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Developing a Preliminary Framework for BIM-Enabled Code Checking of Refuge Area in Korean Law

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TUESDAY AFTERNOON, AUGUST 6, 2024

Technical Session 2 13:20 – 14:50

TS-2a, Room 11 Applied Geometry and Graphics [3], Geometry and Graphics in History [2]

Session Chair:
Michio Kato, The University of Tokyo [Japan]

#065 The geometry of the ramps in Le Corbusier architecture
Wilson Florio and Ana Tagliari

#160 First hypotheses on the geometric genesis of the dome decoration of the church of S. Maria del Monte in Caltagirone
Mariangela Liuzzo and Laura Floriano

#136 Influence of the Joint Research with Kenzo Tange (1971–73) on the Roof Shape of Mannheim Multipurpose Hall by Frei Otto (1975)
Hideo Tomita

#178 The Influence of Hans Vredeman de Vries on the Inlays of the *Certosa di San Martino* in Naples
Stefano Chiarenza

TS-2b, Room 21 Graphics Education [1]

Session Chair:
Caterina Cumino, Politecnico di Torino [Italy]

#017 A Study of Descriptive Vector Statics
Dajun Lin and Pengfei Zheng

#047 Integrating Graphical Methods into Engineering Education: Enhancing Learning and Visualization Skills in University Curricula
Daiva Makuteniene, Romualdas Kliukas, Andrius Čeponis, Olga Ovtšarenko, Hirotaka Suzuki

#050 Exploration of Teaching Mode for Cultivating Students' Scientific Thinking Ability
Dan Xu

#083 Generative perspectives for learning: from theory to visual modeling
Francesca Fatta and Sonia Mollica

TS-2c, Room 22 Geometry and Graphics in History [3]

Session Chair:
Hans-Peter Schröcker, University of Innsbruck [Austria]

#042 A Quadratrix Trammel
Andrew J. Simoson

#097 Ceva's trisectrix from a different perspective; two new methods of an angle trisection
Roman Hašek

#139 Tracing the Evolution: Geometry and Graphics in Digital Humanities Visualization
Zhen Liu and Tianrui Zhu

#008 Converse of Ptolemy's Theorem
Hidefumi Katsuura

TS-2d, Room 32 Engineering Computer Graphics [1]

Session Chair:
Kohei Inoue, Kyushu University [Japan]

#022 A geo+physical methodology to define quasi-developable surfaces based on material properties
Francisco Pérez-Arribas and Héctor Díaz-Ojeda

#087 Artificial Abductive Geometry as a Syntax for Asemic Writings
Fabrizio Gay, Irene Cazzaro

#040 From Text To Augmented Reality: Experimentation of a smart workflow on the works of Malevič And Hadid
Alessandro Martinelli, Giulia Lazzaretto, Agnese Toni, Matteo Cavaglià

#088 Accelerating Nanoparticle Characterization using Synthetic SEM Datasets and Deep Learning Techniques
Liangfu Lin, Zihao Wang, Guang Yang

TS-2e, Room 33 Applied Geometry and Graphics [4]

Session Chair:
Masasuke Yasumoto, Tokai University [Japan]

#032 The geometrical design of light-environment of *"Komorebi"* with the application of two-dimensional grid measurements of illuminance
Yuta Nakamura and Miki Kozaki

#071 Geometric accuracy characterization of small-sized surfaces based on fractal methods
Shoufeng Gao, Dezheng Kong, Yanwu Feng, Yizhi Dang, Baoling Han, Wei Yang, Xianying Tong, Pei Yan, Bin Zhao

#186 Geometric Crystallography: modelling and representation of polyhedral
Pasquale Argenziano, Alessandra Avella and Nicola Pisacane

#128 A Study of a Design Support Method for Generating Revolved Mesh Shapes Using Grasshopper
Shin Tsuchiya

Technical Session 3 15:10 – 16:40

TS-3a, Room 11 Applied Geometry and Graphics [5]

Session Chair:
Hongming Cai, Shanghai JiaoTong University [China]

#084 Water Wave Simulation after a Bubble Rupture
Nobuhiko Mukai, Natsuki Ide, Takuya Tajima, and Youngha Chang

