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Research paper

Free-form External Design using BIM and Development of Grasshopper Model

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Abstract

Background/Objectives: Recently, the number of free-form buildings using BIM(building information modeling) technology is increasing, but it is difficult to design and manufacture non-linear external panels of free-form buildings.
Methods/Statistical analysis: In this study, the research team will develop the technology for easily creating non-linear surface panels using BIM, develop a scalable 3D external design process based on grasshopper module, and validate the engineering feasibility through simulation. The methods for making grasshopper modules are based on optimization techniques, algorithms, analysis of existing cladding panel technology, and analysis of existing fabrication methods
Findings: In order to develop grasshopper model, the first step is generating the optimization algorithm. To find the algorithm, we considered three alternatives, 1) the method of extracting and utilizing the coordinate point in the initial design of Grasshopper and applying the minimum interval to the concept mass of Revit while keeping the original plan, 2) Designing the design through connection of the minimum interval (coordinate point) of the interval on the U. V grid in the concept mass stage using Revit in the early stage, and 3) It is a plan to utilize Dynamo. Then, based on three options, 1) and 2) were combined to develop the technology. And the validation of proposed technology was performed between existing fabrication methods and the proposed methods by 4 major categories.- accuracy, waste reduction, optimization, and congruity. In all aspects, the proposed method was exceeded over the level of existing technique.
Improvements/Applications: The research team developed a design process that can produce exterior panels of free-form buildings through optimization, algorithm, and Grasshopper. The results are applicable to all areas of construction.

Keywords: *Free-form building, external panel, BIM, Grasshopper, non-linear*

1. Introduction

Building Information Modeling (BIM) technology is a global advanced technology that is used in the AEC (Architecture, Engineer, and Construction) field to convert from existing two-dimensional design to three-dimensional design [1]. The area of architectural non-linear surface design, there are few formal design techniques or developed models using BIM technology, which makes it difficult to design and construct surface panels in situ project [2]. Therefore, mechanization, advanced technology, and automation are urged by the development of 3D design technique and model using BIM developed from the existing two-dimensional man-oriented and low-level technology [3].

Increasing construction workability, cost reduction and duration of external panels are increasingly demanded. Much of the work is shifting from manual and two-dimensional (2D) work processes to BIM, which is a three-dimensional information model. Technological developments are underway. Efforts are needed to reduce energy consumption and unnecessary waste by optimizing the external panels. And the shift to computer-oriented design introduced two main changes; the first change should increase ability and the ease of drawing, modeling and communicating architectural forms, which allowed architects to enhance productivity and thus can find more design solutions faster. The second change, in this context, should create the possibility to harness computer processing ability to make and evaluate design solutions [4].

In this study, we will develop the technology for creating free-form surface panels using BIM, develop a scalable 3D external design process, and validate the engineering feasibility through simulation.

2. Differences between Linear and Non-Linear Design

The main difference between linear and non-linear process, besides the unique ability to generate several design alternatives, should do with the non-linear algorithm to generate new ones deriving from both first and divergent alternatives. This helps the designer to integrate successful design solutions from different next-stages in the generation process. The idea of divergent design alternatives has been talked widely in traditional design thinking. Several cases are the discussion on parallel lines of thought by Lawson [5], the discussion on top-down and bottom-up approaches within the space problem by Rowe [6] and Alexander's procedural design method described in his seminal [7]. However, these ideas and manners still stick within linear design. This can be explained by the integration of non-linear design to computers, which were not widely used for design when these ideas were developed.

And the result of the design process concentrates on the adventure of the space, rather than producing an absolute best answer. It allows the architect to think the number of alternatives that the design process would make between the possible solutions. Many alternatives is to be connected to the design stage and the possible difference between the solutions. It is rational to assume that in the preliminary design, while various design point are explored and there is a variety between the generated solutions. In later design, however, only a few solutions would need to be created and a small variation between them is abstracted. Therefore, solutions can be created and discussed in any design process for the entire building form and for parts of the designed form.

