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# A Suggestion of the Alternatives Evaluation Method through IFC-Based Building Energy Performance Analysis

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# A Suggestion of the Alternatives Evaluation Method through IFC-Based Building Energy Performance Analysis

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**Abstract:** In a rapidly changing modern society, the construction industry is facing various issues, including the Fourth Industrial Revolution and climate change. Research on convergence between technologies such as artificial intelligence, AR/VR, IoT, and metaverse, and sustainable technologies such as green buildings and eco-friendly energy is being attempted in each field. The most important thing in the development of these technologies will be the interoperability of data. BIM is a technology that can effectively store data regardless of the size of a building or the amount of information and can be shared and stored without loss of data through an open format called IFC (industry foundation classes). This study aims to present a plan to generate alternatives and evaluate energy performance by analyzing the shape of the envelope for amorphous buildings through IFC. Design elements were derived through analysis of previous studies, and alternatives were automated by developing interfaces that can generate shapes according to the derived design elements. The generated alternatives can be compared and analyzed through the analysis of building energy by developing an evaluation system based on IFC. Based on the quantitative results in the initial design stage, the reliability of the design proposal considering the performance of the building is improved, and the process and cost can be predicted in advance; thus, it is expected to be an efficient decision support tool.

**Keywords:** industry foundation classes (IFC); building information modeling (BIM); parametric modeling; energy performance evaluation; alternatives evaluation

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## 1. Introduction

### *1.1. Research Background*

Digital technology in the construction industry has undergone a major shift in the last ten years, from 2D drawing to building information modeling (BIM), a 3D digital model technology. Despite many benefits, BIM technology required significant changes to 2D-based workflows, which led to a negative response to BIM adoption, but a survey by NBS showed a 60% increase in BIM adoption in 2011 and 2020, with industry experts accounting for more than 70% [1]. Various countries are making efforts to apply and expand BIM technology, and the Ministry of Land, Infrastructure, and Transport announced plans to gradually make public BIM ordering projects and support BIM design in the private sector through the 2030 Building BIM Activation Roadmap [2]. These results suggest that the proportion of BIM in the construction industry is increasing, and the area is expanding throughout the life cycle of the construction industry.

Recently, energy-related issues are drawing attention as the seriousness of climate change has emerged. In order to cope with climate change, many developed countries are promoting mandatory zero-energy buildings and innovative energy efficiency of existing buildings nationwide [3]. In the construction field, interest in sustainable buildings is also increasing, and various studies such as green buildings and zero energy are being conducted. Identifying the energy performance and deriving the optimal alternative at the initial design stage is quite efficient in terms of process and cost. Along with the height and complexity of buildings, there are many limitations in performance analysis according to the shape of amorphous buildings. Therefore, there is a need for a technology to support designers' decision-making through quantitative energy performance evaluation of various types of amorphous buildings in the initial design stage.

Therefore, this study aims to analyze the energy performance of the outer shell of an amorphous high-rise building through industry foundation classes (IFC) and propose a method to quantitatively evaluate design alternatives. In this paper, a study was conducted on the energy performance range in the form of a building envelope and was targeted at amorphous high-rise buildings.

Figure 1 describes the research method of this paper. In the theoretical consideration stage, major design elements were derived from building shape generation and energy performance analysis through analysis of building energy, design alternative evaluation method, and energy performance. As the first step in creating alternatives, the IFC data exchange structure plan and data structure of the objects constituting the building's envelope and the energy performance information were presented accordingly. An alternative generation method was presented by developing an interface that can automate the creation of the shape of the building envelope according to the design elements derived from the theoretical consideration stage. Finally, an open BIM-based alternative evaluation system was devised to analyze and evaluate the energy performance of the IFC data generated in the alternative generation stage. Through this system, a plan was proposed to derive an optimal alternative by analyzing building energy and comparing and analyzing various design plans.

