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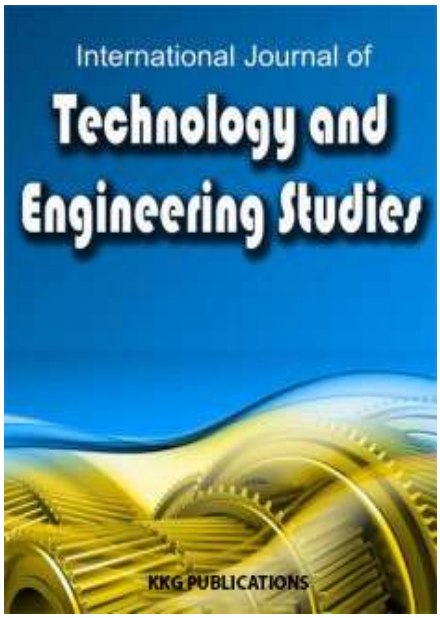

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PANELIZING ALGORITHMS FOR FREE-FORM CONCRETE PANELS CONSIDERING ESTHETIC SURFACES

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PANELIZING ALGORITHMS FOR FREE-FORM CONCRETE PANELS CONSIDERING ESTHETIC SURFACES

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Abstract. This study aims to develop panelizing algorithms for free-form concrete panels considering esthetic surfaces (design aspect). However, the overall design of free-form buildings is significant; whether the shape, size, curvature, and joint of members that compose the buildings make them esthetic or not should be considered. The developed algorithms penalize the buildings already designed to verify the usefulness of algorithms. The study classified the curvature surfaces by Flat surface, Single surface, and Double surface based on the curvature of building designs and developed FCP penalizing algorithms considering esthetic surfaces. The developed algorithms were applied to existing buildings like BMW-Welt, London City Hall, and Heydar Aliyev Center using Sketchup. Further studies are required on penalizing members produced by CNC machines and FCP penalizing algorithms using parametric designs.

INTRODUCTION

For free-form buildings to have a landmark image, their exterior design should be esthetic. Although the overall design of free-form buildings is significant, whether the shape, size, curvature and joint of members that compose the buildings make them esthetic or not should be taken into consideration. The free-form buildings designed are mostly panelized for the esthetic aspect of buildings and convenience of design works. Although the curvature surfaces are created by a digital modeling tool, developed for visual implementation and expression of curvature surfaces, the curvature surfaces should be reinterpreted to actually build them [1]. In other words, the models designed by architects should be newly panelized in consideration of the building construction. Thus, the purpose of this study is to develop Panelizing Algorithms for Free-form Concrete Panels considering Esthetic surfaces (design aspect). The developed algorithms panelize the buildings already designed using Sketchup program, so as to verify the usefulness of algorithms.

PRELIMINARY STUDY

Looking into the studies related to free-form concrete manufacturing technologies, [2], [3] producted EPS-formwork using a CNC machine, and Toyo Ito & Associates [4] conducted a study on producing forms with wood using a CNC machine and to manufacture free-form concrete members. Franken & ABB [5] came up with free-form concrete using a digital form by a CNC machine and acryl glass. CRAFT [6] performed studies on robot automation, construction process, new materials and computer designs for automation of free-form concrete pouring, and conducted a study on manufacturing and using machines for construction automation. IMCRC [5] studied 3D printing method to make free-form concrete members.

The studies related to panelizing of free-form buildings include panelizing using triangle shapes conducted by [7], [8] used a hexagon, Honeycomb shapes to panelize free-form structures, optimizing the panelizing to match the existing designs. [9], [10], [11] performed a study on optimization of free-form curvature surface panels considering the accurate implementation and economic-feasibility of original surfaces in free-form buildings. [12], [13] conducted a study on optimization of panelizing, that is to replace with the panels that lower the production cost of each panel within the range of not damaging the original surfaces in free-form buildings and panelizing method. [14] Proceeded with pilot modeling to extract BIM information on members by applying the method of panelizing curvature surfaces based on the geometric analysis that mathematically defines building shapes. However, the previous studies mentioned above are on optimization of panelizing focused on accurate implementation and productivity of free-form buildings already designed. Therefore, a study on FCP panelizing algorithms considering not only production, but also esthetic surfaces is needed.

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The procedure of FCP production is as shown in Fig. 1. Firstly, there is a free-form building design, FCP data are extracted, a form is manufactured using a CNC machine, and then FCP is produced and installed [15], [16]. Among these stages, manufacturing a form by CNC machine, and producing and installing FCP are part of FCP production-installation((3)~(5) of Fig. 1).

