Optimizing 3D CAD Potential in Japan
Case studies for Precast Concrete Structure

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Abstract: The application of 3D CAD has been gradually expanded in Japan. However, the use of 3D CAD is limited. There is no methodology which makes full use of Building Information Modeling (BIM) in 3D CAD especially for constructability. Object model is a methodology for BIM. Object models are also objects in 3D CAD and have attributes and preset values in parameters. Users can generate unique objects effectively and efficiently by selecting them and changing their parameters. Object model is applied to four popular precast (PCa) concrete construction methods of reinforcing concrete structure in Japan: 1) Conventional construction method, 2) Panel zone joint PCa method, 3) Girder center joint PCa method, and 4) Column reverse joint PCa method. Case studies show that various kinds of girder members can be generated from four object models effectively: L-type object model, T-type object model, X-type object model and I-type object model. Column and slab members can be generated from one object model. They also show that 3D CAD can generate the data related to constructability accurately and quickly: the number of PCa members, the size and weight of PCa members, and the volume of site-cast concrete.

Keywords: Integrated Practice, Building Information Modeling, 3D CAD
Quantity Survey, Construction Process, Methodology

BACKGROUND

Recent 3D CADs are object-oriented. 3D Objects have various attributes. All project stakeholders can access them. Integrated practice is emerging in architecture, engineering, and construction. It is a holistic approach to building in which all project stakeholders and participants work in highly collaborative relationships throughout the complete facility life cycle to achieve effective and efficient buildings [ELVIN, 2007]. The application of 3D CAD has been gradually expanded in Japan. One major area is the support for quantity survey and master program for the construction project.

However, here are some problems in the use of 3D CAD. First, the use of 3D CAD is limited. Big architectural firms and general contractors have their own 3D CAD systems. They have customized their 3D CAD systems. As a result, they are closed for most users in small and medium-sized architectural firms and contractors. Moreover, the operations in general-purpose 3D CAD are different. There is no effective method and procedure for general users to make use of 3D CAD. Secondly, users are compelled to input a lot of 3D data of building. They must control objects of building elements. As the projects progress, they usually add the attributes of objects. This workload is huge. The effective and efficient methodology of 3D data input in the use of widely used 3D CAD is necessary.

AIMS AND METHODS

This research aims to establish the methodology which makes full use of the general-purpose architectural 3D CAD for the integration between architectural design and construction. The methodology which does not restrict any user and any 3D CAD software is necessary. It describes the basic method and procedure of architectural design with general-purpose 3D CAD. Specifically, it gives how to input 3D data and how to make objects of building elements in 3D CAD.

This research adopts object model as methodology. It depends on the structure and construction method. This research introduces the case studies of rigid frame of RC (Reinforced Concrete) structure. There are four construction methods: 1) Conventional construction method, 2) Panel zone joint precast concrete method, 3) Girder center joint precast concrete method, and 4) Column reverse joint precast concrete method. They are popular construction methods, especially for modern high-rise apartments in Japan.

OBJECT MODEL FOR RC STRUCTURE

Object models are models of objects in 3D CAD to generate them effectively and efficiently. Object models are also objects in 3D CAD and have attributes and preset parameters. Users can generate unique objects by selecting appropriate object models and changing their parameters.

In the case of rigid frame of RC structure, object models are skeleton building elements: column, beam and slab. For instance, column has usually some kinds of bar arrangement in one building. The diameter and length of reinforcing bar vary. It is not useful to describe each object of column individually. The design process of column with object model is as follows:

1. Users prepare an object model of column in 3D CAD. In other words, they form a regular pattern of objects. Object models have attributes and parameters. Figure 1 shows the outline of object model. Objects generated from the same object model have the same attributes, but usually have different values in parameters.

