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Parametric Analysis and Design Engine for Tall Building Structures

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Abstract

With the rise in CPU power and the generalization and popularity of computers, engineering practice also changed from hand calculations to 3D computer models, from elastic linear analysis to 3D nonlinear static analysis and 3D nonlinear transient dynamic analysis. Thanks to holistic design approach and current trends in freeform and contemporary architecture, BIM concept is no longer a dream but also a reality. BIM is not just providing a media for better co-ordination but also to shorten the round-the-clock time in updating models to match with other professional disciplines. With the parametric modeling tools, structural information is also linked with BIM system and quickly produces analysis and design results from checking to fabrication. This paper presents a new framework which not just linked the BIM system by means of parametric mean but also create and produce connection FE model and fabrication drawings etc. This framework will facilitate structural engineers to produce well co-ordinate, optimized and safe structures.

Keywords: BIM, Parametric modeling, Structural analysis, Finite element

1. Introduction and Background

It is interesting to know that the A5 CPU used in a hand phone (such as iPhone 4S) or tablet is more powerful than a Cray 2 computer which cost US$17m[1] in 1985. Following the first Z1 computer in 1935, the size of computer is reducing but increase in speed. In 1965, Gordon Moore presented his Moore's Law that the components in integrated circuit doubles every ten years. In early 80's, the availability of minicomputers allowed software applications shifted from military or aerospace industry to domestic use. One of the well known is the release of Unigraphics system by McDonnell Douglas. Unigraphics converted the Automated Drafting and Machining (ADAM) coding into current named as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) applications. Although Unigraphics was already in 3D, the cost of minicomputer was still too expensive for some small firms which were common in buildings industry by that time.

Following the very early Personnel Computer (Apple I) assembled by two youngsters in mid-80's, the cost of computers became more affordable by building industry practices. The work for draftsman changed from hand drawings to 2D CAD drawings and in 90's in 3D drawings. With 3D environment, the true communication language of Architecture, Engineering and Construction (AEC) industry is no longer "drawings" as emphasized by Carl Culmann by 1860's. It is because the structures are getting more complicated and hardly be defined by means of 2D drawings. The definition of drawings nowadays may mean - "3D objects".

At the same time, structural engineers also changed their practice from hand calculations to now very complex 3D nonlinear transient dynamic analysis. Without computers and software, a lot of ideas will still be on a piece of paper. For examples, the geometry of Watercube for Beijing Olympics was created by scripts and then analyzed by computer. The National Stadium geometry was first created by CATIA; box sections were "intruded" following the centerline and twisted to ensure the external envelope which follows the "Bow" shape.

Although there were drawings for both Watercube and National Stadium projects, the 3D computer model were still the key for communication between various parties from designer to fabricators and erectors.

2. BIM

With the popularity of 3D modeling techniques, the industry is moving forward to Building Information Modeling (BIM) in early 20's. According to Ghang Lee[2], "BIM is the "process" of generating and managing building information in an interoperable and reusable way. A BIM system is a system or a set of systems that "enables" users to integrate and reuse building information and domain knowledge through the lifecycle of a building". In the early stage of BIM, structural engineers use BIM to produce the global model of the building structures and

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Figure 1. Photo of National Stadium and WaterCube for 2008 Beijing Olympics (©Marcel Lam Photography).

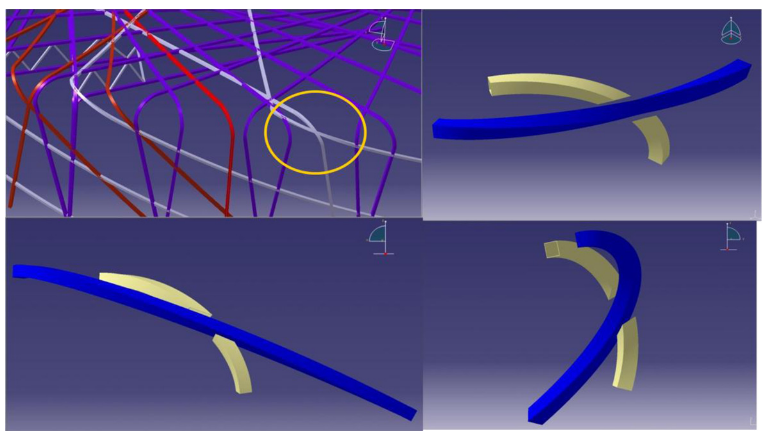

Figure 2. CATIA Model showing the twisting and bending of box elements in National Stadium.