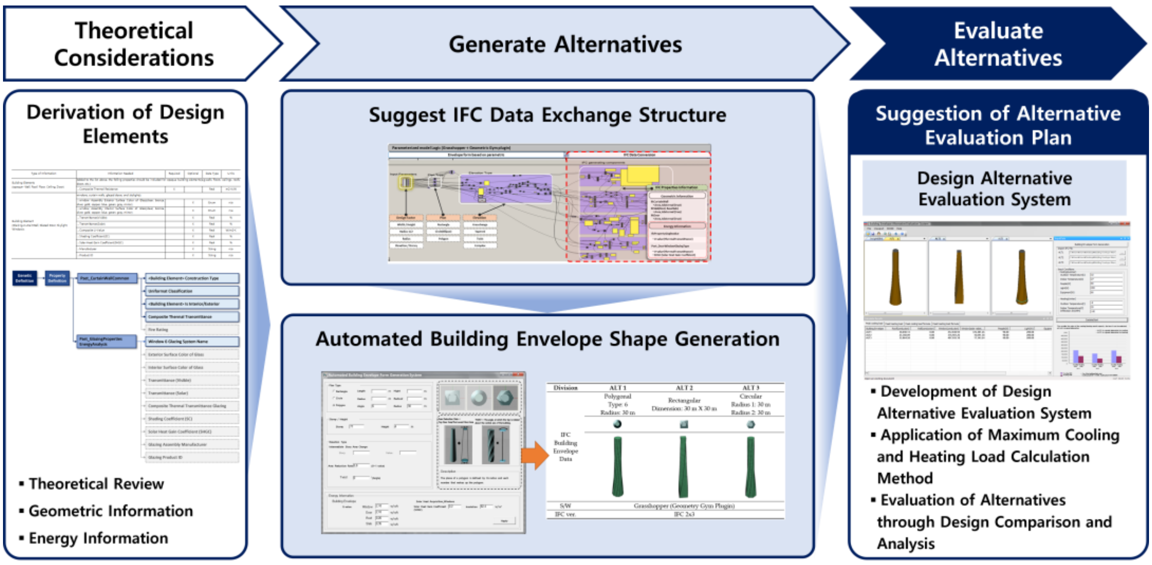


**Figure 1.** The process of this study.

With rapid climate change, interest in the sustainability of buildings is increasing. Therefore, this study proposes a method to evaluate the energy performance of design alternatives by analyzing the envelope shape of atypical buildings through IFC. Identifying the performance of a building in the initial design stage and deriving an optimal alternative will be effective in reducing cost and time risks in the building life cycle.

### 1.2. Literature Review

In this section, the authors investigate the method of evaluating the design alternatives of buildings and derive implications by examining the theoretical consideration of building energy analysis and understanding the current status of BIM-based energy performance analysis.

#### 1.2.1. Evaluation Method for Building Design Alternatives

With the development of digital technology, three-dimensional modeling tools (Catia, Maya, Rhino, Form-z, etc.) have been applied to the entire construction process, resulting in unstructured architectural forms, and continuous generation of early forms [4–6]. Among the methods applied to unstructured building design, the parametric design adjusts the parameters and generates various geometric alternatives to obtain an alternative suitable for the project [7–12].

The purpose of this study is to develop a method that can be applied to quickly generate a design using an interface for creating an automatic form that enables designers to intuitively control various design elements around the frame of the building in the planning stage. In addition, the author proposes the derivation of various factors that affect the formation of the building envelope, the energy performance, and exchange of the IFC data. The author also proposes an alternative method that applies maximum cooling/heating load using the radiant time series (RTS) method. The evaluation program is developed, compared, and analyzed. By taking into account both the design and the energy performance of a skyscraper, it is possible to select a suitable design alternative.

#### 1.2.2. Analysis of Building Energy Performance

In order to promote effective energy saving in buildings, it is necessary to carefully consider the energy efficiency from the planning stage to adopt the optimal system, acquire highly efficient equipment, and rationalize the construction operation. The most important aspect is to accurately estimate the energy demand of the building by accurately calculating the heating and cooling load.

The heating and cooling load can be defined as the amount of energy injected or removed per hour to maintain the indoor environment at the desired temperature and humidity conditions. The heating and air conditioning system is designed so that the required energy can be increased or decreased according to the load, and the capacity is controlled. Precisely calculated cooling and heating loads are the basic design data for the heating and air conditioning systems and components and are used to determine the size of each component of the system with regard to the indoor environment such as piping, ducts, air outlets, air conditioners, boilers, chillers, heat exchangers, and compressors. The calculation of the heating and cooling load, that is, an accurate heating and cooling load, has a decisive influence on the initial cost of the facility, the comfort and productivity of the residents, and the operating costs and energy consumption of the facility [13]. The RTS method, first introduced in ASHRAE Fundamental [14], is a method for simply calculating the cooling load for a building design and is derived from the heat balance (HB) method.

The RTS method can effectively replace all other simplified methods (not thermal equilibrium methods) such as TFM, CLTD/CLF, and TETD/TA. The method was developed to quantify the effect of each component on the overall cooling load. This method is suitable for maximum cooling load calculations but is not suitable for annual energy simulations due to limited assumptions [15]. Therefore, in this study, the author attempted to derive an energy-efficient building design for the architect by applying the RTS method, which can be used to calculate a more precise heating and cooling load for a building from the initial planning stage.

As the importance of building energy reduction and efficiency enhancement is increasing, research is being actively carried out to analyze energy performance by applying BIM [16–31]. Most of the BIM-based energy performance assessment studies are focused on improving the process and information exchange using BIM [32–37] as well as studying interoperability between BIM-based design support programs and energy performance assessment programs [38,39].

