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Knowledge Support and Automation of Paneled Building Envelopes for Complex Buildings using Script Programming

Jungdae Park[1,†] and Jinkyu Im[2]

[1]*Department of Architecture, Kyonggi University, Korea*
[2]*Lab. Smart Geometry, Department of Architecture, Kyonggi University, Korea*

Abstract

Advances in the technology of computational design are giving architects and engineers the opportunity to analyze buildings with complex geometries. This study explores the optimization and automation process using the parametric design method, and uses digital tools to achieve surface representation and panelization for curved shaped office buildings. In this paper, we propose parametric algorithms of dimensional and geometric constraints using the Knowledge-ware scripts embedded in Gehry Technologies' Digital Project. The knowledge-based design methods proposed in this study can be used to systemize the knowledge possessed by experts in the form of data. Such knowledge is required to promote collaboration between designers and engineers in the process of CAD/CAE/CAM. The aim of this study is to integrate the process into design, which establishes an integrated process. This integration enables two-way feedback between design and construction data by combining the methods used in designing, engineering, and construction.

Keywords: Paneled building envelope, Parametric modeling, Knowledge based design, Script programming

1. Introduction

Construction of buildings is directly related to a contemporary production method. Variously shaped buildings that are designed to be landmarks have transformed the urban landscape by applying experimental design and new production methods, which are based on information technology. The introduction of commercial CAD (Computer Aided Design) systems in the 1980s brought about rapid changes in the technology infrastructure of the AEC/FM sector. Since the 2000s, experimental attempts such as free-form architecture design have caused a paradigm shift. In the past two decade, digital technology has not only evolved as a tool for two-dimensional drafting, thus substituting the handiwork previously needed for it, but also as a new media for design. In today's world, Digital technology not only involves three-dimensional modeling, but also knowledge modeling based on attribute data including the functions, uses, characteristics, material properties, relationships, and restraints of an object.

An object-oriented three-dimensional modeling system uses parametric technology, which is different from previous CAD systems. This new modeling system provides limitless design alternatives by controlling the configuration and attribute data of unit objects, and providing a correlation between compounded information of complex objects through variables, i.e., parameters. Moreover, a transformed process based on CAD/CAE/CAM is being introduced, which allows the customization of essential materials for construction by extracting data.

Accordingly, this study suggests parametric design tools, which automatically create an irregular-shaped exterior panel based on design theories resulting from an analysis and systemization of the requirements envelope design of free-form buildings. This analysis and systemization is conducted on the basis of the design methodology that extracts quantitative data based on empirical knowledge of experts in related sectors, which has been accumulated through collaboration between designers and engineers.

First, this study tries to systemically define the design logic of experts applied to the free-form building's exterior panel process, which is achieved by the collaboration between designers and engineers. Second, this paper proposes a paneling process that considers envelope design requirements of irregular-shaped buildings. In addition, it proposes a script-based algorithm to create an external system that adjusts to various conditions such as changes in curvature. The goal of this script-based algorithm is to define a relation between each part of an exterior panel and the assembled products. The assembled products are a combination of various other parts, which are combined together using variables and functional formulas, and taking into considering constraints such as measurements, forms and combinations of these. A pilot modeling was undertaken during this study, wherein a new algorithm was suggested, and applied in order to test whether an integra-

†Corresponding author: Jungdae Park
Tel: +82-31-249-9708; Fax: +82-31-244-6300
E-mail: jdpark@kyonggi.ac.kr

ted control method for two-way design feedback is possible. Further, this study examines the automatic connection and transformation of parametric models. As an envelope design is changed, an exterior panel's detailed materials should also be changed accordingly. In addition, necessary information for the construction of these materials in the form of spreadsheets, based on quantitative data, is provided in this paper.

2. Knowledge-based Design Methodology

2.1. Object-oriented parametric model

Object-oriented parametric technology is applied to implement the knowledge-based design methodology. This technology includes not only information on simple forms but also on the functions, material properties, uses, and structures of objects. Further, it includes information on relations between objects and restraints.

The parametric model sets the information required to define forms as a parameter value. 'Feature' is an independent configuration entity and 'part' is a set of multiple features. The parametric model has a data structure, which constitutes one part by collecting many features on the basis of a parent-child relationship. A Constructive Solid Geometry (CSG)-based CAD system uses a Boolean operation, which is formulated into a tree structure to make complex forms. However, the parametric model uses a hierarchical structure for attribute information and combined information in case of unit and complex objects, respectively.

