Parametric BIM Façade Module Development For Diagrid Twisted Structures

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Abstract:

Building Information Modelling (BIM) is an epochal phenomenon in AEC. Most of the developed countries has already adopted BIM by regulations. Biggest projects around the world executing by BIM which provides more effective project management process. Whole construction progress including; feasibility, design, construction and commissioning became digital visualization. Any required analysis can be done via this model template.

In fact, requesting the complex and sophisticated structures' construction is the main catalyst of developing BIM. Mankind start to design and construct cutting-edges and pushing limit structures. Twisted towers are one of the significant instance of like these structures. This study embrace the twisted towers' façade design which has one of the most complex patterns. So it is thought that if such these towers' façade system can be organized and customized limitlessly, most of the façades systems will be solved for the optimum result.

This study aims to reveal a method which can be used for to develop easily alternative façade systems for construction projects even they have very complex design. One of the most complex structures the twisted diagrid systems which are constructed currently around the world was selected. BIM and computational programming have been used to improve the module.

Keywords –
BIM, Building information modelling, parametric design, computational BIM, visual programming, twisted towers.

1 Introduction

Over the last 10 years, diagrid structures have proven to be highly adaptable in structuring a wide range of building types, spans and forms. In most applications, diagrids provide structural support to buildings that are non-rectilinear, adapting well to highly angular buildings and curved forms. [1]

Until the latter half of the 20th century architectural and structural features of such high-rise buildings had remained almost the same with the prismatic box-type structure being the predominant form. Architects started breaking out of this more than century old trend/convention during the later decades of the 20th century [2]. Today's prevalent use of diagrids in tall buildings is due to their structural efficiency and aesthetic potential. For a very tall building, its structural design is generally governed by its lateral stiffness. Compared to conventional orthogonal structures for tall buildings such as framed tubes, diagrid structures carry lateral wind loads much more efficiently by their diagonal members' axial action [3].

Shawn Ursini, says; Advances in construction, engineering and architectural computer programs have enabled this type of architecture to flourish, but it has required a fundamental rethink of tall buildings.

By the way, Eastman et.al [4] define Building Information Modeling (BIM) as a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format.

It is no coincidence that the birth of the contemporary diagrid building type came at a time when computer-assisted drawing was hitting its stride. The development of Building Information Modelling (BIM) has been critical to ensuring the successful design and fabrication of highly complex structures [1]Construction of diagrids is more challenging compared to conventional structural systems for tall buildings because the system is relatively new and the joints of diagrid structures are more complicated than those of conventional orthogonal structures [3]. This paper aims to emerge that a proposal module based on parametric BIM which can ensure to make decision easily during diagrid structures design to facade systems of diagrid. This issue is one of the main parts of the skyscrapers cause of their energy consuming. While the most extensive area of the buildings are façades, the design decisions that comprises materials, shapes and geometry are very curious. Similarly with the other parts of the Architectural, Engineering and Construction (AEC) industry façade design can be no longer executed by BIM and parametric modules. The pilot design "Agora Garden" designed by Vincent Collebaut has been chosen as a twisted tower and modelled within Autodesk Revit. It constructed with gardens on the façades'. In this study, its façade design joined to parametric module that built with Dynamo. It has developed as a decision maker which considering environmental effects on the façade.

2 Features & Examples Of Twisted Towers As Diagrid Structures

As diagrid systems twisted towers have become a game changer for AEC. As it has been mentioned above, while structures of diagrid systems accept no fault in computation, it should be designed precisely. Traditional building design methods cannot provide to architects and engineers to carry out the design and construction process for such these building types. The concept of diagrid is not new at all: people have always been intuitively familiar with the inherent stability of triangular structures [8] Placement of diagonals is the oldest and most natural solution in steel structures, and has had widespread applications, receiving great popularity among engineers and architects; however the past architects considered diagonals highly obstructive and usually embedded them within the building interior cores [5] All the contents of construction such as; structural optimization, foundation, spatial decisions can be analyzed via BIM. One of the most curious titles of the project for these types is façade design. Since façade systems have significant roles on energy assumption, building functionality and aesthetic of building design of it is quite sophisticated process. While BIM ensure to design detailed model of the façade systems of the twisted buildings, parametric components ease to reach optimization result which is the useful façade design and material [9].

A high-rise structure where its form is the result of a combination of angled facades on the Z axis is termed as Twisted Tower [2]. Innovative and highly sophisticated digital design tools lends immense capabilities to architects and structural engineers to design highly complex geometrical structures which can be materialised making use of cutting edge technologies, traditional as well as specially developed building materials and highly efficient building practices. Recent decades have seen many high-rise buildings with twisted structures. Most of these have achieved iconic status and have become notable landmarks bringing fame to their locality [1].

