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Validation of Support for Creation of License Drawings Using Application for openBIM-Based Automatic Generation of 2D Drawings

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Abstract: In the preparation of drawings and documents required for a licensing process, the main problem is the duplication of work in creating design drawings and Building Information Modeling (BIM) models. To overcome this problem, BIM authoring tools provide a drawing generation function. However, it is difficult to use it in a construction project involving multiple actors using different authoring tools for each design actor. Owing to these problems, the drawing generation program, which is based the on the industry foundation classes (IFC) concept is not limited to the authoring tools used in the project, and it is intended to minimize duplication by outputting drawings in dwg and pdf formats. In this study, the IFC data structure required for generating drawings was analyzed and drawing elements on the basis of the shape and attribute information, certain drawing elements were output as 3D scenes in order to obtain detailed plan, elevation, cross-section, and structural drawings, which are required for an IFC-based licensing process. In addition, 2D drawings were generated through post-processing for obtaining drawing-level outputs. On the basis of BIM design guidelines, it was found that the information required in license drawings can be minimized, and the license licensing process can be based on a separate BIM technology. In other words, based on the licensing environment in Korea, the effectiveness of the automatic 2D drawing generation program was verified through a comparative analysis on the basis of the drawings and information required by assuming that a specific set of drawing elements were required in the existing licensing process and for BIM-based licensing. Furthermore, it was examined whether books required in the licensing process can be replaced by a parking lot plan that can be submitted through a BIM-technology-based legality review system.

Keywords: 2D drawings; building information modeling (BIM); industry foundation classes (IFC); automatic drawing generation

1. Introduction

Recently, with the advent of the fourth industrial revolution, interest in automation technology, such as that used in drones and for artificial intelligence, has increased. The construction sector is attempting to increase productivity and quality by introducing openBIM for automation of work. The introduction of openBIM minimizes the omission of data generated during construction work and thereby facilitates their use for productivity improvement [1]. Moreover, it helps reduce time and cost and increase efficiency through business automation, and therefore, construction industry expect to benefit from the use of building information modeling (BIM) technology. However, problems such as high initial investment and long retraining time for practitioners are hindering the introduction of new BIM technologies. Furthermore, compared to the expected benefits, openBIM-based technology remains at the initial stage of a simple clash detection level, making it difficult to utilize BIM technology smoothly throughout the construction process. In other words, despite the wide use of openBIM, the level and scope of its application by different construction entities differ because of differences in the BIM technologies and in the timing of the application between the construction entities. Even if the actual construction process is converted from a 2D-drawing-based process to a BIM-based process, it is necessary to submit a BIM model and 2D drawings for licensing purposes. Therefore, there is a need for an openBIM-based technology for automatically generating 2D drawings. Such a technology can not only prevent unnecessary work associated with the duplication of tasks in the process of creating BIM models and 2D drawings, but also help overcome difficulties caused by technology gaps. The currently used BIM authoring tool's drawing creation module can be used only with the tool, and additional work is required when the drawing is extracted in the formats of other authoring tools. It is difficult to use if the aforementioned investment in BIM facilities is difficult or if there is a technical gap in practitioners. The objective of this study was to enable an architect's license officer to use drawings based on the industry foundation classes (IFC) to submit applications for licenses after the BIM model is constructed, and to retrieve the drawings required by the license holder in the future. Furthermore, this study sought to identify the components required for permit drawing, analyze the building elements required for generating drawings according to the BIM design document creation guidelines, and implement an openBIM-based automatic drawing generation program that could be used for the licensing process.

2. Status and Literature Review

2.1. Theoretical Considerations of openBIM

BIM involves accumulating data generated during the life cycle of a building in a 3D model, and the data can cover a variety of aspects of the building, such as design, construction, structure, facilities, and maintenance [2]. Building-related information acquired through BIM is computerized, managed, and utilized, and therefore, many advantages of computers, such as high accuracy and secure storage of information, can be utilized. However, because the construction industry is vast and complex, there are various construction subjects, and various software is used to process computerized information by field. In the process of exchanging information between software, information is omitted and errors occur [3]. To overcome these problems, buildingSMART proposed the openBIM concept. This concept is not limited to BIM platforms based on an open format, and facilitates information interoperability and compatibility between platforms. For this concept, IFC, an international standard data format, was developed, and based on the EXPRESS language, property information, shape, and the placement of each building object are defined for each field, as shown in Table 1 [4,5]. IFC is an international standard neutral file format that can be used for BIM data exchange and information compatibility between BIM software used by various organizations in the construction industry. In this format, architectural information is expressed as the relationship between a building object and its property information.

Table 1. Information type of industry foundation classes (IFC).

No.	Information	Contents
1	Geometric information	Definition of the form of the model for each building object (e.g., IfcDoorLiningProtertie, IfcSweptSurface, IfcExtrudedAreaSolid, IfcAxix2Placement3D, etc.)
2	Building elements	Examples of building elements are walls, beams, and doors (e.g., Ifcslab, IfcColumn, IfcBeam, IfcWall, IfcBuildigElementProxy, etc.)
3	Structure elements	Elements used for structural analysis, such as nodes, lines, and loads (e.g., IfcReinforcingbar, IfcStructuralLoad, IfcStructuralMember, etc.)
4	Facility elements	Air-conditioning facility, drainage facilities, fire-extinguishing facilities, electricity (lamps, motors, heat, circuits, etc.), etc. (e.g., IfcBoiler, IfcAirTerminal, IfcChiller, IfcController, IfcLightFixture, etc.)
5	Construction management	Construction resource information related to construction equipment, materials, and workers (e.g., IfcActor, IfcOccupant, IfcMaterialUsageDefinition, etc.)
6	Maintenance	Information on equipment (e.g., IfcUnitaryEquipment, IfcValve, etc.)
7	Construction process	Construction process, procedures, activity, etc. (e.g., IfcProcedure, IfcEvent, IfcTask, etc.)
8	Estimate	Information on the budget of the project (e.g., IfcAsset, IfcCostItem, IfcCostSchedule, IfcCostValue, etc.)
9	Material properties	Information related to properties of materials (e.g., IfcMaterial, IfcMaterialLayer, IfcMaterialLayerSet, etc.)
10	Performers	Information related to workers such as man-hours, Work Breakdown Structure (WBS) etc. (e.g., IfcWorkCalender, IfcWorkSchedule, etc.)
11	Other	Time, constraint relationship, spatial objects, etc. (e.g., IfcSpatialElement, IfcZone, IfcConstraint, IfcRelSpaceBoundary, etc.)