#093 BioImage Analysis of Leaf Morphology Applied in Biomimetic Geometry Design Approach
Biljana Jović, and Anđela Stanojević

#035 Two Simple Methods of Drawing Perspective Drawing by Measuring Point Method
Zhao Qian and Zhai Yan

#054 Representation of the Crescent Moon
Kenjiro Suzuki

TS-3b, Room 21 Engineering Computer Graphics [2]

Session Chair:
Baoling Han, Beijin Institute of Technology [China]

#053 Program Development for the Management of Digital Images in Grip Software
Yuanfeng Wang, Sande Gao, Nobuaki Kamei and Keijiro Nakasa

#207 A new paradigm of approach to survey design using BIM and AI for dynamic monitoring and semantic segmentation: Revealing Areas of Degradation in Historic Buildings for Preservation and Conservation
Carmine Gambardella, Rosaria Parente, Giuseppe Ciaburro

#023 Automatic Pathloss Computation of Wireless Communication Equipment using BIM
Syed Haseeb Shah and Inhan Kim

#039 Developing a Preliminary Framework for BIM-Enabled Code Checking of Refuge Area in Korean Law
Dongyoung Kim and Inhan Kim

TS-3c, Room 22 Graphics Education [2]

Session Chair:
Kumiko Shiina, National Center for University Entrance Examinations [Japan]

#007 Outcome-Based Education (OBE) Guided Project Based Teaching Research in Engineering Drawing
Jun Miao, Weiqiang Feng and Guimei Zhang

#024 Systemic approach to intensification of the educational process for graphical specialties
Gulmarzhan Tuleuova, Temir Galiyev, Maral Yessekeshova, Zhanna Sadykova, Nursaule Tastanbekova and Seifolla Bodikov

Contents

Developing a Preliminary Framework for BIM-Enabled Code Checking of Refuge Area in Korean Law

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Abstract. Building Information Modeling (BIM)-based code checking stands out as a promising area that seeks to automate the translation of building regulations into programmable criteria. Nonetheless, the translation process still faces significant challenges of integrating natural language regulations into a form that computers can process. This gap necessitates manual data entry by users, introducing a bottleneck that undermines the efficiency and user experience of BIM-based code checking systems. This study aimed to develop an algorithm using BIM to automatically identify the presence or absence of refuge areas in high-rise buildings. In order to do so, the author analyzed the hierarchy of building acts to identify the property information that is essential for deter-mining refuge areas. Using property information such as space classification codes, non-combustible materials, fire-resistant structures, special escape stairs, and emergency elevators, a rule-based algorithm was proposed to assess code compliance. The algorithm enables the automatic identification and assessment of refuge areas in BIM models, opening up the possibility of automating regulatory review during the building permit stage. These results show how BIM technology can be used to significantly improve the accuracy of code checking, reducing the workload and potential for human error during the building permit stage. Therefore, this study shows that BIM-based code checking will be a key contribution to improving the overall quality of construction projects.

Keywords: Automated Rule Checking · BIM (Building Information Modelling) · Building Code · Building Permit · Code Compliance Checking

1 Introduction

BIM has introduced revolutionary changes in Architecture, Engineering and Construction (AEC) sector. It merges three-dimensional geometric and functional information to effectively manage and facilitate collaboration throughout the entire lifecycle of a construction project [1]. The introduction of BIM is crucial for overcoming the limitations of 2D-based work processes and enhancing the efficiency projects [2]. Notably, code checking, which enables automated reviews of construction regulations, is one of the essential applications of BIM technology [3, 4]. Code checking automates the review

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of regulations by logicizing them based on BIM data, reducing time consumption and the possibility of human error in the architectural design process [5]. In Korea, active research is being conducted to apply code checking technology for the automated review of the Building Act required at the building permit stage and is implemented through an application called KBIM Assess-Lite. This application is used to determine the conformance of building permit codes based on data in IFC format, which is a BIM data exchange schema in the AEC field.