BIM is a technology that produces and manages all information applied in various fields during the life cycle of a building, and its purpose is to manage consistent data by stage and field. However, in practice, there are difficulties due to problems such as unclear input information at each stage and lack of data compatibility between software. In the case of energy performance analysis, when more detailed and specific energy analysis is conducted, the information entered in the initial planning stage should be continuously available in the subsequent stages, and additional information should be input as the stage progresses. A data conversion step is necessary to maintain the existing data initially input and to compensate for the deficiencies in each step. This requires a mapping process between BIM data and energy analysis software. Therefore, in this paper, we propose a process for IFC-based energy performance evaluation.

#### 1.2.3. Deriving Analysis Results and Implications

Building information is very diverse, including the standards and materials of objects, and is very complex because it is interrelated with each object. The information required for building energy analysis has many difficulties in analyzing energy performance by simple manual operation from such complex building information, and design elements must also change according to energy performance. Two-dimensional drawings or simple 3D modeling have limitations to reflect both data processing and design elements according to building energy performance analysis. Since BIM, which contains building information, contains many possibilities to apply the design process reflecting such energy performance analysis, this study proposes an alternative evaluation method through open BIM-based building energy performance analysis.

The alternative evaluation system developed in this study is expected to be used by architects for energy performance prediction in the initial planning stage. By importing the IFC model (including object and energy property information), energy analysis is performed automatically by the maximum heating and cooling load calculation module engine, and the result can be displayed as a graph and visually confirmed, thereby providing a relatively good design plan.

## 2. Methodology for Creating IFC-Based Building Envelope Automation Alternatives

### *2.1. Deriving Design Elements for Energy Performance Evaluation*

The initial planning stage is an important stage in the design process because the design must reflect various elements related to the plan and elevation. The horizontal element in existing research is divided into a rectangular shape, a circular shape (elliptical shape), and a polygonal shape, while the vertical element uses a planar shape as the center of the envelope form for high-rise buildings. The information required for energy analysis for a building can be defined in various ways. In this paper, for the energy performance analysis of a building, the building envelope model data (IFC information model) is generated, and the design is evaluated by analyzing the building energy in the maximum heating and cooling load (RTS) range.

This study is based on IFC (industry foundation classes) [40], an open BIM with excellent interoperability without relying on BIM authoring tools. Since IFC is a model that contains a very wide range of information, IDM and MVD were used in this study. IDM (information delivery manual) is a construction project or an individual process within a project to define and extract necessary information, and this extracted information is used to develop software by implementing the View required for data exchange as a sub-IFC schema [41,42].

The energy information required for the assessment of design alternatives for energy analysis is shown in Table 1 and Figure 2. To utilize the IFC2 × 3 information model in the field of building energy analysis, the buildingSMART International Federation uses the document titled 'IDM for Design to Building Energy Analysis' [41].

**Table 1.** Information input for building energy analysis (parts).

| Type of Information | Information Needed | Required | Optional | Data Type | Units |
|---|---|---|---|---|---|
| Building Elements (Opaque-Wall, Roof, Floor, Ceiling, Door) | Added to the list above, the following properties should be included for opaque building elements (e.g., walls, floors, ceilings, roofs, doors, etc.) | | | | |
| | Composite Thermal Resistance | X | | Real | $m^2$-K/W |
| Building Elements (Glazing-Curtain Wall, Glazed Door, Skylight, Window) | Windows, curtain walls, glazed doors, and skylights | | | | |
| | Window Assembly Exterior Surface Color of Glass (clear, bronze, silver, gold, copper, blue, green, gray, mirror) | | X | Enum | n/a |
| | Window Assembly Interior Surface Color of Glass (clear, bronze, silver, gold, copper, blue, green, gray, mirror) | | X | Enum | n/a |
| | Transmittance (Visible) | | X | Real | % |
| | Transmittance (Solar) | | X | Real | % |
| | Composite U-Value | | X | Real | W/$m^2$-K |
| | Shading Coefficient (SC) | | X | Real | % |
| | Solar Heat Gain Coefficient (SHGC) | | X | Real | % |
| | Manufacturer | | X | String | n/a |
| | Product ID | | X | String | n/a |