2.2. Necessity for Automatic Generation of 2D Drawings

Contrary to the prediction that 2D drawings would disappear with the introduction of BIM, the demand for 2D drawings by construction actors continues. Y. Kim and coworkers surveyed 242 architects working in small- and medium-sized architect offices. They observed that 17 (7%) of all respondents used BIM. Furthermore, according to the respondents, the problems faced with the use of BIM technology were difficulty in applying it (absence of orders for BIM) (32.6%), lack of manpower (26%), reduced work efficiency (21%), and increased office operating costs (9.4%) [6]. According to a domestic BIM introduction status survey conducted in 2018 in which BIM users and nonusers at Yonsei University's Construction IT Laboratory were surveyed, 86% of the respondents answered "double work occurs" and 72% stated "work increase because of insufficient understanding of BIM by licensed personnel." Among nonusers, 84% of the respondents found it easy to generate various design drawings; in other words, the option "ease of generation of various drawings" had the highest impact [7]. Thus, in the early stages of BIM introduction, despite the BIM software facilitating 3D visualization and 2D drawings, duplication of work resulting from the simultaneous production of additional 2D drawings for licensing or separate design work continues to hinder the widespread use of BIM. A representative reason for the duplication of work is the difference in technology skill levels between the numerous construction actors. In other words, although many actors participate in the design-permit-construction-maintenance stage, design actors in different fields have no choice but to use existing methods, owing to the shortcomings of BIM technologies. For this reason, despite BIM orders increasing and the BIM model design being underway, 2D drawings are required for projects and the duplication of work for practitioners continues. To overcome this problem, 2D drawings should be automatically generated based on BIM data for each design subject. This can prevent the duplication of work in the construction of the BIM model and generation of drawings, which are among the negative factors hampering BIM introduction, apart from increasing productivity and reducing the technological gap by reducing the workload of BIM adopters.

2.3. Automatic 2D Drawing Generation Program and Research Status

There are various methods to create 2D drawings from BIM models. Commercial authoring tools can be combined with a 2D drawing generation module to create drawings. The 2D drawing generation module used in the BIM authoring tool provides a low level of detail, making it difficult to create a detailed design drawing at the same level of detail as computer-aided design (CAD) and to obtain joint details required at the construction level. Moreover, there is no modeling function to effectively add details [8]. Chae Gap-soo et al. [9] identified a problem in creating 2D drawings with the BIM authoring tool: 2D drawings cannot be created in parallel. Byung-Kwon Lee et al. [10] observed that drawings created using the BIM model are not at a level where they can be used at the construction site. They proposed a module that accurately generates the reinforcing bar construction diagram and processing schedule according to the relevant standards, using a 3D frame model for the architectural frame. Furthermore, a data format was derived on the basis of the existing CAD method, BIM + CAD, the combination of BIM + CAD and BIM-based construction book creation items, and overall construction book creation criteria, and design and construction books were presented [11]. Although studies have been conducted to analyze the problems in each method, studies on practical solutions and alternative tools for creating BIM-based design drawings have been insufficient [12]. In previous studies related to the automatic generation of 2D drawings by using the BIM model, the level of each study has been limited to the level of automatic generation of 2D drawings using BIM authoring tools, design process proposals using templates, and some drawings used in construction sites. In particular, there appears to have been no research on creation of 2D drawings by applying standards such as the BIM design book optimization creation criteria. Furthermore, research on solving problems in the 2D drawing generation process is scarce.

2.4. Domestic Licensing Status

The information required for the current domestic licensing process can be divided into architectural drawings and documents. Construction drawings should provide information on the quadrature, layout, parking plan, elevation (two or more), floor and roof plan, cross sections (longitudinal and transverse cross sections), vertical motion details, partial details (main structure, etc.), windows, and construction equipment to be provided. The structural design should provide information on the structural plan, elevation, cross section (for a building that will be subjected to structural safety verification), interior finish, and firefighting equipment [13]. Scanned files of documents and drawings are uploaded through SEUMTER, a governmental E-Submission platform. Decision on grant of permission is notified after a review process that takes 2–4 weeks. It consists of a licensing process that requires re-examination through the SEUMTER after supplementary work if the permit is not obtained. In order to support BIM-based licensing, guidelines have been framed for the preparation of BIM design documents [14]. The guidelines specify the types and standards of drawing required in the licensing process and provide information on how to create drawings; they also include examples of drawings based on a BIM model, and they range from general floor plans to three-dimensional floor plans and cross-sectional views. In addition, the draft delivery management standard, submission data file creation standard (recommended), step-by-step creation model creation process (Level of Detail/BIM Information Level stage standard), design information for and standard specifications of structural objects, etc., are specified. However, the design guidelines are for Autodesk Revit and Graphisoft ArchiCAD software, and it is difficult to use them for other BIM creation tools such as CATIA, Bentley, and Tekla. To overcome this limitation, research should focus on the creation of licensed drawings based on IFC, which is not limited to what can be accessed on all BIM creation tools.

2.5. Overseas Licensing Status

Overseas is also not different from the domestic status. Singapore, Norway, and the United States also use BIM to operate construction projects, but design drawings required at the licensing stage are prepared through additional work in the BIM model. Singapore mandates the submission of BIM models through an E-Submission called CORENET [15]. However, the main purpose is not to review or simulate using the BIM model, but to view the drawings (manual post-processing tasks such as adding annotations and zoning are required) automatically generated through the model. However, the post-treatment process is still done manually, and various R&D projects are in progress to minimize this process [16]. For example, the Building Construction Authority (BCA) iGrant Stage 2 project attempted to develop a program that automatically reviewed the laws on accessibility of persons with disabilities, one of the laws required in the licensing process, using open BIM data. In addition, various R&D tasks are being carried out in various government departments, such as PUB and URA to increase the utility of the BIM model, which is a testament to the lack of high utilization of the BIM model overseas. In addition, Norway established a licensing platform called Statsbygg and built a BIM-based licensing environment. In order to utilize the BIM model, various efforts are being made, including the release of STATSBYGG BIM Manual 1.2 [17]. In particular, 34% of the 131 requirements can be automatically reviewed through BIM-based regulation review, and the remaining 66% require review through drawings and design documents [18]. The US also released the BIM dataset under the leadership of General Services Administration for BIM-based licensing. By allowing a single authoring tool, it provides an information system based on a binary format like Revit. However, the level of detail (LOD) is lowered because the standard is established for the main purpose of reading drawings, rather than direct use of the BIM model [19]. As in the case of Korea, the above-described foreign cases are not directly using BIM data, but are only at the level of model creation for creating licensed drawings [20]. In addition to this, projects are made with individual BIM authoring tools rather than open BIM, resulting in poor accessibility, which is polarizing the technology gap.