3. Related Review on External Design Process

3.1 Optimization Technology Analysis

Free-form external design techniques provide opportunities to develop existing design and implementation processes more efficiently and systematically. A 2D design does not provide exact shape but 3D modeling allows us to examine design forms from the early design stages. As a result, there is the advantage of creating an external design more efficiently and systematically. According to investigation, the optimization techniques used in building BIM consist of defining the structural methods that comprise the free-form surface and the technology for splitting the cladding. This method was applied and analyzed in this research as shown in figure 1.

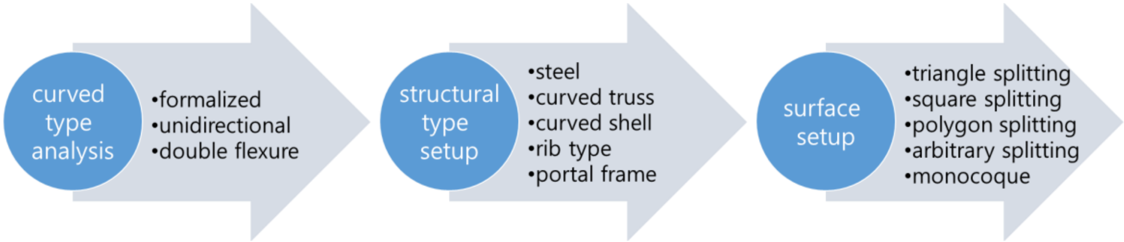


Fig.1: Types and processes for optimization

3.2 Case Study in Optimization Technology

Since there are not many buildings that have been built at present, we will analyze the cases of optimization technology using two representative cases as shown in table 1.

Table 1: Case study in free-form building

Case study	Description
ING BANK & HEAD OFFICES	First implementation Create 3D modeling with digital techniques Resolve cortex optimization using a wooden frame on the structural part Use of stereotyped surfaces
GUGGENHEIM Bilbao Museum	Use Catia to solve irregular designs more digitally Uniformalized curved surface Attach the primary structure and the secondary structure to the connection type

Although the method of manufacturing the external panel has been developed over time and initial optimization has been done unidirectional, the design value can be quantified and objectified by actively using Catia software which is used as a design tool of an airborne ship and so on. However, in the case of Catia, it was analyzed that the price of the program is high, the number of users to use is low, and learning takes a long time, which requires a lot of time for active introduction. This project was conducted using Rhino, Grasshopper and Revit less expensive than Catia. Past irregularities have solved simple envelope solving by primary modeling, but at present they can visualize curves and irregular shapes in the envelope, inner wall, and inner space.

Analyzing another study proposed a method of approximating a free curve with various radius values to a bi-arc that satisfies the tangent at both ends of the line [8]. This method is relatively simple to convert the curve to arc, but it is not linked to production. In shipbuilding industry, there have been researches on curved surface for making ship. Branco and Soares proposed a method of making the shape of a panel made up of regularly spaced lines when the curved surface is a part of a conic and finding the center value of each cone and the radius value [9]. In particular, Yang Liu proposed a method to mesh the conical mesh with the subdivision method in a study conducted with Pottmann [10]. This creates a face with the same mesh behind the face, making it possible for structural members to attach and each face being configurable in a plane. In addition, a researcher introduced modeling methods that can be used to create flat surfaces without creating warping surfaces [11]. The criteria of the architect or expert to start the penalization should be set first, and the specific criteria or figures for creating the panel line should be determined. You should create panels and set up and sort out processing standards where lines intersect or complex geometric shapes. The generated panel measures the curvature, subdivides as necessary, and the final panel is created. Optimization is a method of forming a geometric shape and a method of creating a panel with a mesh considering the optimization method and construction that are not directly related to the production.

Therefore, in this paper, the optimization method is a futuristic quadratic form and it adopts algorithm and method that can be used both inside and outside at the same time to optimize the bending type in two directions to the maximum in one direction and to partially bend in two directions.

3.3 Summary of Existing Optimization Technology

According to the optimization method analyzed above, the site visit and literature of the conventional shell structure for the unstructured structure are investigated and analyzed as like table 2.