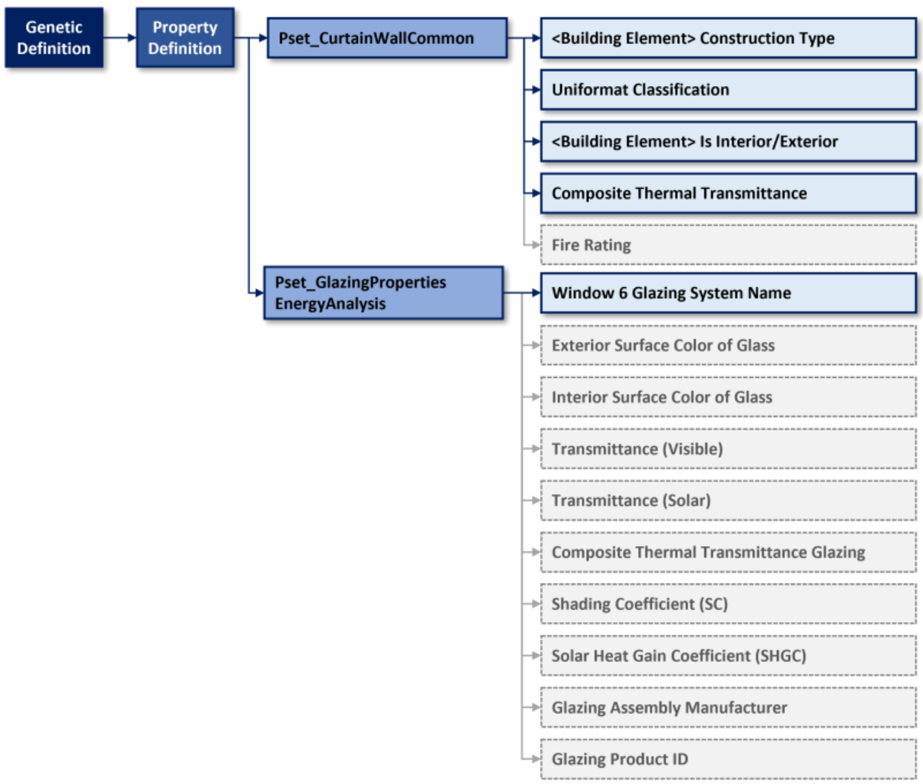


**Figure 2.** IFC model view definition diagram: Curtain Wall (Parts).

In Figure 2, MVD is defined as a set of objects and attributes that define which information items in the model should be exchanged based on the document 'MVD Concept Design to Building Performance Energy Analysis (BPEA)' [43]. As such, in the case of energy performance analysis using open BIM data by analyzing the IDM in Table 1 and the MVD in Figure 2, as an energy element for essential properties, the general building envelope components Window (CurtainWall), Door, Roof, Slab (among the thermal properties of Top and Base), U-value (thermal transmittance), SHGC (solar heat gain coefficient), and insolation were applied as attribute information of the BIM model to derive design elements for alternative evaluation.

### 2.2. Suggestion of IFC Data Exchange Structure

Building information is stored as IFC, which is open BIM standard data from various software. BIM models generated for building energy performance analysis are difficult to use in the energy field through IFC information models because information necessary for converting format data, such as gbXML(IES/Ecotect), IDF(EnergyPlus), IFC(Riuska), etc., is omitted or modified for energy analysis.

Data compatibility, or interoperability, between BIM authoring tools and energy performance analysis programs should be based. In order to develop object-oriented modeling element technology for building design, it is necessary to develop the components constituting the building into an object model based on BIM. That is, there is a need for a method of exchanging through the IFC format, which is standard data.

Therefore, in this section, the outer shell shape information of an atypical building created using the parametric technique through Rhino's Grasshopper is converted into an IFC information model, and IFC object properties and properties for energy analysis are input through BIM software (Geometry Gym). In addition, the conversion method and technology were presented to analyze and verify IFC data in terms of energy. The conversion of the building envelope model created through the BIM design tool (Grasshopper) to the IFC information model is dealt with in detail, the data exchange method in the IFC information model is reviewed, and the data structure for solving problems occurring during data exchange is presented.

Rhino and Grasshopper, which are parametric modeling tools, are BIM design tools that are typically used to create an atypical building model, but the model created by this tool does not generally include information possessed by architectural objects. Geometry Gym, a plug-in that can be used in Rhino and Grasshopper, can create and exchange BIM and structure models, and create IFC2 $\times$ 3 and IFC4-based data. Geometry Gym gives architectural object information necessary for the construction industry to the shape model created in Grasshopper and converts it into an IFC file to be compatible with other BIM tools.

In the Geometry Gym plug-in, there are objects such as IfcFloor, IfcWall, IfcSlab, IfcRoof, IfcCurtainWall, IfcDoor, IfcWindow, etc. The 'IFC data conversion' mentioned in the previous section creates a number of models according to changes in geometric information and energy analysis information through the Geometry Gym plug-in, and it can continuously create new alternatives by adjusting variables based on the analysis results. It can be expressed as a characteristic and evolvable trait. In addition, all generated information is set as parameters, allowing free shape change and change of element information such as section, material, thickness, etc.

Attribute information for energy performance analysis is defined as IFC2 $\times$ 3 Pset as an important factor representing window thermal characteristics of GlassLayers, GlassThickness, FillGas, GlassColor, IsTempered, IsLaminated, IsCoated, IsWired, Translucency, Reflectivity, BeamRadiationTransmittance, SolorHeatTransmittance, ThermalTransmittanceSummer, ThermalTransmittanceWinter within 'Pset_DoorWindowGlazingType' as shown in Figure 3.