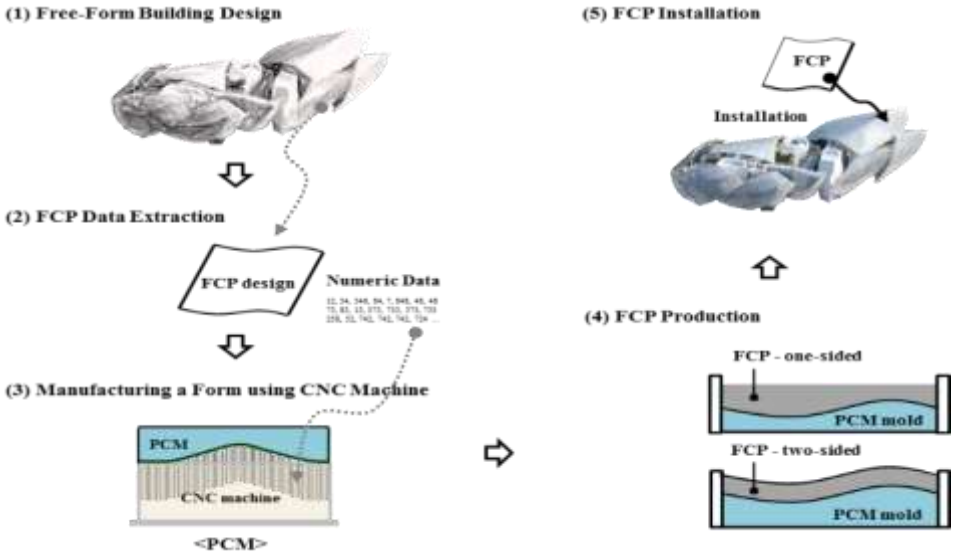

Fig. 1. Process of FCP production [15]

Surfaces of free-form buildings can be divided into a flat surface and a curved surface. The curved surface is classified into a single-curved surface and a double-curved surfaced based on Gaussian curvature. The maximum and minimum values of curvature at a point on the curvature surface are multiplied to calculate Gaussian curvature. If it is 0, it is the single-curved surface, and if a negative or positive number, it is the double-curved surface. This is shown in Fig. 2.

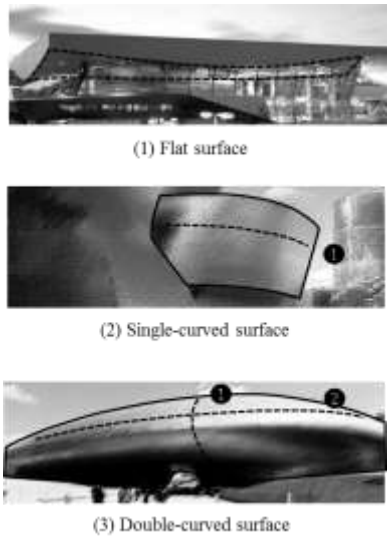

Fig. 2. Free-form building surface types

FCP PANELIZING ALGORITHMS

How beautifully the shape of buildings is implemented depends on the location of joints in free-form buildings, so it is a factor to be considered upon FCP panelizing [15], [16]. Algorithms for panelizing to produce a building designed by architects are as described in Fig. 3. The building surfaces are

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divided into Flat/Single-curved/Double-curved surface based on Building Design data, and the surface pattern is defined by Pattern data. The criteria for FCP panelizing are set based on the reference point/axis of the surface taking into account of the pattern. For panelizing of beautifully-shaped designs, it should be first considered whether to panelize in regular or irregular forms, or horizontally or vertically. Then, zoning of the surfaces is performed. After this, a detailed panelizing considering proportion, symmetry, gradation, contrast, repetition, rhythm and scale is conducted. After reviewing the esthetic aspect and errors of joints produced by panelizing, the members are designed in detail.

BMW-Welt's roof is the case of flat surface, London City Hall side is the case of single-curved surface and Heydar Aliyev Center is the case of double-curved surface, where Sketchup program was used. For a harmonious panel composition, the building envelope is FCP-panelized, consistently in 2m*2m size. As shown in Fig. 4, the angle of surfaces is zoned for easier works.