Meanwhile, the legal system in Korea is organized in a hierarchical relationship. At the building permit stage, the top-tier regulation primarily reviewed is the Building Act, which is supplemented and specified by lower-tier regulations such as the Enforcement Decree of the Building Act and Enforcement Rule. This hierarchical structure allows for systematic and smooth review of regulations by addressing the basic provisions presented in the higher law in more de-tail in the lower laws. However, in this process, some Building Acts may have ambiguously stated information even in the subordinate regulations. In such cases, users must directly input additional property information into the BIM model to enable BIM-based evaluation. For example, the definition of refuge area is specified in Article 34, Paragraph 5 of Enforcement Decree of The Building Act as a refuge area established on the middle floor of a building for the purpose of escape or safety [7], but the specific information needed for BIM-based evaluation is not provided in the lower law. Therefore, users must directly input additional information about refuge area through parameters. While this approach has the advantage of clearly distinguishing property information in the BIM-based code checking algorithm, it also increases the amount of property information that users must input as the project's scale grows. This can raise the likelihood of errors during the information input process, conflicting with the primary goal of BIM-based code checking to improve work efficiency and ensure the reliability of results. Therefore, minimizing the additional property information that users must directly add when evaluating BIM models at the building permit stage requires a meticulous analysis of the relationship between regulatory requirements and BIM data.

In this study, we propose an algorithm based on rule-based analysis of relevant laws to automatically determine the property information of refuge area in high-rise buildings using BIM. At this time, high-rise buildings are defined by Article 2, Paragraph 1, Item 19 of the Building Act as buildings with a floor count of 30 or more or a height of 120 m or above [7]. The essence of this research is to exclude qualitative regulatory items not suitable for evaluation in BIM and instead utilize clear and quantitative regulations. This approach aims to reduce the manual input of property information for objects required by traditional methods. By using the proposed rule-based property information discrimination algorithm, the amount of information users need to input directly decreases, reducing the workload for code checking and the likelihood of human error. This will not only play a significant role in improving the quality of BIM design but also contribute to enhancing the reliability of BIM-based code checking results for regulations associated with the property information of refuge area.

The paper is structured in the following manner: Sect. 2 presents a literature review, highlighting the distinctions from existing studies, Sect. 3 presents the methodology of the re-study, including the analysis of relevant regulations and the proposal of a BIM-based evacuation zone determination algorithm. Section 4 shows the implementation results through a case study, and Sect. 5 presents the conclusion summarizing the research findings and contributions.

2 Literature Review

Kim, I et al. 2013 [8] developed an automated code checking module for high-rise buildings evacuation regulations using open BIM technology. The evacuation-related regulations were structured to summarize the conditions and criteria to be reviewed, and then the corresponding IFC (Industry Foundation Classes) property information was derived. Based on this, a ruleset was developed. This module can verify crucial regulations such as Standard for the installation of emergency elevator and Standard for the installation of refuge area, thereby suggesting the potential for enhancing BIM data quality. However, automated code checking relies on the accurate input of property information according to BIM model creation standards. Despite this dependency, it is an essential step to ensure the reliability and accuracy of the BIM model, acting as a critical determinant of model quality. Furthermore, Kim, I et al. 2016 [9] developed a pre-defined document to automate Building Act review using BIM models by mapping certain regulatory items to BIM model objects and properties. Based on existing research and IFC data structure, Korean building code analysis criteria were derived. And then, based on this, the information specifications that users need to enter in advance were created by mapping the object and property information of BIM to implement some legal items. This approach was proposed as a solution to the time-consuming and error-prone manual code checking process at the building permit stage. It contributes to resolving issues of design delays and increased costs at the building permit stage, producing a pre-defined document that improves design quality and BIM technology usage, offering possibilities for further expansion and accuracy enhancement. In 2020, a methodology for classifying escape stairs based on open BIM was presented [10]. The requirements for classifying three types of stairs were extracted from the laws and regulations for reviewing escape stairs, and an algorithm for automatic classification of escape stairs was proposed based on them. A modeling method for applying the algorithm was presented, and the suitability of the results was verified by applying it to open BIM-based software. This study demonstrated the feasibility of reviewing building codes for escape stairs using only BIM models. Jo, G et al. 2016 [11] developed an extended space classification system to compensate for the limitations of standardization and representation of BIM data in existing construction information classification systems aimed at BIM application. It was developed by selecting spatial items from construction related laws and regulations and performing an appropriateness analysis by comparing the initially selected space items with standard references such as the facility project master plan. This expanded system was applied to the BIM field, which greatly improved the possibility of integrated data management and utilization. This research has the potential to play an important role in the utilization and development of BIM technology by suggesting ways to improve the efficiency of BIM data management and contribute to the quality improvement of construction projects.