Interconnected parameters consist of tuning parameter, operation parameter and extract parameter. Based on these parameter values, it is possible to set constraints for attribute information on unit/complex units.

Knowledge-based parametric design used in the CSG-based CAD system can be used to control interconnected objects by changing parameters since these parameters control restraints and relations, which are set to meet the user's requirements. This system extracts geometric forms and cost-efficiently controls attributes, which, in turn, allow the convergence of model information and general information on the project including design, production, combination, and maintenance management. Knowledge-based engineering modeling, which automatically connects with CAD/CAE/CAM technology, enables the extraction of visual configuration and construction data, which allows us to obtain the best possible joint structure of materials and details for irregular-form buildings.

2.2. Information logic using script

One could use computer programming for logical descriptions of knowledge within design in the form of specific languages or symbol systems; this is a way to use script. Common CAD programs feature a function of programing design knowledge in the form of script by using the embedded language of the application itself. By applying principals of form generation, they use scripts to program an algorithm in order to automatically create these principals.

Knowledge-based parametric modeling uses components, which define the design logic and knowledge patterns found in the application: User Defined Feature (UDF). It also examines the interoperability of configuration information and engineering modeling data.

GC Script by *Bentley Systems Generative Components*, *Knowledge Ware* by *Gehry Technologies Digital Project, GDL* by *Graphisoft ArchiCAD*, and *MAX Script* by *Autodesk 3D Studio MAX* are good examples of knowledge-based scripting techniques provided by common programs. When it comes to the operation principals of parametric design, *Generative Component* and *Grasshopper3D* use a stack-based method, while *Digital Project* and *Autodesk MAYA* use an associative history-based parametric method. This study uses *Gehry Technology*'s *Digital Project* for automatically extracting data on the best exterior panel and material information taking into consideration various design alternatives and their constructability for free-form building envelopes. This definitions of design logic in this study use rules provided by *Digital Project*'s *Knowledgeware* module which introduced the CATIA platform to the construction industry and tries to define the design logic by using script "if" statement. The script "if" statement is used to synchronize parameters only when the certain specified conditions are met.

3. Knowledge-based Parametric Envelope Design

3.1. Pilot study on the envelope shape of free-form architecture

Before proceeding with this research, we conducted a pilot study on irregular multistory office buildings to review the fundamental planning aspects during their early design stage. This pilot study tries to extract variables, which define parametric relations by optimizing the required conditions of the program. Based on these variables, the pilot study reviews design alternatives.

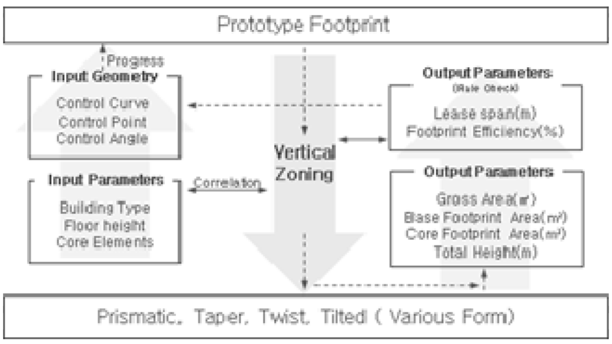

Figure 1. A Review for the Parameters of Parametric Design. Reference: Im, J. & Park, J. (2013).

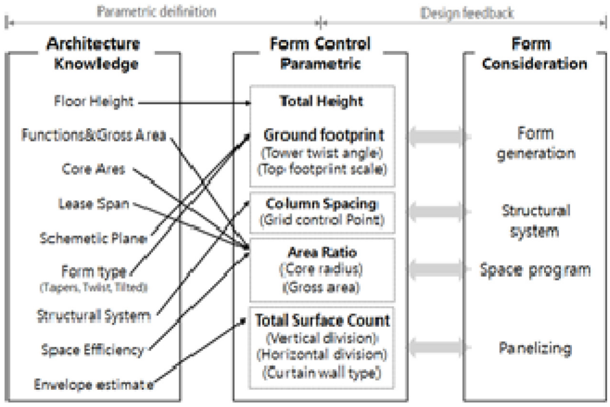

Figure 2. Complex Correlations among Design Aspects. Reference: Im, J. & Park, J. (2013).

In this paper, we review the correlations between various design aspects including core, lease span, elevator, and total height. Further, we analyze the space planning efficiency, which is the ratio of whole area to rentable area. According to the vertical zoning combination of mixed-use buildings, forms of high-rise office buildings are divided into four types: Prismatic, Taper, Twist, Tilted.