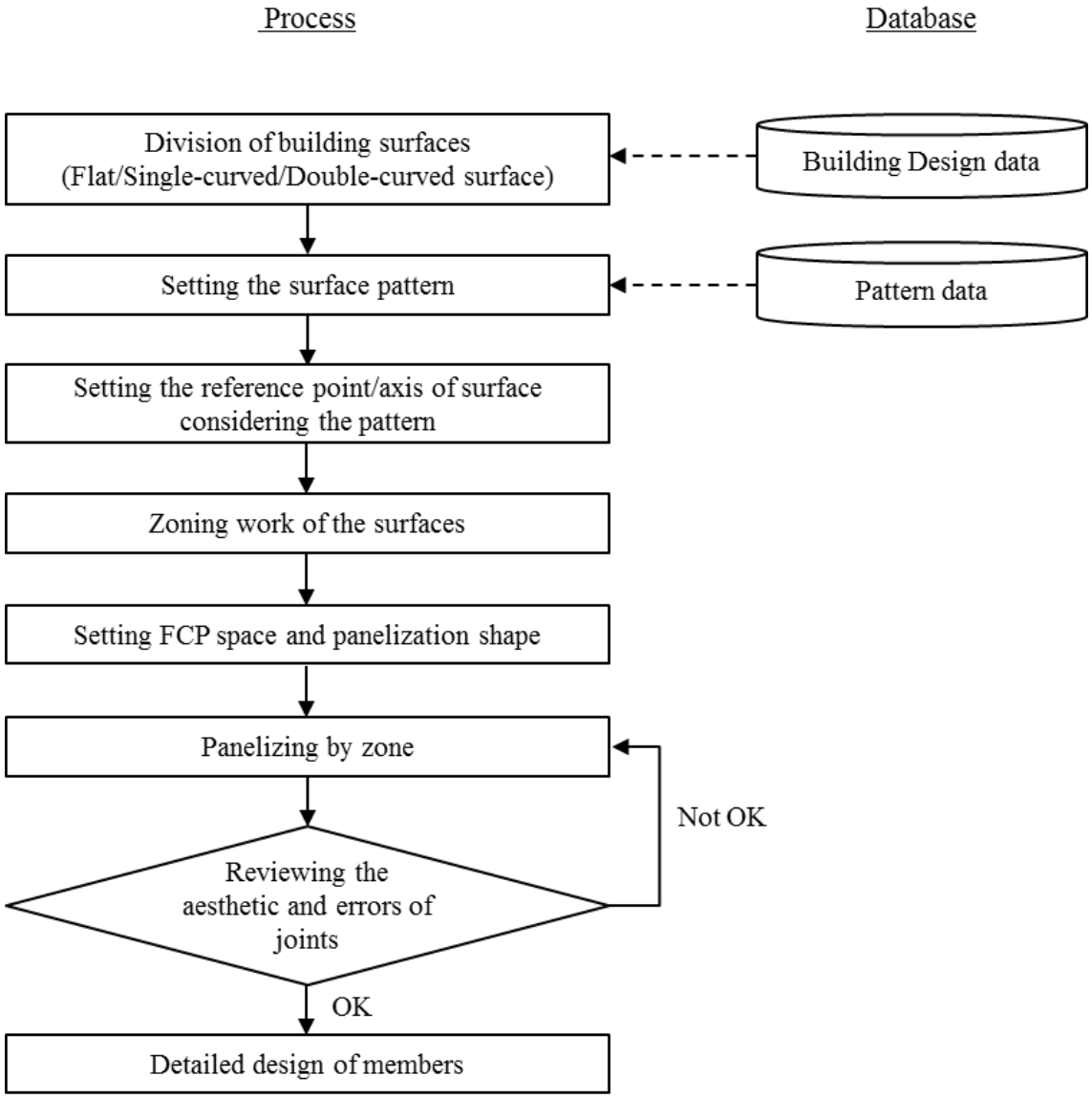

Fig. 3. FCP panelizing algorithms

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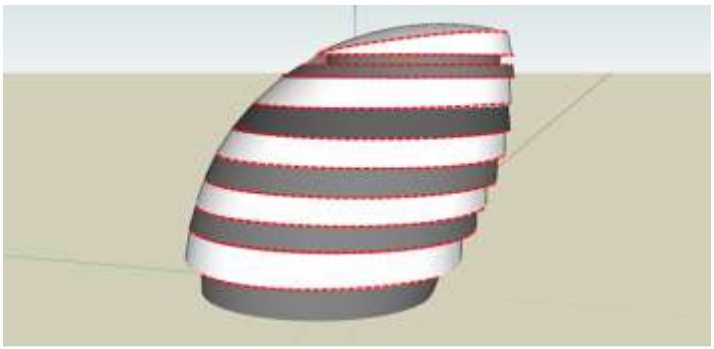
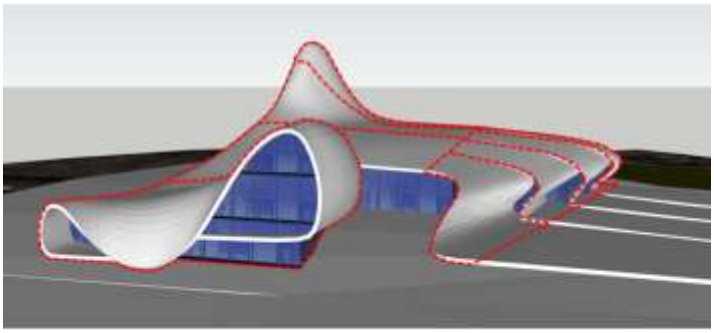