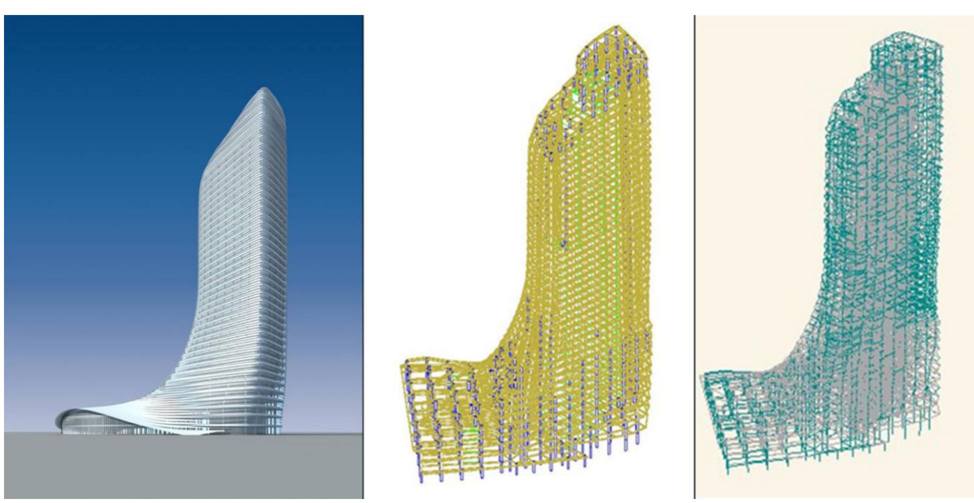

Figure 3. Architect Image (With courtesy of Studio PeiZhu) Vs Revit Model Vs GSA Structural Model.

BIM is only a tool to produce computer models. Figure 3 show an architectural image of a building project, the Revit 3D and GSA (structural analysis) model. Through BIM tools, engineers can extract the floor plan and produce the floor plan in seconds as Figure 4.

3. Parametric Modeling

Because of the trends in free form surface, contemporary architecture requirement and buildings getting taller, the automation of generating the global structural

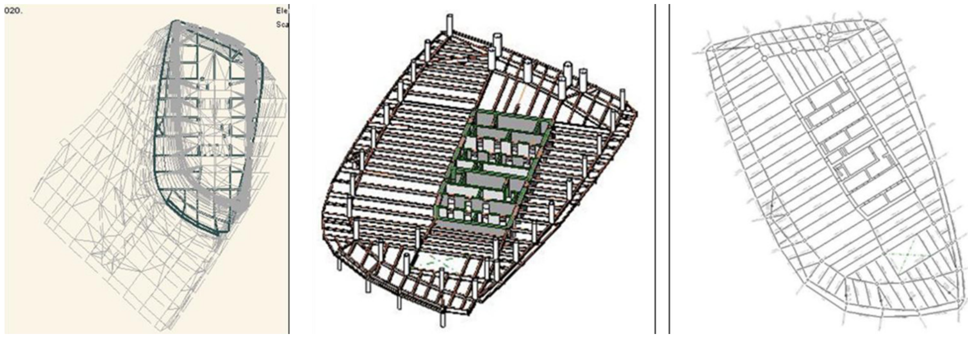

Figure 4. Extract of 2D and 3D floor plan from 3D BIM model.

model is not good enough to meet the speed and complexity requirement. The use of object oriented concept, genetic algorithm and parametric modeling techniques are now applied to structural analysis and design and even construction and fabrication drawings.