In the SD stage, which illustrates early ideas of designers, *McNeel Rhino3D* is used to intuitively create various configurations. In this study, the forms were extracted out of digital models by using *Gehry Technologies' Digital Project.* Further, the section profile of the envelope was extracted so that parametric control was made available and the floor plan was redefined.

The parameter values are defined to represent the four form types of high-rise buildings (Extrusion, Tapers, Twisters, Tilted) based on a section profile. First, extract the elevation and plane schema and place constraints on the elevation and plane profile to represent varied forms.

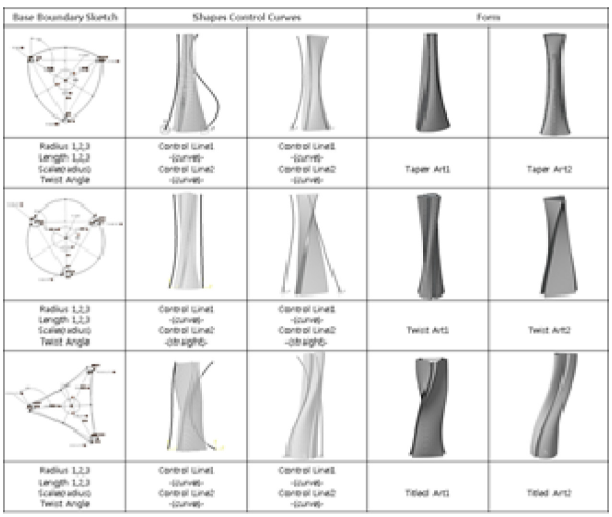

Figure 3. Parametric Form Variations of the Office Building. Reference: Im, J. & Park, J. (2013).

Make sure that the circle's radius is automatically calculated according to the distance to the control curve so that section profile of each floor is automatically altered.

3.2. Optimization process for curved surface representation

As mentioned in the previous section, this study proposes an algorithm for an automated process, which is based on architectural form generation techniques that provide a free-form office building's envelope design at an early design stage. Parametric modeling for an exterior panel system can be optimized for the changing curvature of curved surfaces with the new algorithm.

The optimizing process of curved surface representation is completed by the paneling process, which sets a reference line that divides irregular envelope design. This includes deployability analysis, which helps determine if the panel is deployable by measuring its curvature. This analysis is necessary for determining the panel's constructability. Gaussian analysis is used to examine the deployability for complicatedly curved spaces by measuring their curvature. It is a rationalization process that is used to measure complex curved surfaces, thus, testing if they can be constructed as planar surfaces initially.

Tessellation can be performed based on the reference lines set during paneling. There are several ways of tessellating free-form curved spaces: a regular tilting of regular polygonal panels of the same shape, a non-periodic tilting with all different panels, and a band partitioning using geodesics.

Digital Project's *PowerCopy* and *UserFeature*, and the *Knowledgeware* module script is used to create an algorithm to review the design and control hundreds of curtain wall panels as an exterior system. By using *PowerCopy* and *UserFeature*, each object's attribute information is automatically connected to each other. Advanced replication feature is also provided by the aforementioned methods to conduct a repeated modeling process for parametric transformation. *UserFeature*, in particular, is a user-defined design method, which could respond to curvature changes of irregular envelope formation by patterning designers' intention and construction method.

In order to replicate the user-defined exterior panel in an Envelope.CAT Part file, which carries information on an envelope, *Catalog*'s *Description* and *UserFeature* are linked. A large number of exterior panels for an office building's irregular envelopes are automatically created through the replication feature, which applies patterns defined by *Knowledge Template*'s script.

4. Exterior Panel Modeling with Optimized Algorithm

4.1. Curtain Wall Parameters Constraint

Based on the pilot study and exterior panel process, a modeling pilot study was conducted. An optimized algorithm was applied to pilot modeling by using *Digital Project*. First, for the parametric form control, each measurement was set on the plane, following which, the constraints were defined for each geometric aspect in the design, such as line, point, and surface, based on the dimensional and geometric constraints of these aspects and the main reference plane and points.

When measuring the degree of curvature, configuration information of the plane's base footprint includes parameters such as curtain wall-to-slab depth, parameter value of the curtain wall and detail joint, and the number and site of the curtain walls. More complex correlations are defined as a 'Formula'using variables and constraints. Since the plane configuration is geometrically related to the measurement of materials, parametric variation is possible after a specific value is edited as a variable.