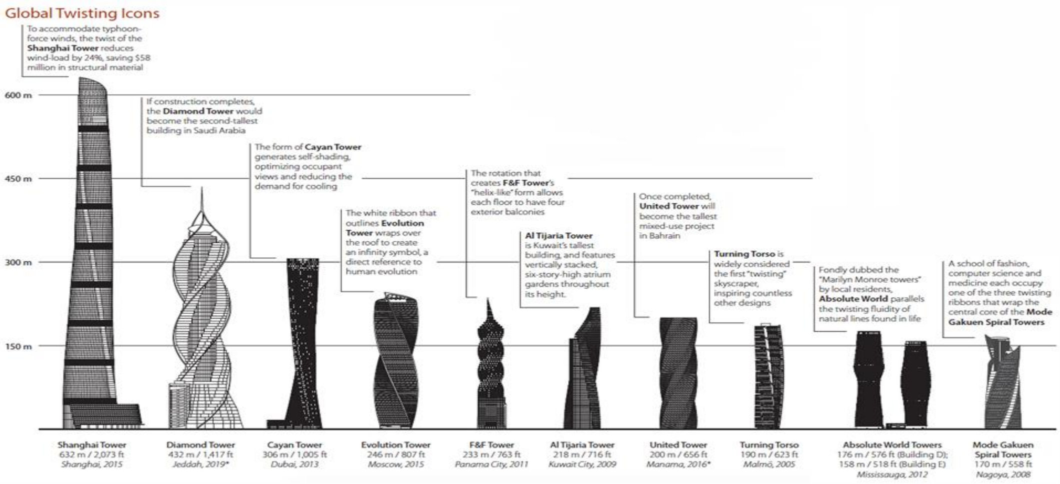

Figure 1. The tallest diagrid twisted towers around the world

A twister is a building with floors that lie horizontally rotated around a vertical axis. This axis usually lies in the centre of the floor plan. Often there is a cylindrical core, around which floor-wings lie. The structural members, mullions and contours all circle helically upward around the rotation axis, resulting in a non-orthogonal superstructure. In a simple Twister all floors are identical and rectangular; they are positioned with a fixed incremental rotation. This type of design can make a building more aerodynamic and energy efficient, leading to an increasing number of twisted tall buildings entering the planning stages throughout the world.

The design for Capital Gate in Abu Dhabi makes a more unobtrusive gesture on the façade regarding the location of the diagrid situated behind the triangular glazing. While the two-storey module size, designed to support the building's 18^0 lean, constitutes one of the smallest modules to date, the member sizes are large and to translate this to the visual appearance of the façade would have been quite overbearing. Instead, a slight colour change at the visible grid is used to acknowledge the pattern of the diagrid structure [10]. In general, these sorts of twisted building forms tend to subdue the reading of the module through the façade.

Figure 2. Famous diagrid structures with façades

3 BIM Model Of The Twisted Tower

Principally in the concept of this study, a selected twisted tower has been the template of the study and it has been modelled as BIM. While selecting the project It is considered that the structure is already completed and opened to use the and the building should have twisted floors and façades together. Some twisted towers have only twisted façades not floors. It is thought that twisted floors with twisted façades give more opportunities for variable joints and so variety design solutions.

3.1 Selected Twisted Tower As a Template

Design of Vincent Callebaut Architecture "Agora Garden" (Figure: 3) has been found proper with the requirements that indicated at the top. Vincent Callebaut defines the tower as : "The 21 storey tower which is currently under construction in the Xinjin District of Taipei City, Taiwan, is directly modeled after a strand of DNA — a double helix twisting 90-degrees from base to top with each level turning by 4.5 degrees.

Figure 3. Selected twisted tower (Agora Garden) model to develop parametric module

According to the architects, this unique form provides solutions to 4 main objectives:

- To be perfectly integrated in the North / South pyramidal profile of the Building Volume along with its East / West rhomboidal profile as well as the North-South reverse pyramid profile.
- To generate a maximum of cascades for suspended open-air gardens, not part of the floor area ratio.
- To offer every resident exceptional panoramic views of the Taipei skyline by multiplying the transversal views, especially towards the very close Taipei 101 tower and the Central Business District."
- To generate from a flexible standardized level a progressive geometry which ensures the privacy of each apartment by avoiding direct visual axes.

3.2 Generating The Digital BIM Model Of The Twisted Tower

The BIM model of the tower was created by using Autodesk Revit. Since the main purpose of this study is optimizing the façade geometry, only the components related with façade was modelled (Figure: 4) The core of the tower as a circle has been placed with parametric properties such as radius. Beside this the vierendeel parts was modelled as floors from ground level to 21st level. The angel of the floor around Z axis changed as

4,5 degree floor by floor. At the end, the first floor has been rotated 90 degree when it reached at 21st level.