Although Pro-Engineer may be classified as the first parametric software in the domestic market, it is mainly developed for product design from toys to cars. With parametric modeling, the design (model) dimensions can be adjusted at any time in the design process while the associated dimensions which described the design will change in according with the pre-defined relationship.

This is extremely useful in tall building design especially when the building envelope is not a constant (which is always the case) such as Figure 5.

In the case the structures is straight in the external surface which the variables are only the square at the top and bottom, the designer can easily define the relationship of each four vertical corner edges by means of its relative and/or functions.

Besides the exterior, the designer can also define other structural components such as core, columns, bracing, and outriggers.

Once the parameters for the components are defined, engineer can update and modify a particular or several dimensions to produce the design which he/she is looking

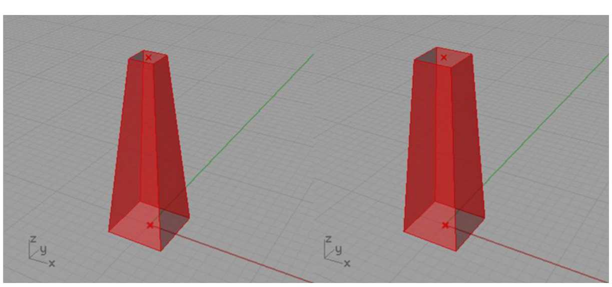

Figure 5. Parametric Models for a same height and base size of a building with different size at roof.

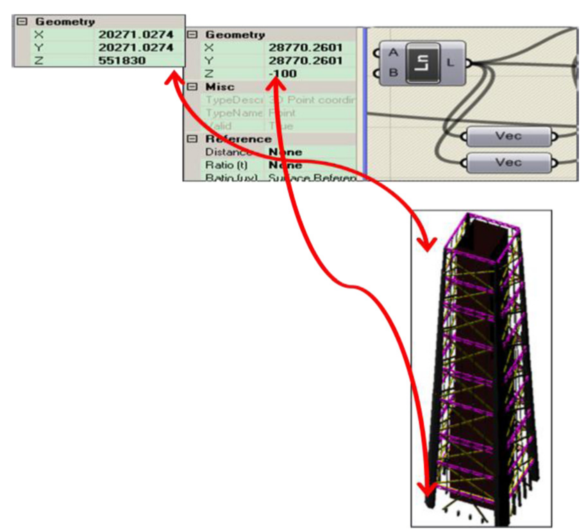

Figure 6. Geometry object defined by parameters and component.

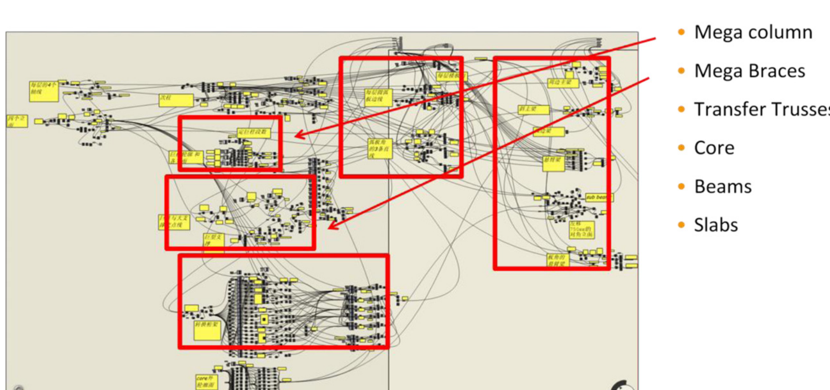

Figure 7. Structural element objects.

for. Figures 9 shows the change of the bracing pattern.

The word parametric means the geometric definitions of the design, such as dimensions and topology, can be varied at any time in the design process. Parametric modeling is accomplished by identifying and creating the key features of the design with the aid of computer software. The design variables, described in the sketches and described as parametric relations, can then be used to quickly modify/update the design.

Depends on the tool chosen by the engineer, some tools require and/or allow user to use scripting to drive the input and output.