Additionally, Lotfi, N. et al. 2021 [12] developed a framework for Post-Earthquake Fire (PEF) evacuation assessment of high-rise buildings using BIM. This involved using

Pyrosim for a monitoring process to assess the feasibility of evacuation routes and simulate smoke and fire spread across multiple floors. Mirzaei-Zohan, S. A. et al. 2023 [13] developed a new integrated agent-based framework using BIM to safely evacuate occupants in buildings during emergencies. The framework was developed based on BIM-based simulation, analyzing existing research and empirical observations to ensure the reliability of simulation results by securing models with more diverse behavioral modes than before. It was applied to a real commercial building to evaluate the safety of evacuation, and the results were analyzed to determine a safe design plan. Yakhou, N. et al. 2023 [14] introduced a framework for integrating fire evacuation models into BIM, considering data exchange from a fire safety engineering perspective. Based on research in fire protection engineering, parameters for input to BIM were defined, and output parameters were extracted based on the process of utilizing evacuation simulations. This led to the development of a prototype system combining Revit and Pathfinder, which was validated to show the interoperability of the data.

The analysis of previous studies revealed that in Korea's building permit stage, research exists on deriving additional information required for automated code checking beyond BIM modeling guidelines. Moreover, various frameworks have been proposed to assess evacuation-related regulations based on BIM. However, among the items reviewed based on BIM, research related to refuge areas necessitated further investigation, and it was analyzed that fundamentally, users must utilize parameters within BIM authoring tools to add information for evaluating refuge areas based on BIM. This manual property input by the user reduces the efficiency of the work and has the potential to reduce the reliability of the code checking results. Therefore, this study aims to identify which floors are suitable for refuge areas without user input of parameter-based property information for refuge area.

3 Methodology

Figure 1 illustrates the research methodology for a BIM-based algorithm for automatically determining refuge area at the building permit stage. The process will be explored section by section according to this methodology.

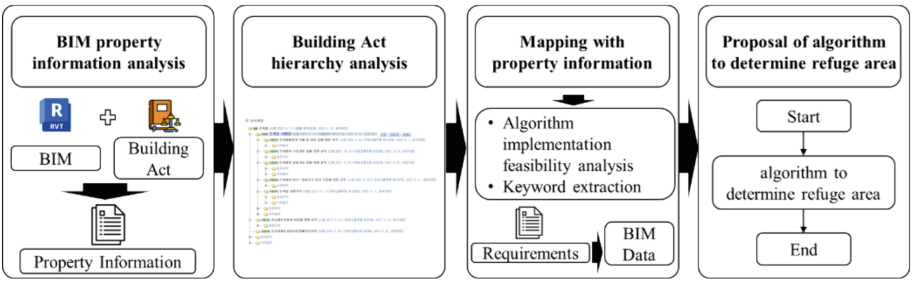


Fig. 1. Methodology for proposal of BIM-based refuge area determination algorithm

3.1 Property Information Used in BIM for Code Checking

In Korea, applying BIM-based code checking at the building permit stage requires targeting BIM models at the BIL (BIM Information Level) 30 level, in accordance with the Public Procurement Service's Framework Guidelines for BIM Application for Facilities Projects v2.1 [15]. However, due to varying detailed material representation and shape representation methods across different design firms, it can often be challenging for users to achieve the desired results. To address this, modeling guidelines necessary for code checking have been established, and following these guidelines, property information needed for BIM models has been standardized for input, allowing for a consistent process of review across various BIM models. This study specifically utilizes five key pieces of property information for automatically determining refuge area, as shown in Table 1, which plays a crucial role in ensuring the accuracy and regulatory compliance of BIM models.