2.6. Result

BIM can increase work efficiency by implementing a real building in a virtual space. However, in the early stages of BIM introduction, 2D and 3D processes coexist for practitioners to create a BIM model and 2D drawings [20]. Consequently, practitioners feel burdened. The existing BIM model cannot generate 2D drawings in sufficient technical detail, cannot use it below the level of the generated drawings, and generates drawings using optimization standards or standard formats to increase productivity. Although this has been proposed, there is a lack of research to solve the problems related to the introduction of BIM. The present study is expected to enable the automatic extraction and submission of license drawings that meet the minimum conditions required for the license by simplifying the drawings, according to BIM design guidelines, based on an openBIM-based automatic 2D drawing generation program. This study is different from previous research, in that a standard format is used to generate 2D drawings, rendering the user's skill level and technical environment immaterial. The proposed method for generating 2D drawings improves productivity and construction work by applying optimization criteria to increase practicality in the actual licensing process. It is expected to improve design efficiency too. Moreover, based on the licensing environment in Korea, the design contents required in the design drawing-based licensing process and the BIM-based licensing process were compared. Design elements that can be simplified were derived, and accordingly, validation was conducted to see if it could support efficient design work for licensing.

3. Implementation of Automatic 2D Drawing Generation Program

3.1. Overview of Automatic 2D Drawing Generation Program

3.1.1. Overview of IFC-Based 2D Drawing Generation

The IFC-based 2D drawing generation process is shown in Figure 1. First, for the visualization of the IFC file, IFC information is parsed to classify the property information of an object and presentation information for expressing the shape of a model. When the presentation information is separated and stored in memory, solid information, namely shape information, can be generated from it. The Open Cascade library is used to convert the mesh to a 3D shape representation, and the user can use the Direct X library to visualize the 3D shape. It is implemented so that IFC files can be viewed on a 3D screen. For the creation of plan and sectional views, a visualization screen for 2D drawings is generated using a mesh cutting algorithm. Since the lines remaining on the opposite side of the section generated through mesh cutting are unnecessary for drawing, they are removed through the hidden line removal algorithm, and vector information for the output is generated. Subsequently, for the creation of annotation elements (dimensions, grids, levels, etc.) required in the generated drawings, information is generated in the IFC model and depicted in the generated drawings. The generated drawings can be extracted and stored in dwg, pdf, and bcf formats, and they facilitate the exchange of information required during the licensing process.

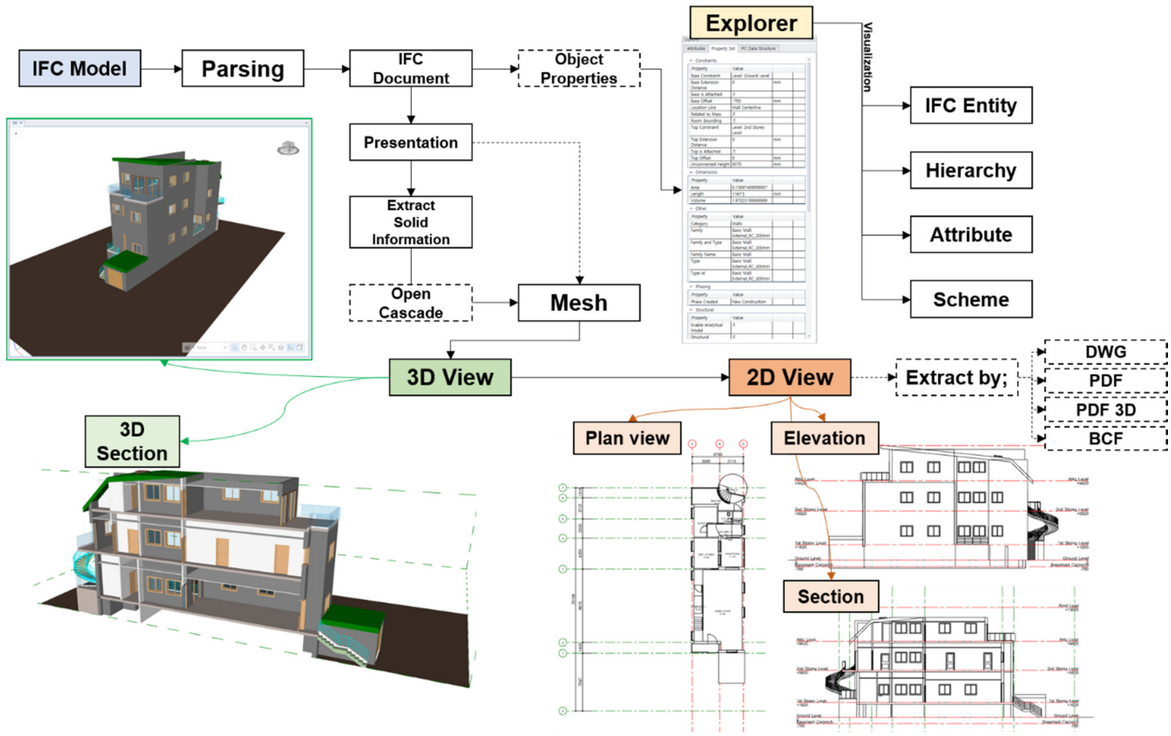

Figure 1. Process diagram depicting the process of the program for the openBIM-based automatic generation of 2D drawings.

In addition to this, through the Explorer function, it is possible to view the IFC information and property information of each object, not just drawing information, and visualize schema and hierarchy information for each entity. In other words, the amount and quality of information in the existing drawings can be improved by inserting and viewing the annotation information in the existing drawing format in the units of each object.