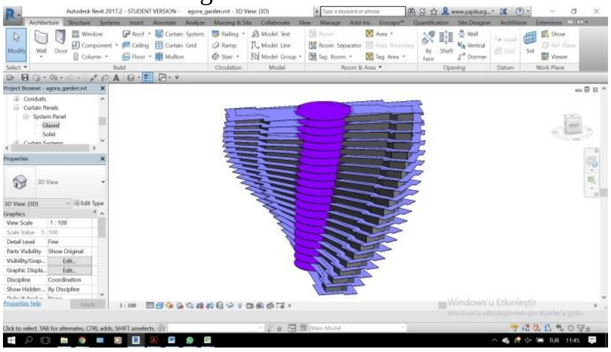

Figure 4. Selected tower's BIM model creation (from Autodesk Revit)

The parametric network was generated by Dynamo (Figure: 5). The rotation of the floors can be customized and the walls placed automatically thanks to parametric network.

The network of floors placement and rotation was established within the visual programming (Figure: 4). The main purpose of the network is to set a template of adjustable rotational floors for BIM. This is not only providing to design twisted structures easily and effectively rather than manual methods also generates to reach the optimal solution of the façade design. It is probably emerge that the angle of the storey floors' rotation required to be changed. The existing project has glass walls for exterior. Owing to its green architecture and design considerations this twisted tower hasn't any curtain wall system or any façades. Despite this status, a parametric façade grid system which enables to adjust via variety of analysis, has been generated (Figure: 5). The grids of façade can be changed by geometry included 3d rotation and translation.

The façade design method was offered with visual parametric programming. Once in Revit interface, mass modelling is used for general façade shape. Since twisted towers generally have curvilinear surface, mass modelling with points should be used for façade. For quite specific façade design mass surface converted as divided surface (Picture :). The countless alternatives can be endeavoured to reach the optimum design even though the shell associated with multiple shapes and amorphous geometries thanks to divided surface. The whole cell of the divided surface might be customizated such as colour, dimension, etc. customization. The "divded surface" node which is in visual programming Dynamo was used for this progress

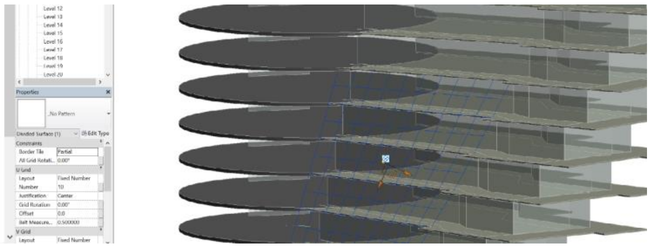

Figure 5. Façade developlent on the BIM model

3.3 Parametric Networks and Features Of The BIM Model

Design stages that applied parametric method are programming, site planning, massing, structure planning, and facade planning. The objectives of the method are project's time efficient, human related advantages (non-determinant decision-making, creativity, pattern recognizing, and advantages by using computers [6]. As mentioned above, the variables of the model has been defined within the parametric network. The panels and mullions of the façade can be changed thanks to this network. The network of the Dynamo loop enables to designers creating many façade alternatives included variety panel dimensions & materials, join types and etc easily for this type of towers. Once, the elements which is composing the surface of the BIM model select via the node of the "select model elements". The floor edges was defined as lines which can be manipulated by their start-end points and by their angles. The storey number of the tower linked to the Dynamo network and it can be tried for any number. Façade surface placed at given storeys and floors' edge.

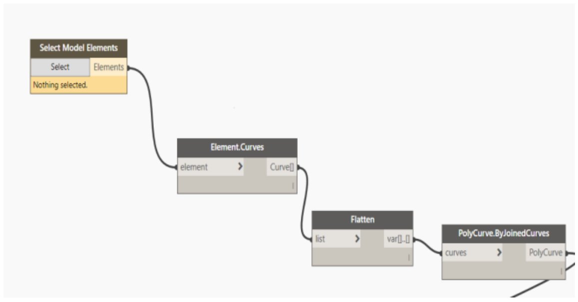

Figure 6. Parametric module development process

The caotic data from the edge lines of the floors arranged with list and list filter nodes. It gives variety opportunities such that any edge of the floor can be unchanged when the others manipulated. The joint component such as rivets and screws can be placed and count even among many alternatives. The grid system enabling to design variety façade options can be placed with any distance from the floors. As adaptive family 3d amorphed panels which dimensions' can be changed via Dynamo nodes generated, it is possible to place a prominent panel system in any geometry on the façade grid system.