Table 2: Investigate the method of the surface panel for free-form building

Surface continuity	Regularity of the pattern	Method	Panel type	Basic rules	Panel curvature
Discontinuity	Regular pattern	Triangular paneling	Triangle		Plane
		Square paneling	Square		Plane
Continuity	Regular pattern	Mesh creation with simple iso-spacial copy	Square	Set baseline Copy horizontally and vertically to baseline	Plane, one-way, two-way curved surface
		Patch logic	Regular polygon	Geometric type analysis Patch creation	Plane, one-way, two-way curved surface
		Temporary front	Square	Temporary front creation	Plane, one-way, two-way

		creation method		Set baseline and create an isometric copy line Create vertical lines on isosceles copy lines Corner cleanup	curved surface
		Mosaic	Polygon	Setting the baseline pattern Pattern combination Cut according to combination	Plane, one-way, two-way curved surface
	Irregular pattern	Subdivide method	Polygon	Set up rules Cut in basic unit Subdivision when exceeding allowance	Plane, one-way, two-way curved surface
		Complex paneling method	Polygon	Combine two or more paneling methods	Plane, one-way, two-way curved surface

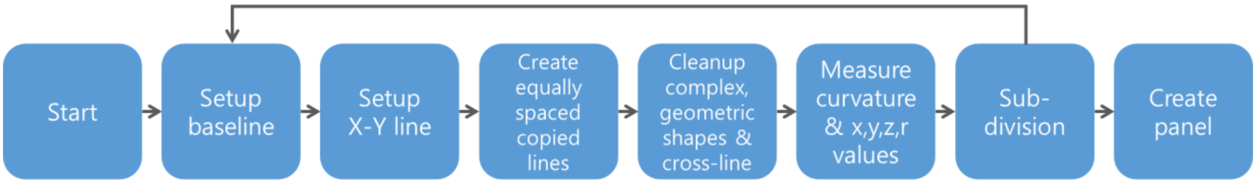


Fig 2: Flow chart of GTPPM

The penalization method can be varied depending on various factors such as the geometry of the envelope, the intention of the architect, the mathematical panel creation algorithm, and the project cost. However, in this paper, the complex penalization algorithm uses GTPPM (The Georgia Tech Process to Product Modeling) and can be summarized in the flowchart as shown in the figure 2.

4. Development of Optimization algorithms

4. 1 Optimization Algorithm Selection Method

The following three methods are considered to generate the optimization algorithm.

Alt1) the method of extracting / utilizing the coordinate point in the initial design of Grasshopper and applying the minimum interval to the concept mass of Revit while keeping the original plan as shown in figure 3.

Alt2) designing the design through connection of the minimum interval (coordinate point) of the interval on the U. V grid in the concept mass stage using Revit in the early stage