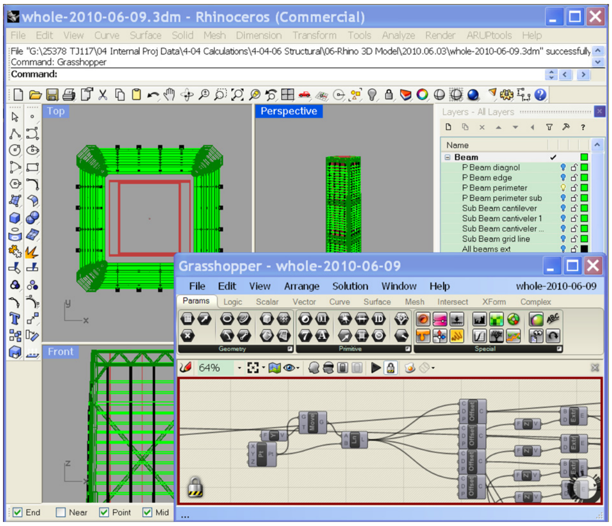

Figure 8. Building object.

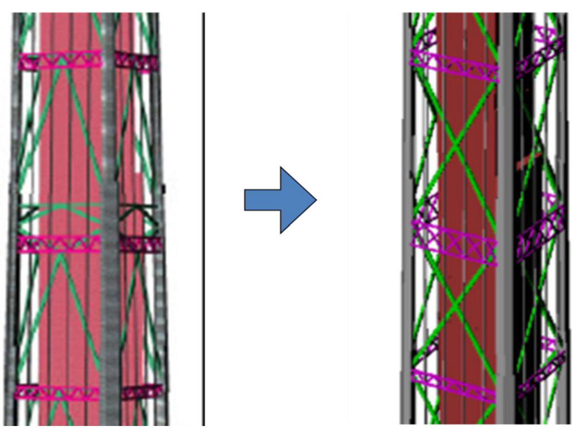

Figure 9. Bracing pattern can be changed by just updating some of the key parameters.

4. Parametric Modeling and Computer Design Optimization (CDO)

The development of parametric modeling technique extends the application of CDO from member section optimization to topology and structure system optimization. In the early design stage we need consider different types of schemes and make a choice by comparison. For example, concrete or steel? Column spacing? Braced or not? Need outriggers or not? The comparison will give us the direction to find a most effective structure and give information to client to make the decision. Parametric modeling is the base of this kind of optimization study and makes it possible to generate different structure schemes automatically.

5. Analysis and Design Engine (ADE)

As mentioned before, besides the global geometry information can be adjusted and generate the global structural model. For simple structures, program such as Revit or so can easily convert the BIM model to structural analysis program with its design modules. However, for tall buildings, this process is not that straight forward because the components in tall building usually require special handling and cares. The conventional use of BIM for structural engineers is on the co-ordination and the generating of the global analysis model. However, with complex structures, a minor change in a beam may introduce days or weeks of adoptive work in preparing the connection shop drawings. Instead of letting the BIM

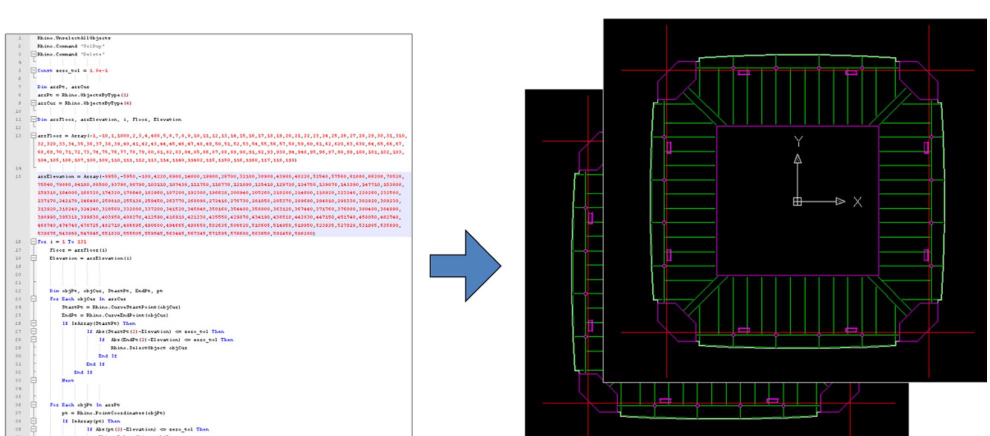

Figure 10. The extracting of the story framing plan by scripts.