4.2. Parametric Subdivision Surface

Based on the curvature analysis and deployability analysis of irregular forms, sections are divided and envelope types are classified. The steps involved in the construction process of the parametric subdivision surface are mentioned in the following lines. First, define the items and categories of the extracted data, which are necessary for this construction. These definitions are decided according to the panel's detailed materials. Second, design a history tree structure, which defines the logical hierarchy based on the correlations among data.

Based on the pilot study, the envelope of an irregular office building is subdivided into 6 faces, and can be classified as one of the 27 types. Panel types were chosen by controlling parameter values. Faces were divided according to the stories and the number of curtain walls. After this process, a reference point for material creation was set and essential information was extracted.

The data structure of our parametric model is in the form of a tree. Complex objects which control overall configuration are saved as DRV.CAT' Product files. Geometry information which could be a reference for the material creation is saved as a DRV Reference Geometry file. Parameters that control curtain wall-to-slab depth or tessellation are saved as a DRV parameters CAT part file. Tessellation information that could be a reference for a curtain wall creation is saved as an Envelope DRV.CAT' part file.

4.3. Parametric Assembly and Panelization

The steps for parametric assembly and panelization are defined in the following steps. Set input values for Panel Node (Point), Daylighting Factor (Scale), Million Line (Curve), Transom Line (Curve), Class Area (Square Meters), and Class Type (Integer) for configuration information on detailed materials which an exterior panel consists of. These materials carry not only configuration information but also attribute and location information of each unit. Based on this information, each unit is combined into a project environment. In the exterior panel's DRV file

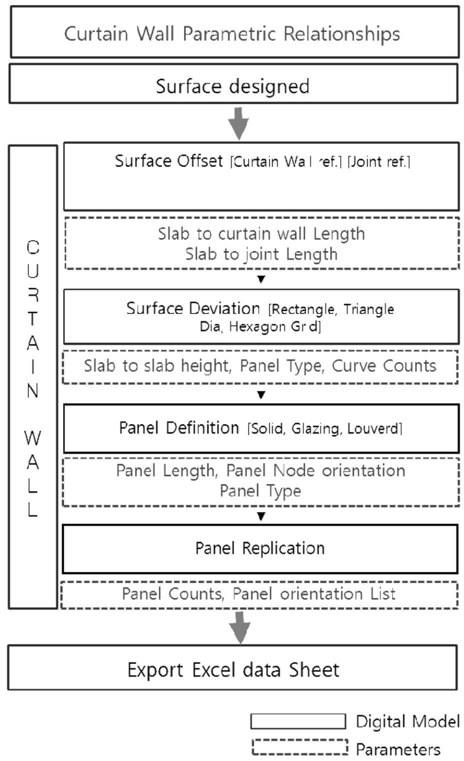

Figure 4. Reference Drive Geometric.

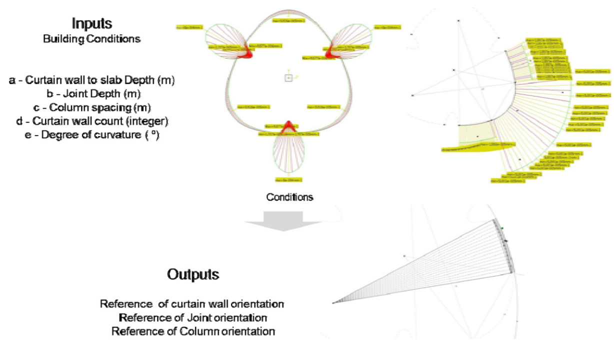

Figure 5. Parametric Relationship of Exterior Panel.

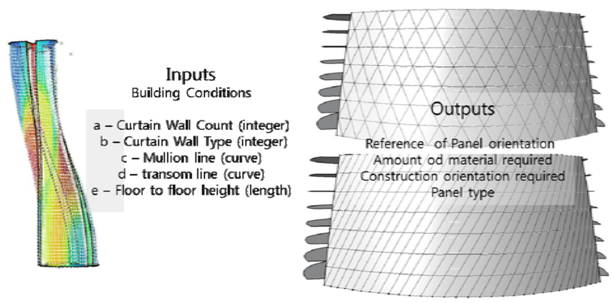

Figure 6. Inputs and Outputs of Envelope Subdivision.

that is composed to be adjusted to the overall data struc-

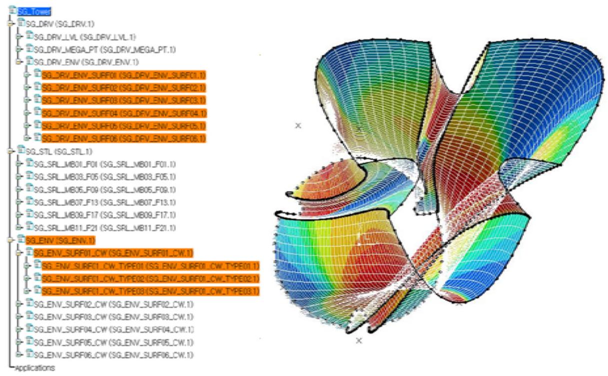

Figure 7. History Tree Structure of a Digital Project.