3.1.2. Object Shape Data Structure

The shape data structure of an appropriate model must be defined in an effective manner in order to generate plan, elevation, and section views in a 3D model. The use of an object shape data structure for expressing 3D shape information generally involves a triangular mesh. However, in this study, since tasks such as the cutting of a section and generating a section line on the corresponding surface were performed, a relatively complicated calculation was required when a triangular mesh was used, and unnecessary lines could be generated in addition to the section line. Furthermore, since the task of creating cross-section shape was important, an object shape data structure was created to effectively perform the task. The basic shape structure of the object is shown in Figure 2. It was defined as a polygon consisting of a polyline with holes. The example below the polygon is a shape with a single hole in a square, but the method presented in this study allows multiple holes in the polygon. In this method, cutting is performed in a cutting plane, which is shown in Figure 2, and a mesh is then generated using a triangular network. This is the concept that the grid is defined as a triangular or tetrahedral cell at every node of the grid.

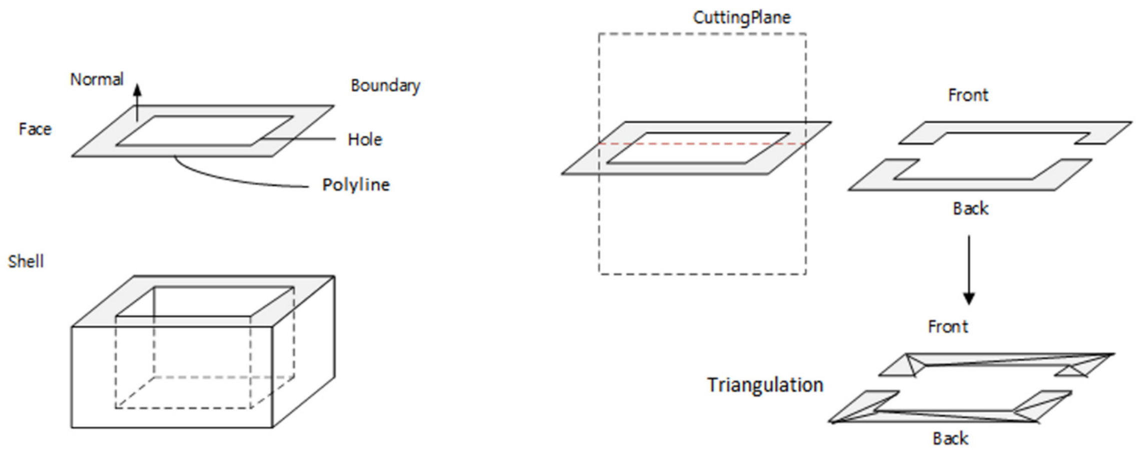

Figure 2. Fundamental data structure used to project a 3D shape onto a 2D drawing.

3.2. *Automatic Generation of 2D Drawings*

Generation of Elevation, Section, and Plan View

(1) Generation of elevation

The elevation basically represents the right and left elevation shapes in the front and rear. The line indicating the elevation can be divided into two types: the intersection of the object faces and the absence of such intersection. Furthermore, a contour is formed at the boundary of the protrusion. For example, for curved surfaces, as shown in Figure 3, there is no line formed at the intersection of the object faces, but the part where outlines should be displayed depends on the elevation direction. The contour between two faces is visualized according to the direction of line of sight.

When the elevation is displayed on the interface screen of system, camera is aligned with the X (left), -X (right), Y (front), and -Y (back) axes, and the projection method is displayed in the orthogonal mode on the screen. When the elevation is shown on the screen visualizing the IFC model, the invisible objects behind the faces of the objects visible in the elevation are masked and rendered invisible. To display the elevation on the computer screen, the triangular faces of the obscured objects are drawn with the background color. This may result in unwanted lines in addition to those visible on the elevation appearing in the background color. Therefore, it is possible to display the elevation on the screen in a fast and effective way by not using a separate removal operation for the obscured object.

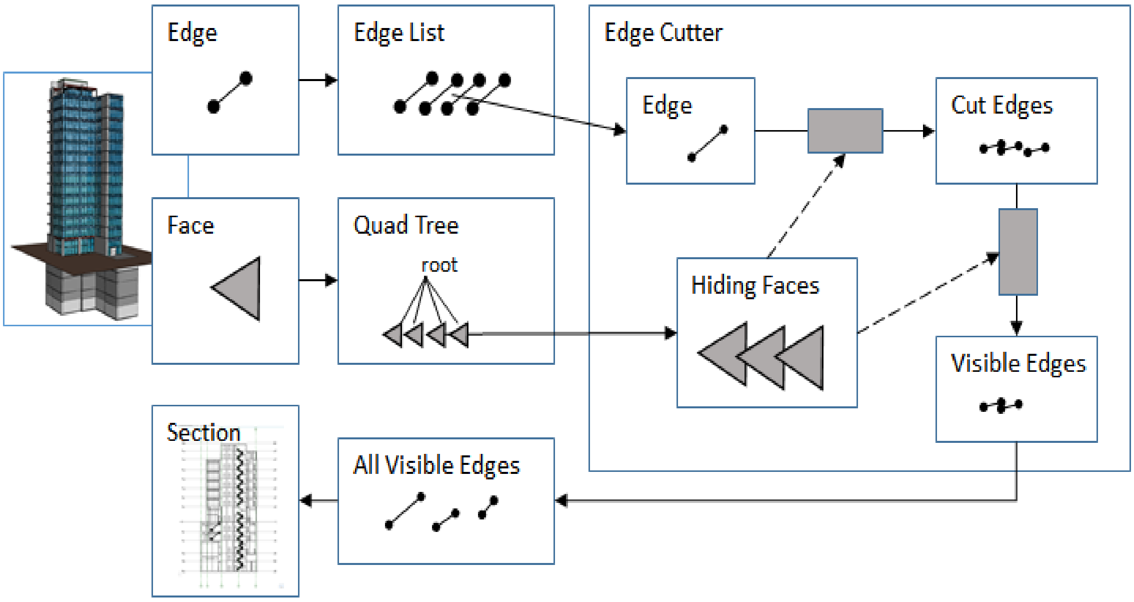

Figure 3. Perimeter and outline of the elevation.