Space classification codes represent a system that expresses each space within a building with a five-digit numerical code [11, 16]. When space names are entered in natural language, the same space can be represented by various names in different BIM models, leading to difficulties in accurate recognition by the program. By converting the names of spaces into numerical codes, space classification codes can be used as a basis in the code checking process to prevent errors in space recognition. This code is composed of a major category, a sub-category, a minor category, and a detailed category, each represented by one digit, one digit, one digit, and two digits, respectively. For example, the space classification code for refuge area is '33302', meaning a functional compartment space (major category '3'), a common internal space in facilities (sub-category '33'), and a space related to evacuation and fire protection (minor category '333').

In addition to space classification codes, key pieces of property information used for automatically determining refuge areas include non-combustible materials, fire-resistant structures, special evacuation stairs, and emergency elevators. Non-combustible materials are classified into non-combustible, partial combustible, and flame retardant material, each graded according to tests suitable for the respective materials. Fire-resistant structures refer to the capability of a building to withstand structural deformation during a fire for a specified period, significantly enhancing the safety of the building. Special evacuation stairs and emergency elevators are classified according to whether they meet specific standards set by regulations. These property information elements can cover a broad and sometimes ambiguous range as specified by regulations, making them challenging to handle in BIM models at the BIL 30 level. Therefore, it is important to add separate BIM parameters during model creation to specify this information effectively for code checking.

Table 1 illustrates the property information used to discern the presence of a refuge area. Space classification code and non-combustible material possess string value, whereas fire-resistance structure, special escape stair, and emergency elevator are determined dichotomously based on whether checkboxes are active, thus they do not have separate string value. Although these properties require user input by adding project parameters in the BIM authoring tool, they have unique BIM property names and string values even when converted to IFC format, which we utilize during the permit legislation review process.

Table 1. User-entered BIM property information required for code checking

BIM property name	BIM Parameter type	String Value
Space classification code	Text	33302
Non-combustible material	Text	Non-combustible material, partial combustible material, frame retardant material
Fire-resistant structure	Boolean	–
Special evacuation stair	Boolean	–
Emergency elevator	Boolean	–

3.2 Building Act Hierarchy Analysis

The top-tier regulation related to refuge area is defined by the Building Act. However, the level of detail in representing this information becomes more specific in the subordinate regulations. That is, the conceptual definition is basically made in the Building Act, but the specific content is handled in the subordinate regulations. The Enforcement Rules then present specific regulations that must be complied with for the installation of such refuge area. The regulations concerning refuge areas are closely linked from the upper law to the lower laws, and their relationship can be diagrammed as shown in Fig. 2. These regulations have a complex relationship with each other and must be considered comprehensively. This study focuses on determining the presence of refuge areas based on BIM and does not include analysis on where refuge areas are installed. Therefore, this study focuses on how the Standard for the installation of refuge area, specified in Article 8–2 of Building Fire Protection Structure Rule, can be applied and evaluated in a BIM environment.

3.3 Mapping with Property Information for BIM Based Code Checking

Article 34 of the Enforcement Decree of the Building Code defines a refuge area as a refuge space installed on the intermediate floor of a building for the purpose of evacuation or safety [7]. Based on this definition, clear information input is required to determine the existence of a refuge area in a BIM environment. However, since the basic functions of BIM are limited in representing information, additional property information is required for code review. In particular, the keyword refuge area plays an important role in BIM analysis and is categorized under the space classification code 33302 [16].

An essential task in BIM-based code checking is to identify codes that specify additional information needed to determine the definition, extract the required content from the code text, and correlate it with BIM data. In this process, the installation standards