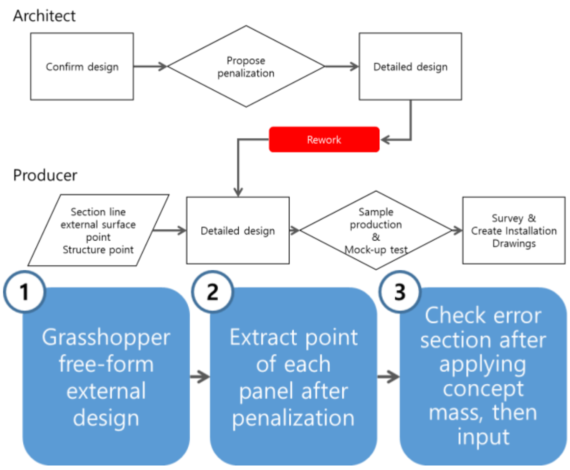


Fig 3: Flow chart of 1st alternative

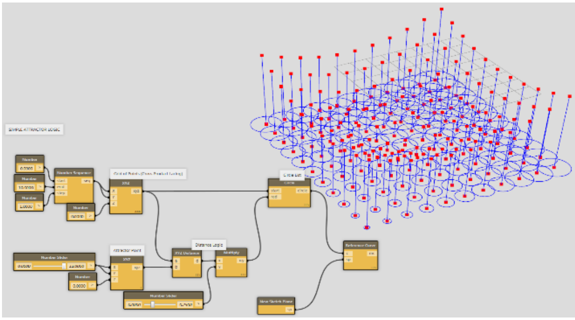


Fig 4: Dynamo 1

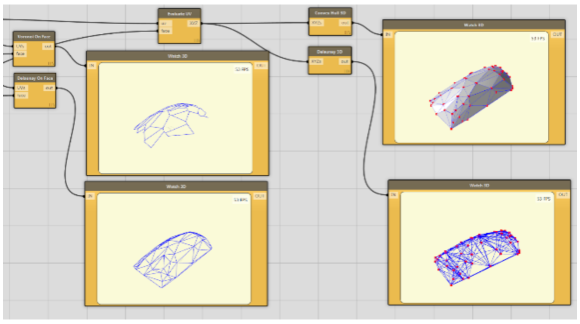


Fig 5: Dynamo **2**

Alt3) it is a plan to utilize Dynamo. By eliminating the Grasshopper design phase and using Revit, which is a middle and low-cost BIM tool, it is possible to solve the parametric / algorithm method of Grasshopper through Vasari and Dynamo interworking with the work of irregular panel and other parts as shown in figure 4 and 5.

In this method, existing non-informal modeling overcomes limitations and omits interworking, minimizing interworking time and minimizing the amount of data lost due to object compatibility problems. However, it seems that it would be unreasonable to include all atypical forms in alt1. Based on this, alt1 and alt2 were combined to develop the technology. And the content suitable for this task was processed as shown in figure 6.

4.2 Development of Grasshopper Module

The methods for making grasshopper modules are based on optimization techniques, algorithms, analysis of existing cladding panel technology, and analysis of existing fabrication methods.

The method of manufacture is as follows in table 3.

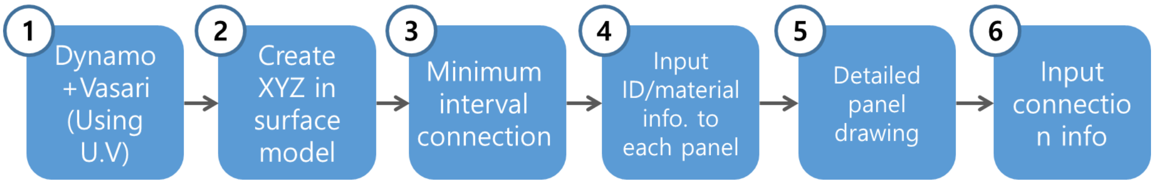
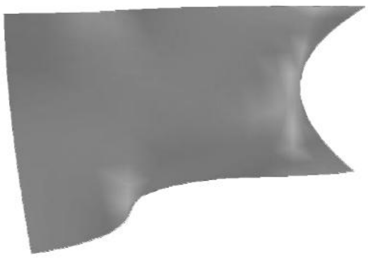
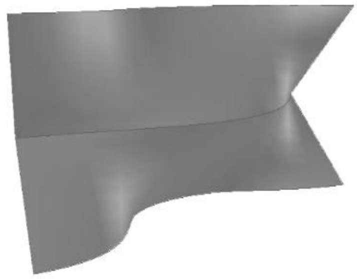
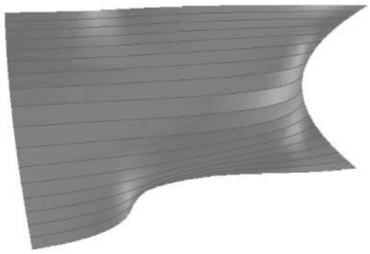
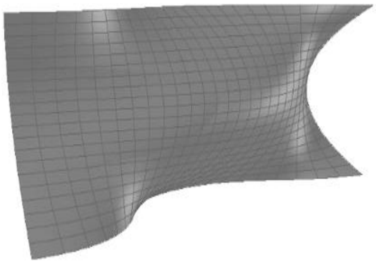
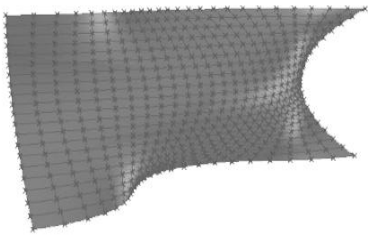
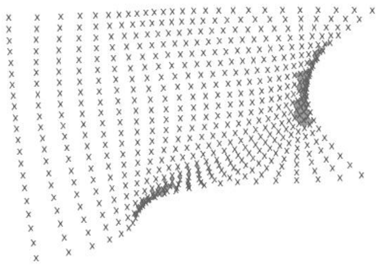
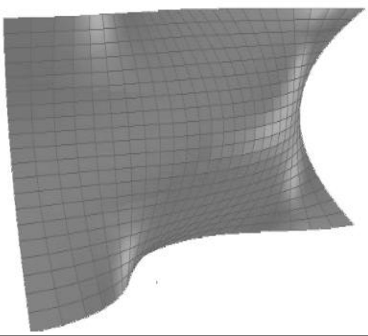
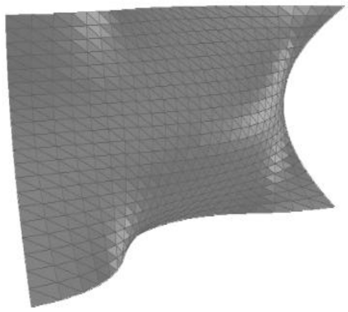


