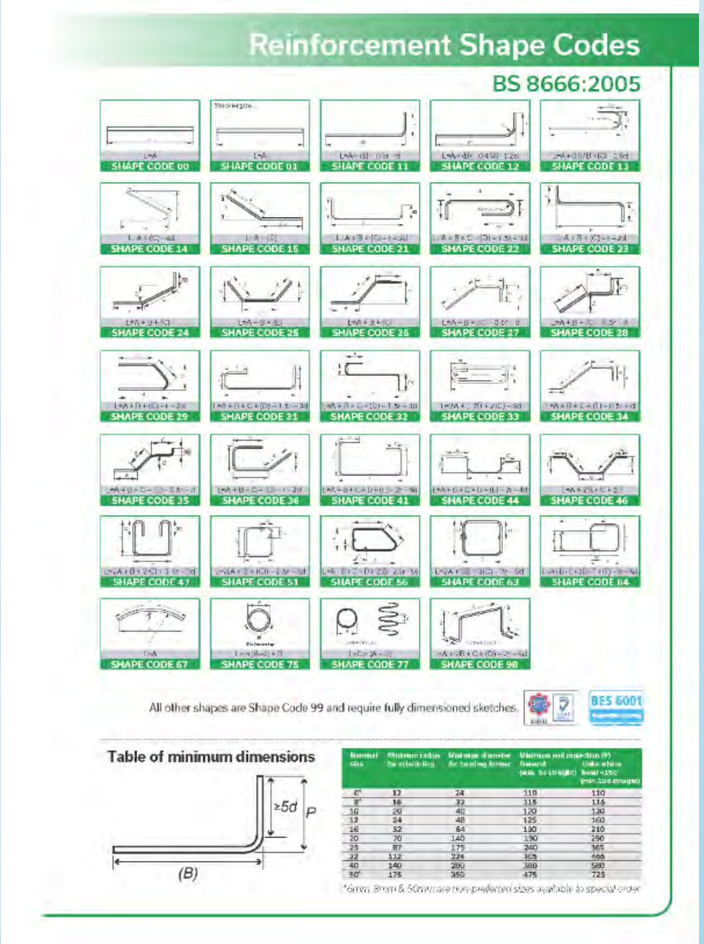
  Minimise total segment length = A’ + B + C + B + E’

  where the clashes can be resolved

  by changing A’ & E’ to mainly adjust the position of the bends

  and changing B & C to avoid the clash





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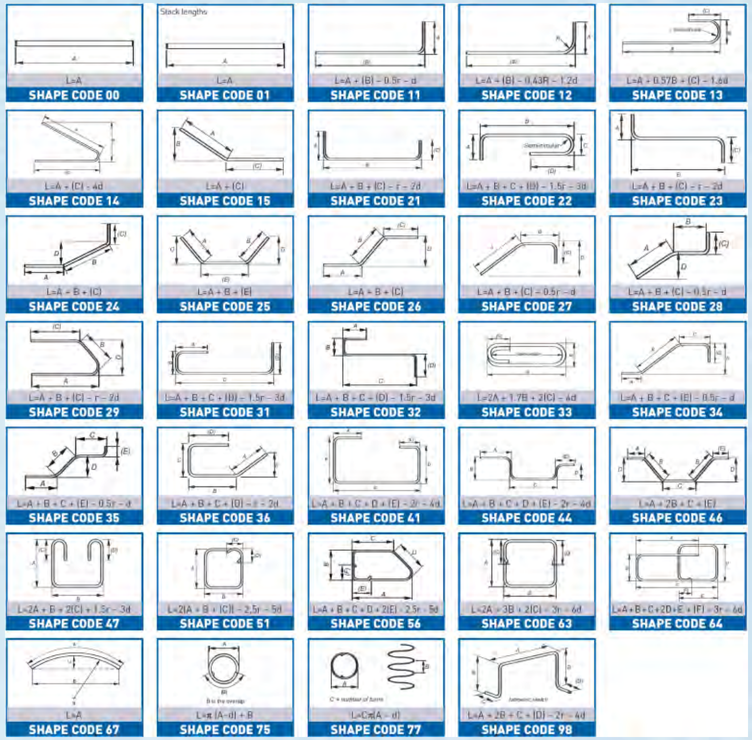
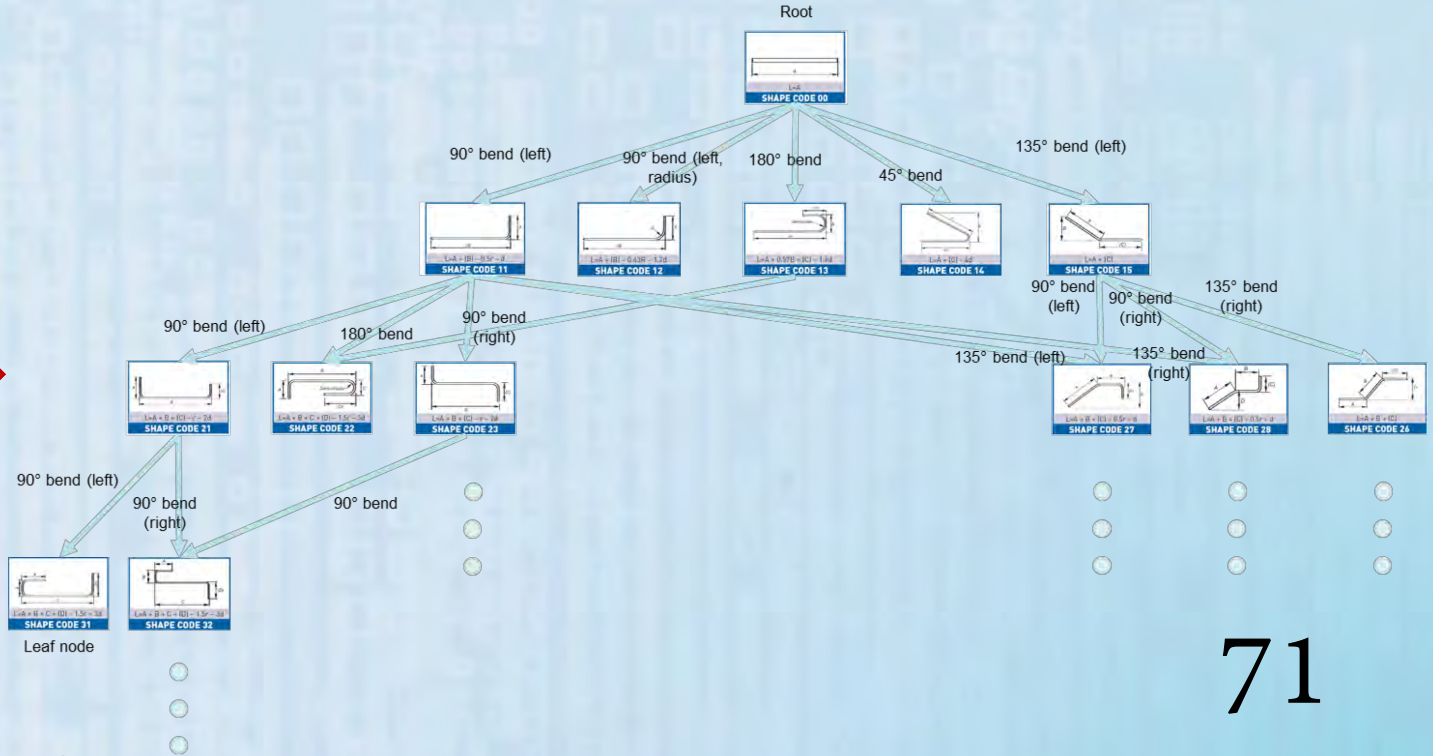
1.3. Parametric Clash Avoidance

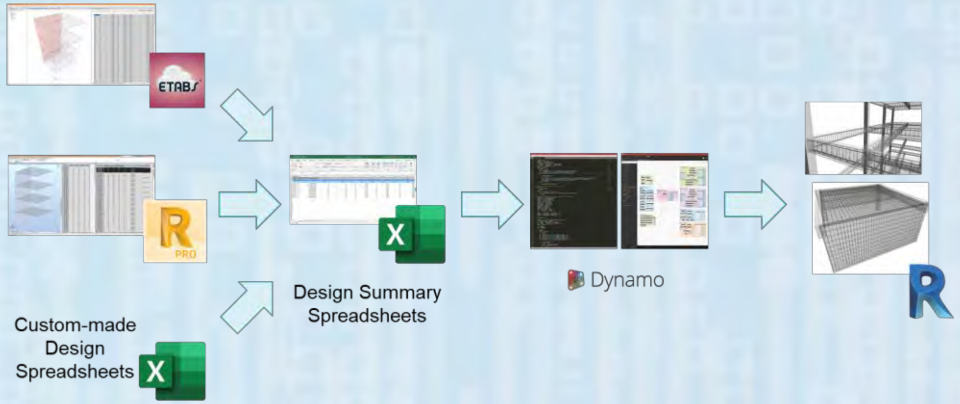
- **A hierarchy tree structure is proposed for maintaining the bending and reshape of rebars**
  - The shape code (BS8666) is used
  - From the root straight shape 00 to the other shapes with different combinations of bending types and orientations





1.3. Parametric Clash Avoidance

- **Illustrative examples**
- **Automatic generation** of rebar BIM model in **Dynamo**
  - ➢ Read inputs from structural analysis software (e.g., Etabs)
  - ➢ Inputs in a spreadsheet



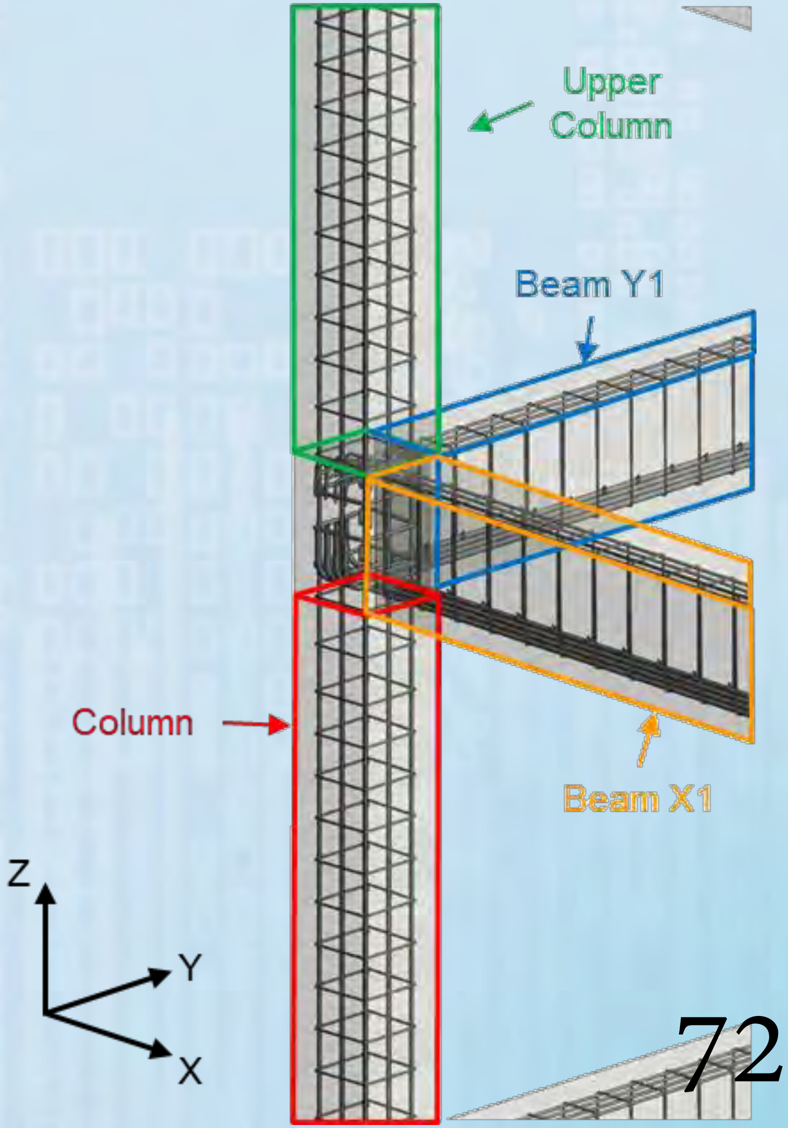


TABLE: Beam-Column Connectivity Desgin Summary								
Story	Column Unique Name	Upper Column Unique Name	Beam X1 Unique Name	Beam X2 Unique Name	Beam Y1 Unique Name	Beam Y2 Unique Name	BCJ Shear Size mm	BCJ Shear Spacing mm
Story4	17		77		113		16	160
Story4	1		65			113	16	160
Story3	18	17	78		114		16	160
Story3	2	1	66			114	16	160
Story2	19	18	79		115		16	160
Story2	3	2	67			115	16	160
Story1	20	19	80		116		16	160
Story1	4	3	68			116	16	160