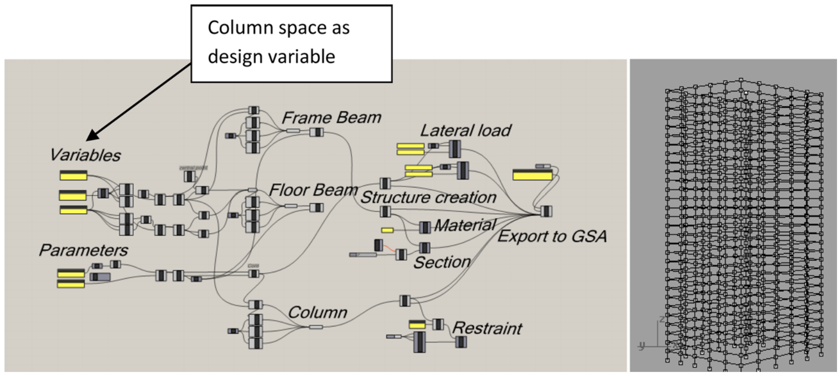

Figure 11. Parametric modeling to generate different structure systems.

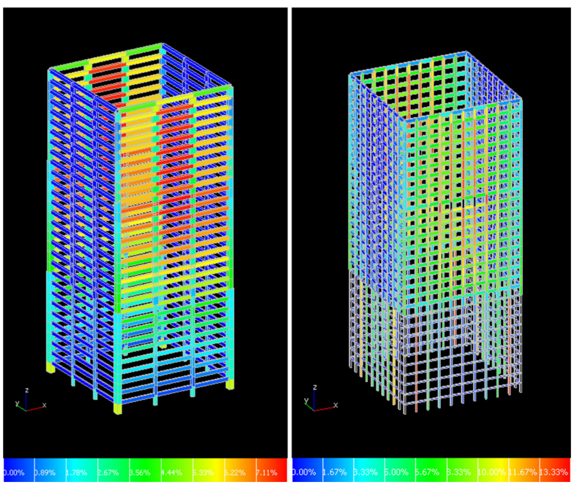

Figure 12. Virtual work analysis results for different schemes.

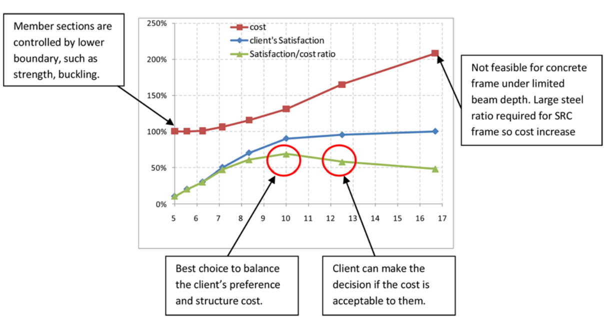

Figure 13. Results comparison and evaluation.

model to lead the design, the authors introduce a framework named as Analysis and Design Engine (ADE) which revoke the full control and managed by the engineer. BIM becomes a communication media with other parties such as architects and services engineers. The model information is actually hosted by Grasshopper[3] base ADE. ADE is an object base framework which allows future expandable and ease of maintenance. Though ADE, engineer can obtain the following information within seconds:

1. General layout drawings for plan and elevation;

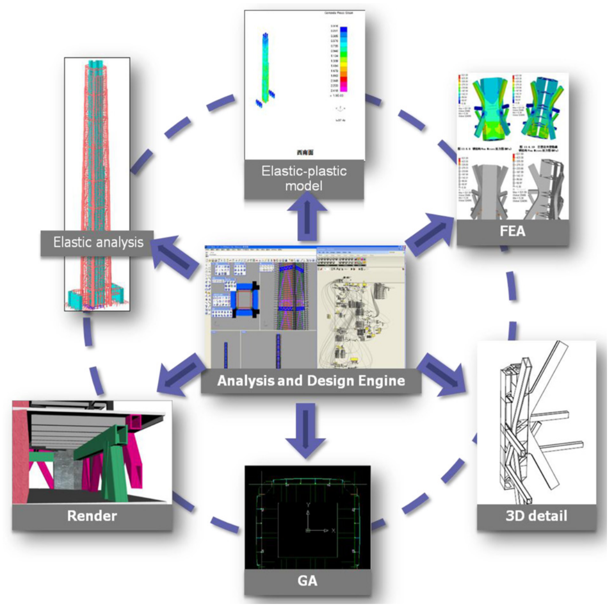

Figure 14. Frameworks for Analysis and Design Engine (ADE).

2. Linear model for code base design with graphical analysis results for visualization and presentation;
3. Nonlinear keyword file for LS-Dyna analysis to ensure the structures will not collapse in severe earthquake (i.e. performance check);
4. Connection geometry in IGES for Finite Element Processing including Pre-processing in generating meshing, analysis and post-processing.
5. 3D connection shop drawings in X-Steel format for fabrication.
6. Detailed section definition.

The diagrammatic drawing of the Analysis and Design Engine (ADE) is show by Figure 14.

As shown in Figure 18, the column section sizes and steel ratio can be determined by analysis. But the detailed section design is still complex including cavity partition, exact plate position, steel plate thickness etc. Parametric modeling was used to generate a set of detailed sections automatically after setting some logic rules and con-

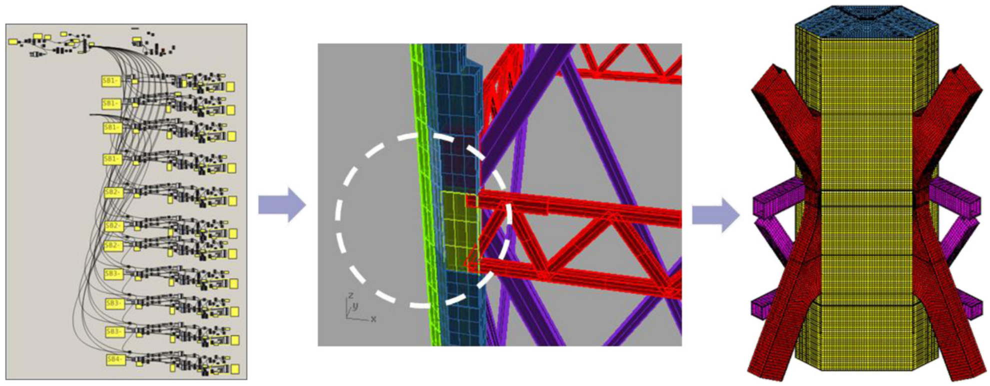

Figure 15. Finite Element Model generated by ADE.

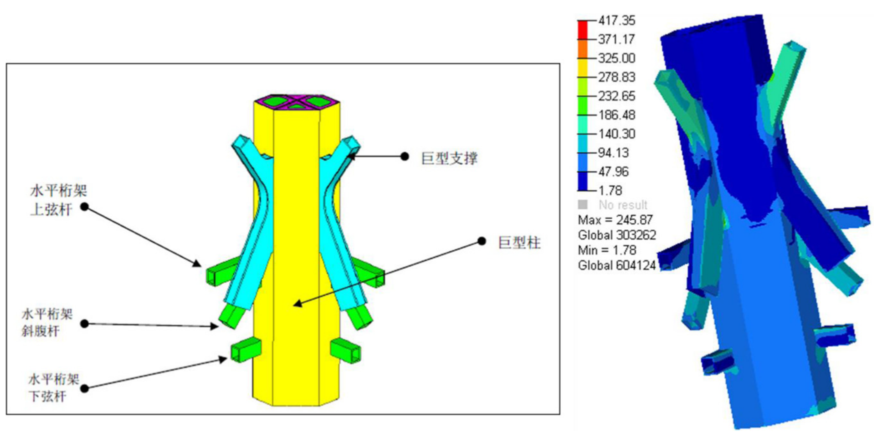

Figure 16. FE analysis results after optimization.