Fig 6: Process model of this research

Table 3: Grasshopper module's making

1) Freedom curve model with curvature throughout the model (initial design)	2) Half division - Adjustment of curvature through segmentation (2-way curvature)
	
3) Lateral division - One way, but not constant distance.	4) Two-directional division of the existing plane (same as the existing U.S.V system)
	
5) Create a sitting point on the work surface	6) Extracts and connections of the seating points to the unstructured reference plane (straight line)
	
7) Create rectangle flat panel in 2-way model (Each panel is manufactured in two directions).	8) Generation of triangle flat panel in 2-way Model (Triangle is the most frequently used form in architecture, with cheaper unit prices and easier to manufacture than reputation.)
	

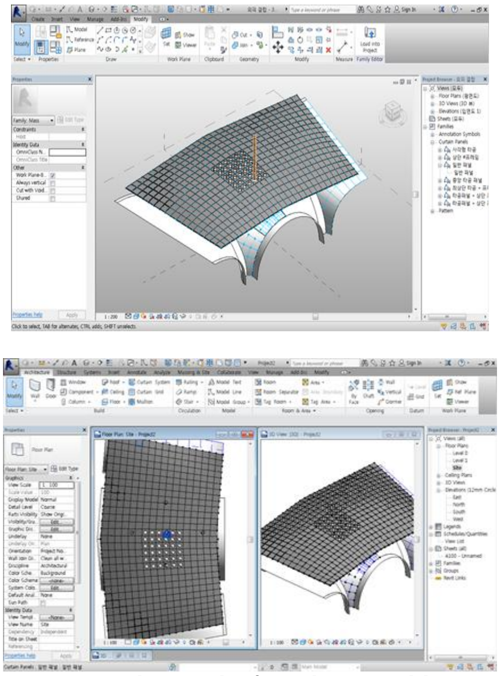


Figure 7: The example of Grasshopper modeling

The figure 7 shows an example of grasshopper modeling made through the above eight steps.

5. Validation of the Proposed Methods

The validation was performed between existing fabrication methods and the proposed methods by 4 major categories.

5.1 Accuracy Validation

The existing drawings are placed in three dimensions, and the dimensions of the placed drawings are measured. The model is verified by comparing the numerical values of the existing drawing in figure 8 and the three-dimensional drawing in figure 9. As a result, it was found that 99.6% were consistent.