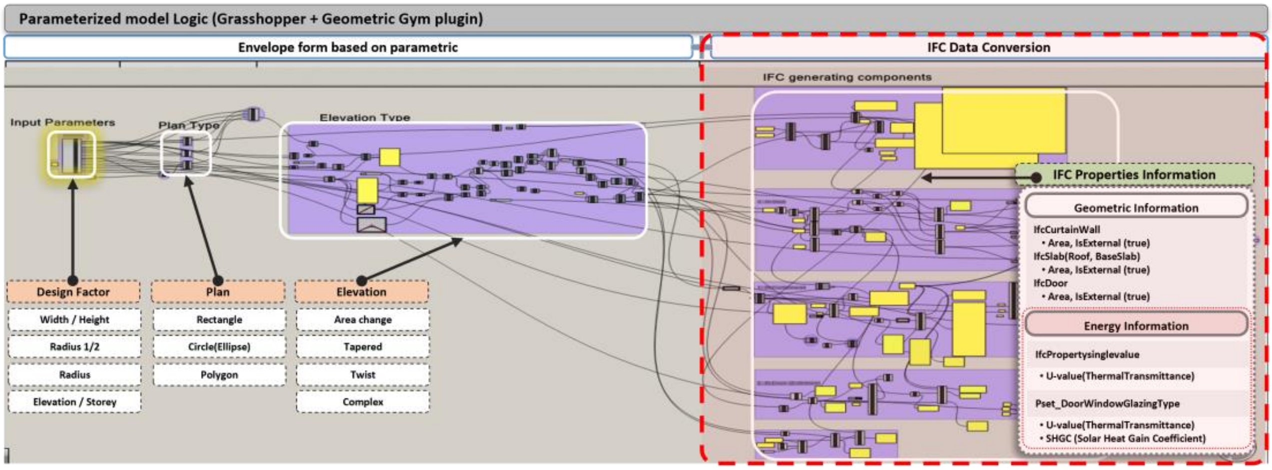


**Figure 3.** The envelope form generation logic.

## 2.3. Development of Automated Building Envelope Form Generation System

The interface shown in Figure 4 is executed in conjunction with the Grasshopper component. Since Grasshopper basically supports VB (visual basic) script component, this system was also developed based on VB, and it is also possible to output to Excel.

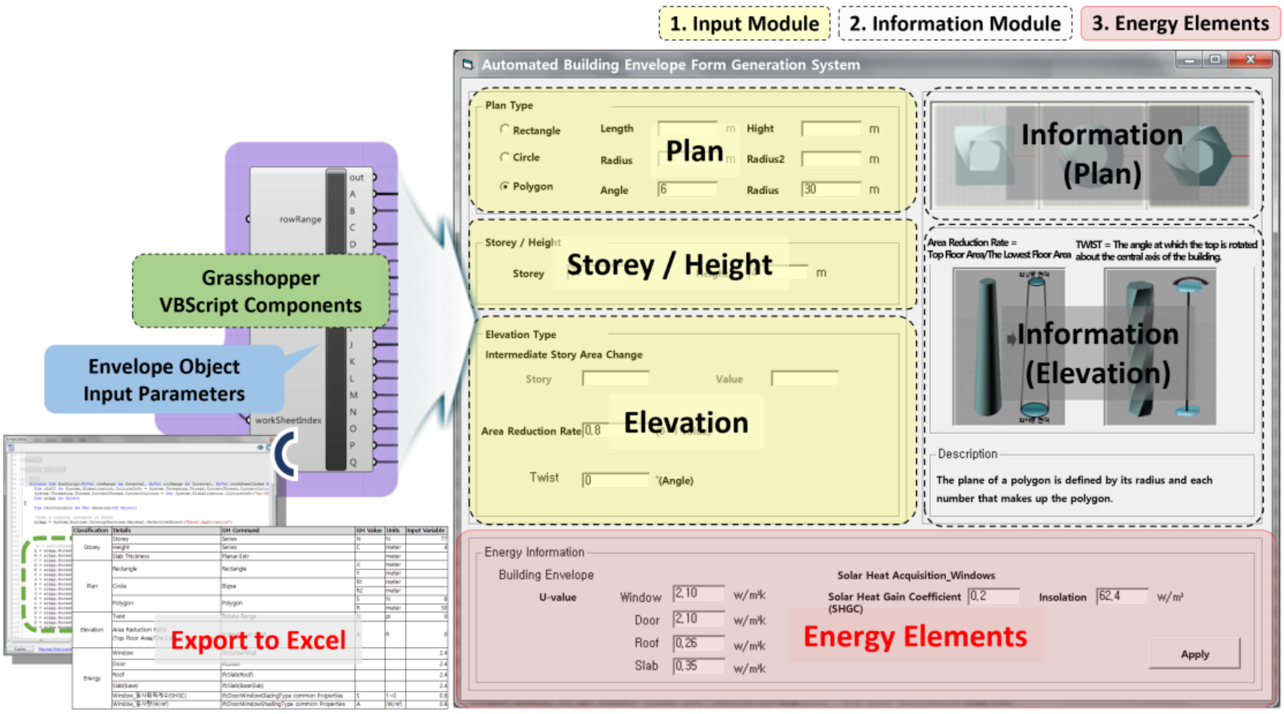


**Figure 4.** The interface of automated building envelope form generation system.

Because the form of a high-rise building is created by the interrelationship of numerous design elements, the interface is composed of basic design elements necessary in the planning stage. The implemented interface is divided into an input module that can input planar elevation and floor information required for initial shape creation of a high-rise building, and an information module that displays the shape of the planar elevation according to the input information. It is intuitively configured for easy use by designers.