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Illustrative examples

- **Illustrative examples**
- **Automatic generation** of rebar BIM model in **Dynamo**
  - Read inputs from structural analysis software (e.g., Etabs)
  - Inputs in a spreadsheet

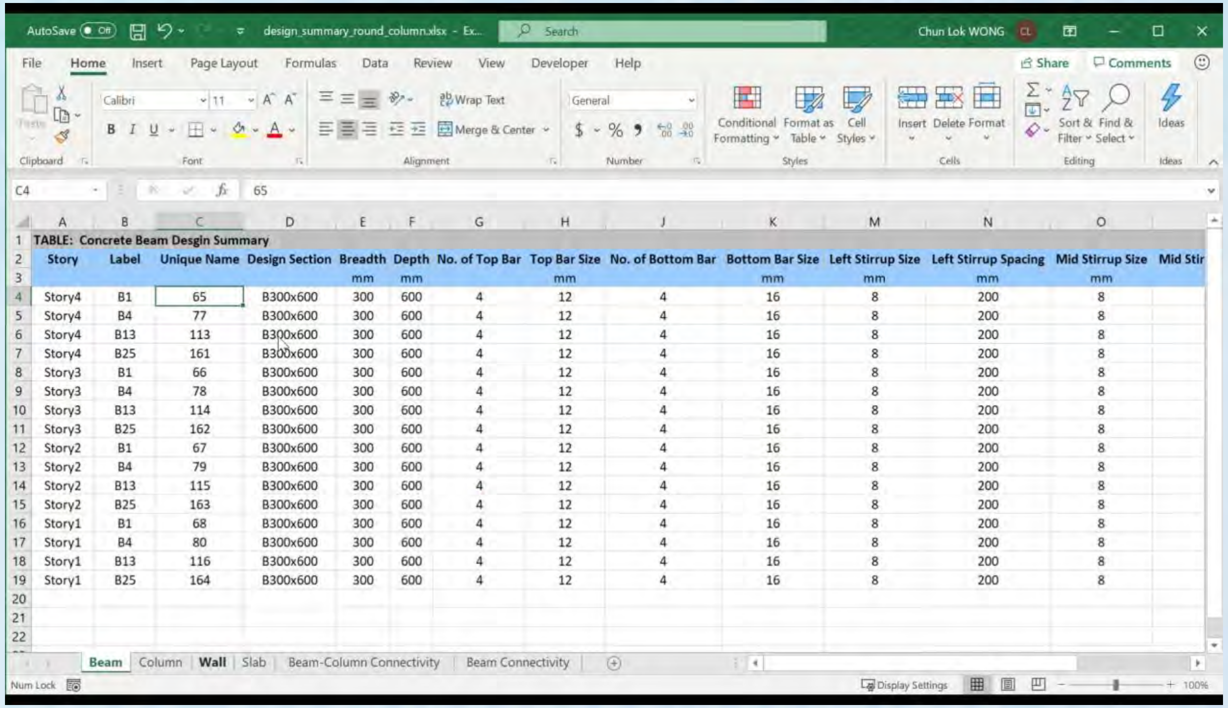
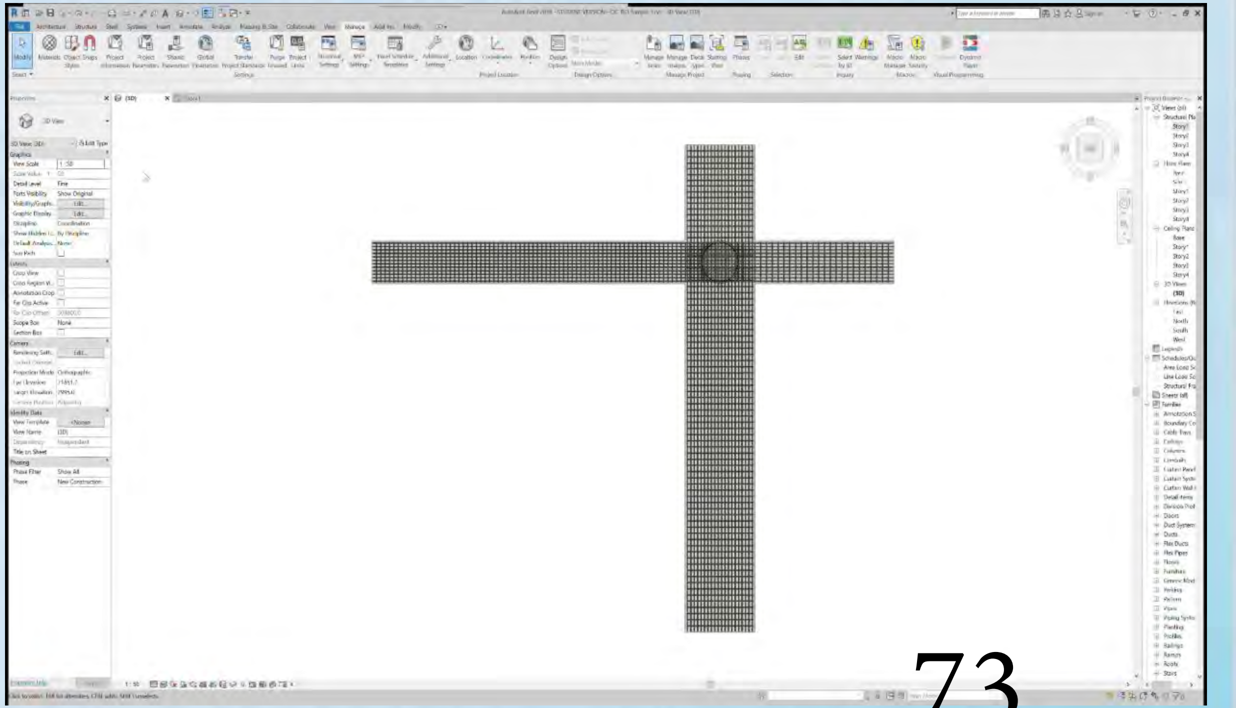


TABLE: Concrete Beam Desgin Summary

Story	Label	Unique Name	Design Section	Breadth	Depth	No. of Top Bar	Top Bar Size	No. of Bottom Bar	Bottom Bar Size	Left Stirrup Size	Left Stirrup Spacing	Mid Stirrup Size	Mid Stir
				mm	mm		mm		mm	mm	mm	mm	
Story4	B1	65	B300x600	300	600	4	12	4	16	8	200	8	
Story4	B4	77	B300x600	300	600	4	12	4	16	8	200	8	
Story4	B13	113	B300x600	300	600	4	12	4	16	8	200	8	
Story4	B25	161	B300x600	300	600	4	12	4	16	8	200	8	
Story3	B1	66	B300x600	300	600	4	12	4	16	8	200	8	
Story3	B4	78	B300x600	300	600	4	12	4	16	8	200	8	
Story3	B13	114	B300x600	300	600	4	12	4	16	8	200	8	
Story3	B25	162	B300x600	300	600	4	12	4	16	8	200	8	
Story2	B1	67	B300x600	300	600	4	12	4	16	8	200	8	
Story2	B4	79	B300x600	300	600	4	12	4	16	8	200	8	
Story2	B13	115	B300x600	300	600	4	12	4	16	8	200	8	
Story2	B25	163	B300x600	300	600	4	12	4	16	8	200	8	
Story1	B1	68	B300x600	300	600	4	12	4	16	8	200	8	
Story1	B4	80	B300x600	300	600	4	12	4	16	8	200	8	
Story1	B13	116	B300x600	300	600	4	12	4	16	8	200	8	
Story1	B25	164	B300x600	300	600	4	12	4	16	8	200	8	



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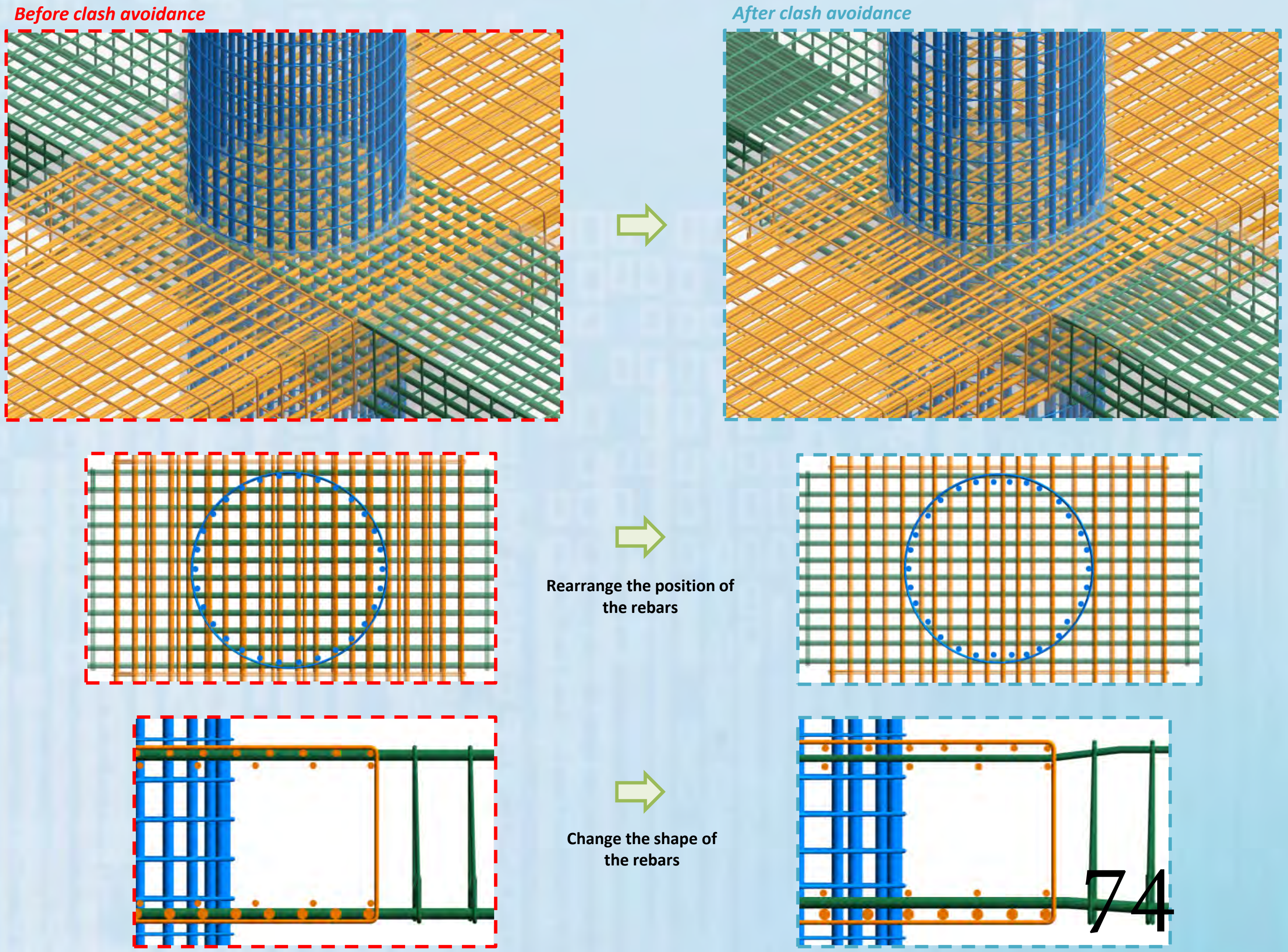
Illustrative examples