2. Users generate a unique column object with an object model, and describe the detail by changing the value in parameters of object model: dimension of skeleton, reinforcing bar arrangement, thickness of protective concrete cover, bar diameter, bar length and so on. They can draw a variety of specification with some object models. Figure 2 shows the combination of objects of column. It realizes the variability in establishment of the arrangement of reinforcing bar. Figure 3 shows a list of reinforcing bar arrangement in a high-rise apartment building. The arrangement of reinforcing bar is patterned. In the case of column of RC structure, users can decide the object model and choose the arrangement of reinforcing bar from the list. As a result, the values in parameters of object model are semi-automatically set.

3. Like column, users prepare object models and describe the detail for beam and slab. This proposed methodology also gives the procedure of design. In this case, the column is first. The girder is second. The slab is last. This order closely parallels the order of quantity survey. For instance, the order follows Japanese Quantity Survey Standard.

4. With the integration between 3D CAD and scheduling software, it is also possible to simulate the construction process.

This research shows case studies of some construction methods. In addition, users can develop the methodology of generation of object model. Users can make full use of widely-used architectural 3D CAD with this methodology, especially for quantity survey and simulation of construction.

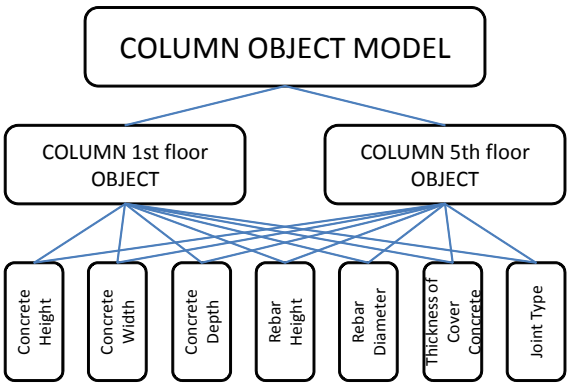

Figure 1 Outline of Object Model

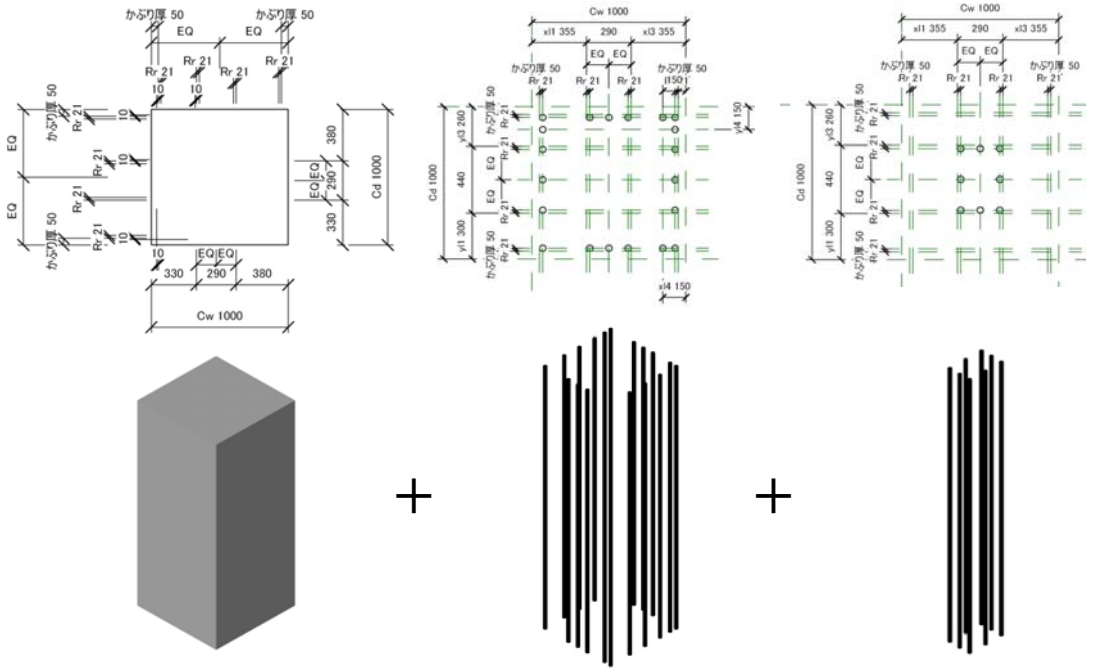

Figure 2 Combination of Building Element in Column of RC structure

		OUTSIDE		
		4 × 4	5 × 5	6 × 6
INSIDE	0 × 0			
	2 × 2			
	3 × 3			

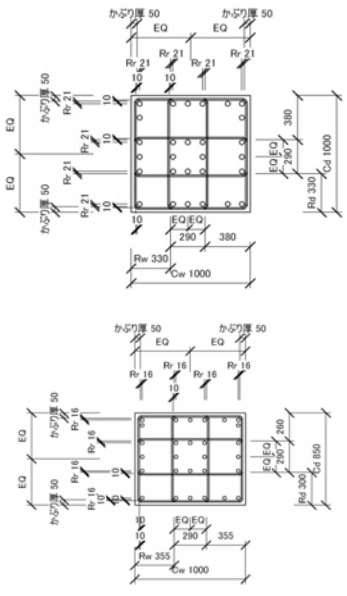

Figure 3 Reinforcing Bar Arrangement List

CASE STUDIES IN RC CONSTRUCTION METHODS

Object model is applied to four popular construction methods of RC structure in Japan: 1) Conventional construction method, 2) Panel zone joint PCa method, 3) Girder center joint PCa method, and 4) Column reverse joint PCa method.

The same building model is used in this application. Figure 4 shows the plan of structural building element. The frame of RC structure is rigid. The plan is a simple grid. Both numbers of spans are four. The length of span between columns lies in the range between 6,000 mm and 7,200 mm.