In this paper, based on the parameters of the building envelope design elements and Grasshopper components integrated into one through a simple interface, we developed an automated building envelope form generation system that can automate shape creation.

In this system, the designer can create the envelope shape of a high-rise building simply by inputting design parameters for envelope design through the interface of the developed system rather than modeling directly through the modeling tool. In addition, designers unfamiliar with digital modeling tools such as Grasshopper can easily use it, and various design alternatives can be presented to designers only by numerical input of design variables such as form information and energy elements.

## 3. Evaluation of Alternative Automation for Building Envelope Based on IFC

### 3.1. Development of Building Envelope Alternative Evaluation System

In order to compare and analyze design plans promptly and rationally, it is necessary to develop an evaluation module that can reflect the requirements of energy performance analysis for open BIM-based design alternative evaluation and verify the evaluation results. This alternative evaluation system was developed using the MFC (Microsoft foundation class) function based on Microsoft Visual Studio; IFCEngine.DLL was used as an IFC parser that extracts object information from IFC files; and OpenCascade6.5.4 was used as a viewer function for expressing shape information.

The practical application scope of the building envelope alternative evaluation system is the architect (user) of the architectural office, and the application of energy performance evaluation is limited to the building energy consumption evaluation and the maximum cooling and heating load (RTS method) described in Section 1.2. The building envelope alternative evaluation system creates the building envelope shape using the parametric technique and the building member-centered shape using the BIM design tool, and then converts it into IFC data to evaluate the energy consumption of the building and analyze the maximum cooling/heating load. Furthermore, it was developed to evaluate the optimal design alternatives considering energy efficiency using the results calculated from the system.

Figure 5 shows the process of the building envelope alternative evaluation program, and it is executed as a process of steps (1) to (5). Step (1) is to create design alternatives (ALT1, ALT2, ALT3) by creating an IFC information model from the automation interface. In step (2), the three types of design alternatives (ALT1, ALT2, ALT3) created through step 1 are imported into the alternative evaluation system. In step (3), the IFC building envelope model data of ALT1, ALT2, and ALT3 loaded in the alternative evaluation system can be checked in three dimensions. Step (4) can set the basic input conditions (cooling and heating) of the loaded ALT1, ALT2, and ALT3. In step (5), the maximum cooling/heating load calculation result is calculated through the IFC building envelope model data of ALT1, ALT2, and ALT3 and the input conditions set in step 4. The result information is expressed as a numerical value on the left and a graph on the right together with 3D shape information.

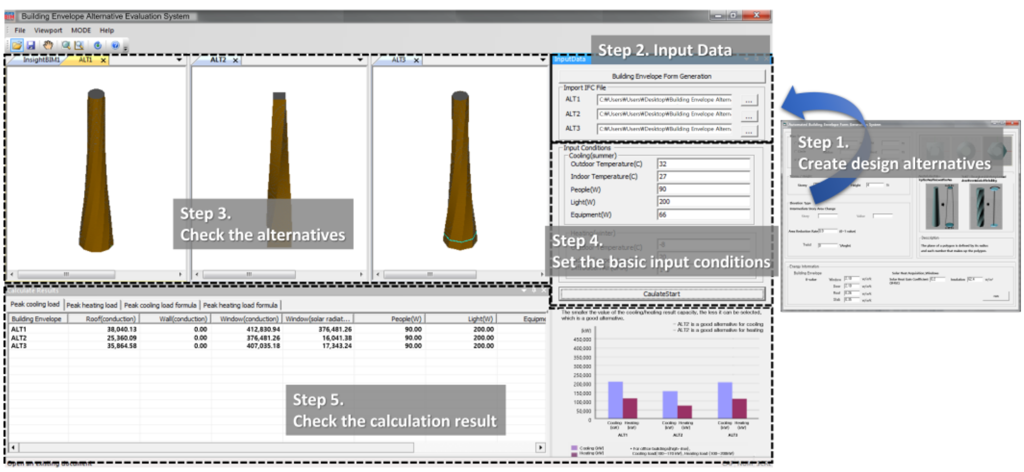


**Figure 5.** The process of building envelope alternative evaluation system.

If it is necessary to modify the design alternatives, the IFC building envelope model data is regenerated through the automation interface in step (1), and energy performance analysis is performed in steps (2) to (5) again based on the quantitative design alternative evaluation results. In terms of efficiency, the most optimal design can be selected quickly.