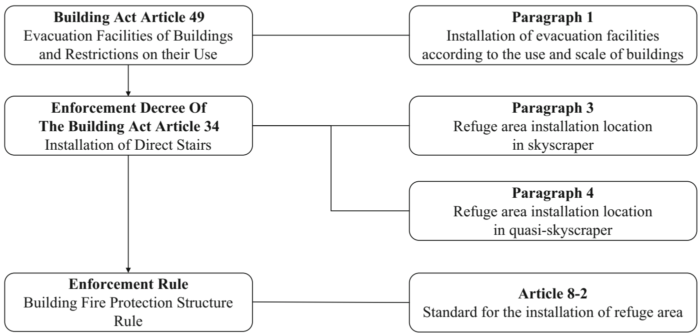


Fig. 2. Building Act hierarchy related to refuge area

for refuge areas according to Article 8.2 of the Building Evacuation Structural Members Rules were reviewed. Currently, a binary approach is adopted to determine the requirements extracted from the code for items that cannot be represented by basic features, based on user-parameterized property information in the BIM model. However, programmatically identifying refuge areas prior to performing code checking poses challenges in ensuring the reliability of the results. To address these challenges, a method is proposed to preview the installation standards in the BIM model to identify floors that are suitable as evacuation zones. The installation standards for evacuation zones include detailed criteria in clauses 1 through 3, with clause 3 in particular specifying 10 items. However, there is a difference between the level of detail required by the regulation and the BIM level of BIL 30, making it difficult to evaluate all items based on BIM. Therefore, this study analyzed keywords that can be associated with BIM in the regulation to determine the feasibility of evaluating each item in a BIM environment.

Table 2 provides a comprehensive summary of the results of selecting regulations that could be evaluated using BIM technology and analyzing the requirements of those regulations. In this selection process, the first criterion was whether the regulations could be evaluated based on BIL 30 representable objects. The second criterion was to use only quantitative information in evaluating the regulations, making the evaluation process clearer and more objective. As a result, only those regulatory items that met these two criteria were mapped to the required property information within the BIM data, providing an approach to BIM-based code checking. Most BIM property information requires user input, but in the case of Room property, user input is not required because height information is basically included when creating a room object.

3.4 Refuge Area Determination Algorithm

Based on the requirement analysis conducted in Table 2, an algorithm has been developed, as shown in Fig. 3, to automatically evaluate the relevant regulations in a BIM environment. Refuge areas are spaces related to evacuation that must be installed in high-rise buildings, hence evaluation criteria were added based on Article 2, Paragraph 1, Item 19 of the Building Act, which specifies the definition of high-rise buildings. As a result, a total of 10 logical type evaluation criteria were derived.

Table 2. Requirements for determining refuge area

Article 8-2, Building Fire Protection Structure Rule	Requirement	BIM property information
Paragraph 1	Use one floor of the building as a refuge area	Building classification code
	The space that can be installed on the same floor as the refuge area is the space for installing construction equipment	Building classification code
	Must be partitioned with fire resistant structure	Fire-resistant structure property
Paragraph 2	Special escape stairs are installed as a route to move to the upper and lower floors through the refuge area	Special escape stairs property
Paragraph 3, Subparagraph 2	The interior finishing materials of the refuge area are made of non-combustible materials	Non-combustible material property
Paragraph 3, Subparagraph 3	The stairs leading from the interior of the building to the refuge area have the structure of special escape stairs	Non-combustible material property
Paragraph 3, Subparagraph 4	An emergency elevator must exist in the refuge area	Emergency elevator property
Paragraph 3, Subparagraph 8	The height of the refuge area must be at least 2.1m	Room property

First of all, the algorithm declares a variable that returns the result type and evaluates the conditions of the high-rise building to determine whether it is necessary to install a refuge area. Then, as a data collection step for the evaluation, space classification codes, structural members, interior finishing members, elevators, and ceiling heights are extracted for the floors with refuge areas. In particular, for objects, property information is also extracted. Afterwards, four types of evaluation are started. Structure of refuge area is a review of the features of each space and compares them with the information in the property information. If structural members and finishing objects are used for all spaces, there are various types of objects, but the algorithm can respond to multiple types of objects because the ‘fire-resistant structure’ property is the same for structural members and the ‘non-combustible material’ property is the same for finishing objects, according to the Modeling Guide for Open BIM-based Code Checking. Stairs of the refuge area are evaluated for the presence of special evacuation stairs, as well as the passage of the refuge area on the evacuation route from upper floors to lower floors. Elevators of refuge area reviews whether there is an emergency elevator, and then measure the ceiling height of refuge area and compare it to 2.1 m.