The objects of this study are the columns of third floor and the girders and slabs of fourth floor in a high-rise apartment in Japan. This is one cycle of construction in RC structure. From the view point of material, the objects are concrete, reinforcing bar and form.

1. CONVENTIONAL CONSTRUCTION METHOD

All concrete of structural building elements including column, girder and slab is basically casted at the construction site in the conventional construction method. Recently the precast concrete slab and industrialized slab decks have been popular. Therefore, the conventional construction method in this case study includes the adoption of half precast concrete to the slab.

The procedure of construction in the conventional construction method is as follows. First, the reinforcing column units including bars and hoops, which are usually pre-fabricated at the assemble yard, are set. Then, the forms of columns are set. Secondly, the forms of girders are set. Then the reinforcing girder units including bars and stirrups, which are also usually pre-fabricated at the assemble yard, are set and connected together. Thirdly, the half PCa slabs or industrialized slab decks are set. Finally, all concrete are casted at the construction site. Concrete of column is sometimes casted separately before girder and slab.

Object models in conventional construction method are simply one column object model, one girder object model and one slab PCa object model. Figure 5 shows a slab object generated from the slab PCa object model composed of concrete object and reinforcing object. Table 1 shows the bill of quantity for slab PCa object. Four kinds of slab PCa objects are totally generated. The weight of PCa member lies between 2.1 ton and 2.8 ton.

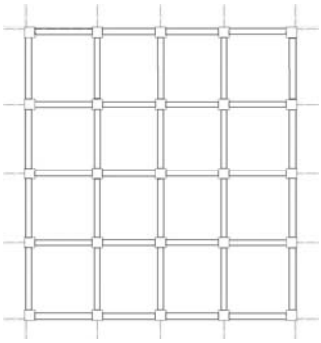

Figure 4 Plan of Structural Building Element

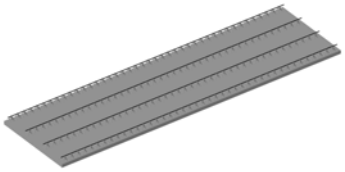

Figure 5 Slab Precast Object

Table 1 Bill of Quantity for Slab Precast Object

Slab Type	Number of Object	Concrete		Reinforcing Bar		PCa Element		PCa Total Weight
		Volume	Weight	Volume	Weight	Weight	Subtotal	
S1	20	0.863 m3	1.985 ton	0.023 m3	0.181 ton	2.165 ton	43.309 ton	106.471 ton
S2	4	1.127 m3	2.592 ton	0.030 m3	0.236 ton	2.828 ton	11.310 ton	
S3	20	0.819 m3	1.884 ton	0.022 m3	0.173 ton	2.056 ton	41.128 ton	
S4	4	1.070 m3	2.461 ton	0.028 m3	0.220 ton	2.681 ton	10.723 ton	