### *3.2. Analysis and Verification Results for Buildinig Envelope Alternative Evaluation System*

To verify the building envelope alternative evaluation system based on energy performance analysis, three alternatives were selected as shown in Table 2. The IFC information model selected for the purpose of comparison of results was generated as IFC2 × 3 version through Grasshopper and Geometry Gym plugin. The horizontal load acting as the main structural element of a building is applied to the basic shape plan based on structural safety and efficiency, so it can be classified through the shape of the building, such as a square, a rectangle, a triangle, a circle or a polygon, and a combination of several figures. In Table 2, IFC building envelope model data were generated in hexagonal (ALT1), square (ALT2), and circular (ALT3) shapes.

**Table 2.** Information about target IFC building envelope model.

| Division | ALT 1 | ALT 2 | ALT 3 |
|---|---|---|---|
| IFC Building Envelope Data | Polygonal<br>Type: 6<br>Radius: 30 m | Rectangular<br>Dimension: 30 m × 30 m | Circular<br>Radius 1: 30 m<br>Radius 2: 30 m |
| |  |  |  |
| |  |  |  |
| S/W | Grasshopper (Geometry Gym Plugin) | | |
| IFC ver. | IFC2 × 3 | | |

For the analysis of the maximum cooling/heating load of the building, the analysis conditions of the target IFC building envelope model data (ALT1, ALT2, ALT3) in Table 2 are presented in Table 3. Table 3 reflects the design conditions for building energy analysis as an example of a building in Seoul, Korea. The design conditions were based on 'Rules on Building Facility Standards, etc.' announced by the Ministry of Land, Infrastructure and Transport notice and 'Design Outdoor/Indoor Temperature/Humidity Criteria for Calculating Capacity of Cooling and Heating Devices' [43] and 'ASHRAE 90.1', an energy-saving building design standard [14] in the United States.

The analysis of the alternative evaluation required basic design conditions for external loads (conducting loads, solar radiation loads), indoor loads (device loads, lighting loads, occupant loads), intrusion outside air, walls, and windows, and set numerical values for the target building envelope as shown in Table 3.

**Table 3.** Analysis conditions for target building.

| Division | | Contents |
|---|---|---|
| Location | | Seoul |
| Latitude | | 37.313394 |
| Longitude | | 126.554151 |
| Scale | Height | 318 m |
| | Storey | 69 |
| | Sky height | 4.6 |
| Design Temperature | Cooling(°C)<br>Heating (°C) | Outside: 32 °C Inside: 27 °C<br>Outside: −8 °C Inside: 20 °C |
| Indoor Heat | Occupant (W/m$^2$) | Sensible heat: 20<br>Latent heat: 35<br>Residence density: 31 |
| | Light (W/m$^2$) | 20 |
| | Equipment (W/m$^2$) | 20 |
| Infiltration | Air change | 0.5 ac/h |
| U-value | External wall | 0.47 |
| | Roof | 0.29 |
| | Slab | 0.58 |
| | Window/Door | 3.40 |
| SHGC | Window/Door | 0.53 |
| Solar Absorption | Window/Door | 0.50 |

Table 4 shows the results of comparison and analysis of each alternative for the maximum cooling and heating load performance of the IFC building envelope model data (ALT1, ALT2, and ALT3). The numerical values of the IFC object information elements were extracted from the IFC building envelope models (ALT1, ALT2, and ALT3), and the results were derived by summing the items applied with the RTS calculation formula of the maximum cooling and heating load as follows.

**Table 4.** The results of alternative evaluation.

| | ALT 1 | | ALT 2 | | ALT 3 | |
|---|---|---|---|---|---|---|
| | Cooling (kW) | Heating (kW) | Cooling (kW) | Heating (kW) | Cooling (kW) | Heating (kW) |
| External wall conduction | 80.9 | 96 | 67.9 | 96 | 93.9 | 96 |
| Roof conduction | 62.9 | 95.2 | 58.5 | 88.5 | 69 | 98.5 |
| Window conduction | 187.1 | 351.6 | 160.8 | 250.9 | 460.8 | 390.9 |
| Window sunrise | 590.8 | - | 331.6 | - | 691.6 | - |
| Occupational heat | 185 | - | 185 | - | 185 | - |
| Light heat | 298 | - | 298 | - | 298 | - |
| Equipment heat | 385.1 | - | 385.1 | - | 385.1 | - |
| Intrusion outside | 190.2 | 194.9 | 190.2 | 194.9 | 190.2 | 194.9 |
| Total | 1980.0 | 737.7 | 1677.1 | 630.3 | 2373.6 | 780.3 |

For the maximum cooling load ((1) + (2) + (3)):

(1) Conducting load (IfcSlab (top), IfcSlab (base), IfcCurtainWall) = Area (IfcElementQuantity) × U-value (Pest_CurtainWallCommon-ThermalTransmittance) × design temperature.
(2) Solar load (IfcCurtainWall) = Area (IfCElementQuantity) × SHGC (Pest_DoorWindow GlazingType-SolarHeatGainTransmittance) × SolarAbsorption.
(3) Human body heat + Equipment heat + Light heat (see basic analysis conditions in Table 3).