(2) Generation of section

A section view is created by cutting the BIM model appropriately for the section view face desired by the user and by isometrically projecting the section view face in a direction perpendicular to the section view. A building can be cut in a reference plane as follows:

(i) The camera is positioned on the basis of coordinates of the cutting reference plane, and all objects intersected by the cutting plane perpendicular to the cross section are cut.
(ii) The boundary line of the cut faces becomes the boundary line displayed on the screen.

As in the case of creating an elevation, when a cross section is displayed on the screen for rapid cross-section representation, the building object's cross section is represented such that the objects behind the cross section are covered. This study provided an interface for setting a reference line of the cross section at the user's desired location in a plane, and a cross section was then created using the reference line.

(3) Generation of floor plan

Floor plan generation is a special form of section generation. Floor plan view is cut from the 1.2 m reference line upward from the bottom boundary surface of each layer and isometrically projected downward. Unlike the section generation calculation method, information such as the outline of the bottom face of the objects was used for creating the floor plan, in order to reduce the calculation time in the floor plan generation process.

Information on the door opening direction can be generated in IfcDoor. The IfcDoor entity contains only location information and information about the opening direction. For the examination of the detailed form and type of inquiry, the Profile representation in the IfcDoorStyle parameter can be referred to. IfcDoor has attribute information, which is called separate footprint. Although this information is not expressed as a 3D shape, it contains information that can indicate the opening and closing directions of door, etc. in 2D drawings. The development program uses the property information to create the floor plan of the door object, as shown in Figure 4.

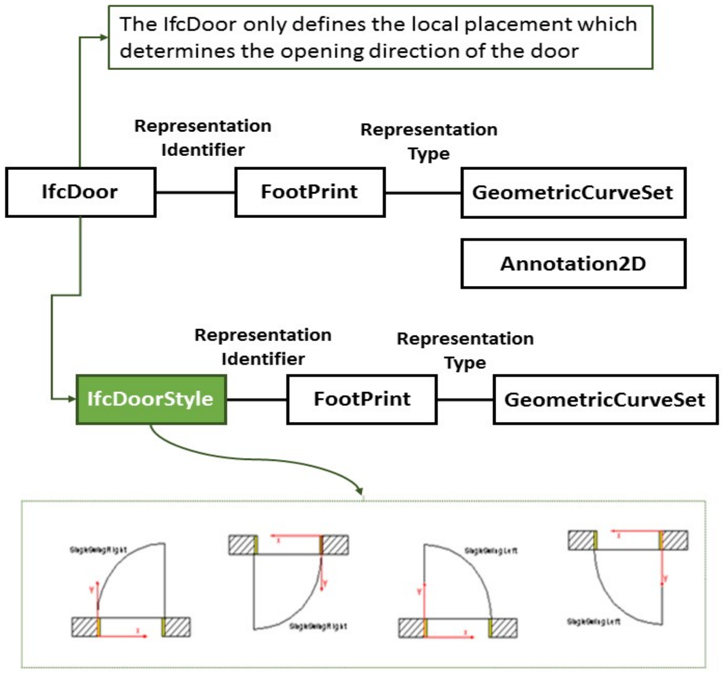

Figure 4. Derivation process of IfcDoor data.

The floor plan information generated in this manner can be expressed using the Direct X 3D library in a 3D scene instead of a 2D scene, as shown in Figure 5. There are many limitations in expressing rich 2D information, and future studies should focus on overcoming them.

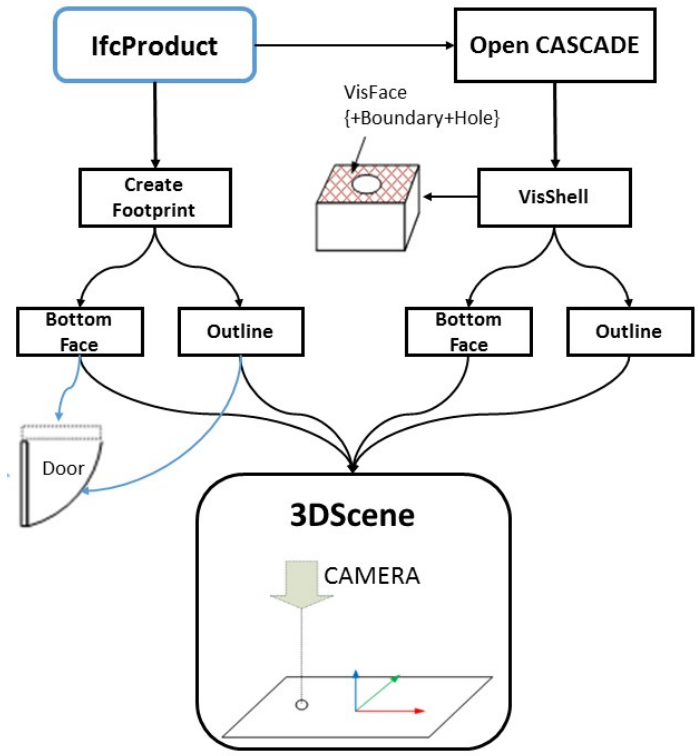

Figure 5. Fundamental algorithm to generate plan drawings.

(4) Annotation

A grid is introduced on the basis of the IfcGrid property. The display position of the dimension line may vary depending on what the architect intends to express. Dimension lines are created using the grid, and they obey the rules below.

Rule 1. They indicate the spacing between all grid lines.

Rule 2. They display the overall dimensions of a face.

Rule 3. If the dimension line spacing is less than 1.0 m, it is not displayed.

In addition, if spatial information is to be displayed, the name of IfcSpace object is obtained, and the area information of corresponding object is extracted to express the area information in the area property in the property set. The space area is extracted based on IfcSpace drawn in the BIM model. Since the space area is used for the purpose of area review or the actual space area is affected by the purpose of area review or the type of space and related laws and regulations, a separate review is required to calculate the exact area under the regulations.

(5) Hidden line removal

After the creation of the cross section of the 3D model, hidden lines (hidden lines) behind the cross section must be removed in order to output the drawing. When the user sees a floor plan, elevation, or section on the screen, the hidden line is hidden for achieving a high speed. Hidden line removal involves the following steps:

(i) Convert all lines and faces to the current screen coordinates (the horizontal axis of the screen is the X axis, the vertical axis is the Y axis, and the depth direction perpendicular to the surface is the Z axis).
(ii) All elements (lines and triangles) entered on the screen are divided into quad trees.
(iii) A quad tree and a line or face that spans multiple areas are split.
(iv) The elements in the quad tree node are cut and hidden in the front element according to the distance from the screen.