- Semi-automatic clash avoidance



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R&D Progress

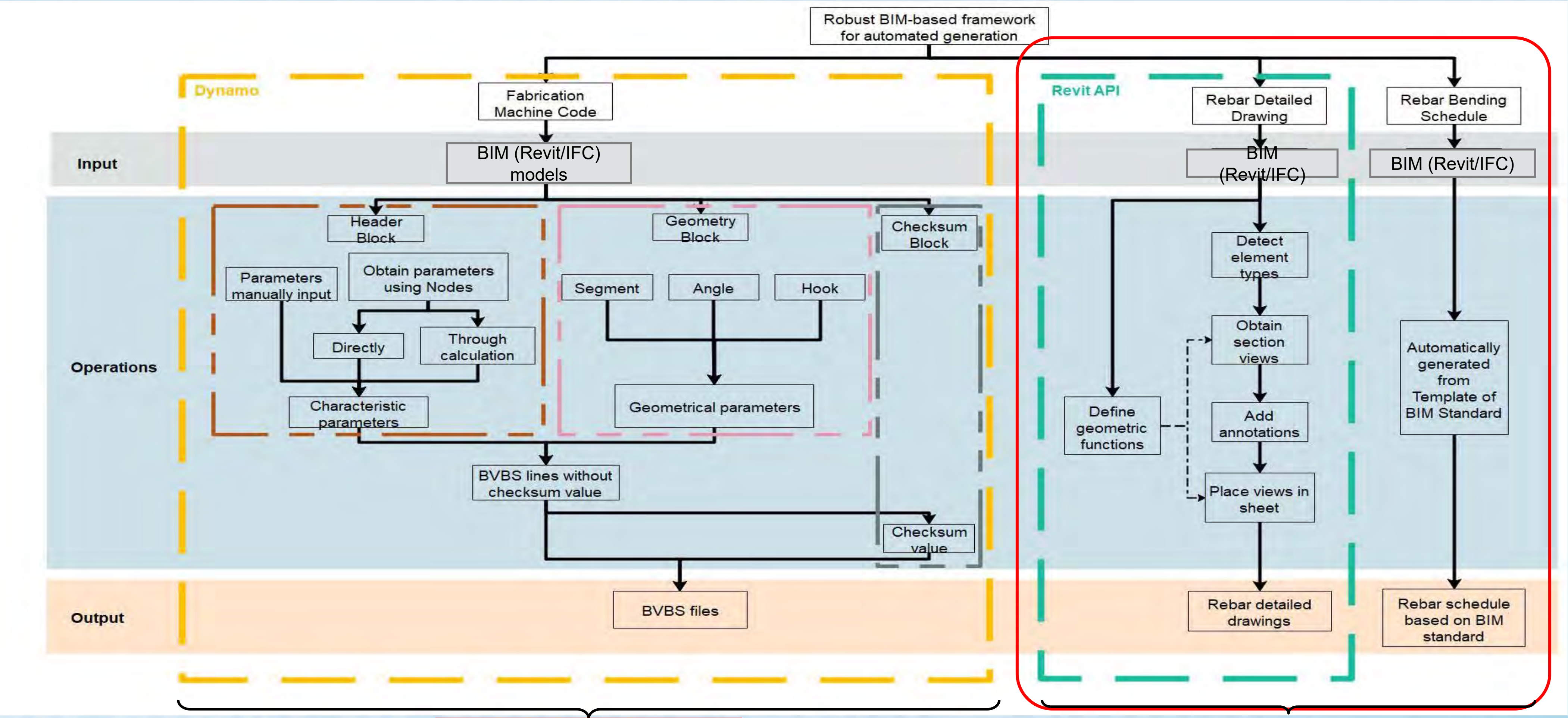
1. Clash-free steel reinforcement design:

1.1. Optimal design formulation
1.2. Rebar design optimization
1.3. Parametric clash avoidance solver

2. Automatic rebar prefabrication:

2.1. Generation of BVBS
2.2. Generation of rebar detail drawings and schedule
2.3. API for automated drawing generation

2. Procedure of Prefabrication Automation



Mostly done

In progress

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2.1. Generation of BVBS

- **Covers all 31 rebar types in the shape code**

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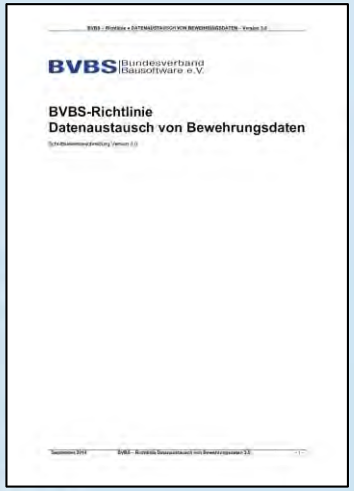


2.1. Generation of BVBS

- BVBS (BundesVereinigung der Bausoftware) is the numerical data structure developed for most types of fabrication machines to perform rebar cutting and bending
  - V3.0 published in Sept 2019
  - In German

j	r	i	p	l	n	e	d	g	s
Project#	Drawing#	Revision#	Position	Length	Amount	Mass Unit	Diameter	Steel Grade	Bending Diameter

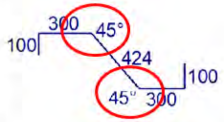
Header Block

Checksum Block

```
BF2D@H P1@rL1@iLI1@p5@12350@n0@e1.448@d10@gH@s40@v@G 130@w90@r260@w452.8@w90@1130@w0@C96@
BF2D@H P1@rL1@iLI1@p6@12350@n0@e1.448@d10@gH@s40@v@G 130@w90@r260@w452.8@w90@1130@w0@C95@
BF2D@H P1@rL1@iLI1@p1@12550@n0@e1.571@d10@gH@s40@v@G 2540@w0@C80@
BF2D@H P1@rL1@iLI1@p2@12775@n0@e1.709@d10@gH@s40@v@G 130@w90@12540@w90@1130@w0@C67@
BF3D@H P1@rL1@iLI1@p3@11600@n0@e0.986@d10@gH@s40@v@Gx0@y0@z490@x0@y170@z0@x290@y0@z0@x0@y-170@z0@x0@y0@z490@C94@
BF2D@H P1@rL1@iLI1@p4@13250@n0@e2.002@d10@gH@s40@v@G 260@w90@180@w90@1180@w-90@12770@w0@C74@
```

Terminator of attributes

Beispiel 3:



Der Geometrieblock lautet:
Gl100@w90@l300@w45@l424@w-45@l300@w-90@l100@w0@

Der vollständige Datensatz lautet:
BF2D@Hj**TestPDF**@r**417**@ia@p**1**@l**1224**@n**10**@e**1.087**@d**12**@g**B500A**@s**48**@v@
Gl100@w90@l300@w45@l424@w-45@l300@w-90@l100@w0@
C65@CRLF

(113 Zeichen)

Shape Type Group
Two-dimensional rebar(BF2D)
Three-dimensional rebar(BF3D)
Spiral links(BFWE)
Mesh(BFMA)
Lattice girders(BFGT)

Involved in the example (2D & 3D)

Geometry Block

l	w	r	x, y, z
Segment Length	Angle	Radius (For curved segments)	Coordinates

Block	
Shape Type Group	Recognition code
Header Block (H)	Provides data about identification and characteristics of the rebar
Geometry Block (G)	Describes the rebar's shape bending geometry
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

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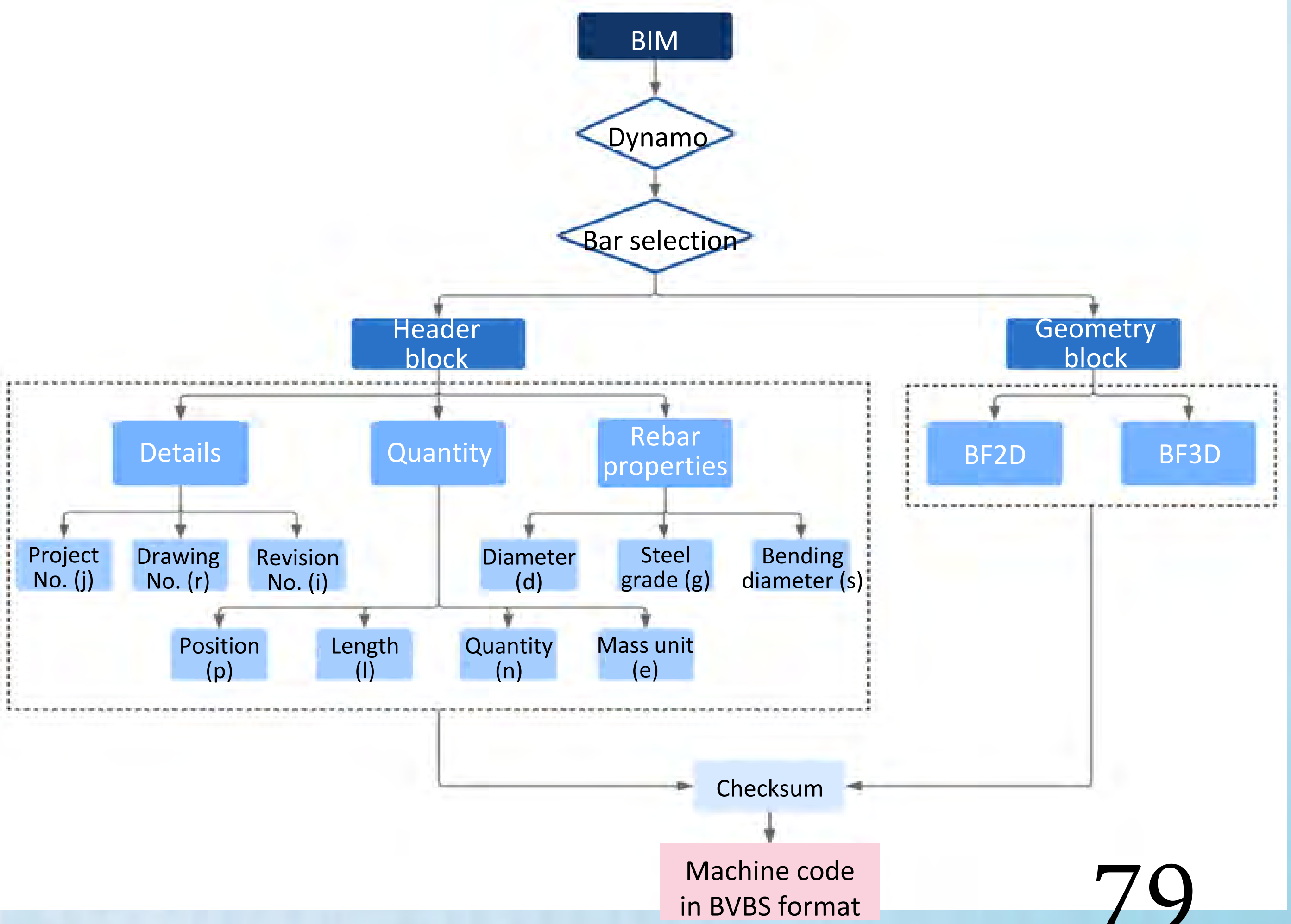
2.1. Generation of BVBS