2. PANEL ZONE JOINT PRECAST CONCRETE METHOD

Panel zone joint precast concrete method is a PCa construction method whose joints of girder PCa units are at the panel zone, that is, the intersection of column and girder. All structural building elements: column, girder and slab are PCa members in this construction method. Figure 6 shows the layout of PCa members. Figure 7 shows the main PCa members in this construction method: column PCa unit and girder PCa units. The column PCa units are basically the same form. There are two kinds of girder PCa units. One is set at the outer area of plan and has an exterior wall. The other is set at the inner area and has no exterior wall.

The procedure of construction in the panel zone joint precast concrete construction method is as follows. First, the column PCa units including bars and hoops are set. Secondly, the girder PCa units including bars and stirrups are set. Half of them are usually pre-jointed to the two-span girder PCa unit and are set. The rest are used as one span girder PCa unit and are set at the right angles of the two-span girder PCa unit. As a result, the joints of reinforcing bar of PCa units at the panel zone are in one direction only. Thirdly, the half PCa slabs are set. Finally, concrete at the panel zone and the slab are casted at the construction site.

Object models in panel zone joint PCa method are one column PCa object model, two girder PCa object models and one slab PCa object model. Figure 7 shows a column PCa object, a one-span girder PCa object without exterior wall and a two-span girder PCa objects with exterior wall. Eight types of girder objects generated from two girder PCa object models composed of concrete object and reinforcing object. Table 2 shows the bill of quantity for girder PCa objects. The number of girder PCa objects is forty. The weight of PCa member lies between 3.7 ton and 5.2 ton.

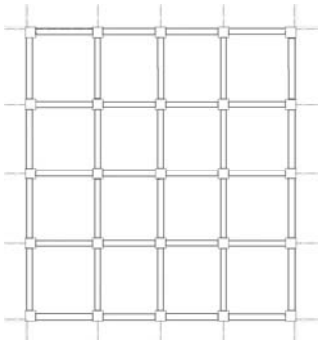

Figure 6 Layout of Precast Members

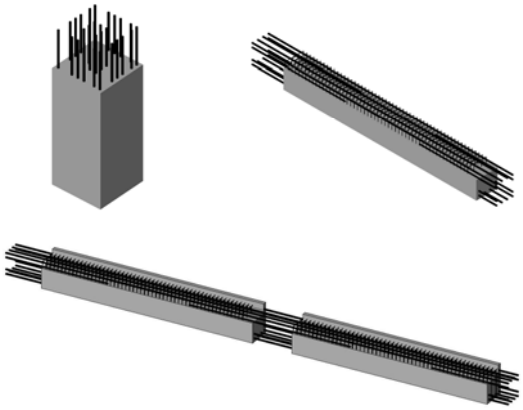

Figure 7 Main Precast Members in Panel Zone Joint Precast (Upper Left: Column, Upper Right: IG1, Lowe:2 pieces of OG1)