An example image is shown in Figure 6.

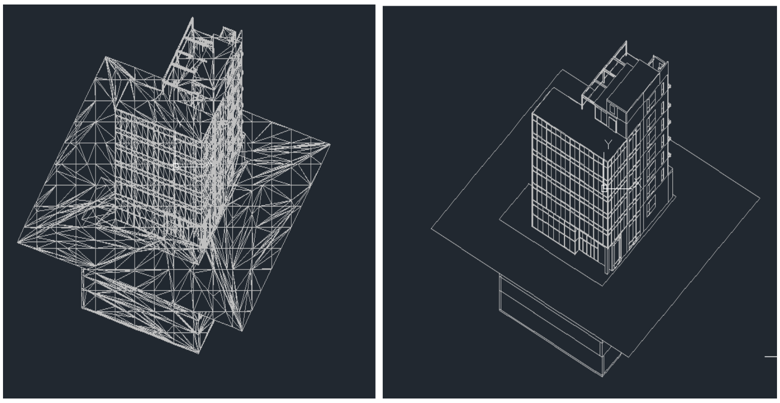

Figure 6. Hidden line removal (example image).

4. Validation of Automatic 2D Drawing Generation Program

4.1. IFC Viewer and Information Specification Review

The program developed in this study can create and utilize 2D drawings of desired parts according to the user's needs after the creation of BIM model, thereby reducing the duplication of design work and generating accurate drawings on request to increase work efficiency. It was aimed at increasing productivity. The program uses IFC, an international standard format. The program can be used for creating drawings of a location desired by the user, regardless of the availability of a variety of authoring tools. Moreover, even if there is a difference in skill level of actors at each stage, drawings can be created by using IFC files.

The program can also be used as an IFC viewer to check the information in IFC file. It is possible to view the information in each BIM object, and the program's capability is not limited to generating drawings. A separate information window is provided to facilitate information acquisition, and user convenience is enhanced by providing functions such as a search function to find only the desired information and an explorer that can provide information on the BIM model. The program developed in this IFC-based study reduces the error in information transmission by using a standard format, and by notifying the user of location and specifications of information. It also provides a 3D viewer to confirm the accuracy of IFC file created by the authoring tool. This is useful not only to satisfy requirements at the licensing-construction stage and to overcome difficulties associated with differences in the skill level between staff members, but also to easily review the accuracy of information when using various BIM review tools for reviewing alternatives at each stage of the design process.

4.2. Reflection of BIM Design Book Optimization Criteria

The openBIM-based automatic 2D drawing generation program developed in this study was designed to generate 2D drawings according to the optimization criteria of BIM design book [13]. This program can facilitate the implementation of a BIM-based licensing process by simplifying the information to be provided in the drawings, and by replacing the elements required for the generation of the license drawings with BIM information. Table 2 summarizes the information that should be provided in drawings in the architectural field according to the BIM design book optimization criteria, and information on existing design drawings.

The information included in existing permit drawings has many elements that should be provided as annotations in the drawings, such as the architectural overview and the area for each application and the size of parking lot, the interior material deadline, and parking plan. However, the use of BIM optimization criteria will minimize the elements required in drawings, and other necessary items can be obtained from BIM information. Items left out because of minimization will be provided by BIM information, provided by other software. For example, it is possible to directly check the height and dimensions indicated in the license drawings from the BIM information. It is also possible to automatically check the items to be checked in the elevation, section, and floor plan of each drawing by using review software, such as Solibri Model Checker, KBim Assess, and SBim Assess [21]. In particular, it provides quantitative evaluation results for items required by licensing regulations, such as the size of buildings, the distance and height between various objects, parking lanes, and evacuation lanes [22]. In addition, in the case of Korea, KBim Library is distributed by the Building Smart Association and provides a library for producing design books, including drawing elements required for the existing license in the BIM model. Furthermore, structural statement templates and the BIM Execution Plan are provided on the basis of architectural objects and attribute information [23]. Accordingly, it is possible to reduce manpower input through automation and the use of BIM technology. In other words, the items to be provided in the drawings can be minimized by automating the review of the required items in the design book creation process.

Table 2. Design documentation items required at the licensing stage in Korea.

Type of Document	Contents	Derivable Items
Architectural plan	Outline (location, site area, etc.)	
	Regional District and City Planning Matters	
	Building scale	
	Parking area size (parking line, provision of parking lot, etc.)	√
Layout	Scale and bearing	
	Length and width of the road facing the site	√
	Longitudinal and horizontal view of the site	√
	Distance from the building line and land boundary line to the building	
	Parking circulation and outdoor parking plan	√
	Public open area and landscape plan	
Floor plan	Floor plan of the first floor and standard floor	√
	Location of pillars, walls, windows, etc.	√
	Location of fire protection zones and fire doors	√
	Location of corridors and stairs	√
	Location of elevator	√
Elevation	Elevation plan of 2 or more sides	√
	External finishing material	
	Plan for installation of signboards and building plates	√
Section	Longitudinal and horizontal sections	√
	Building height, height of each floor, and ceiling height	√
Structure	Main structural plane and section	√
	Detailed drawings of main structural parts	
	Structure confirmation	
Interior finish	Types of wall and ceiling finishes	

4.3. Simplification of BIM-Based Permit Drawing

4.3.1. BIM-Based Permit Drawing Extraction

As mentioned in Table 2, six types of drawings are required in the licensing process, and for each type of drawing, the minimized list of items are provided. However, although it is possible to simplify drawing creation items by applying BIM technology, separate and detailed drawings are required for major parts, the distance from the building line to the site boundary, and the external material finish of the elevation. In addition, because the current administrative system structure requires the simultaneous submission of BIM models and drawings, it is necessary to create a permit drawing. Such a drawing could be useful in the licensing process. In other words, a detailed review of the license holder will be possible through the submission of drawings and review results for the items that can be derived. To this end, it is required to create a BIM model according to the BIM design guidelines and to simplify drawing items by using it. In other words, items that can be accessed from BIM information, through the submission of drawings and models, the license holder will enable a detailed review of the licensing standards and conditions. For this, a BIM model should be created according to the BIM design guidelines and drawing items should be simplified using it.