- From IFC-based BIM model to BVBS
- Input: BIM model (Revit / IFC)
- Output: BVBS strings
- Tool:
  - Revit 2020
  - Dynamo 2.1.0



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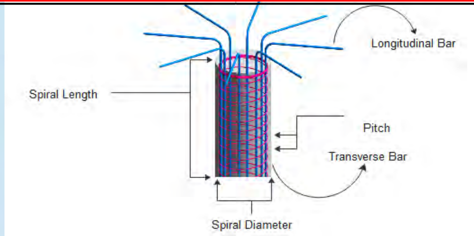
2.1. Generation of BVBS

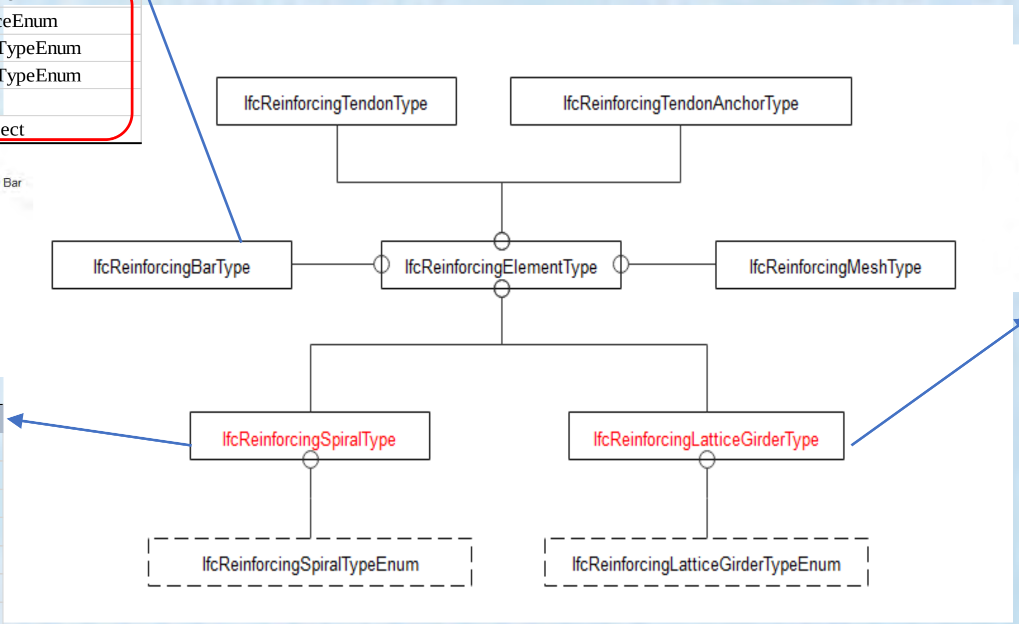
- From IFC-based BIM model to BVBS – extension of IFC schema

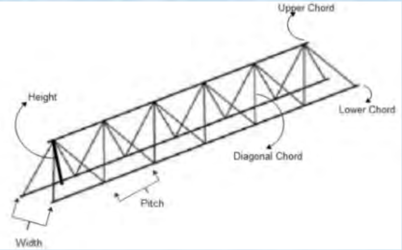
#	Attribute	Type
10	PredefinedType	IfcReinforcingBarTypeEnum
11	MarkNumber	IfcReal
12	NominalDiameter	IfcPositiveLengthMeasure
13	CrossSectionArea	IfcAreaMeasure
14	BarLength	IfcPositiveLengthMeasure
15	MassUnit	IfcPositiveLengthMeasure
16	BarSurface	IfcReinforcingBarSurfaceEnum
17	HookAtStart	IfcReinforcingBarHookTypeEnum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

Existing Attributes

Extended Attributes







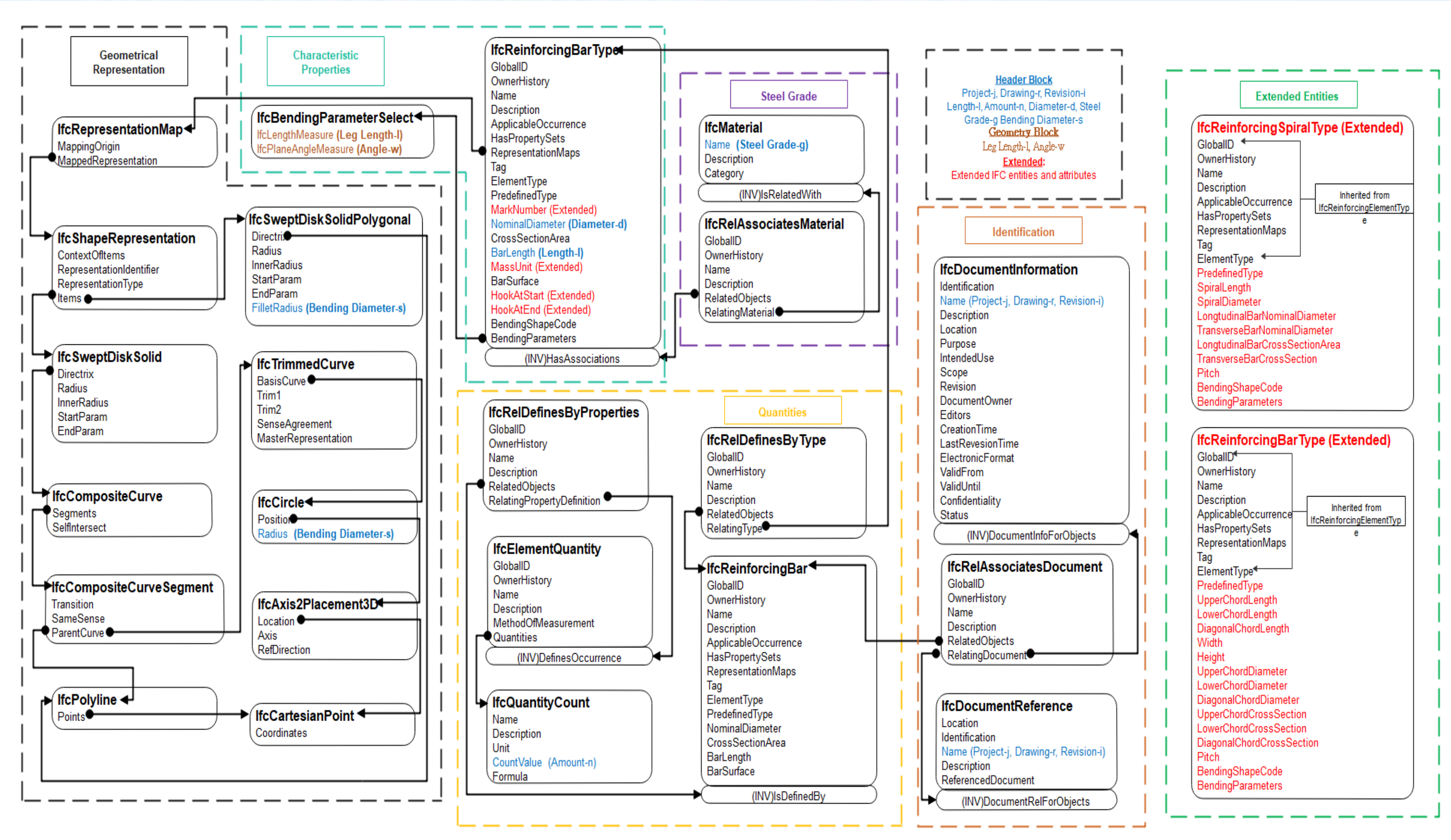
#	Attribute	Type
10	PredefinedType	IfcReinforcingSpiralTypeEnum
11	SpiralLength	IfcPositiveLengthMeasure
12	SpiralDiameter	IfcPositiveLengthMeasure
13	LongtudinalBarNominalDiameter	IfcPositiveLengthMeasure
14	TransverseBarNominalDiameter	IfcPositiveLengthMeasure
15	LongtudinalBarCrossSectionArea	IfcAreaMeasure
16	TransverseBarCrossSection	IfcAreaMeasure
17	Pitch	IfcPositiveLengthMeasure
18	BendingShapeCode	IfcLabel
19	BendingParameters	IfcBendingParameterSelect

#	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

Extended Entities

2.1. Generation of BVBS

- From IFC-based BIM model to BVBS – extension of IFC schema



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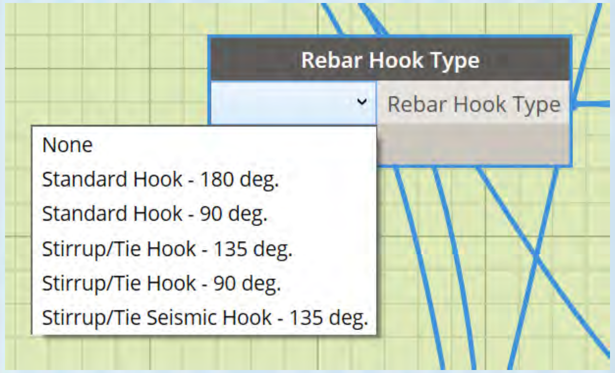
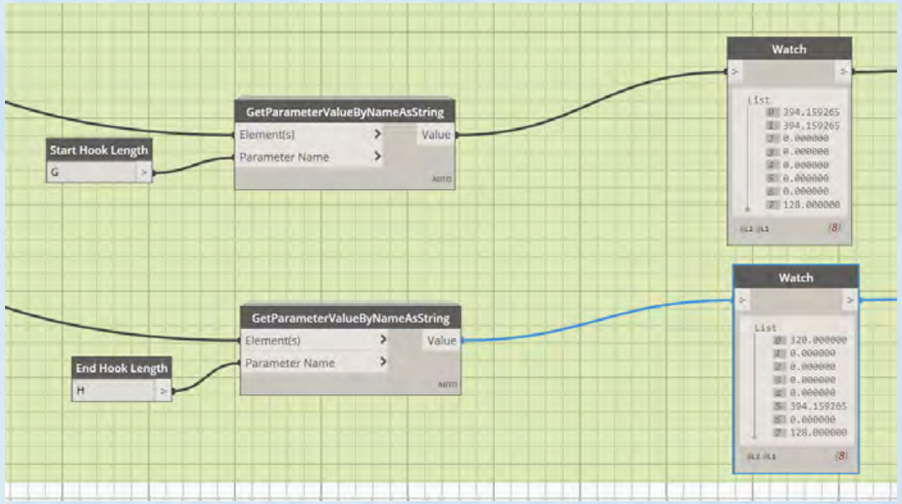
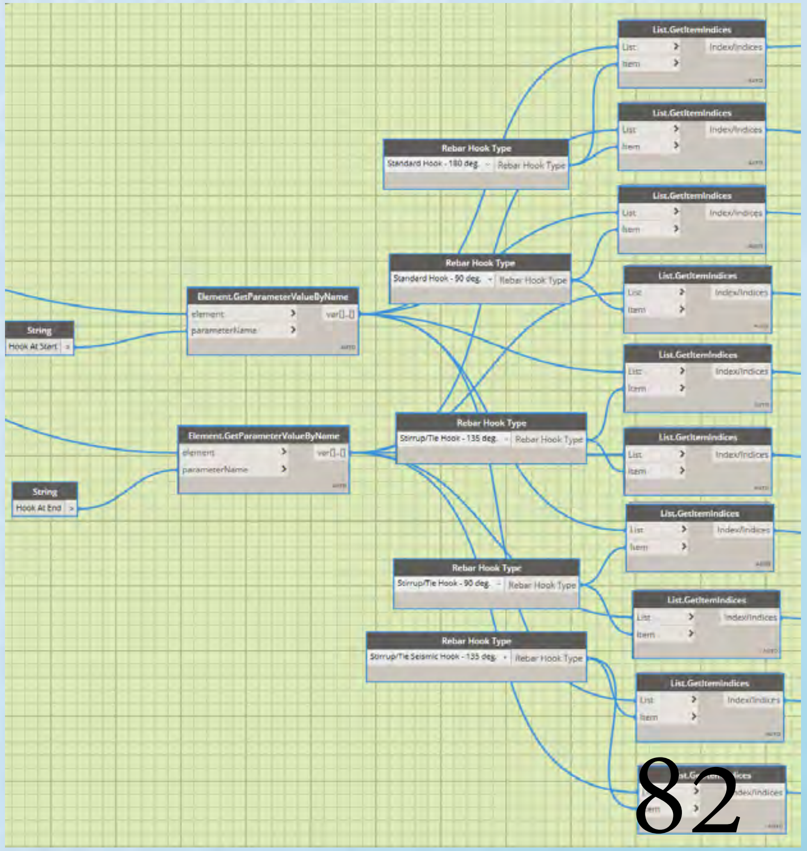
2.1. Generation of BVBS