Table 2 Bill of Quantity for Girder Precast Member in Panel Zone Joint Precast

Girder Type	Number of Object	Concrete		Reinforcing Bar		PCa Element		PCa Total Weight
		Volume	Weight	Volume	Weight	Weight	Subtotal	
OG1	4	1.757 m3	4.041 ton	0.100 m3	0.785 ton	4.826 ton	19.304 ton	
OG2	4	1.903 m3	4.377 ton	0.105 m3	0.824 ton	5.201 ton	20.805 ton	
OG3	4	1.625 m3	3.738 ton	0.084 m3	0.659 ton	4.397 ton	17.588 ton	
OG4	4	1.820 m3	4.186 ton	0.094 m3	0.738 ton	4.924 ton	19.696 ton	
IG1	6	1.432 m3	3.294 ton	0.098 m3	0.769 ton	4.063 ton	24.377 ton	175.281 ton
IG2	6	1.552 m3	3.570 ton	0.105 m3	0.824 ton	4.394 ton	26.363 ton	
IG3	6	1.325 m3	3.048 ton	0.084 m3	0.659 ton	3.707 ton	22.241 ton	
IG4	6	1.484 m3	3.413 ton	0.094 m3	0.738 ton	4.151 ton	24.907 ton	

3. GIRDER CENTER JOINT PRECAST CONCRETE METHOD

Girder center joint precast concrete method is a PCa construction method whose joints of girder PCa units are at the center of span between columns. All structural building elements: column, girder and slab are PCa members in this construction method. Figure 8 shows the layout of PCa members. Figure 9 shows the main PCa members in this construction method: column PCa unit and girder PCa units. The column PCa units are basically the same form. There are four kinds of girder PCa units: L-type PCa, T-type PCa, X-type PCa and I-type PCa.

The procedure of construction in the girder center joint precast concrete construction method is as follows. First, the column PCa units including bars and hoops are set. Secondly, the girder PCa units including bars and stirrups are set. L-type PCa and T-type PCa have exterior wall. The rest, X-type PCa and I-type PCa, haven't them. Thirdly, the half PCa slabs are set. Finally, concrete at the joint area and the slab are casted at the construction site.

Object models in girder center joint PCa method are one column PCa object model, four girder PCa object models and one slab PCa object model. Eleven types of girder objects generated from four girder PCa object models composed of concrete object and reinforcing object. Table 3 shows the bill of quantity for girder PCa objects. The number of girder PCa objects is thirty one. The weight of PCa member lies between 2.1 ton and 8.6 ton.

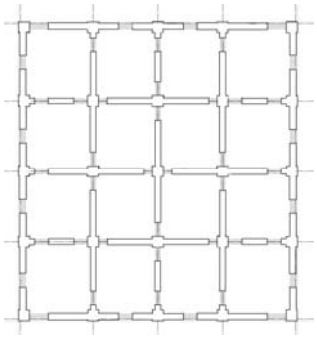

Figure 8 Layout of Precast Members

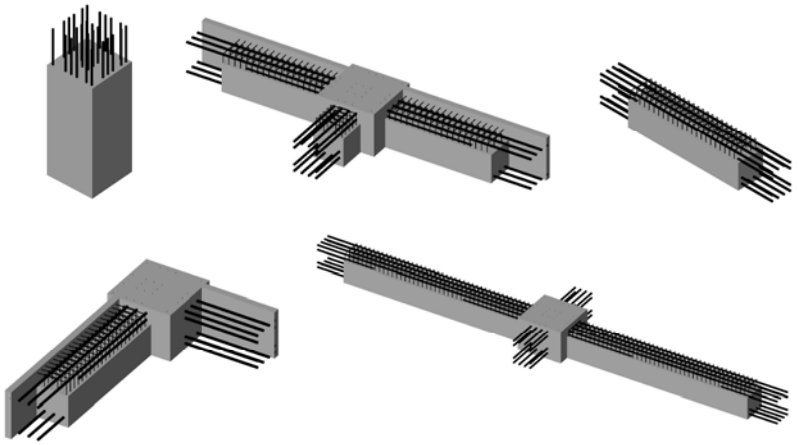

Figure 9 Main Precast Members in Girder Center Joint Precast
(Upper Left: Column, Upper Center: T1, Upper Right: I1, Lower Left: L1, Lower Right: X1)

Table 3 Bill of Quantity for Girder Precast Member in Girder Center Joint Precast