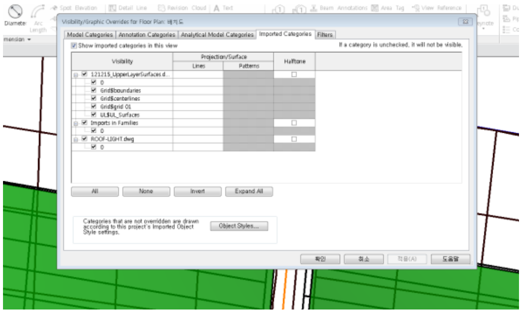


Figure 8: Placing existing drawings in 3D

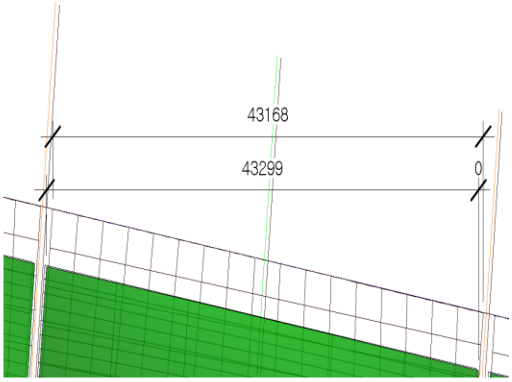


Figure 9: Comparison with existing drawings

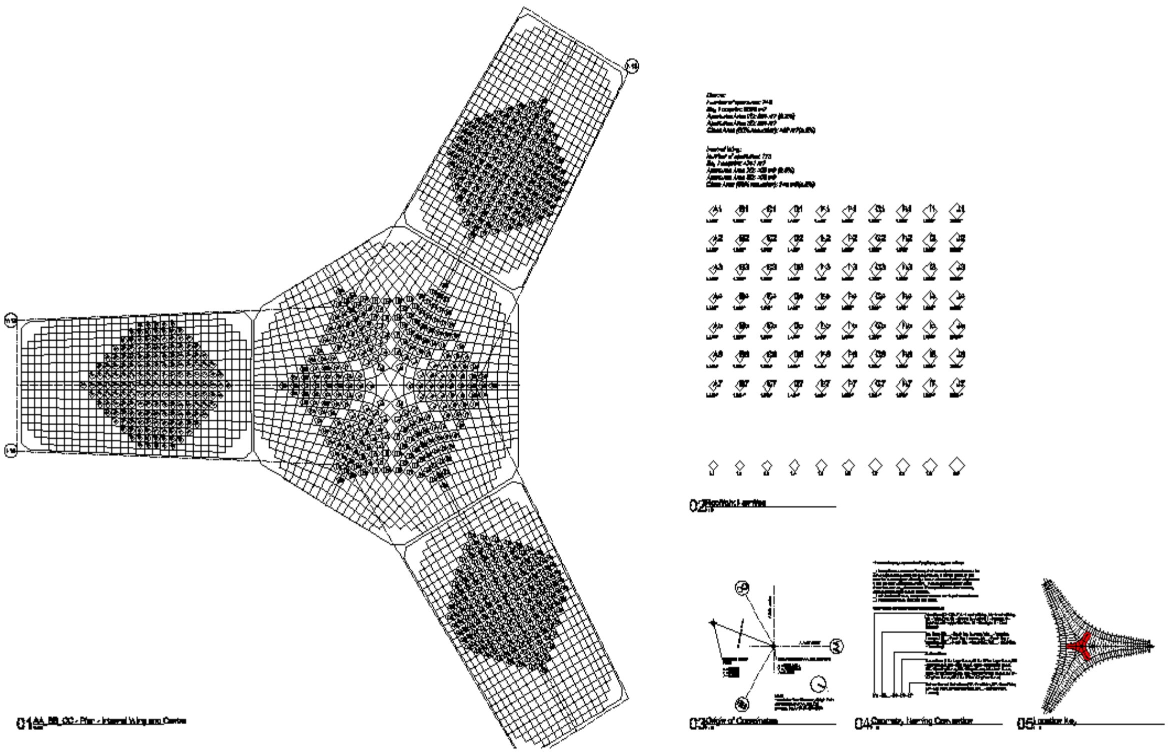


Figure 10:.Quantity information in existing drawings

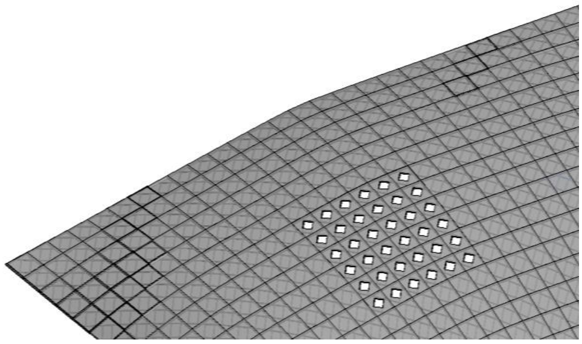


Figure 11: The applied module area

5.2 Waste Reduction Validation

For the quantity, there are a method of measuring by area and a method of measuring by volume. In the case of this external panel, it proceeds by measuring area and quantity.