(1) London City Hall



(2) Heydar Aliyev Center

Fig. 4. Zoning of building surface

Heydar Aliyev Center is a building composed of double-curved surfaces, and it is panelized in uniform sizes taking into consideration of harmony and contract based zoning. Although panelizing is conducted based on zoning, errors are generated during panelizing as illustrated in Fig. 5. A precise work is required to prevent panelizing errors.

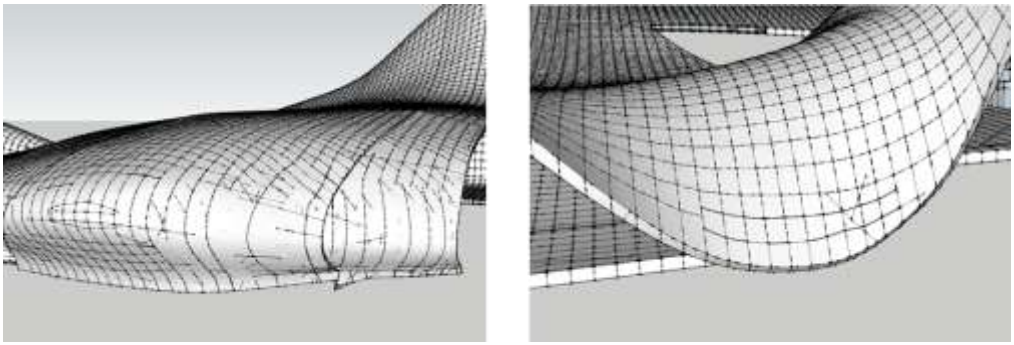


Fig. 5 .Parts with panelizing errors (heydar aliyev center)

Since it is difficult to come up with a design with repetitive and rhythmic surfaces when merely size and curvature are considered, an aesthetic joint design is needed. As a result of panelizing based on the size, curvature and joint, it is found that FCP is made within 0.5~2.5m. As shown in Fig. 6, it is three models of panelization.

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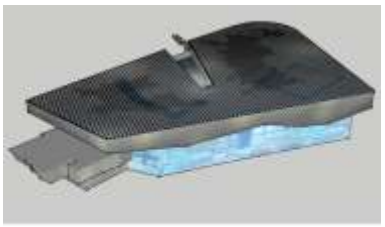
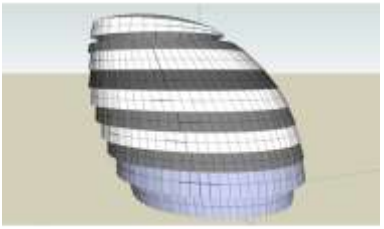
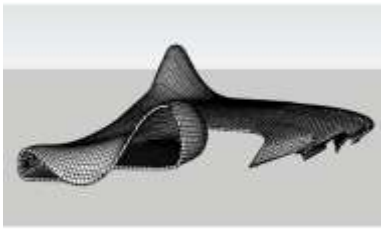


(1) BMW Welt



(2) London City Hall



(3) Heydar Aliyev Center

CONCLUSION

The study classified the curvature surfaces by Flat surface, Single surface and Double surface based on the curvature of building designs, and developed FCP panelizing algorithms considering esthetic surfaces. The developed algorithms were applied to existing buildings like BMW-Welt, London City Hall and Heydar Aliyev Center using Sketchup program. The following results were drawn from the study.

First, there should be criteria for zoning prior to FCP panelizing, and zoning of buildings designed should be based on such criteria.

Second, although FCP panelizing may be automated, the parts with errors should be manually panelized.

Further studies on panelizing of members that can be produced by CNC machines, as well as on FCP panelizing algorithms using parametric designs and Rhino program are required.

Declaration of Conflicting Interests

No conflicts of interest are present in current work.

Acknowledgment

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