Girder Type	Number of Object	Concrete		Reinforcing Bar		PCa Element		PCa Total Weight
		Volume	Weight	Volume	Weight	Weight	Subtotal	
L1	4	1.597 m3	3.673 ton	0.087 m3	0.683 ton	4.356 ton	17.424 ton	
T1	4	2.649 m3	6.093 ton	0.138 m3	1.083 ton	7.176 ton	28.704 ton	
T2	2	2.078 m3	4.779 ton	0.115 m3	0.903 ton	5.682 ton	11.364 ton	
T3	4	2.371 m3	5.453 ton	0.130 m3	1.021 ton	6.474 ton	25.895 ton	
T4	2	2.273 m3	5.228 ton	0.125 m3	0.981 ton	6.209 ton	12.418 ton	
X1	2	2.711 m3	6.235 ton	0.195 m3	1.531 ton	7.766 ton	15.532 ton	183.316 ton
X2	2	2.791 m3	6.419 ton	0.186 m3	1.460 ton	7.879 ton	15.759 ton	
X3	4	3.082 m3	7.089 ton	0.195 m3	1.531 ton	8.619 ton	34.477 ton	
X4	1	3.029 m3	6.967 ton	0.198 m3	1.554 ton	8.521 ton	8.521 ton	
I1	4	0.750 m3	1.725 ton	0.047 m3	0.369 ton	2.094 ton	8.376 ton	
I2	2	0.869 m3	1.999 ton	0.054 m3	0.424 ton	2.423 ton	4.845 ton	

4. COLUMN REVERSE JOINT PRECAST CONCRETE METHOD

Column reverse joint precast concrete method is a PCa construction method whose joint of column PCa units is in the opposite direction. All structural building elements: column, girder and slab are PCa members in this construction method. Figure 10 shows the layout of PCa members. Figure 11 shows the main PCa members in this construction method: column PCa unit and girder PCa units. The column PCa units are basically the same form. There are three kinds of girder PCa units: L-type PCa, T-type PCa and X-type PCa.

The procedure of construction in the column reverse joint precast concrete construction method is as follows. First, the column PCa units including bars and hoops are set. Secondly, the girder PCa units including bars and stirrups are set. L-type PCa and T-type PCa have exterior wall. The rest, X-type PCa, hasn't them. In this method, there is no reinforcing bar over the column PCa unit. Therefore, girder PCa units can be moved over the column PCa units horizontally to connect girder PCa units together with the grout. This method decreases the concrete volume of the connection of girder PCa units with site-cast. Thirdly, the half PCa slabs are set. Finally, concrete at the joint area and the slab are casted at the site.

Object models in column reverse joint PCa method are one column PCa object model, three girder PCa object models and one slab PCa object model. Eight types of girder objects generated from three girder PCa object models composed of concrete object and reinforcing object. Table 4 shows the bill of quantity for girder precast objects. The number of girder PCa objects is twenty five. The weight of PCa member lies between 7.1 ton and 8.8 ton.