- Geometry Block in BVBS defines the shape of rebar (Counter clockwise: Positive)
  - Segment length + Angle + Segment length + Angle + Segment length + …
- Hook
  - Hook Angle
  - Index of rebar with hook
  - Start/End Hook Length (Segment G&H)



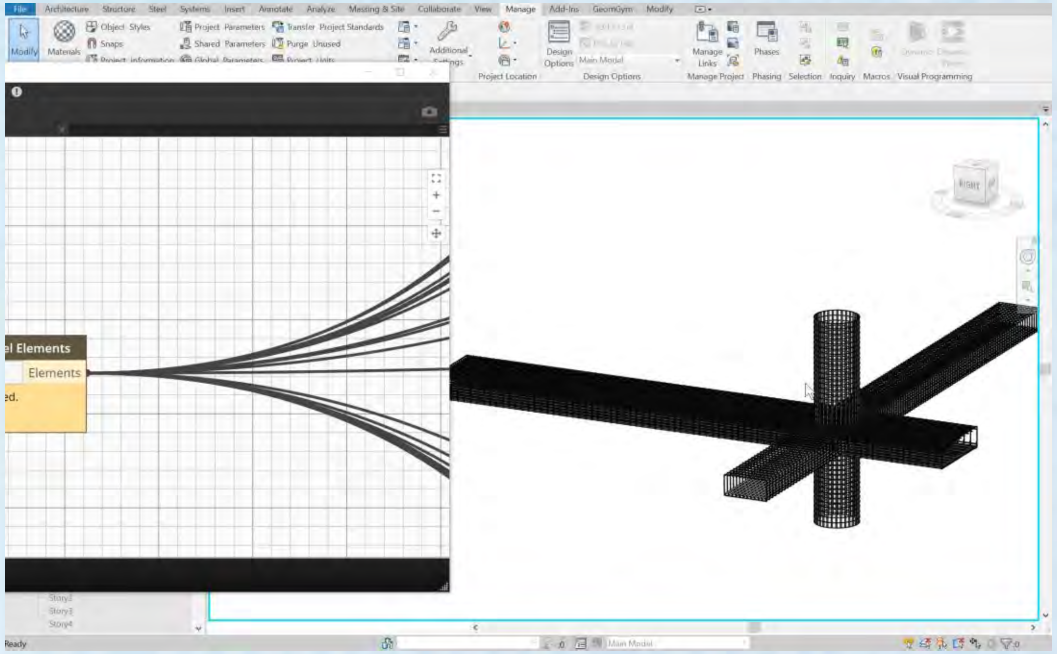




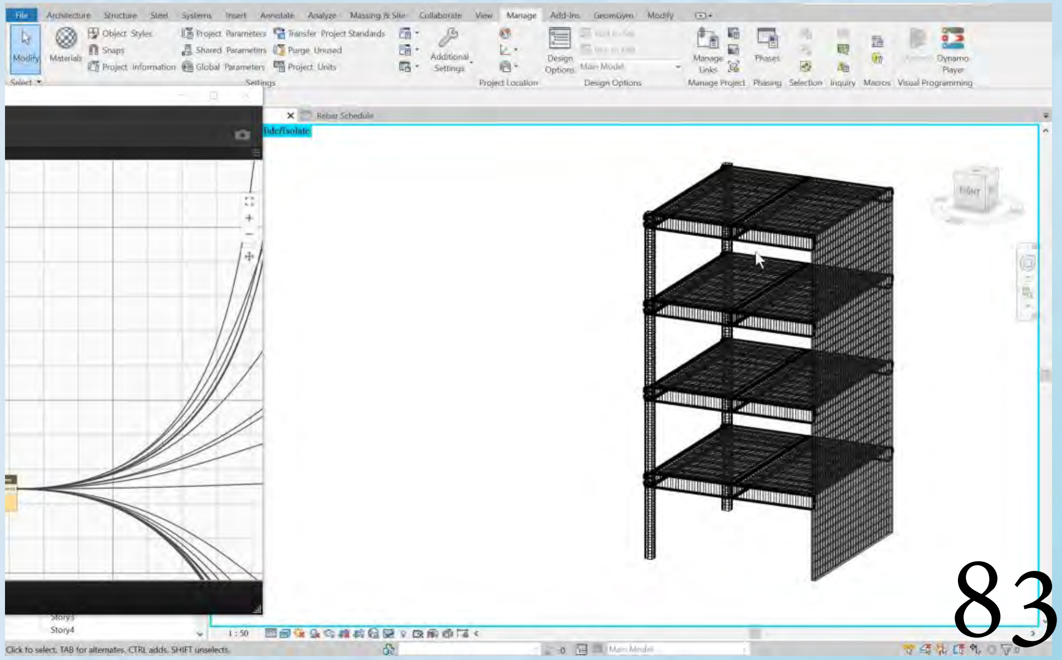
2.1. Generation of BVBS

- Illustrative examples using the developed Dynamo program
- Tool:
  - Revit 2020
  - Dynamo 2.1.0

Circular column joint

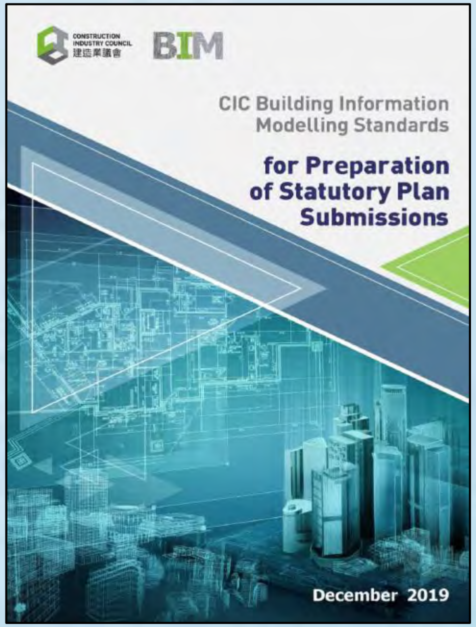


RC frame structure



2.2. Generation of Bar Drawings and Bending Schedules

- Automatic generation of rebar schedule and detailed drawing is based on



Sheets (all)
- E001 - EXCAVATION & LATERAL SUPPORT GENERAL NOTES
- E002 - EXCAVATION & LATERAL SUPPORT LAYOUT PLAN
- E003 - EXCAVATION & LATERAL SUPPORT SECTIONS (1 OF 2)
- E004 - EXCAVATION & LATERAL SUPPORT SECTIONS (2 OF 2)
- E005 - EXCAVATION & LATERAL SUPPORT CONSTRUCTION SEQUENCE (1 OF 2)
- E006 - EXCAVATION & LATERAL SUPPORT CONSTRUCTION SEQUENCE (2 OF 2)
- E007 - EXCAVATION & LATERAL SUPPORT ELEVATION
- E008 - EXCAVATION & LATERAL SUPPORT WORKS MONITORING PLAN
- E009 - EXCAVATION & LATERAL SUPPORT WORKS PUMPING TEST SETTING OUT PLAN
- P001 - GENERAL NOTES FOR FOUNDATION
- P002 - PILING LAYOUT PLAN
- P003 - PILING SECTION A & SECTION B
- P004 - PILING SECTION C
- P005 - COLUMN / WALL LOADING PLAN
- P006 - COLUMN / WALL LOADING SCHEDULE
- P007 - LOADING INTENSITY PLAN
- P008 - PILE LOAD SCHEDULE
- P009 - FOUNDATION MONITORING PLAN
- P010 - PILE CAP REINFORCEMENT LAYOUT PLAN (1 OF 2)
- P010A - PILE CAP REINFORCEMENT LAYOUT PLAN (2 OF 2)
- P011 - COLUMN AND WALL STARTER DETAILS
- P11a - COLUMN AND WALL STARTER DETAILS
- P012 - TIE BEAM DETAILS & SCHEDULE
- P013 - PILE CAP LAYOUT PLAN
- P014 - GENERAL NOTES FOR PILE CAP
- R001 - STEEL STRUCTURE FLOOR PLAN
- R002 - STEEL STRUCTURE DETAIL
- S001 - GENERAL NOTES FOR SUPERSTRUCTURE
- S002 - TYPICAL FLOOR FRAMING PLAN
- S003 - BEAM R.C. SCHEDULE
- S004 - BEAM R.C. DETAIL
- S005 - COLUMN R.C. DETAIL
- S005a - COLUMN R.C. DETAIL
- S006 - WALL R.C. DETAIL (1 OF 2)
- S007 - WALL R.C. DETAIL (Schedule)
- S008 - WALL R.C. DETAIL (2 OF 2)
- S009 - SLAB R.C. DETAIL
- S010 - STAIRCASE R.C. DETAIL
- S011 - WATER TANK R.C. DETAIL

Sheets in Template

Two sheets needed for each component which consists of two types of drawings respectively:
- Drafting view
- Real section views & elevation views

External software (CAD) is needed for drafting views

Sheets covered in the project	Included drawings & schedules
Beam RC Schedule	• RC Beam Schedule • Beam RC Detail
Beam RC Detail	• Beam RC Detail
Column RC Detail	• Column Rebar Table • Column Beam Joint Detail • Column Critical Zone
Wall RC Detail	• Wall RC Detail Legend • RC Wall Schedule • Wall RC Detail
Wall RC Detail (Schedule)	• Wall RC Table
Slab RC Detail	• Slab RC Details