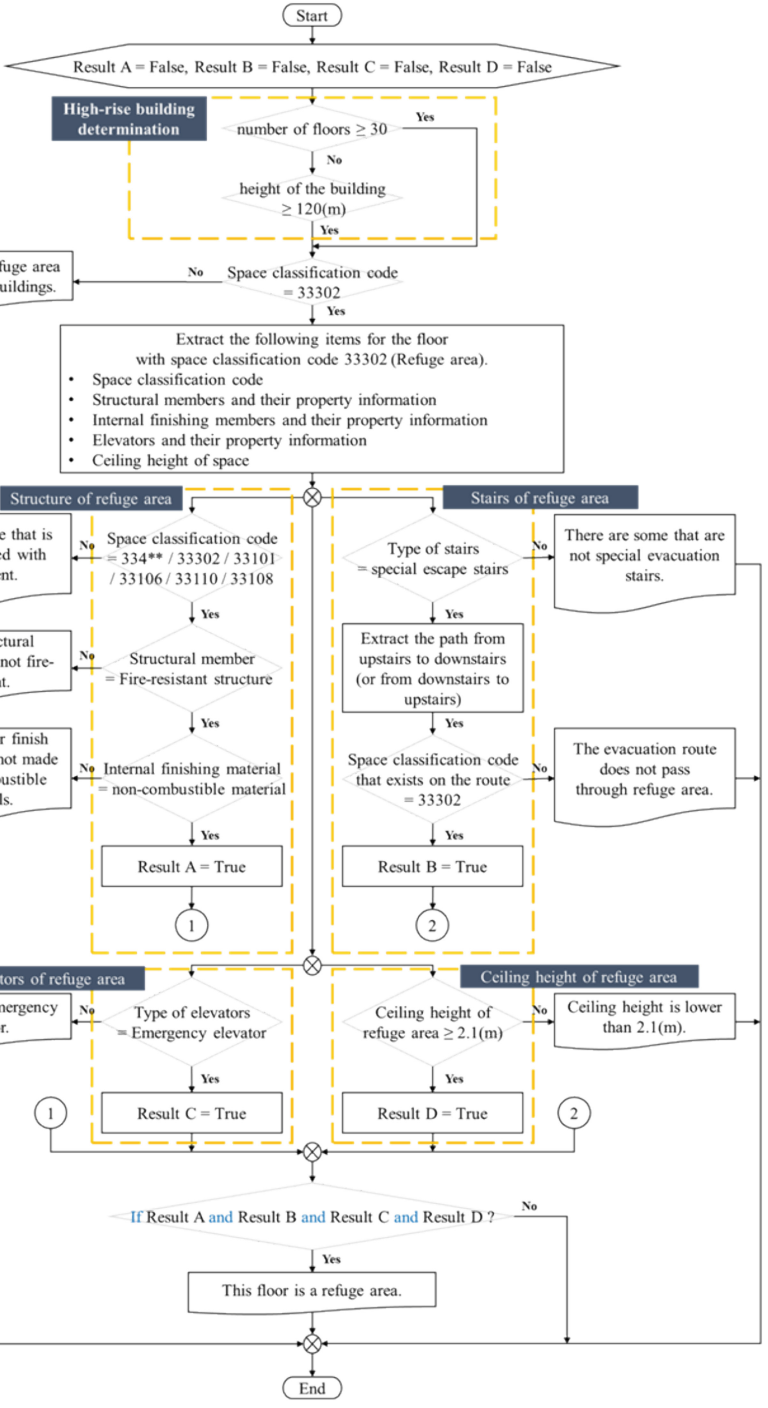
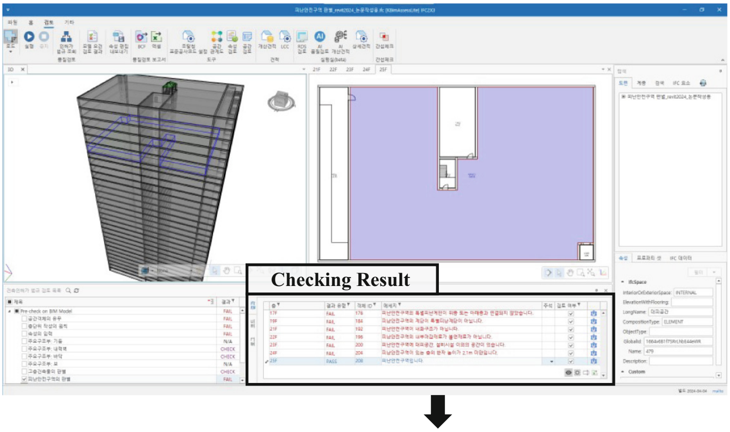