For the maximum heating load ((1) + (4)):

(1) Conducting load (IfcSlab (top), IfcSlab (base), IfcCurtainWall) = Area (IfcElementQuantity) × U-value (Pest_CurtainWallCommon-ThermalTransmittance) × design temperature.
(4) Infiltration heat (see basic analysis conditions in Table 3).

The maximum cooling load of the ALT1 building was 1980.0 kW, and the maximum heating load was 737.7 kW. The maximum cooling load of the ALT2 building was 1677.1 kW, and the maximum heating load was 630.3 kW. The maximum cooling load of the ALT3 building was 2373.6 kW, and the maximum heating load was 780.3 kW. As a result of the analysis, in order to reduce the maximum cooling load of the target building, it is necessary to first block the effect of solar radiation through windows, and to reduce internal heat generation and intrusion due to lighting, and in the case of maximum heating load, it is necessary to consider insulation of windows and structures. (Table 5)

**Table 5.** The comparison of results of the developed program and EnergyPlus.

| | ALT 1 | | ALT 2 | | ALT 3 | |
|---|---|---|---|---|---|---|
| | **Cooling (kW)** | **Heating (kW)** | **Cooling (kW)** | **Heating (kW)** | **Cooling (kW)** | **Heating (kW)** |
| Evaluation program developed in this study | 1980.0 | 737.7 | 1677.1 | 630.3 | 2373.6 | 780.3 |
| EnergyPlus | 2017.9 | 749.5 | 1720.9 | 640.8 | 2429.6 | 791.2 |
| Difference | −37.9 (1.97%) | −11.8 (1.65%) | −43.8 (2.70%) | −10.5 (1.73%) | −56 (2.42%) | −10.9 (1.44%) |

To reduce the maximum cooling load of the target building, it is necessary to limit the influence of solar radiation through the windows and to reduce the internal heat and intrusion external air from the room, the equipment, and the lighting. With the maximum heating load, it is necessary to consider heat insulation.

In this chapter, the automated alternative generation interface and alternative evaluation system presented in Sections 2 and 3.1 were verified. Three alternatives (ALT1, ALT2, ALT3) were generated according to various design elements in the alternative generation interface, and the maximum cooling/heating load of each alternative was derived by applying actual building data and design conditions. Through this study, it is possible to simply extract the most efficient design proposal among several alternatives according to the shape of the building envelope, and the derived results can play an important role in decision-making because quantitative grounds have been applied through mathematical calculations.

## 4. Conclusions

In this study, a method to compare and evaluate various design proposals by analyzing the energy performance of the IFC-based building envelope was presented and verified. Design factors that affect energy performance were derived through theoretical consideration, and criteria for analyzing energy performance according to the shape of the building's outer skin were presented in the initial planning stage. By examining the use cases of BIM-based building data exchange, and analyzing problems occurring during data exchange, the conversion method and data exchange structure of the IFC information model created in the BIM design tool were presented.

An interface was developed to input information and energy elements necessary for initial shape generation so that an alternative to building envelope design could be generated. The implemented interface makes it easier to utilize BIM design tools with complex usage, and numerical input alone can generate various design alternatives with design requirements applied.

An IFC-based building envelope alternative evaluation system was developed to evaluate various types of design alternatives on the same basis and derive optimal alternatives. In this system, design information converted into IFC data can be analyzed for building energy requirements and maximum cooling and heating loads (RTS method), and each alternative can be automatically evaluated. It is possible to generate alternatives with different energy information from the building form, through the interface of automated building envelope form generation system; generate new designs based on analysis results from the developed system; or supplement existing designs to derive optimal energy-efficient alternatives.

In this paper, three design alternatives were generated from the automated building envelope form generation interface, and IFC-based building envelope alternative evaluation system was performed by applying sample data of actual buildings. It was verified that design information of each alternative can be extracted through the automation system and decision-making can be made easily and quickly through the calculated results.

In this study, alternative evaluation was performed in the scope of the building envelope, so for practical application after the initial design stage, the scope of architecture, equipment, machinery or electricity, and new and renewable energy must be expanded. Since continuous energy efficiency-related information is required even during the operation and management period after the completion of the building, research to manage the data is needed. This study is expected to present the basic direction of building energy-related certifications or public orders as it is possible to predict the energy efficiency of buildings in the initial planning design stage through the energy performance evaluation of the building envelope. In addition, if energy-related information generated and consumed throughout the life cycle of a building is combined with technologies such as artificial intelligence, IoT, and metaverse, it will be able to play a key role in future technologies.

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