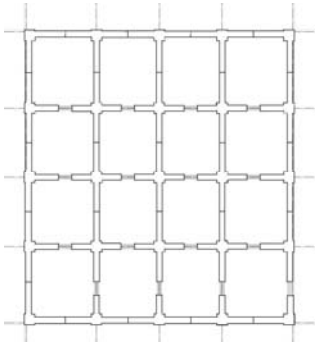

Figure 10 Layout of Precast Members

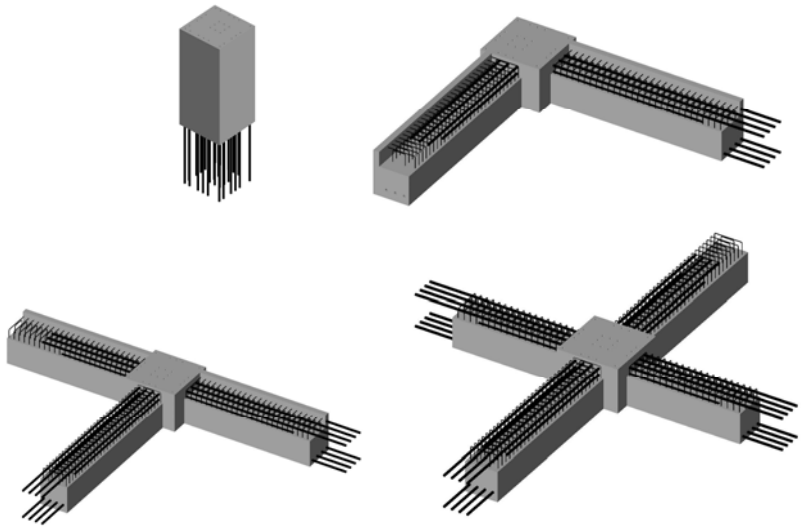

Figure 11 Main Precast Members in Column Reverse Joint Precast
(Upper Left: Column, Upper Right: L1, Lower Left: T1, Lower Right: X1)

Table 4 Bill of Quantity for Girder Precast Member in Column Reverse Joint Precast

Girder Type	Number of Object	Concrete		Reinforcing Bar		PCa Element		PCa Total Weight
		Volume	Weight	Volume	Weight	Weight	Subtotal	
L1	1	2.681 m3	6.166 ton	0.124 m3	0.973 ton	7.140 ton	7.140 ton	206.345 ton
L2	1	2.674 m3	6.150 ton	0.123 m3	0.966 ton	7.116 ton	7.116 ton	
L3	1	2.674 m3	6.150 ton	0.123 m3	0.966 ton	7.116 ton	7.116 ton	
L4	1	2.258 m3	5.193 ton	0.114 m3	0.895 ton	6.088 ton	6.088 ton	
T1	3	3.173 m3	7.298 ton	0.155 m3	1.217 ton	8.515 ton	25.544 ton	
T2	3	2.834 m3	6.518 ton	0.135 m3	1.060 ton	7.578 ton	22.734 ton	
T3	6	3.161 m3	7.270 ton	0.165 m3	1.295 ton	8.566 ton	51.393 ton	
X1	9	3.209 m3	7.381 ton	0.181 m3	1.421 ton	8.802 ton	79.214 ton	

EFFECT OF 3D CAD AND OBJECT MODEL

Table 5 shows the comparison of number of object model and object for four construction methods of RC structure. In the cases of column PCa member and slab PCa member, the number of object model is one. In the case of girder PCa member, the number of object model is the range from two to four. Girder PCa members are grouped in four object models in case studies: L-type object model, T-type object model, X-type object model and I-type object model. That is, users can generate a variety of girder PCa objects by customizing the four kinds of object models from practical standpoints of precast concrete construction methods.

Table 6 shows the comparison of bill of quantity for four construction methods of RC structure. Conventional construction method has few PCa members and the maximum volume of site-cast concrete. On the other hand, the others have many PCa members and less volume of site-cast concrete. Column reverse joint precast has the minimum number of girder PCa members and the minimum volume of site-cast concrete. It also includes the maximum size and weight of PCa member.

These case studies show that 3D CAD can generate the accurate data related to construction quickly. From practical standpoints of construction, these data at design stage are useful. For instance, the volume of site-cast concrete and the number of PCa members are necessary to plan the schedule of construction project. The maximum size and weight of PCa member is necessary to examine the number and power of crane. These case studies show that these data with 3D CAD can support constructability and the efficient comparison of construction methods at design stage.

Table 5 Comparison of Object Model and Object in 4 Construction Methods

Precast Concrete Construction Method	Precast Concrete											
	Column			Girder					Slab			
	Model	Type	Object	Model	Type	Object	Concrete Joint		Grout Joint	Model	Type	Object
Conventional	—	—	—	—	—	—	—	— m3	—			
Panel Zone Joint Precast	1	4	25	2	8	40	25	18.8 m3	—			
Girder Center Joint Precast	1	4	25	4	11	31	46	15.5 m3	—	1	4	44
Column Reverse Joint Precast	1	4	25	3	8	25	16	5.6 m3	24			