An example of a parking lot is a simplified license drawing element, such as that shown in Figures 7 and 8. However, in the case of BIM format, information such as the level difference, parking plan line (parking object), and parking space for a disabled person includes the attribute information of each object. The contents are described in Section 4.3.2. In the existing CAD format, most of the information required for the parking lot should be expressed in drawings and annotations. In other words, by reviewing information that excludes data that are visualized on a per-instance basis in the IFC data, a review of the license may be possible. In the case of a drawing provided by our proposed program, the drawing is created by visualizing only IfcGrid object among the annotation elements. However, the drawings required in the licensing process include several annotation objects, but by constructing a licensing environment based on the BIM design guidelines and by submitting a license in the IFC format, the types of drawings and design books required in the licensing process are simplified. In other words, by submitting an IFC file for checking and extracting the drawings, the license holder can minimize the cost required to acquire information on the concerned building; the designer can also use BIM instead of preparing drawings for the permit. Through the implementation of a design-based project, the BIM model can be used for licensing, and accordingly, it is possible to proceed with the licensing process at the currently presented drawing level, through the automation of the legality review process involving drawing creation and licensing.

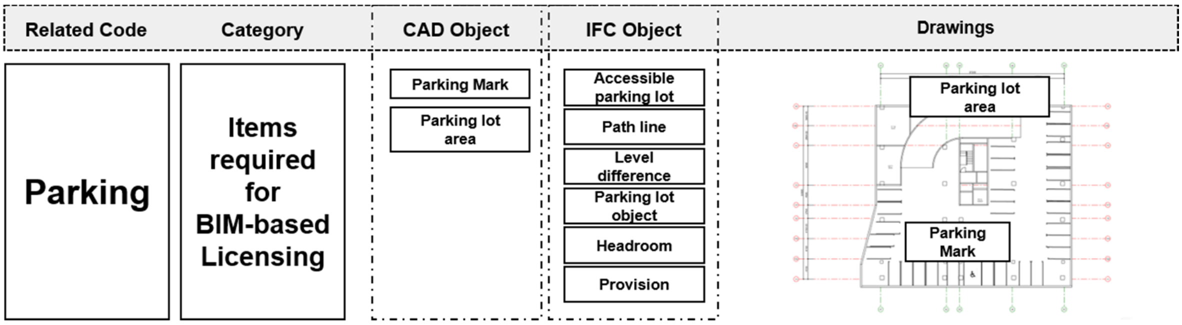

Figure 7. Drawing requirements and example drawings in the building information modeling (BIM) format.

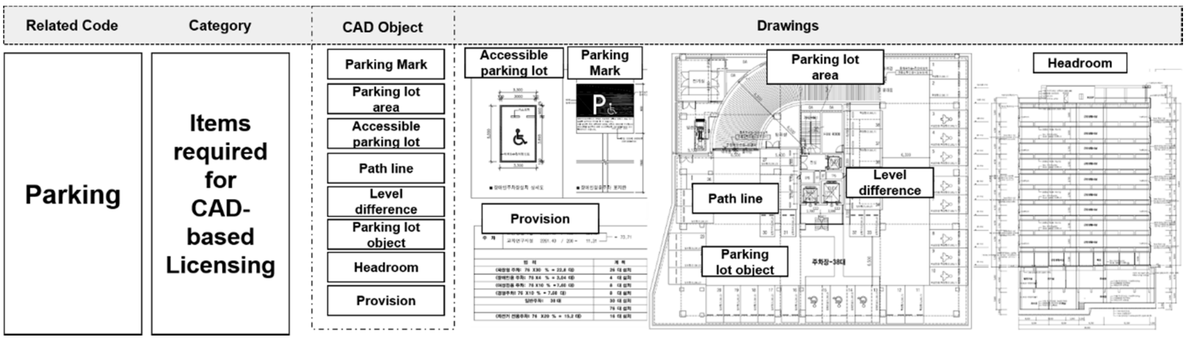

Figure 8. Drawing requirements and example drawings in the computer-aided design (CAD).

4.3.2. Review of BIM-Based Licensing Laws

As mentioned in Section 4.2, it appears that drawings can be generated using various guidelines for BIM-based design drawings. Administrative and institutional measures have been prepared for BIM-based design drawings, and improvements have been made in procedures and related laws for BIM books according to the level of submission of design documents by stage and subject [24,25]. In addition, several studies have been conducted to improve the institutional and technological aspects of BIM-based construction projects, and such studies continue to be performed [26]. Among them, a system for automating the review of building codes related to licensing based on BIM information is being implemented.

For example, among the items specified in Table 2, it is possible to automate the calculation of the size of parking lot on the basis of BIM technology. SBim Assess software is commercial software that enables the automatic review of laws related to "Accessible" among laws and regulations managed by the Building Construction Authority in Singapore. With this software, it is possible to review parking-lot-related laws and regulations required for licensing, such as parking lot size and accessible parking lot ratio based on the BIM model. We reviewed about 50 items, such as headroom, accessibility, stairs, ventilation, safety from falling, and lift, and presented the results of the review so that they could be used in the review process in the licensing process of Singapore. The contents are shown in Figures 9 and 10 [27].