The reason for this is that there is information on the corresponding part in the existing drawings in figure 10 and 11, and the table 4, so that the information and BIM information can be directly compared.

5.3 Validation of Modeling Optimization Rate

In the case of conventional modeling, a lot of deformation is generated in the conventional modeling (red area) in figure 12, and even if the modeling is possible, the actual construction efficiency is rapidly decreased and the cost is increased. In the case of modeling optimization in figure13, it can be used as a criterion for minimizing the red color. As a result of this experiment, it was developed that the distribution of the green and blue panels that can be easily constructed by reducing the portion was developed. As a result of the experiment, it was possible to manufacture the exterior panel while utilizing the concept of the existing design by about 80%.

Table 4: The quantity comparison between existing method and the 3D model

Quantity: 2D based 1 panel		Quantity: 3D based 1 panel	
Size		Size	
Average 6.41 ㎡		Average 6.152 ㎡	
Quantity measured in one zone			
Quantity	Area	Quantity	Area
94	602.54 ㎡	94	578.288 ㎡(-24.252 ㎡)

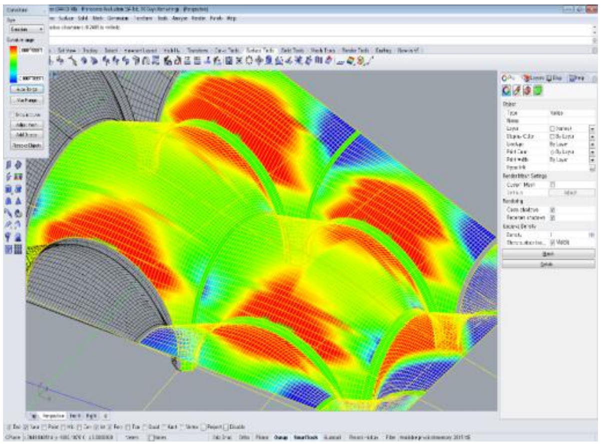


Figure 12: Existing way

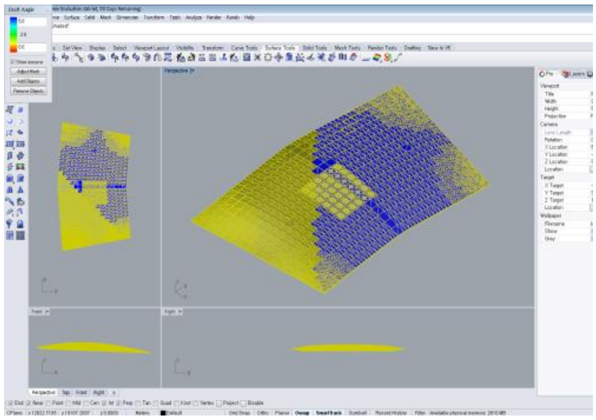


Figure 13:. Optimization way

In the case of modeling using the proposed module, the optimization can be applied to the one-way flat plate, which is easy to construct as a whole.

5.4 3D Drawing Congruity

3D Drawing congruity is a comparison between the drawings of existing drawings in figure 14 and the image file extracted from 3D in figure 15.

We compared the images from the existing drawings and the Revit images in a planar manner to confirm the agreement, and some unfavorable parts were also found. This part seems to have to be further developed in the future. This allowed the results developed in this study to be verified. And the following table 5 shows the validation results.