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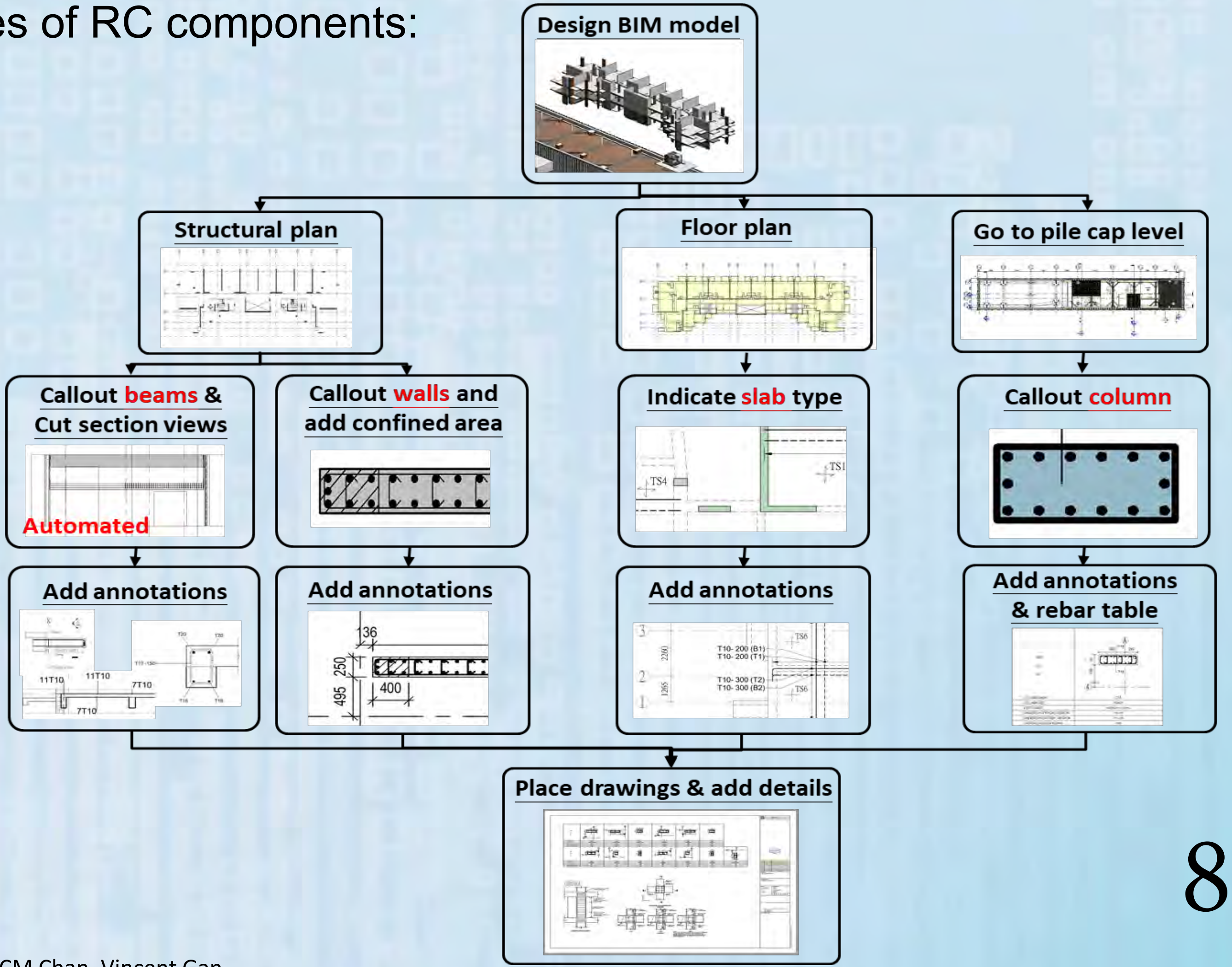
2.2. Generation of Bar Drawings and Bending Schedules

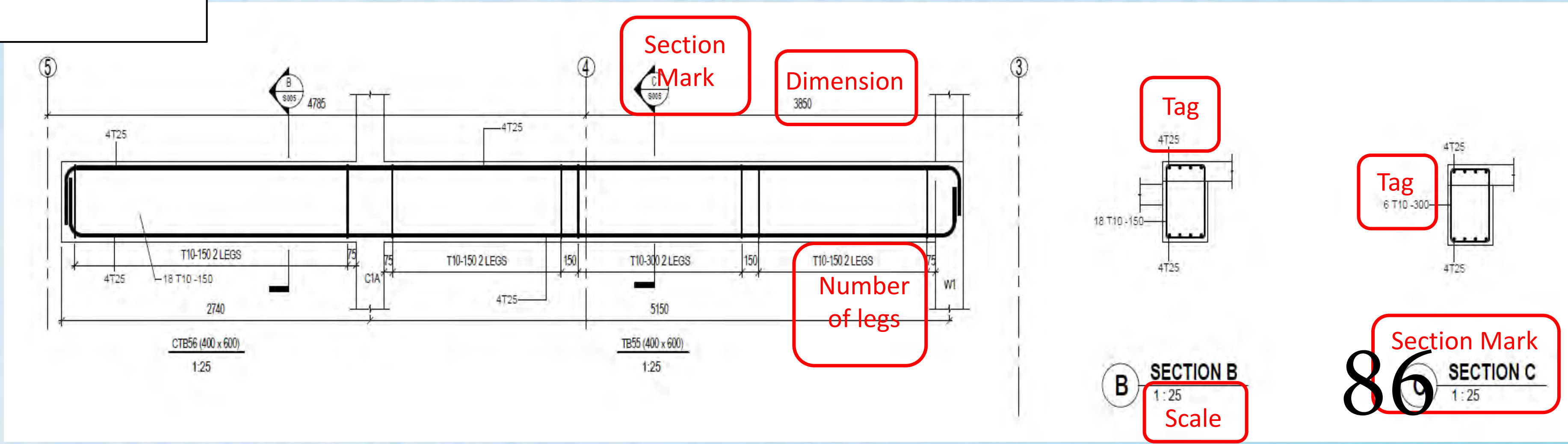
- Proposed framework for different types of RC components:



2.2. Generation of Bar Drawings and Bending Schedules

- Beam R. C. Detail - examples

Key elements of Beam R. C. Detail
- **View**
  - **Elevation view**
  - **Section view**
- **Annotation**
  - **Tag : Shape & Spacing(only for stirrups)**
  - **Dimension**
  - **Number of legs**
  - **Section mark**
  - **Scale**



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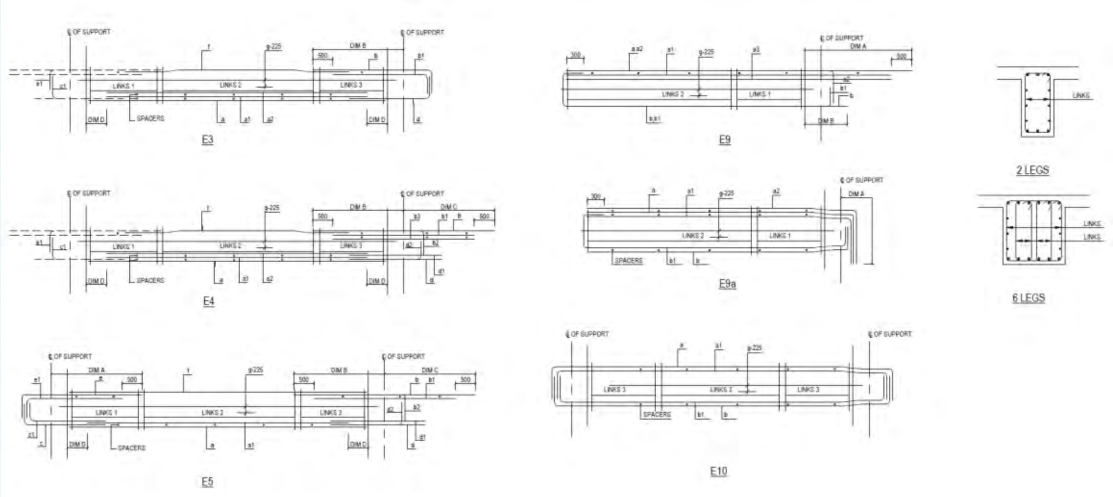
2.2. Generation of Bar Drawings and Bending Schedules

- Beam R. C. Schedule - examples

R.C. BEAM SCHEDULE

BEAM MARK	BEAM SIZE (BXD)	ELEV. REFER	REINFORCEMENT a	a1	a2	b	b1	c	d	e	f	g	LINKS 1	LINKS 2	LINKS 3	DIMENSION A	B	C	D
CTB1	200 x 300	E9	2T20	-	-	-	2T16	-	-	-	-	-	←	T10-150(2 LEGS)	→	2550	-	-	-
CTB1a	200 x 300	E9	2T20	-	-	-	2T16	-	-	-	-	-	←	T10-150(2 LEGS)	→	2550	-	-	-
CTB51	200 x 600	E9a	2T20	2T20	2T20	2T20	-	-	-	-	-	T10-225 E.F.	←	T10-150(2 LEGS)	→	1000	-	-	-
CTB54	200 x 600	E9a	2T20	2T20	2T20	2T20	-	-	-	-	-	T10-225 E.F.	←	T10-150(2 LEGS)	→	1000	-	-	-
TB2	200 x 300	E10	2T16	-	-	2T16	-	-	-	-	-	-	←	T10-200(2 LEGS)	→	-	-	-	-
TB3	400 x 600	E5	4T25	-	-	4T25	-	4T25	4T25	4T25	4T20	-	←	T10-200(4 LEGS)	→	-	1300	1000	-
TB4	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1000	1800	-
TB5	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1800	-
TB6	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1800	-
TB7	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1800	-
TB8	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1800	-
TB9	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1800	-
TB10	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1800	1000	-
TB11	400 x 600	E4	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(2 LEGS) TORSIONAL LINKS + T10	→	-	1000	1300	-
TB12	400 x 600	E3	4T25	-	-	4T25	-	-	4T25	-	4T20	-	←	T10-200(4 LEGS)	→	-	-	-	-
TB13	250 x 600	E10	2T25	-	-	2T25	-	-	-	-	-	-	←	T10-200(2 LEGS)	8T16-200(2 LEGS)	-	-	-	-
TB14	250 x 600	E10	2T25	-	-	2T25	-	-	-	-	-	-	←	T10-200(2 LEGS)	8T16-200(2 LEGS)	-	-	-	-



Key parameters of R.C. Beam Schedule

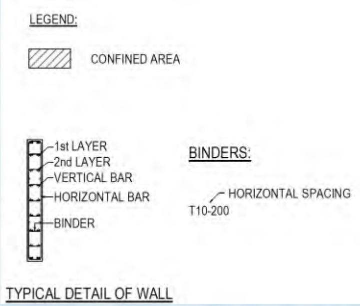
- Beam mark & size
- Elevation reference
- Reinforcement
  - Location
  - Shear links
- Dimension

Changed key elements of Beam R. C. Detail (Schedule version)

- Annotation
  - Size & quantity => Location
  - Center line of support
  - No section mark
  - No scale