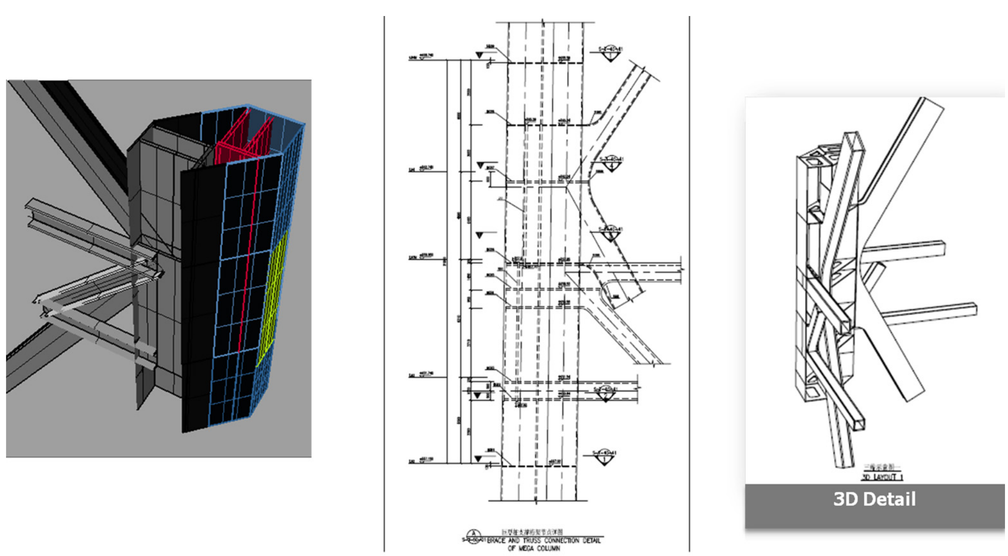

Figure 17. 3D image and construction drawings generated by ADE.

straints, such as the maximum thickness difference between two connecting plates, maximum free width/thickness ratio. When section sizes and steel ratio change, the detailed section definition can be adjusted accordingly.

6. Conclusion

This paper presented a review of the historical development of BIM system and modern applications of parametric modeling techniques in tall building modeling.

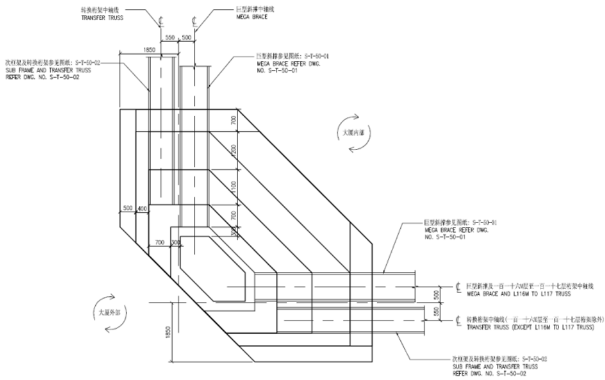

Figure 18. Detailed composite section definition by ADE.

Figure 19. Image of 597m tall Goldin Finance 117 Building (With Courtesy of P&T).

A new framework of Analysis and Design Engine (ADE) is introduced in not just converting the geometry information into computer model but also linked to LS-Dyna for Nonlinear transient analysis, Finite Element pre- and post processor for FE analysis. Furthermore, it can also generate construction drawings including connection details. Finally, this ADE module was successfully tested in the 600 m tall Goldin Finance 117 project in Tianjin, China.

Acknowledgements

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