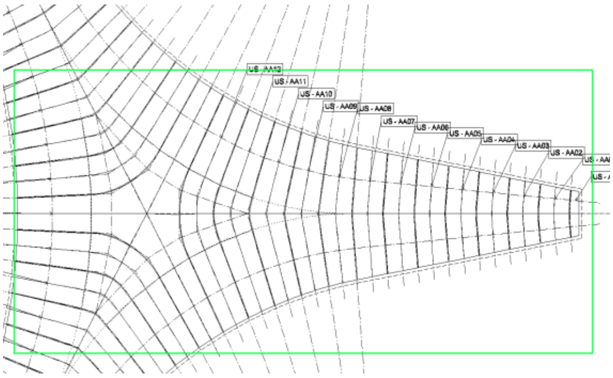


Figure 14:. Existing drawing

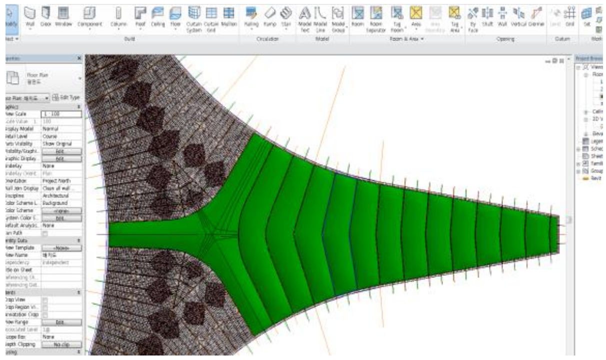


Figure 15: 3D applied drawing

Table 5:. Comparisons results

Performance	Metric	The level of existing technique	Comparison method	The level of proposed method
Accuracy	%	80%	3D comparison	90%
Waste reduction	%	20%	3D quantity comparison	14%
Optimization	%	60%	3D comparison	80%
Congruity	%	60%	3D comparison	85%

6. Conclusion

The research team has developed a BIM based technology for design of free-form exterior panels, which is still incomplete and has a lot of manual work in current circumstances. In order to solve these difficulties, we developed a design process that can produce exterior panels of amorphous buildings through the following method. In this paper, the optimization method is a futuristic quadratic form and adopts an algorithm and a method that can be used both inside and outside at the same time to optimize the bending type in two directions to the maximum in one direction and to partially bend in two directions method. In the initial design of the Grasshopper, the coordinate points are extracted, utilized and the minimum interval is applied to the concept mass of Revit to maintain the original plan (Coordinate points). The design process was constructed by combining the design methods through the minimum interval connection. The results are presented in both structural and free-form external panel design, thus making it possible to solve surface panels before and after construction. The effects obtained from this project are as follows.1) Improve construction and accuracy of building panel 2) Reduction of production cost and shortening of air 3) It is possible to optimize the building which expresses national technology and culture in a form that can be constructed. 4) Much of the process of manual and two-dimensional work can be replaced by BIM, a three-dimensional information model. 5) Reduced energy consumption through optimization of envelope 6) Reducing unnecessary waste by developing an optimization technique for the envelope. In the future, the technology of free-form external panels can be expanded to other project for example cultural properties. Etc.

Acknowledge

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References

[1] Ku K, Pollalis S, Fischer M, Shelden D. 3D model-based collaboration in design development and construction of complex shaped buildings. Journal of Information Technology in Construction. 2008;13:458-485.
[2] Iyengar H, Sinn R, Zils J. Unique Steel Structures in Spain: The Guggenheim Museum Bilbao and the Hotel Arts, Barcelona. Journal of Constructional Steel Research. 1998;46:10-11.
[3] Cohen-Steiner D, Alliez P, Desbrun M. Variational shape approximation. ACM Transactions on Graphics. 2004;23(3):905-914. DOI:10.1145/1186562.1015817
[4] Grobman YJ, Yezioro A, Capeluto IG. Non-Linear Architectural Design Process. International Journal of Architectural Computing.2010 Jan;8(1):41-53.
[5] Lawson B. How Designers Think:The Design Process Demystified. Oxford: Architectural Press; 1997.
[6] Rowe PG. Design Thinking. Cambridge: MIT Press; 1987.
[7] Alexander C. Notes on the Synthesis of Form. Cambridge: Harvard University Press; 1964.
[8] Meek DS, Walton DJ. Approximation of discrete data by G1 arc spline. Computer-Aided Design. 1992;23(10):301-306.DOI:10.1016/0010-4485(92)90047-E
[9] Branco JNR. Soares CG.Mapping of shell plates of double curvature into plane surface. Journal of Ship Production. 2005;21(4):248-257.
[10] Liu Y. Pottmann H.Wallner J. Yang YL. Wang W.Geometric modeling with conical meshes and developable surfaces. ACM 52 Transactions on Graphics. 2006;25(3):681-689.
[11] Aumann G. Degree elevation and developable B´ezier surfaces. Computer Aided Geometric Design. 2004;21:661-670

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