2.2. Generation of Bar Drawings and Bending Schedules

- Wall R. C. Detail Legend
- R. C. Wall Schedule



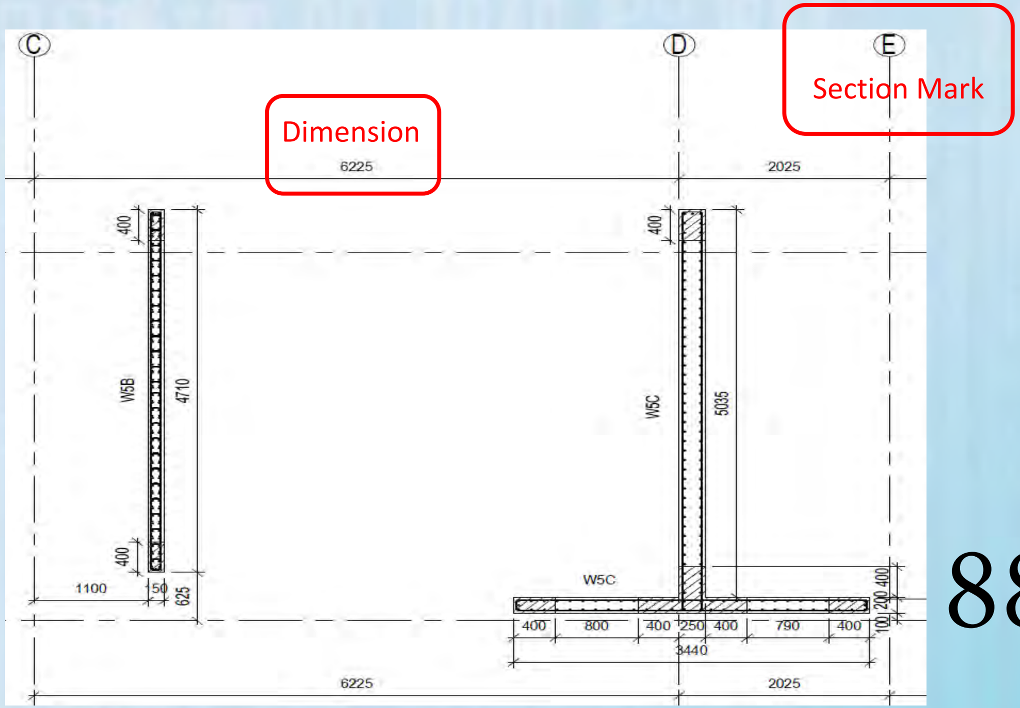
R.C. WALL SCHEDULE

FLOOR	WALL MARK	CONCRETE GRADE	THICKNESS (mm)	VERTICAL BARS	HORIZONTAL BARS	BINDER		STEEL RATIO (%)
						HORIZONTAL	VERTICAL	
3/F	W1	C60	250	T40-150	T10-150	T12-300	150	3.4
3/F	W2	C60	250	T25-125	T12-125			1.3
3/F	W3	C60	200	T20-125	T10-100			1.3
3/F	W4	C60	150	T20-150	T10-150			1.4
3/F	W4	C60	200	T20-125	T10-100			1.3
3/F	W5A	C60	200	T20-125	T10-100			1.3
3/F	W5A	C60	250	T25-125	T12-125			1.6
3/F	W5B	C60	150	T20-100	T10-150	T12-200	150	2.1

Key elements of R. C. Wall Schedule
- **Floor**
- **Wall Mark**
- **Concrete grade**
- **Thickness**
- **Bars**
- **Binders**
- **Steel ratio**

(Bars / Binders:)
- Horizontal
- vertical

Key elements of WALL R. C. Detail
- **Dimensions**
- **Section marks**



Different from beam details

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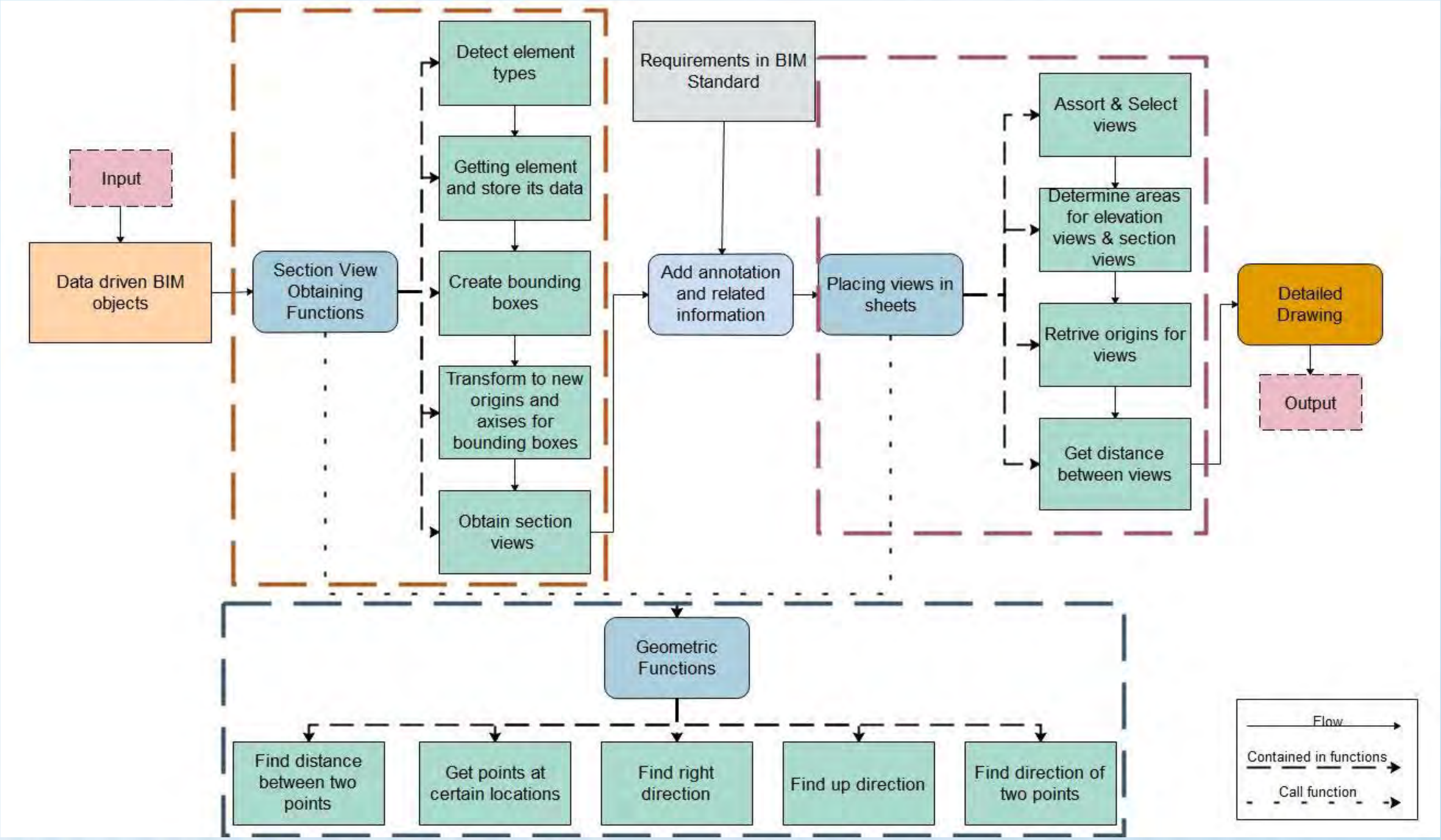
2.2. Generation of Bar Drawings and Bending Schedules

- Proposed framework for generation of detailing drawings and rebar bending schedule:



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2.3. API for Automated Drawing Generation

- Obtain views
  - Obtain the horizontal component
  - Predefine functions to determine locations

```
2 references
public static Autodesk.Revit.DB.XYZ FindMidPoint(Autodesk.Revit.DB.XYZ first, Autodesk.Revit.DB.XYZ second)
{
    double x = (first.X + second.X) / 2;
    double y = (first.Y + second.Y) / 2;
    double z = (first.Z + second.Z) / 2;
    Autodesk.Revit.DB.XYZ midPoint = new Autodesk.Revit.DB.XYZ(x, y, z);
    return midPoint;
}

1 reference
public static Autodesk.Revit.DB.XYZ FindFirPoint(Autodesk.Revit.DB.XYZ first, Autodesk.Revit.DB.XYZ second)
{
    double x = (first.X + second.X) / 8;
    double y = (first.Y + second.Y) / 2;
    double z = (first.Z + second.Z) / 2;
    Autodesk.Revit.DB.XYZ firPoint = new Autodesk.Revit.DB.XYZ(x, y, z);
    return firPoint;
}

1 reference
public static Autodesk.Revit.DB.XYZ FindSecPoint(Autodesk.Revit.DB.XYZ first, Autodesk.Revit.DB.XYZ second)
{
    double x = (first.X + second.X)*7 / 8;
    double y = (first.Y + second.Y) / 2;
    double z = (first.Z + second.Z) / 2;
    Autodesk.Revit.DB.XYZ secPoint = new Autodesk.Revit.DB.XYZ(x, y, z);
    return secPoint;
}
```

1. Determine locations of section views

2.3. API for Automated Drawing Generation

- Obtain views
  - After obtaining bounding boxed, functions of location determination are called
  - Origins and axis need to be adjusted

```
BoundingBoxXYZ m_box;       // Store the BoundingBoxXYZ reference used in creation
BoundingBoxXYZ m_box1;
BoundingBoxXYZ m_box2;
```

```
Boolean GenerateBoundingBoxXYZ()
{
    Transaction transaction = new Transaction(m_project.Document, "GenerateBoundingBox");
    transaction.Start();
    // First new a BoundingBoxXYZ, and set the MAX and Min property.
    m_box = new BoundingBoxXYZ();
    m_box.Enabled = true;
    Autodesk.Revit.DB.XYZ maxPoint = new Autodesk.Revit.DB.XYZ(LENGTH, LENGTH, 0);
    Autodesk.Revit.DB.XYZ minPoint = new Autodesk.Revit.DB.XYZ(-LENGTH, -LENGTH, -HEIGHT);
    m_box.Max = maxPoint;
    m_box.Min = minPoint;

    // Set Transform property is the most important thing.
    // It define the Orgin and the directions(include RightDirection,
    // UpDirection and ViewDirection) of the created view.
    Transform transform = GenerateBeamTransform();
    if (null == transform)
    {
        return false;
    }
    m_box.Transform = transform;
    transaction.Commit();

    // If all went well, return true.
    return true;
}
```

Pre-defined parameters for bounding boxes

2. Generate multiple bounding boxes

3. Transform to new origins and axis

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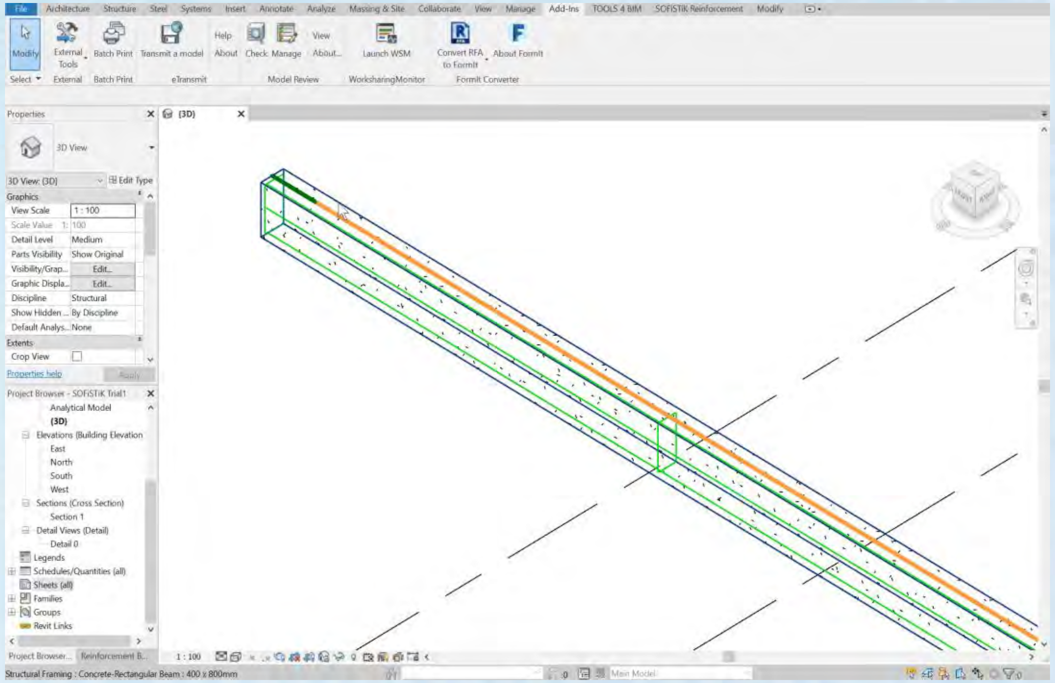
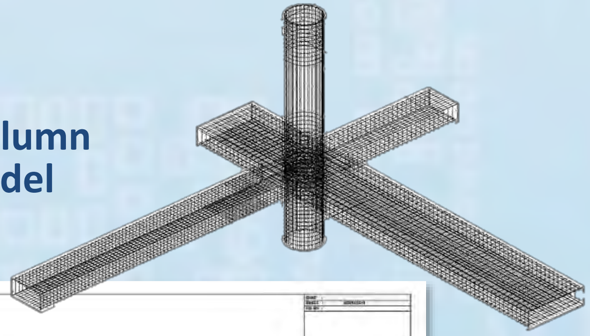
2.3. API for Automated Drawing Generation