Fig. 3. Refuge area determination algorithm

After performing the evaluation at each of these steps, if the user fails to meet any of the criteria during the process, a ‘FAIL’ result is displayed, and the user is informed at which step they failed to meet the criteria. Conversely, if the conditions are met, each of the four types of evaluation results will return a logical value of ‘True’, and finally, a ‘PASS’ result can only be derived if all types of logical values are ‘True’.

4 Implementation Through Case Study

To verify the accuracy of the algorithm, a 30-story test BIM model was created and evaluated by using KBIM Assess-Lite. The test BIM model provided refuge areas on the 17th, 19th, 21st, and 25th floors for review, and the algorithm separated the conditions to allow for different results. The BIM model was created in compliance with the modeling guide for legal review, and the property information was entered according to the algorithm so that only the 25th floor could be evaluated as a compliant refuge area. According to Fig. 3, there are nine message boxes that can be extracted, but the messages ‘There is no refuge area in high-rise building’ and ‘There is no emergency elevator’ were not output. In the case of the first message box, the refuge area was created for review, and the second message box was excluded because most floors share an elevator due to the characteristics of the building.



Number of Floor	Type of Result	Message
17F	FAIL	The evacuation route does not pass through refuge area.
19F	FAIL	There are some that are not special evacuation stairs.
21F	FAIL	Some structural members are not fire-resistant.
22F	FAIL	Some interior finish members are not made of non-combustible materials.
23F	FAIL	There is space that is not associated with equipment.
24F	FAIL	Ceiling height is lower than 2.1(m).
25F	PASS	This floor is a refuge area.

Fig. 4. Refuge aera determination results from BIM-based code checking program

The seven cases excluding these two message boxes are shown in Fig. 4. It can be seen that the evaluation results for floors 17 through 24 all resulted in 'FAIL' as intended, with different messages for each floor. Also, the 25th floor resulted in a 'PASS' result, which is also as intended. These results indicate that nothing was missed in the evaluation process, and as a result, it can be concluded that the algorithm successfully extracts floors with refuge areas.

5 Conclusion

This study aimed to develop an algorithm capable of determining the presence of refuge areas within high-rise buildings based on BIM. To achieve this, it first identified the property information needed for refuge area determination at the building permit stage in Korea using BIM, and analyzed the hierarchical structure of the Building Act to select essential regulations for code checking. Afterward, we mapped the information specified in the relevant laws and regulations to the BIM data. Based on the extracted and mapped information, we proposed an algorithm to identify and evaluate the refuge area of high-rise buildings in a BIM environment, and verified the algorithm through a test BIM model. This enables users to automatically determine the floors where refuge areas exist by utilizing input values of property information required for BIM-based code checking.

This study serves as foundational work for automatically determining refuge area based on rules, including the proposal of an algorithm. The proposed algorithm is expected to enable the automation of code checking during the building permit stage, but converting it into a programming language and the subsequent validation process are essential for its application in actual building permit code checking program. Therefore, future research must importantly address the conversion of the algorithm into programming language and validate its applicability in actual code checking environments. If the rule-set automation of property information, such as the automatic determination of refuge areas, is applied through subsequent research, it will be necessary to expand the range of automatically determinable property information. This shows the potential to significantly enhance work efficiency during the design phase by reducing the amount of information users must input at the building permit stage. Moreover, as code checking becomes possible with minimal information input, the frequency of human errors during the information input process is also expected to decrease. Such an approach will play a vital role in extending the use of BIM technology in the architecture field and maximizing accuracy and efficiency during the design and permitting processes. Therefore, the automation of code checking using BIM technology is poised to become a key element in improving the overall quality of construction projects.

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