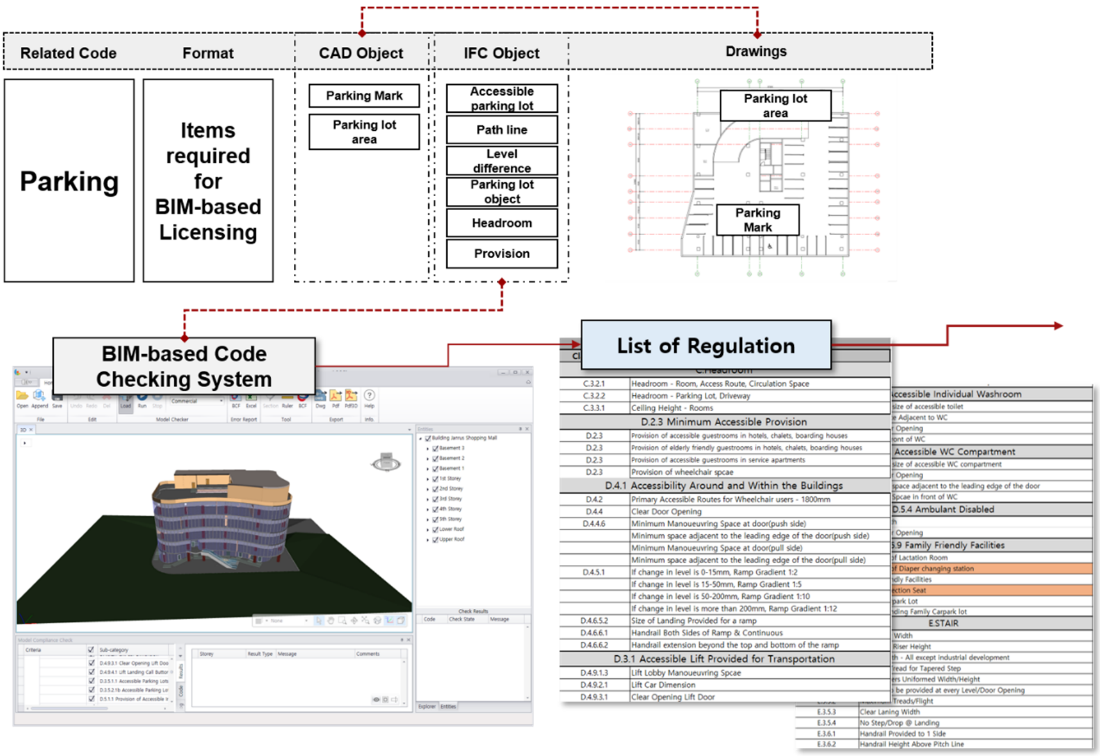

Figure 9. Review of BIM-based parking lot licensing laws (SBim Assess) for the licensing.

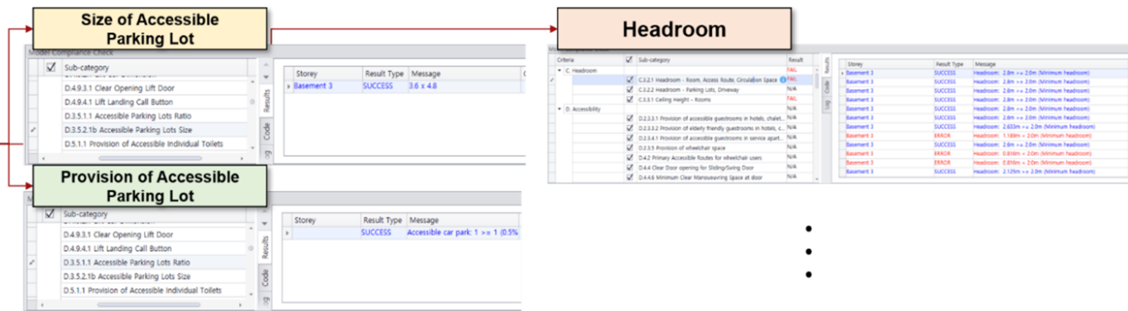

Figure 10. Review of BIM-based parking lot licensing laws (SBim Assess) for the licensing (continue).

As in the previous example, it is possible to review items related to the size of parking lot required in the licensing process involving the parking lot plan. On the basis of shape and property information of the parking lot objects, the size of each section is measured to review the conditions of parking lot for general/disabled people, and the provision item is reviewed based on the calculated parking lot object to review the parking lot section of building. Drawings and various plans that are required to be submitted during the licensing process are required for the review of above items. Automation of the review of various items by using BIM technology can minimize the number of drawing items required. In other words, license drawings can be generated with the minimal expression level suggested in this study, and the use of BIM standard format will promote the widespread use of openBIM in the construction industry.

5. Conclusions

In this study, we developed a program to generate 2D drawings from a BIM model and to analyze the information in IFC file. The program can be used not only in the design stage, but also in the overall construction project. Following the development of BIM technology, various authoring tools have been developed. However, the efficiency of BIM is low since different authoring tools employ different data standards [28]. Therefore, it is essential to use a standard format to render the various BIM tools compatible in terms of the data employed by them [29,30].

In this study, openBIM, which can be used regardless of the BIM authoring tool employed, was used, and for the improvement of its practicability, it was modified to automatically generate drawings for permits in conformance with the BIM design book optimization criteria. Using openBIM, a designer can avoid the duplication of work in creation of drawings for licensing after the construction of the BIM model, and the official or contractor in charge of licensing can create the desired drawing from the IFC file sent by designer, without requiring a separate authoring tool. OpenBIM can effectively handle the entire construction process, and it will reduce the initial investment cost, such as the cost of purchasing authoring tools and training costs, and time.

This paper mainly described the generation of plan, section, and elevation from an existing 3D model. Currently, 3D and 2D drawings are mainly provided for building/structure/facility objects in the automatic 2D drawing generation program, and only dimension information based on each grid object is included in the drawings. However, apart from construction object information, annotation information is also required in license drawings. Currently, the annotation information of IfcGrid is presented, but the main annotation information (text, dimension line, void expression, etc.) is not presented. In view of cases where all the necessary information in a 2D drawing cannot be obtained only with a cross section of a 3D shape such as a drawing representation of a door object, research should continue to focus on devising an appropriate way to present annotation elements in drawings by generating separate information in the IFC file. In addition, it is necessary to examine ways to improve the licensing system to clarify the responsibilities of 2D drawings extracted from the BIM model for the licensing process.

By automatically generating drawings based on IFC data, it will be possible to reduce the BIM-based design workload. In addition, although this study has been verified based on the Korean licensing environment, it is expected to be developed based on the international standard format, so that it can be used in overseas licensing and various BIM-related fields. This will be able to solve problems such as compatibility between BIM software and technology gap between sites, which are common problems at home and abroad, with the same design technology as this study based on the international standard format.

The automatic 2D drawing generation program based on openBIM can be utilized at all stages from the BIM environment to the design-licensing-construction-maintenance stage. The use of the program in the licensing process is expected to eventually expand the utilization range of the BIM model. In addition, minimizing the difference in BIM technologies used by construction entities can facilitate the widespread use of BIM. In the existing design process, which is dependent on the type of authoring tool or level of BIM technology used, it has been felt necessary to use a specific authoring tool or separately create a 2D drawing and a BIM model to avoid redundancy or duplication of work. However, the use of automatic 2D drawing generation program based on openBIM will promote the efficient use of BIM by construction entities and will improve the work efficiency and process in the entire construction process of a construction project.

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