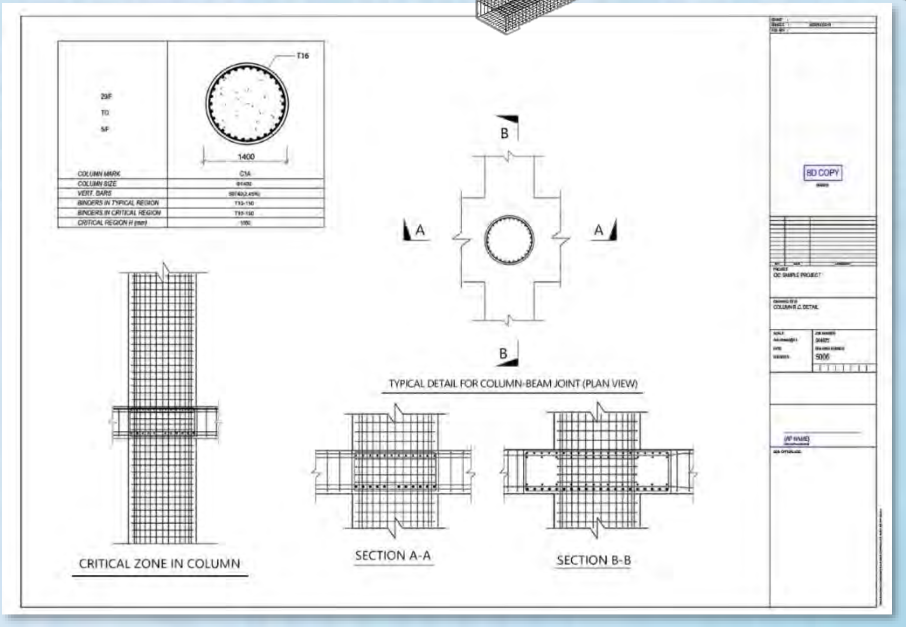
- As the target output, sample drawing is generated based on a joint model
- Tools:
  - Revit API 2020
  - Revit SDK 2020

Cutting and placing views



Circular column joint model





Sample drawing from proposed framework in accordance with BIM standard

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Future Agenda

Future Work

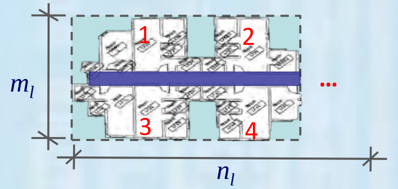
- Design optimization:
  1. To carry out design optimization for shear walls using genetic algorithms
  2. To enhance the automatic parametric clash avoidance solver and extend its applicability to different RC joints

- Automated prefabrication:
  1. To verify the BVBS code generation from rebar BIM models (testing in prefabrication yard)
  2. To improve automatic generation of rebar drawings (testing with pilot site from HKHA)

- Pilot Study:
  1. Identify and decide the pilot site (e.g., Wing Tai Road, HA projects)

Relevant R&D – Design of Modular High-rise

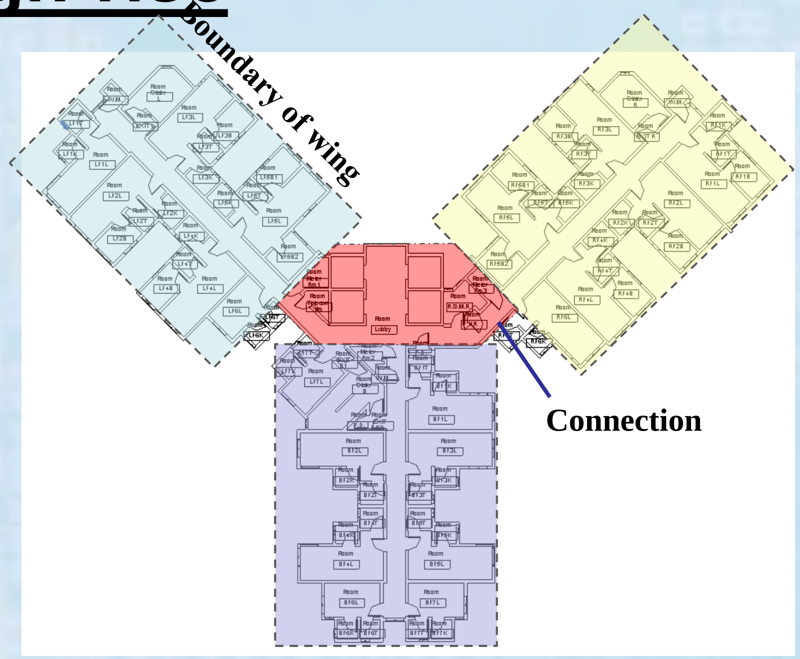
- Combination of modular flats for each wing



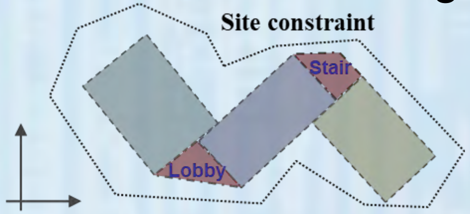
$$\sum_{l=1}^{L} F_w^l = F_w^1 + F_w^2 + \cdots + F_w^L$$

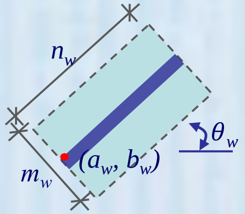
Design constraints for wing:

- Topology
- Dimension of wing



Geometric combination of wings and connections





$$\tau = \sum_{w=1}^{W} \sum_{l=1}^{L} F_w^l + \sum_{P} Z_p \quad \text{wherein} \sum_{l=1}^{L} F_w^l \in [m_w, n_w, a_w, b_w, \theta_w]$$

7 Variables & 6 Design Constraints

Design constraints for entire layout:

- Site constraint
- Number of occupant
- Accessibility (distance between stair and flat)
- Building shape (area and side aspect ratio)

➔ Generative Design

(Source: Gan, V.J.L., Wong, H.K., Tse, K.T., Cheng, J.C.P., Lo, I.M.C., and Chan, C.M. (2019) "Simulation-based evolutionary optimization for energy-efficient layout plan design of high-rise residential buildings." Journal of Cleaner Production, 231, 1375-1388.)

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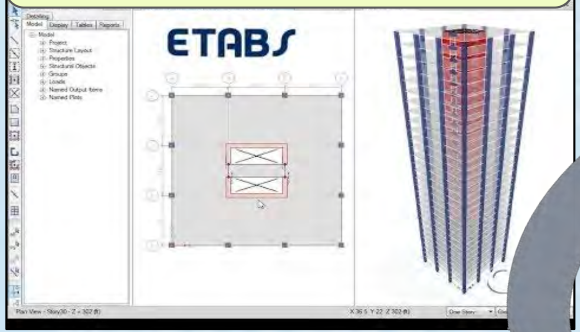
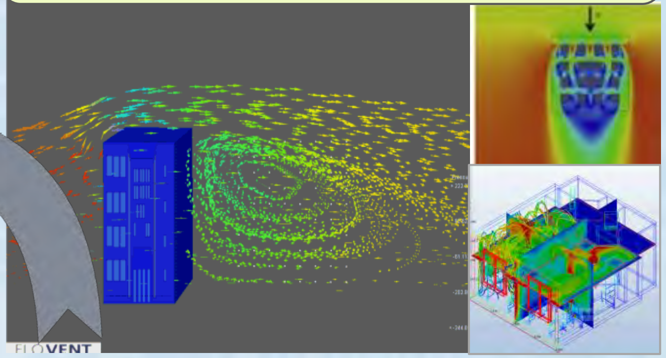
Relevant R&D – BIM for Sustainable Modular Buildings

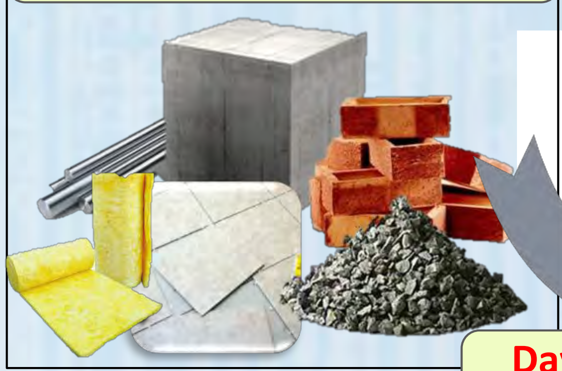
Structural analysis & design optimization



Wind effects on tall buildings & computational fluid dynamics (CFD)

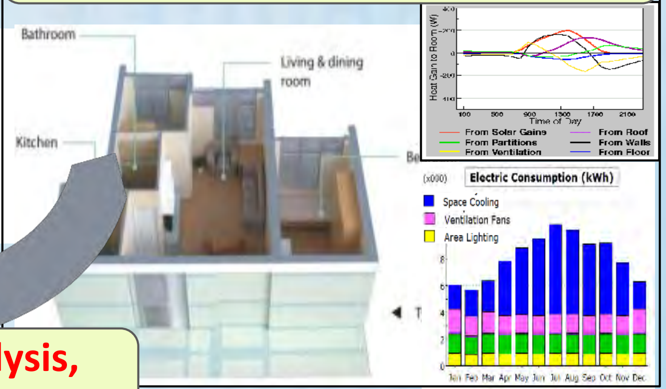


Low carbon materials & sustainable procurement



Integrated design platform using Building Information Modeling (BIM)

Building energy simulation & thermal analysis



Daylighting and shadow analysis, View analysis, Cost analysis, etc.

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Collaborators

We appreciated the **support** from **government department**, **contractor**, **rebar manufacturers**, and **professional organizations**.

- Hong Kong Housing Authority
- Chun Wo Development Holdings Ltd.
- Shiu Wing Steel Ltd.
- VSC Construction Steel Solutions Ltd.
- MES Service Ltd.
- Global BIM Center of Excellence
- Institution of Civil Engineering Surveyors (ICES)

BIM-based Rebar Design Optimization and Prefabrication Automation

THANK YOU!

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Technical Seminar
Webinar on Experience Sharing of a Showcase using Prefabricated Rebars Cum Research on BIM-based Rebar Design Optimisation & Automation
21 August 2020