Table 6 Comparison of Bill of Quantity in 4 Construction Methods

Precast Concrete Construction Method	Precast Concrete									Sitecast Concrete		Total Concrete
	Column			Girder			Slab					
	Concerte	Reinforcing Bar	Number	Concerte	Reinforcing Bar	Number	Concerte	Reinforcing Bar	Number	Girder Joint	Slab (Girder)	
Conventional	— m3	— ton	— piece	— m3	— ton	— piece	42.4 m3	8.9 ton	44 piece	— m3	272.8 m3	
Panel Zone Joint Precast	57.5 m3	19.8 ton	25 piece	63.2 m3	30.0 ton	40 piece	42.4 m3	8.9 ton	44 piece	18.8 m3	133.5 m3	
Girder Center Joint Precast	57.5 m3	19.8 ton	25 piece	66.3 m3	30.9 ton	31 piece	42.4 m3	8.9 ton	44 piece	15.5 m3	133.5 m3	315.2 m3
Column Reverse Joint Precast	57.5 m3	19.8 ton	25 piece	76.2 m3	31.2 ton	25 piece	42.4 m3	8.9 ton	44 piece	5.6 m3	133.5 m3	

CONCLUSIONS

This research verified object model to establish the methodology for Building Information Modeling. It is how to describe objects in Building Information Modeling for constructability. This research verified the effect in four popular precast concrete construction methods of rigid frame of Reinforced Concrete structure: 1) Conventional construction method, 2) Panel zone joint precast concrete method, 3) Girder center joint precast concrete method, and 4) Column reverse joint precast concrete method.

Four Object Models can generate Objects of PCa Girder Member

In the case of precast concrete methods of rigid frame, various kinds of girder members can be generated from four object models: L-type object model, T-type object model, X-type object model and I-type object model. Column and slab members can be generated from one object model. Whether object model includes the exterior wall can be a factor which derives a new one from the existing one.

3D CAD can generate the Data for Constructability at Design Stage

3D CAD can generate the data accurately and effectively: the number of PCa members, the size and weight of PCa members, and the volume of site-cast concrete.

Case studies of Building Information Modeling with object model show the above function with widely-used 3D CAD. Object model can be widely-used methodology of Building Information Modeling especially for constructability.

REFERENCES

Elvin, G (2007) Integrated Practice in Architecture Mastering Design-Build, Fast-Track, and Building Information Modeling, John Wiley & Sons, Inc., 2007

Imai, Y and Kimoto, K (2007) Practical Use of 3D CAD in Production Design Part 1 Quantity Surveying with Wide-Use 3D CAD Application Software, Proceeding of The 77th Architectural Research Meetings 2006,Volume 2, March 2007, Kanto Chapter, Architectural Institute of Japan, 253-256.

Imai, Y and Kimoto, K (2007) Practical Use of 3D CAD in Production Design Part 2 Detailed Quantity Surveying with Wide-Use 3D CAD Application Software, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, Volume F-1, August 2007, Architectural Institute of Japan, 1311-1312.

Kataoka, M (2007) Theory and Application of Automated Construction Planning Using Construction Method Templates, Proceedings of 23th Symposium on Building Construction and Management of Projects, July 2007, Research Committee on Building Economics, Architectural Institute of Japan, 99-106.

Kimoto K and others (2006) How to Develop Computer-Aided Engineering Systems in Project Management for Building Construction, Proceedings of 22th Symposium on Building Construction and Management of Projects, July 2006, Research Committee on Building Economics, Architectural Institute of Japan, 179-186.

Sone, H and others (2004) Cost Estimate and Possibility of Cost Control Due to Production Design Using 3D-CAD in Production Design (Part1), Proceedings of 20th Symposium on Building Construction and Management of Projects, July 2004, Research Committee on Building Economics, Architectural Institute of Japan, 333-338.

Yuasa Y and Toyoda Y (2004) Development of Visualization System of Construction Process, Proceedings of 20th Symposium on Building Construction and Management of Projects, July 2004, Research Committee on Building Economics, Architectural Institute of Japan, 319-326