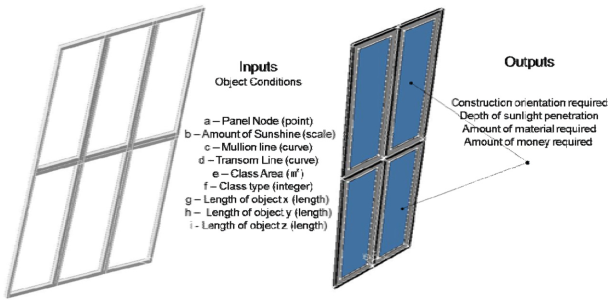

Figure 8. Input/Output variables between unit member.

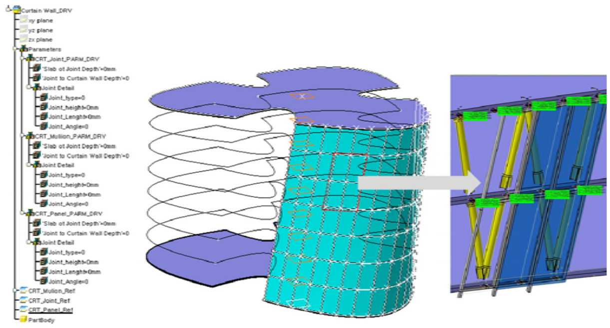

Figure 9. Exterior Panel Assembly.

ture, each unit file's location is set regarding relations between materials. After combining detailed materials in the project environment and forming an exterior panel, parameters could be edited and operated through the project environment, thus, making it possible to integrate control in a Master Model.

Therefore, in a project environment, combination of single units could be controlled and edited in an integrated way by controlling global variables and thus, overall forms. Unit members of an exterior panel have geometric global parameter input values and are correlated with a project environment. A unit member's size, angle, material, and attribute information could be edited within each single unit.

Certain types of exterior panels can be combined into one to form a single unit. Such combined units can be used as parts in another project environment. They could create a combination module when combined with different types of exterior panels in accordance with parameter's relationship. Single units could be combined according to their designated relationships to create or modify various modules.

All materials consisting of an exterior panel are related each other by parameters. They need to utilize data required in a project environment. Moreover, they need to support collaboration between designers and engineers efficiently.

UDF and Replication features are applied to the exterior panel types assembled using the aforementioned steps. A script should be defined that automatically panelizes the exterior panel based on the curvature conditions, on changing the panel's form, height, and quantity.

The panelization algorithm proposed in this paper allows exterior panels to synchronize attribute information with restraints conditions using UDF functions.

5. Conclusion

This study proposed a script-based algorithm to create exterior panels in case of free-form buildings that can be utilized to support the optimization and automation of an exterior panel through functions that extract data such as measurements, quantities and floor plans for material production, which are necessary for construction. In our proposed algorithm, a parameter-based pilot modeling process is used that regulates restraints of exterior panels into three conditional statements. This could raise the efficiency of the optimization and automation process as a design support tool by utilizing scripts.

In other words, modeling could be used to control activities of geometric parameters by activation/inactivation in accordance with the various conditions. Moreover, aspects such as a three-dimensional wireframe, curve, and surface could be easily transformed so that users can easily access and view information on screen during the designing process. Under a certain provision, geometric parameters as well as external variables such as volume, bulk, and material information could be applied more easily. In particular, customized materials that can change their forms and attributes in accordance with the curvature of the curved surface are required in building construction. It is shown that it is possible to extract material information using a single unit by applying our proposed algorithm.

In this study, knowledge-based design methods were applied to follow the varied and complex design trends of contemporary architecture. Knowledge-based design methods systemize the knowledge inherent in experts in a form of data. This knowledge of experts is necessary to promote collaboration between designers and engineers. The ultimate goal of knowledge-based design is to integrate the process into design, which establishes an integrated process. This integration enables two-way feedbacks among design and construction data by combining design, engineering, and construction.

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