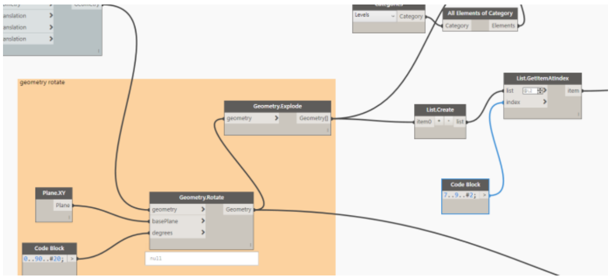

Figure 7. Filtering among multi lines

4 Using the BIM Façade Module As Decision Making Tool

On the instance of the BIM model, multi façade panel geometries, different colour of the façades and the angle of the grids was analysed as per shading and solar lighting. The analysis has been summerized, note that variety types of analysis can be done on the façade systems. Dynamo nodes were used for trying various alternatives to get the optimum solution (Figure. 8).

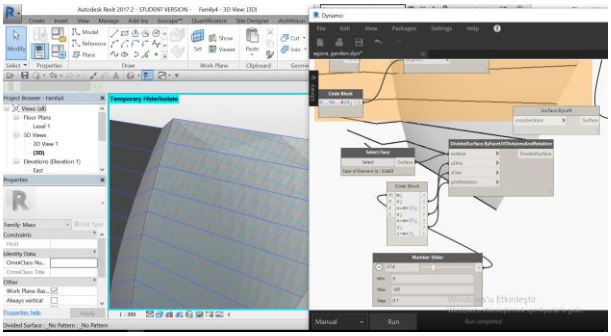

Figure 8 : Fine tuning for optimum façade panel geometry

As mentioned above the façade analysis has been executed on the panel geometry and panel colours. Combinations with the color and geometry of the panel has been connected by the nodes of Dynamo. The colour of the panels has been placed randomly by the "math random" node. It can be inferred from the analysis that how the contrast of colours effect on the interier light and shadow. In addition to this the light and shadow map of the project can be created. The lighting level and shading area was measured depends on the façade combinations. Not only horizontal and vertical grid distance has been connected by the parametric formula but also the angles of the grid lines put into the formula. In addition the mullions' angles and materials might be customized along to the light sourcing and shadow analysis. The network enables to the experts that they make the analysis such as: energy, sunlight, shadow and artificial light.

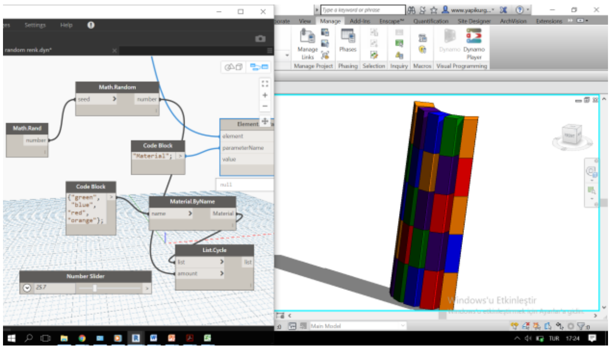

Figure 9. Façade colouring by Dynamo

Twisted geometry provides that more alternatives can be created rather than straight face. If the façade geometry were straight the combination types with geometry & colour would be 10 times less than twisted.

5 Conclusions and Further Studies

Façades are the widest areas of the buildings. They should be analyzed efficiently for energy saving and comfort. Variety alternatives should be tried to reach the most effective solution. In traditional methods only few façade options can be analyzed cause of cost and time especially. If the structure have complex surface, it is much more harder. A BIM based parametric module was generated. This module is unique with regards to specify just for twisted towers. As twisted towers' have rotated floors and curvilinear surfaces in sync, they deserve more efficient façade analysis and most effective selection. Such these modules enable to designers and constructors to reach most efficient solution at the end of so many analysis. The selected twisted façade gives to search more alternatives and it provided to get the best solution as far as possible.

BIM and parametric design getting more curious role in AEC in consequence of seeking energy efficiency buildings whose analysis are complex and cautic. The practical and open source modules should be generated for every unique structures. Additionally, augmented reality (AR) or virtual reality (VR) options which enables to evaluate to the building façade performance to professionals, architects or engineers will be enhanced. Such these modules can be assisted to the analysis developments.

It is thought that the twisted surfaces provides more advanteges to the AEC to construct more sustainable structures and new materials competible with such these shapes will be invented from the nature. Building such these sophisticated buildings and those all analysis are no longer easier than the past thanks to BIM and parametric design tools.

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